OSUN 2026



EDITED BY:

Olajuyigbe S. O. PhD
Agwu, O. P. PhD
Asinwa, I. O. PhD
Iyiola, A. O. PhD
Ugbong, E. A. PhD

FOREST ECOSYSTEM CONSERVATION: A ROADMAP FOP RESILIENT ECONOMIES AND ENVIRONMENTAL SUSTAINABILITY

National Organizing Committee (NOC)

Dr Israel O. Asinwa*
Dr Abubakar Adamu
Dr. Joy Oghenekevwe Arabomen
Mr Bello Rufa'i Wali
Dr. Ugbong Emmanuel Akomaye
Mr. Maza Victor Hikon
Dr. Asinwa Israel O.
Dr. Isaac Oyewo
Mr. Phillips Gbenga
Mr Kamalu Muktar Aliyu
Mr Usman Adamu Yarima
Hudu Abdul-Azeez Baba
Mr Adewale Agbo-Adediran
Dr. Onyekachi Chukwu
Dr Alobi Obaji Alobi

Local Organizing Committee (LOC)

Adenike-Adeniyi Evelyn AREMO*
Adeola Aarinola ADEBOYEJO
Ayodeji Augustine ADAJA
Adams Ovie IYIOLA
Ayotunde Samuel KOLAWOLE
Ameenat Abiodun ADERIBIGBE
Samuel Olubori AFOLABI
Dr. Abiola Elizabeth OJELEYE
Precious OLuwayemisi OLADEJO
Mrs. Adebanke Praise AKERELE
Abosede Blessing AKANDE
Bibitayo Ayobami OWOLABI
Adeyemi Oluseye AKINYEMI

indicates Chairperson

Held at the Faculty of Renewable Natural Resources Management, College of Agriculture and Renewable Natural Resources, Osun State University, Nigeria, from 19th – 21st of May, 2026.

Copyright © 2026, ISTF, Nigeria. All rights reserved.

No part of the proceedings maybe reproduced without the permission of Author(s) and Editors. **Email**: 2026istfnigeria.osun@gmail.com

ISBN: 978-978-788-795-0

Published by: ISTF-Nigeria on the 19th May, 2026

Disclaimer:

Information documented in this book of conference proceedings is a result of the intellectual efforts of the authors. The editors of this conference proceedings made every effort in editing and correction to ensure the accuracy of the works. However, the editors are not responsible for any errors, mistakes, and plagiarism that may be found in any paper. Any views expressed in this proceeding are the views of the authors. Authors are responsible for any error, mistake and plagiarism in their papers. It is in no way represents the opinions or standpoint of the Editors and ISTF, Nigeria.

TABLE OF CONTENTS

Welcome address of the President xii

Welcome address by the Executive Officer ISTF xiv

Keynote Address xviii

Goodwill Message xxxviii

Lead Paper Presentation

Forest Policy and Governance For Sustainable Forest Management Towards The Nation's Economic Development xxxix

Sustainable Forest Products Development And Utilisation For Economic Development In Nigeria xlvii

Estimating Benefits From The Nigerian Forests: Market And Non-Market Valuations lxviii

Potential of Non-Timber Forest Products in Forest Conservation And Economic Development: A Case Study of Herbal Medicine lxxiv

Information and Communication Technology, Artificial Intelligence and Their Impacts on Forest Ecosystems lxxxv

Technical Sessions

Subtheme 1: **IMPROVING ECONOMIC BENEFITS FROM FORESTS: OPPORTUNITIES AND CHALLENGES** 1

DETERMINANTS OF GINGER (*Zingiber officinale*) PRODUCTION IN KAJURU LOCAL GOVERNMENT AREA OF KADUNA STATE, NIGERIA **(Ariyo et al)** 2

RELATIONSHIP BETWEEN INPUT AND OUTPUT OF AGROFORESTRY FARMS IN ADAMAWA STATE, NIGERIA **(Boni et al.)** 13

FACTORS INFLUENCING AGROFORESTRY TECHNOLOGIES ADOPTION AMONG RURAL FARMERS IN KADUNA STATE, NIGERIA **(Sirajo et al.)** 25

SOCIO-ECONOMIC BENEFITS OF ONIGAMBARI FOREST RESERVE ON RURAL DWELLERS IN OLUYOLE LOCAL GOVERNMENT AREA, OYO STATE. **(Odeyale et al)** 36

CORRELATION BETWEEN CAUSES OF LAND USE CONFLICT AND SOCIO-ECONOMIC STATUS OF FOREST DWELLERS IN ONDO STATE, NIGERIA (**Aluko et al.)** 46

AGROFORESTRY: A TOOL FOR ENHANCING SMALLHOLDER FARMERS IN ODEDA LOCAL GOVERNMENT AREA, OGUN STATE, NIGERIA **(Ugege et al.)** 57

Subtheme 2: **LAND USE AND LAND COVER CHANGE: IMPACTS ON FOREST LANDSCAPE DEGRADATION** 68

CHANGING LANDSCAPES, CHANGING FORESTS: EVIDENCE OF LAND USE DYNAMICS AND FOREST DEGRADATION IN SELECTED NIGERIAN FOREST LANDSCAPES **(Ofordu, C.S.)** 69

PHYTO-EXTRACTION OF POTENTIAL TOXIC ELEMENTS FROM GOLD MINE CONTAMINATED SOIL USING *Terminalia superba* ENGL. DIELS **(Oyedijo et al)** 80

THE IMPERATIVE OF URBAN TREE PLANTING FOR BEAUTIFICATION AND CLIMATE AMELIORATION IN NIGERIAN CITIES (**Obadimu and Olowoyo)** 89

FOREST DEGRADATION IN NIGERIA: CONSERVATION CHALLENGES, RESPONSES, AND PATHWAYS FORWARD (**Oyetunji et al)** 96

CHALLENGES FACING PRIVATE FORESTRY ESTABLISHMENTS IN NIGERIA **(Alagbada and Ayeni)** 113

EFFECT OF AGROFORESTRY PRACTICES ON YIELD AND SOIL PROPERTIES IN JERE AND KONDUGA LOCAL GOVERNMENT AREAS, BORNO STATE (**Garba er al)** 122

PHYTOCHEMICAL COMPOSITION AND COMPARATIVE ANTIBACTERIAL ACTIVITY OF STEM AND LEAF EXTRACT OF *CISSUS QUADRANGULARIS* AND CONVENTIONAL ANTIBIOTICS AGAINST SELECTED BACTERIA. **(Olateru et al)** 141

ENVIRONMENTAL AND HEALTH RISKS OF URBAN FLOODING IN JERE LOCAL GOVERNMENT AREA, BORNO STATE, NIGERIA (**Umar et al)** 149

SPATIOTEMPORAL DYNAMICS OF VEGETATION CARBON DENSITY IN SELECTED LOCAL GOVERNMENTS, OSUN STATE, NIGERIA (2006–2022) (**Afolabi et al)** 157

TREE SPECIES DIVERSITY AND COMPOSITION OF PUJE FOREST AND RAFINKADA SWAMP IN WUKARI LOCAL GOVERNMENT AREA, TARABA STATE, NIGERIA **(Maza et al)** 168

EVALUATING ECOSYSTEM RESTORATION APPROACHES FOR DEGRADED LAND HOTSPOTS: A CASE STUDY OF JIGAWA STATE, NIGERIA (**Iroko et al)** 182

REGENERATION DYNAMICS AND POPULATION STRUCTURE OF WOODY SPECIES IN AFAKA FOREST RESERVE, NIGERIA. (**Sodimu et al)** 195

SPATIAL VARIATION OF LEAD IN ROADSIDE TREE LEAVES ALONG A TRAFFIC DENSITY GRADIENT IN KADUNA CITY, NIGERIA. (**Sodimu et al)** 207

Subtheme 3: **FOREST POLICY AND GOVERNANCE FOR SUSTAINABLE FOREST MANAGEMENT** 217

TROPICAL FOREST GOVERNANCE AND FOREST COVER DYNAMICS (2000–2020): IMPLICATIONS FOR RESILIENT ECONOMIES AND ENVIRONMENTAL SUSTAINABILITY **(Owese et al)** 218

ENVIRONMENTAL ECONOMICS PERSPECTIVE OF GOOD FOREST GOVERNANCE AND POLICY FOR TRANSFORMING FORESTRY RESEARCH INTO MARKETABLE EXHIBITION PRODUCTS **(Ajayi et al)** 230

PARTICIPATION WITHOUT POWER: COMMUNITY PARTICIPATION AND STAKEHOLDER ENGAGEMENT IN FOREST GOVERNANCE IN SOUTHWESTERN NIGERIA **(Akinyemi et al)** 247

ECOLOGICAL IMPACTS OF UNSUSTAINABLE WOOD HARVESTING IN ONIGAMBARI FOREST RESERVE, OYO STATE, NIGERIA **(Akinyemi et al)** 255

EFFECTS OF RECURRENT FIRE ON VEGETATION STRUCTURE AND REGENERATION DYNAMICS IN ONIGAMBARI FOREST RESERVE, NIGERIA **(Akinyemi et al)** 267

EVALUATING THE DRIVERS OF LAND DEMAND AMONG RURAL AND URBAN FARMERS IN OYO STATE, NIGERIA **(Ganiyu et al)** 275

THE CAUSES AND CONSEQUENCES OF SPATIAL DISTRIBUTION PATTERNS OF TREE SPECIES IN TROPICAL RAINFORESTS **(Ogundotun and Falade)** 283

Subtheme 4: **WATERSHED MANAGEMENT AND GREEN ECONOMY** 289

INFLUENCE OF LAND USE TYPES ON WATER QUALITY IN OSUN RIVER WATERSHED ECOSYSTEMS, SOUTHWESTERN NIGERIA **(Akintan et al)** 290

Subtheme 5: **FOREST PRODUCTS DEVELOPMENTS, UTILIZATION AND SUSTAINABLE ECOSYSTEMS** 307

MODEL IDENTIFICATION AND SENSITIVITY ANALYSIS OF FACTORS AFFECTING *Clarias gariepinus* DRIED IN A SEMI-AUTOMATED GAS-FIRED DRYER **(Ogunsola et al)** 308

ATTITUDES OF SECONDARY SCHOOL STUDENTS TOWARDS ENVIRONMENTAL CONSERVATION EDUCATIONAL PROGRAMS IN SOME SELECTED SCHOOLS IN OYO STATE, NIGERIA **(Olawale et al)** 317

ASSESSMENT OF EXPLOITATION PATTERNS AND CONSERVATION STATUS OF INDIGENOUS TIMBER SPECIES IN SAWMILL CLUSTERS OF ODIGBO LOCAL GOVERNMENT AREA, ONDO STATE, NIGERIA **(Akomolede et al)** 332

EFFECT OF MOISTURE SORPTION STATE ON THE TRANSVERSE DIMENSIONAL CHANGE OF *Terminalia ivorensis* A.Chev. WOOD **(Adebayo et al)** 342

ASSESSMENT OF THE INFORMATION NEEDS FOR THE DEVELOPMENT OF TIMBER MARKETING INFORMATION SYSTEM IN SOUTHWESTERN NIGERIA **(Falana et al)** 347

TROPICAL TREE BREEDING AND GENETIC IMPROVEMENT IN CLIMATE-RESILIENT FORESTRY: A BIBLIOMETRIC ANALYSIS **(Awosan et al)** 361

POTENTIAL IMPACT OF INTEGRATED PEST MANAGEMENT STRATEGIES FOR CONTROLLING INSECT PESTS OF *Balanites aegyptiaca* Linn. AT SEEDLINGS STAGE **(Soba et al)** 375

POSSIBLE APPLICATION OF SECONDARY RECOVERED WOOD FOR THE MANUFACTURING OF SPACE MANAGEMENT ENHANCEMENT HOUSEWARE **(Ugbong E.A.)** 386

ECOLOGICAL AND AXIAL VARIATION IN THE DENSITY OF *Eremospatha macrocarpa* (G.MANN & WENDL.) WENDL. RATTAN IN TWO NIGERIAN ECOLOGICAL ZONES. **(Ogutta and Okanlawon)** 402

UTILIZATION OF ANIMAL-DERIVED LIPIDS AS AN ALTERNATIVE MEDIUM FOR OIL HEAT TREATMENT **(Adejoba et al)** 409

OPTIMIZING SEED GERMINATION OF CHRIST'S THORN JUJUBE (*ZIZIPHUS SPINA*-CHRISTI (L.) DESF. USING PRIMING TECHNIQUES IN KADUNA NORTHERN GUINEA SAVANNA ECO-ZONE, NIGERIA. **(Rasheed et al)** 417

GERMINATION DYNAMICS OF *Prosopis africana* GUILL. AND PERR. SEEDS AS INFLUENCED BY PRE-SOWING TREATMENTS IN KADUNA NORTHERN GUINEA SAVANNA ECOLOGY ZONE OF NIGERIA. **(Adebayo et al)** 424

EFFECTS OF SELECTED INTEGRATED SOIL FERTILITY MANAGEMENT ON THE EARLY GROWTH PERFORMANCE OF *Adansonia digatata* Linneus SEEDLINGS **(Iroko and Salami)** 433

FISH SPECIES ABUNDANCE IN ACADJA SYSTEM OF FISH PRODUCTION USING PALM FRONDS AND BAMBOO CUTTINGS ON BADAGRY LAGOON, LAGOS STATE. **(Sunnuvu et al)** 442

Subtheme 6: **INFORMATION AND COMMUNICATION TECHNOLOGY: ARTIFICIAL INTELLIGENCE AND THEIR IMPACTS ON FOREST ECOSYSTEM.** 453

PREDICTING CLIMATE-DRIVEN HABITAT SHIFTS OF *Afzelia africana* Sm IN WEST AFRICA USING A MACHINE LEARNING APPROACH **(Ugege et al)** 454

DIGITAL FORESTS: INFORMATION AND COMMUNICATION TECHNOLOGY, ARTIFICIAL INTELLIGENCE AND THEIR IMPACTS ON FOREST ECOSYSTEMS **(Emmanuel et al)** 464

Subtheme 7**: NON-TIMBER FOREST PRODUCTS AND FOREST CONSERVATION** 475

INFLUENCE OF DIFFERENT STORAGE MEDIA ON *CITRUS PARADISI* MACFAD (GRAPE FRUIT) PRESERVATION. **(Ojelabi et al)** 476

SURVEY OF NON-TIMBER FOREST PRODUCTS AND THEIR USES AMONG ENCLAVES IN ONIGAMBARI FOREST RESERVE, OYO STATE. **(Haastrup et al)** 485

ANALYSIS OF PHYTOCHEMICALS IN *Holarrhena floribunda (L)* PARTS FOR ORGANIC MANURE PRODUCTION **(Babalola et al)** 490

GROWTH PERFORMANCE OF *Shorea roxburghii* G. Don SEEDLINGS UNDER DIFFERENT WATER REGIMES AND SOIL TEXTURAL CLASSES. **(Rufai et al)** 501

THREATS TO HONEYBEES: HONEYBEES AND BEEKEEPING PRACTICES IN MANGU LOCAL GOVERNMENT AREA, PLATEAU STATE, NIGERIA **(Erhabor et al)** 512

SOURCES AND USES OF BITTER KOLA AMONG DWELLERS IN EKITI STATE, NIGERIA **(Olowoyo et al)** 520

NON-TIMBER FOREST PRODUCTS AS PATHWAYS FOR FOREST ECOSYSTEM CONSERVATION AND RESILIENT ECONOMIES **(Amaechi et al)** 532

LAND USE AND LAND COVER CHANGE: IMPACT ON URBAN FOREST LANDSCAPE **(Obadimu et al)** 543

ASSESSMENT OF FRUIT QUALITY, SEED GERMINATION AND SEEDLING GROWTH OF *Parkia biglobosa* (Jacq.) R.Br. ex G.Don AND *Tamarindus indica* L. FROM THREE PROVENANCES IN THE SAVANNAH ECO-REGION OF NIGERIA **(Addra et al)** 567

NON-TIMBER FOREST PRODUCTS IN NORTHERN NIGERIA: AN ASSESSMENT OF ABUNDANCE IN TOFA LOCAL GOVERNMENT AREA, KANO STATE, NIGERIA **(Inuwa et al)** 580

WILD-HARVESTED NTFPS AS GENETIC RESERVOIRS: A SYSTEMATIC REVIEW OF IRVINGIA SPECIES AND THEIR ROLE IN CLIMATE RESILIENCE **(Jayeoba et al)** 590

POPULATION ECOLOGY OF CLIMBERS IN THE DEPARTMENT OF FORESTRY AND WILDLIFE ARBORETUM, UNIVERSITY OF UYO, UYO, NIGERIA **(Gideon et al)** 604

SEEDS POSITIONING AND SOWING DEPTH FOR THE GROWTH OF *Adansonia digitata* Linnaeus IN THE SUDAN SAVANNAH ECOZONE OF NIGERIA **(Salami et al)** 613

CHLOROPHYLL AND NUTRITIONAL LEVELS OF SELECTED INDIGENOUS PLANT LEAFY VEGETABLES IN SUDAN SAVANNAH OF NIGERIA **(Salami et al)** 624

EARLY GROWTH RESPONSE OF GINGER (*Zingiber officinale* ROSCOE) TO LEAF LITTERS OF SELECTED NITROGEN-FIXING ALBIZIA TREES **(Adelani et al)** 635

EFFECTS OF *Moringa oleifera* LEAF EXTRACT ON THE GROWTH AND YIELD OF TOMATO (*Lycopersicum esculentum*) **(Adewoye et al)** 642

EVALUATION OF PROXIMATE AND PYTOCHEMICAL COMPOSITIONS OF SOME SELECTED FOREST FRUITS **(Adeniran and Olusola)** 651

THE IMPACT OF EXTERNAL FUNDING SUPPORT IN BIODIVERSITY CONSERVATION IN NIGERIA: CASE STUDY OF THE RUFFORD FOUNDATION
(Moshood and Amusa) 662

ACUTE TOXICITY AND PISCICIDAL POTENTIAL OF *Calotropis procera* EXTRACT ON *Clarias gariepinus* FINGERLINGS **(Akinyemi et al)** 689

LIVELIHOOD BENEFITS, EXPLOITATION CONSTRAINTS, AND COMMUNITY PERCEPTIONS OF NON-TIMBER FOREST PRODUCTS IN ISEYIN LOCAL GOVERNMENT AREA, NIGERIA **(Ajagbe et al)** 698

FLORISTIC COMPOSITION OF TREE SPECIES AND STRUCTURE IN EMERALD FOREST, IKOYI, OSUN STATE, NIGERIA **(Ige and Olasupo)** 709

GENOTYPE BY ENVIRONMENT INTERACTION ANALYSIS IN *Dacryodes edulis* (G. Don) H.J. Lam: A MEASURE TOWARDS A MULTIPURPOSE TREE BREEDING IN NIGERIA **(Alaje et al)** 726

ECONOMIC ANALYSIS OF LOCUST BEAN (*Parkia biglobosa*) MARKETING IN BORNO STATE, NIGERIA **(Hassan and Zira)** 738

COMMUNITY PARTICIPATION IN ENVIRONMENTAL CONSERVATION: A CASE STUDY OF IDO LOCAL GOVERNMENT AREA **(Oyewumi et al)** 748

SUSTAINABLE HARVESTING OF FOREST FRUITS AS A CONSERVATION STRATEGY: A REVIEW **(Ademola I.T.)** 756

INTERACTIVE EFFECTS OF NANOPARTICLE CONCENTRATION AND EXPOSURE DURATION ON GERMINATION DYNAMICS OF *Spondia mombin* SEEDS **(Ajadi et al)** 765

Subtheme 8: **WILDLIFE AND ECOTOURISM POTENTIALS IN ECOSYSTEM CONSERVATION** 781

WILDLIFE-BASED ECOTOURISM AS A TOOL FOR ECOSYSTEM CONSERVATION IN TROPICAL FORESTS **(Akinola, O.O.)** 782

DIET AND FORAGING ECOLOGY OF THE LAUGHING DOVE (*Streptopelia senegalensis*) IN ILARO FOR SUSTAINABLE ECOTOURISM DEVELOPMENT OF Ogun State, Nigeria. **(Okosodo et al)** 788

Subtheme 9: **CLIMATE CHANGE MITIGATION, ADAPTATION AND FOREST-BASED SOLUTIONS** 797

FOREST ECOSYSTEMS IN CLIMATE CHANGE MITIGATION AND COMMUNITY RESILIENCE IN SOUTHERN NIGERIA: A SYSTEMATIC REVIEW WITHIN AN AFRICAN CONTEXT **(Arabomen O.J)** 798

FIRE DANGER INDEX (FDI) AS A TOOL FOR FOREST FIRE EARLY WARNING SYSTEM AND ITS IMPACT ON FOREST ECOSYSTEM **(Mba et al)** 808

ALLOMETRIC EQUATIONS FOR BIOMASS ESTIMATION AND CARBON SEQUESTRATION POTENTIAL FOR *Tectona grandis* Linn. f. AND *Gmelina arborea* Roxb. IN NORTH-CENTRAL NIGERIA **(Popoola et al)** 813

DESIGN AND FABRICATION OF AN INDIGENOUS MULTIPURPOSE COOKSTOVE UTILIZING BRIQUETTES, BIO-GEL, BIOGAS, AND LPG **(Akingba et al)** 825

PERFORMANCE EVALUATION OF COMBUSTION CHARACTERISTICS OF BIOGEL, FIREWOOD, LPG, AND BIOGAS FROM ORGANIC FEEDSTOCK **(Akingba et al)** 844

AN INTEGRATED ANALYSIS OF CARBON STOCKS AND CREDIT POTENTIAL IN CROSS RIVER NATIONAL PARK, NIGERIA. **(Onoriemu and Ita)** 853

AGROFORESTRY SYSTEMS: A SUSTAINABLE INTEGRATED STRATEGY FOR CLIMATE CHANGE MITIGATION AND ENVIRONMENTAL SUSTAINABILITY IN NIGERIA **(Bolaji et al)** 864

ASSESSMENT OF THE RESILIENCE OF AGROFORESTRY HOUSEHOLDS TO CLIMATE VARIABILITY IN OMO FOREST RESERVE, OGUN STATE, NIGERIA **(Bobadoye et al)** 877

SIGNIFICANT ROLE OF BIOENERGY IN CLIMATE CHANGE MITIGATION (**Adebisi et al)** 890

ADAPTING AQUACULTURE TO CLIMATE CHANGE: EVIDENCE FROM SMALLHOLDER FISH FARMERS IN OYO STATE, NIGERIA **(Oyewo et al)** 895

EVALUATING CLIMATE-INDUCED CHANGES ON FISH SPECIES RESILIENCE IN ERINLE RESERVOIR, OSUN STATE, NIGERIA. **(Iyiola et al)** 910

ECOLOGICAL DISTRIBUTION AND CONSERVATION STATUS OF THE GENUS VITEX IN NIGERIA. **(Adeniji and Abdulrahman)** 922

BIOMASS ACCUMULATION, STAND STRUCTURE, AND CARBON STOCK ESTIMATION OF *TECTONA GRANDIS* PLANTATION IN AGO-OWU FOREST RESERVE, SOUTHWESTERN NIGERIA **(Agbo-Adediran et al)** 927

KNOWLEDGE LEVEL AND CONSTRAINTS FACED BY SMALLHOLDERS FARMERS IN COPING WITH THE EFFECTS OF CLIMATE CHANGE IN OYO STATE.**(Oyewole et al)** 939

ABOVE GROUND BIOMASS, CARBON SEQUESTRATION POTENTIAL AND BIODIVERSITY OF TREE SPECIES IN AHMADU BELLO UNIVERSITY, BOTANICAL GARDEN IN SAMARU – ZARIA, KADUNA STATE, NIGERIA. **(Sodimu et al)** 946

QUANTITATIVE ASSESSMENT OF EXHAUST EMISSIONS AND THEIR IMPACT ON CLIMATE CHANGE IN NIGERIA. **(Agbeja et al)** 958

ISTFIC2026

WELCOME ADDRESS OF THE PRESIDENT, DR ONYEBUCHI PATRICK AGWU, AT THE 4TH ISTF INTERNATIONAL CONFERENCE THEMED "FOREST ECOSYSTEM CONSERVATION: A ROADMAP FOR RESILIENT ECONOMIES AND ENVIRONMENTAL SUSTAINABILITY" HELD AT OSUN STATE UNIVERSITY ON 19TH MAY, 2026



Distinguished guests, keynote speakers, members of the academia, researchers, professionals, policy makers, students, development partners, ladies and gentlemen, It gives me immense pleasure and honour to welcome you all to the 4th National Conference of the International Society of Tropical Foresters, Nigeria Chapter (ISTF-NIG), holding here at the College of Agriculture and Renewable Natural ResourcES, Faculty of Renewable Natural Resources Management, Ejigbo Campus of Osun State University.

On behalf of the Executive members of ISTF-NIGERIA, I warmly welcome all our participants, especially guests who have travelled from different institutions, organizations, and parts of Nigeria and beyond to be part of this important gathering. Our conference theme, "Forest Ecosystem Conservation: A Roadmap for Resilient Economies and Environmental Sustainability," is timely and highly relevant given the growing environmental challenges confronting our nation and the global community.

Today, forest ecosystems are under severe pressure from deforestation, climate change, biodiversity loss, unsustainable land-use practices, urbanization, and other anthropogenic activities. These challenges threaten not only our environment but also the livelihoods, food security, and economic resilience of millions of people who depend directly and indirectly on forest resources.

This conference therefore provides a strategic platform for intellectual discourse, knowledge sharing, scientific innovation, and collaborative engagement among scholars, professionals, environmentalists, government agencies, non-governmental organizations, students, and industry stakeholders. We expect that the deliberations and recommendations from this conference will contribute meaningfully to policy formulation, sustainable forest management practices, environmental conservation, and national development.

As tropical foresters and environmental stewards, we must continue to advocate for sustainable utilization and conservation of our forest resources for present and future generations. We must strengthen research, capacity-building, community participation, and institutional partnerships to achieve resilient economies and environmental sustainability.

I wish to sincerely appreciate the management of Osun State University, particularly the College of Agriculture and Renewable Natural Resources, and the Faculty of Renewable Natural Resources Management, for providing the enabling environment and support for hosting this conference. I also commend the Local Organizing Committee, members of ISTF-NIG, sponsors, partners, and volunteers whose dedication and commitment made this conference a reality.

To our keynote speakers, lead paper presenters, and participants, we deeply value your contributions and active participation. I encourage everyone to take full advantage of the technical sessions, interactions, and networking opportunities provided during this conference.

As we gather to deliberate on issues related to forest ecosystem conservation and sustainability, may our discussions yield innovative ideas, practical solutions, and lasting collaborations that will positively impact our forests, our environment, and our society.

Once again, I warmly welcome you all to this conference and wish you a fruitful, successful, and memorable stay throughout the conference period.

Thank you, and God bless.

Dr. Onyebuchi Patrick AGWU
President
International Society of Tropical Foresters, Nigeria Chapter

ISTF-NIG 2026

WELCOME ADDRESS BY THE EXECUTIVE OFFICER-ISTF GLOBAL, DR SHEILA WARD, AT THE 4TH ISTF INTERNATIONAL CONFERENCE THEMED "FOREST ECOSYSTEM CONSERVATION: A ROADMAP FOR RESILIENT ECONOMIES AND ENVIRONMENTAL SUSTAINABILITY" HELD AT OSUN STATE UNIVERSITY ON 19TH MAY, 2026

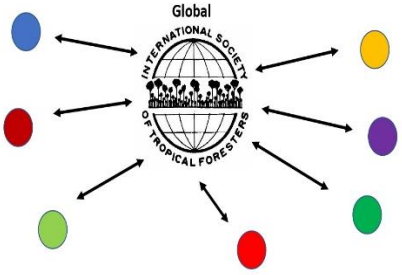


International Society of Tropical Foresters-Global

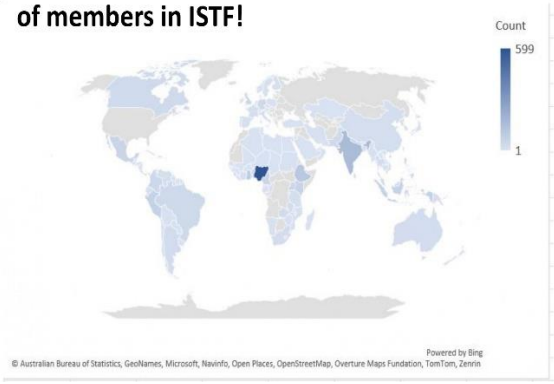
- Collaborative, information sharing network in support of sustainable use and conservation of our tropical forest resources
- ~2800 members in ~130 countries
- Chapters:
  - *Africa:* Nigeria, Ghana, Rwanda, Democratic Republic of Congo
  - *Latin America:* Mexico, Panama, Peru, Puerto Rico
  - *Asia-Pacific*: Nepal, India, Indonesia
  - *North America:* Yale University, North Carolina State University
  - Others in formation

ISTF-Global and Chapters

- ISTF-Global: the central connector of ISTF members and chapters
- ISTF-Global as an information-sharing network to promote the sustainable use and conservation of tropical forests
- Semi-autonomous chapters for local action



Nigeria is the country with the greatest number of members in ISTF!



ISTF-Global

- Focus on being a communication network
- Open to all individuals interested in and committed to the sustainable use and conservation of tropical forests and resources
- Founded in the 1950s "in response to a worldwide concern for the fate of tropical and subtropical forests".
- "Committed to the protection, wise management and rational use of the world's tropical forests".
- ISTF-Global Board elected by the membership, international leadership
- For now, ISTF-Global is dues-free, but chapters may charge dues to support their activities.

ISTF-Global Board

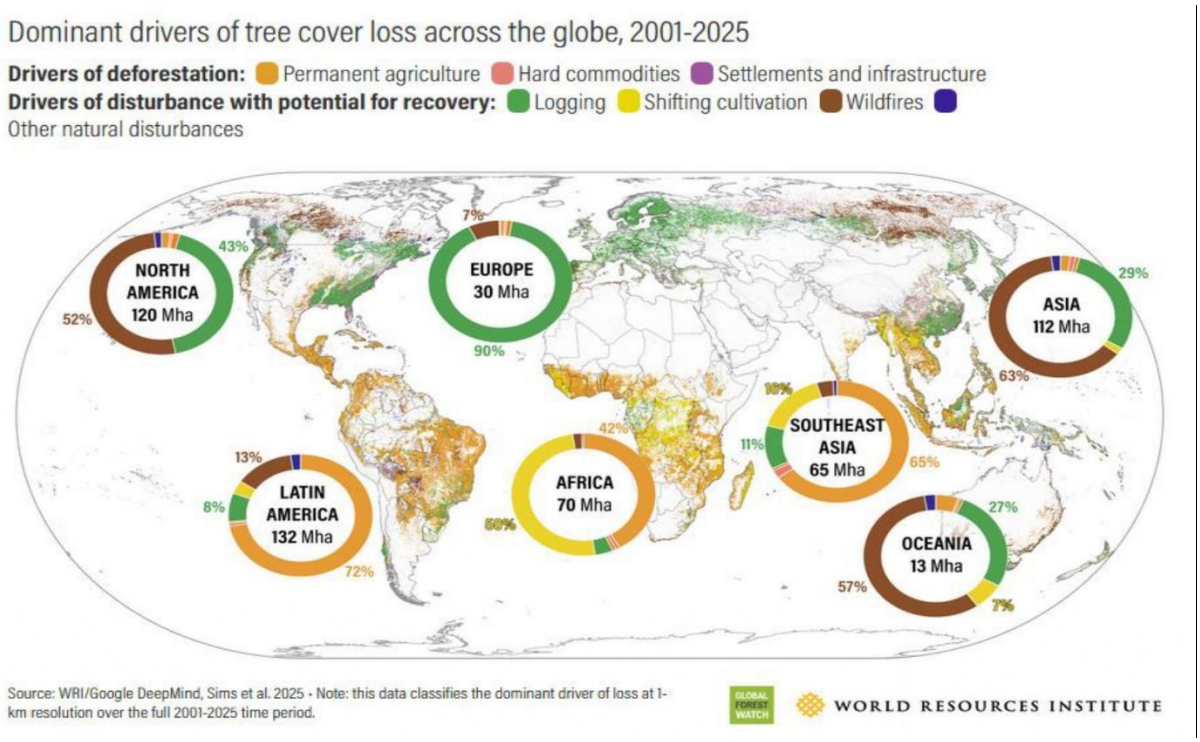
- **President:** Patrick Durst *(Thailand, USA)*
- **Vice-President:** Akwasi Asamoah *(Ghana)*
- **Secretary:** Stewart Mior *(Canada)*
- **Treasurer:** Ruth Metzel *(USA)*
- **Tropical Africa Representative:** Elias Nelly Bafapkurera *(Rwanda)*
- **Tropical America Representative:** Luis Armando Aznar Molina *(Mexico)*
- **Tropical Asia-Pacific-Australia Representative:** Fatima Shirin *(India)*
- **Executive Officer:** Sheila Ward (non-voting, not elected) *(Puerto Rico, USA)*

Why join ISTF?

- Keep up-to-date on tropical forests around the world
- Information resources available on funding sources and other topics
- Get the word out on your work through ISTF publications, blog
- Develop collaborations and increase your achievement
- Webinars on forestry issues

ISTF Information Sources

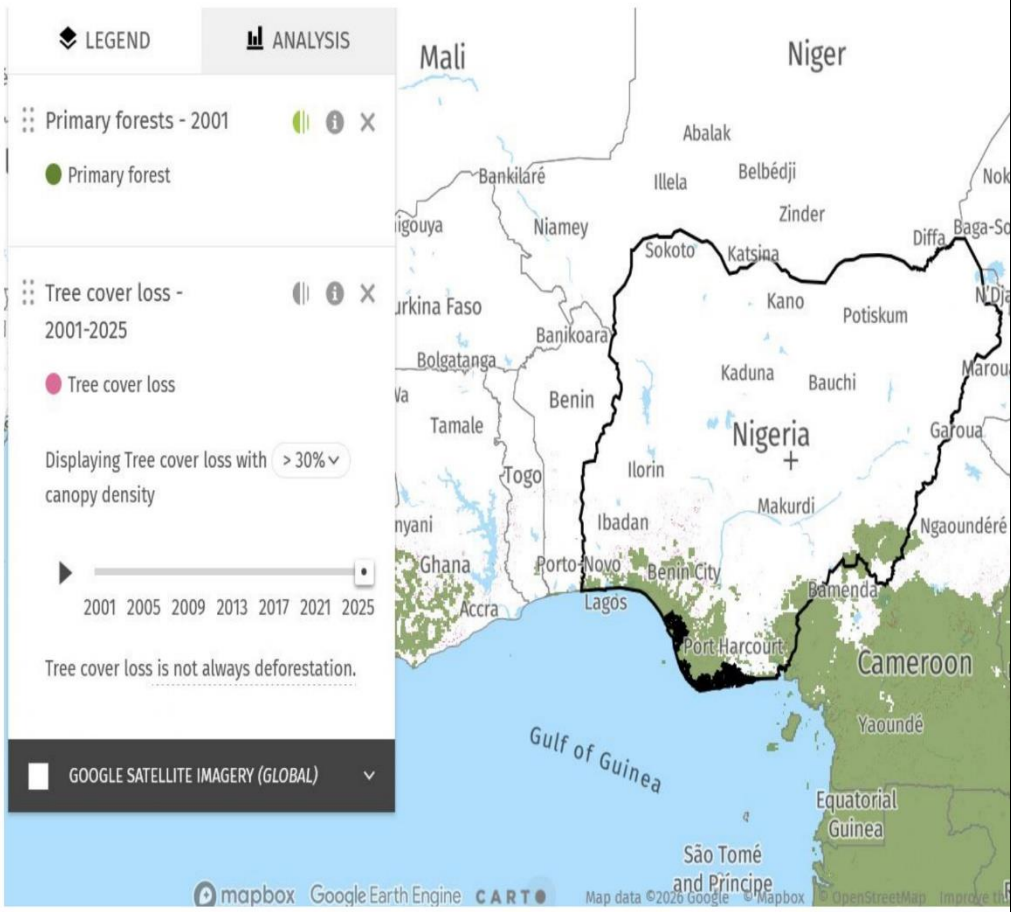
- ISTF Newsletter: https://drive.google.com/drive/folders/12_nPVrsJWJEJ9jV_E_wM8MJNEjr-v_gj?usp=sharing
- ISTF Update: https://drive.google.com/open?id=17giDrC5kek2H9QknllhvPICSOAXUQjwL
- ISTF Online Library: https://drive.google.com/drive/folders/1ahlZxeP-8WqPbIowfs_CGNsnuyDlX41D?usp=drive_link
- ISTF website: https://tropicalforesters.org
- ISTF Facebook group page: https://www.facebook.com/groups/2262122534/
- ISTF Linked-In group: https://www.linkedin.com/groups/12150640/
- ISTF twitter: @tropforester https://twitter.com/tropforester
- ISTF Bluesky: https://bsky.app/profile/tropicalforesters.bsky.social
- ISTF YouTube channel: https://www.youtube.com/@istf-global



Remaining primary forest in Nigeria 2025: < 4%

10-22% tree cover

https://www.globalforestwatch.org



UN Decade of Ecosystem Restoration 2021-2030

- Tropical countries have people with the will and the knowledge to improve forest and ecosystem sustainability.
- A major short fall is the funding to make this possible.
- ISTF-Global is trying to help with this in several ways:
  - Actively searching for various funding sources
  - Information on potential funders available at https://drive.google.com/drive/folders/1Zjfkjb1DBK80CEcUeQRRNGjzPL5xpr56?usp=sharing
  - Terra Viva Grants Directory

Terra Viva Grants Directory https://www.terravivagrants.org/

- Funding for projects and research remains a high hurdle for ISTF members and chapters.
- To this end ISTF has incorporated the Terra Viva Grants Directory, to assist in locating funding.
- TVG is directed towards developing countries
- TVG covers opportunities in agriculture, fisheries, forestry, biodiversity, conservation, wildlife, energy, climate change, and water resources.
- Funding News, Profiles of Grantmakers, and Simple Search on the website are open access.
- Funding Alerts, Monthly Updates, and Advance Search of the database are available with modest paid subscriptions.



KEYNOTE ADDRESS BY SECRETARY-CEO, AFRICAN FOREST FORUM NAIROBI, KENYA, PROF LABODE POPOOLA, AT THE 4TH ISTF INTERNATIONAL CONFERENCE THEMED "FOREST ECOSYSTEM CONSERVATION: A ROADMAP FOR RESILIENT ECONOMIES AND ENVIRONMENTAL SUSTAINABILITY" HELD AT OSUN STATE UNIVERSITY ON 19TH MAY, 2026

FOREST ECOSYSTEM CONSERVATION: A ROADMAP FOR RESILIENT ECONOMIES AND ENVIRONMENTAL SUSTAINABILITY

Labode POPOOLA
Professor of Forest Economics and Sustainable Development
Executive Secretary-CEO
African Forest Forum
Nairobi, Kenya
L.Popoola@cifor-icraf.org

UNIOSUN, Ejigbo Campus, May, 2026

Key Insights on Global Forests: FAO 2024 Report

Deforestation Reduction

Indonesia: 8.4% decline (2021-2022). **Brazil's Amazon:** 50% decline (2023). Global mangrove loss reduced by 23% from 2000-2020

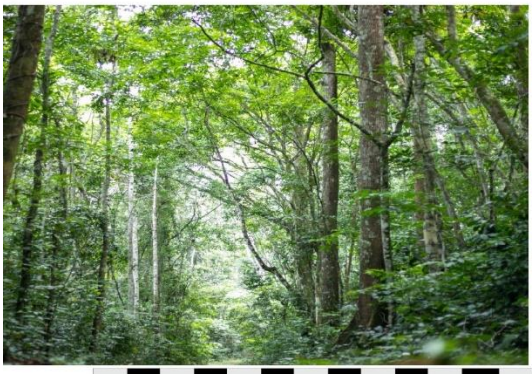
Wildfires & Emissions

Boreal forests contributed ~25% of wildfire CO_2 emissions in 2021

Global wildfire CO_2 emissions in 2023 reached 6,687Mt—exceeding EU fossil fuel emissions



FAO 2024 Report: Key Insights on Global Forests



Africa's Forests: Vital Global Resource

637 million ha of forests (16% of global); 446 million ha of wooded land (31% of global). African forests: crucial for CO_2 sequestration, supporting 500 million people, food security, livestock, and tourism

Global Trade of Forest Products

Non-timber products are essential to 6 billion people

Pine nuts, mushrooms, and truffles exports reached $1.8 billion in 2022

FAO 2024 Report: Key Insights on Global Forests



Wood Production & Demand

Record production at 4 billion m^3/yr; 49% of global wood harvested as woodfuel, rising to 90% in Africa.

Global roundwood demand could rise 49% by 2050, mainly for industrial use.

Forest Loss & Insect Impact

25 million ha of U.S. forests projected to lose 20% of basal area by 2027 due to pests

Summary of the outlook…

- **Deforestation and Degradation:** Tropical forests (Amazon, Congo Basin, Southeast Asia) continue to experience the highest rates of loss due to agriculture, logging, and infrastructure expansion.
- **Climate Change Impact:** Rising temperatures, droughts, and wildfires are intensifying forest vulnerability worldwide.
- **Regional Trends:**
  - **Africa:** Congo Basin forests face rapid clearing for agriculture and mining. Same trends have been observed in other African countries, including Nigeria
  - **Asia:** Southeast Asia struggles with palm oil expansion, though reforestation programmes in China show progress.
  - **Latin America:** Amazon deforestation remains high but Brazil has pledged stronger enforcement.
  - **Europe and North America:** Forests are relatively stable, with focus on sustainable timber and carbon storage.

It is worth noting that the informal sector is essentially a key part of "the private sector" in African forestry and must be accordingly involved in the development of an African forestry bioeconomy and trade.

The high proportion of informal and small-scale operators in Africa, with the presence of few global players, underlines the important role which these small and often informal operators have for African forestry, along with sustainable rural development.



A critically important fact is that in Africa the average percentage of forests under private ownership is only 6%, while 75% is under public ownership; and 19% has yet to have its ownership or data accuracy established. As regards private ownership, there are three sub-categories, namely:

i. forests owned by individuals (4%)

ii. forests owned by business entities or institutions (11%); and

iii. forests owned by local, tribal or indigenous communities (85%).

Only about 25% of Africa's forests have management plans, which is a serious gap. These statistics have an important bearing on:

a) the national planning and partners with whom investors can collaborate to move the industry forward, and

b) the key players in the sector.

The international dimension to the challenges of the forestry sector

To complicate these challenges, is the international dimension introduced by the European Union through its Regulation (EU) 2023/1115 of the European Parliament and of the Council of 31 May 2023.

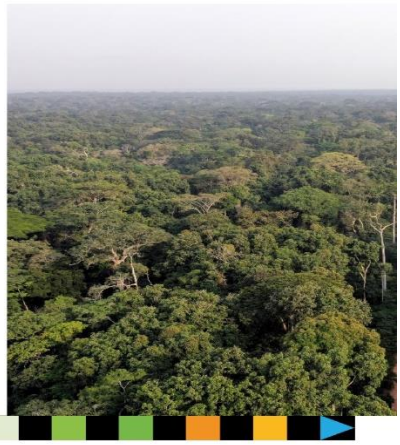
The EUDR bans making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010, entered into force 29 June 2023. Its provisions were to become applicable on 30 December 2024.

Among others, the EUDR prohibits placing or exporting products in/from the EU market that do not comply with its legality and sustainability requirements.

There have been global reactions, particularly from Africa and Asia, regarding the implications of the Regulation on trade between the EU and other continents, particularly, Africa.

The Challenges, the disconnect in the Forestry Sector

According to Africa European Centre for Investment and Trade (AECiT) (2023), in Africa, there is currently an average of 19% of total forested areas available for harvesting and processing forest products, although in West and Central Africa, the percentage is as high as 28%.



In the regions of Southern and Eastern Africa, whose vast natural hardwood forests get far less attention than those of the tropical rain forests of West and Central Africa, the percentage is 15%.

The natural dry forests of Africa, including the areas largely covered with mopane forests and the wooded savannahs, cover an area that is two and a half times the size of the Congo Basin rainforests, and supports many more millions of people than the latter, as well as being the location for many of the continent's major cities.

- Postponement is still under discussion and politically sensitive: The European Parliament and the Council of the EU must now agree on the proposed amendment. The S&D and Greens Groups have already expressed opposition, while right-wing factions are strongly in favour of the delay. There is also a chance that right-wing groups might push for additional amendments to weaken certain provisions of the regulation.
- On the Council's side, the Hungarian Presidency will decide which ministerial formation (Environment or Agriculture) will handle the discussions, as well as the timeline for deliberations. Most Member States are expected to support the delay.

A combination of the outlined challenges and disconnects, therefore, make the objective of increasing Africa's share in the global wood-based commodities trade a daunting task. Though daunting, these challenges are not insurmountable, considering the several and multiple opportunities that a sustainably planned, developed and managed forestry sector holds for Africa.

The international dimension to the challenges of the forestry sector

In reaction to this, the EU issued a statement to strengthen support for EUDR implementation and proposed extra 12 months of phasing-in time till December 2025, responding to calls by global partners.

The EUDR implementation has again been postponed, with large companies having to comply effective 30 December 2026, while small and micro enterprises have until **30 June 2027.**

It should be noted that as yet, the recently issued statement by the EU does not bring any reprieve to stakeholders outside of the European Union. For example:

- No policy reversal: The draft proposal delays enforcement but does not change the core rules. This postponement is presented as a means to facilitate smoother implementation and allow for better stakeholder preparedness for the EUDR.

The international dimension to the challenges of the forestry sector

To complicate these challenges, is the international dimension introduced by the European Union through its Regulation (EU) 2023/1115 of the European Parliament and of the Council of 31 May 2023.

The EUDR bans making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010, entered into force 29 June 2023. Its provisions were to become applicable on 30 December 2024.

Among others, the EUDR prohibits placing or exporting products in/from the EU market that do not comply with its legality and sustainability requirements.

There have been global reactions, particularly from Africa and Asia, regarding the implications of the Regulation on trade between the EU and other continents, particularly, Africa.

The Opportunities

The expanding demand for forest products

According to FAO (2024), wood-use efficiency increased by 15 percent between 1961 and 2022. Given rapidly changing environmental conditions and rising demands on forests, more innovation is needed in the forest sector to actualize these opportunities.



Key findings of Lock *et al's* study indicate that:

- Global consumption of roundwood is likely to increase by about 10% to 2.2 billion cubic metres by 2030, supported by strong economic and population growth in Asia. Similarly, woodchip consumption is also expected to increase by about 40% to 350 million cubic metres by 2030.
- Globally, the sustainable harvest of existing wood fibre resources is expected to be sufficient to meet rising global consumption up to 2030, with wood prices increasing modestly at a rate of 1% annually in nominal terms.
- Large shifts towards imports of roundwood and woodchips in Asia are expected by 2030 as the sustainable yield of local supplies reach capacity. It is expected that these imports will be supplied by producers in Europe and North America, increasing the amount of interregional trade in global wood markets.
- Roundwood production and exports from Australia and New Zealand are expected to be stable and remain constrained by the sustainable yield of existing forest resources.

Three imperatives will drive such innovation:

a. escalating stressors, including climate change, which will require new forest and land management approaches;

b. the shift towards a bioeconomy in which wood will be a major input; and

c. the opportunities offered by the vast range of non-wood forest products for potentially billions of smallholders.

d. New values or recently recognized old values of forest (carbon credit, biodiversity credit etc)

The demand for wood and other forest products continues to show opportunities for a viable forestry sector. According to Lock *et al* (2021) international trade in wood products has become increasingly important over the past 30 years. Global wood products trade increased 143% to US$244 billion between 1990 and 2019 (FAO 2021). The largest contributor to this expansion in trade has been economic growth and demand from China with imports of wood products to the country increasing by 760% to US$49 billion (FAO 2021).

Market Overview

Market Growth and Value: The global wood market valued near USD 992 billion in 2024, projected to reach USD 1,251 billion by 2030 with a 4.7% Compound Annual Growth Rate.

Furniture and Packaging Demand: Furniture and packaging sectors drive high demand for solid and engineered wood, promoting eco-friendly paper products.

Engineered Wood Innovations: Innovations like cross-laminated timber and glulam offer sustainable alternatives to steel and concrete in construction.

Urbanization Driving Demand: Rapid urbanization boosts demand for timber in housing and infrastructure development worldwide.

Green Buildings: In some European countries such as Sweden, it is now common to see whole wood multi-storey buildings.





Figures 1 and 2: Trends in wood demand by regions and selected countries. Source: Lock *et al* (2021)

Figures 1, 2 and 3 capture the trends in projected wood demand:

Though the study was largely silent on Africa, the continent's population growth and modest advances towards industrialization will demand substantial amounts of wood and fibre.

The question is, will Africa take advantage of this opportunity?

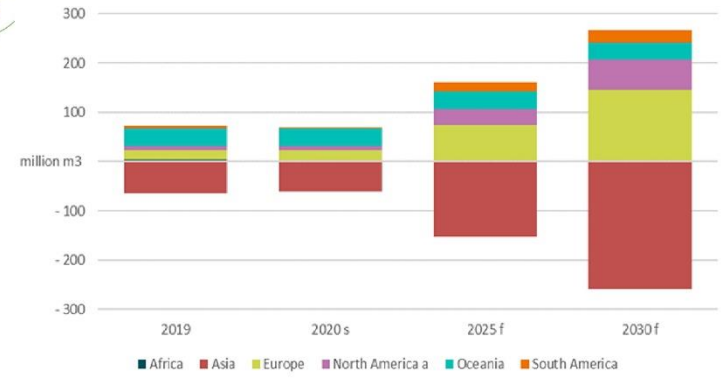


Figure 3: The growing roundwood production deficit in Asia from 2020 to 2030 is expected to be met by increased roundwood exports from Europe and North America. Source: Lock *et al* (2021)

The report also shows the growing roundwood deficit in Asia, which Africa can also cautiously take advantage of (see figure 3)

Forests and Bioeconomy

- The growing global interest in bioeconomy also offers great opportunities to the forestry sector in Africa. Forests are a foundation of a green economy sustaining a wide range of sectors and livelihoods.
- Forests improve people's wellbeing in numerous ways: directly by providing resources for basic needs such as energy, shelter and food; and indirectly by providing the ecological foundations for GDP in many other sectors: agriculture, tourism, water supply, health etc.
- Considerable attention is being given now to the role of forests in climate change mitigation under the banner of REDD+. This can also be an entry point for recognising the various non-marketed or under-valued services that forest landscapes provide beyond climate change mitigation.
- There is also a growing demand for eco-friendly products. Its roles and advantages in sustainable pulping process are summarized in figure 4:

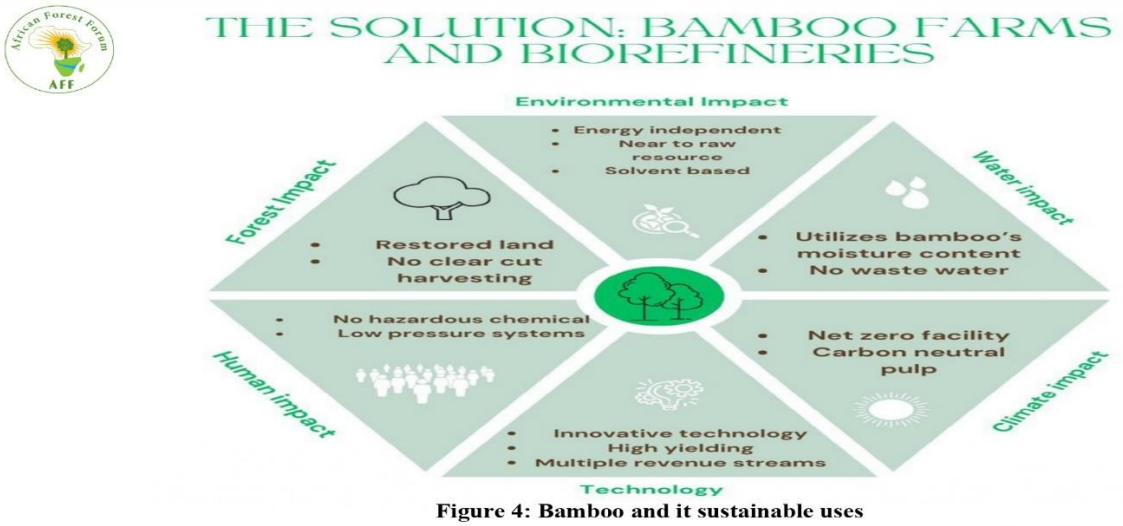


Figure 4: Bamboo and it sustainable uses

The burgeoning Youth Population as change agent in sustainable forestry development and management

By 2050, Africa's youth population is projected to double to over 830 million. The OECD reports that by the same year, the continent's working-age population (15-64 years old) will rise from 849 million in 2024 to 1.56 billion, accounting for 85% of the global workforce increase

In a 2024 African Youth Survey, conducted by PSB Insight indicates that despite the challenges they face, the entrepreneurial spirit of African youth shines as a beacon of hope and potential

An impressive 71% of young Africans plan to start their own business within the next five years, reflecting a strong desire to take control of their economic futures and contribute to their countries' development





- Directing the attention of the youth to the forestry sector, which is Africa's future gold can have positive impact on landscape restoration and sustainable development of the continent
- Young people bring new ideas and far-reaching ambition that can help conserve African forests, sustain efforts on reforestation, and slow down the alarming rate of deforestation and land degradation
- When empowered, they can build climate resilience and adaptive capacity in their communities even though they are among the most vulnerable populations which will be overly affected by climate change
- By harnessing their potential, resilient communities that prioritize environmental stewardship can be nurtured while promoting the broader societal goals of peace, security, and forest bioeconomy for sustainable development

The African Continental Free Trade Area (AfCFTA)

Africa is big! She has huge potential for the supply of forest and tree resources, just as it has the capacity to consume them. Over the years, however, there have been a lot of impediments to free trade within the continent

The African Continental Free Trade Area Agreement tends to portend good omen towards creating trade opportunities between and among African countries

The concept of free trade is hinged mainly on the theory of comparative advantage. According to its proponents, free trade policies generally promote the following features:

- Trade creation owing to no barriers
- Increased exports
- Economies of scale
- Increased competition
- Making use of surplus raw materials

Global forest products

Trade in forest products may constitute veritable friendship cords and serve as an international currency puller in Africa

They attract currency and are the most internationally distributed commodities. For example, as far back as 1970, Nigeria's petroleum products attracted 21 international currencies, while timber products were sold to 34 countries

This confirms that a well-planned and developed forestry sector holds great potential in sustainable intra-continental trade in Africa, with positive impacts on the economies of both producing and consuming countries

Figure 5 shows movements of forest products, particularly wood within the ECOWAS sub-region

Figures 6, 6.1 and 6.2 show different dimensions of trade. This intra Africa trade, if properly harnessed, will improve the GDPs of the member countries

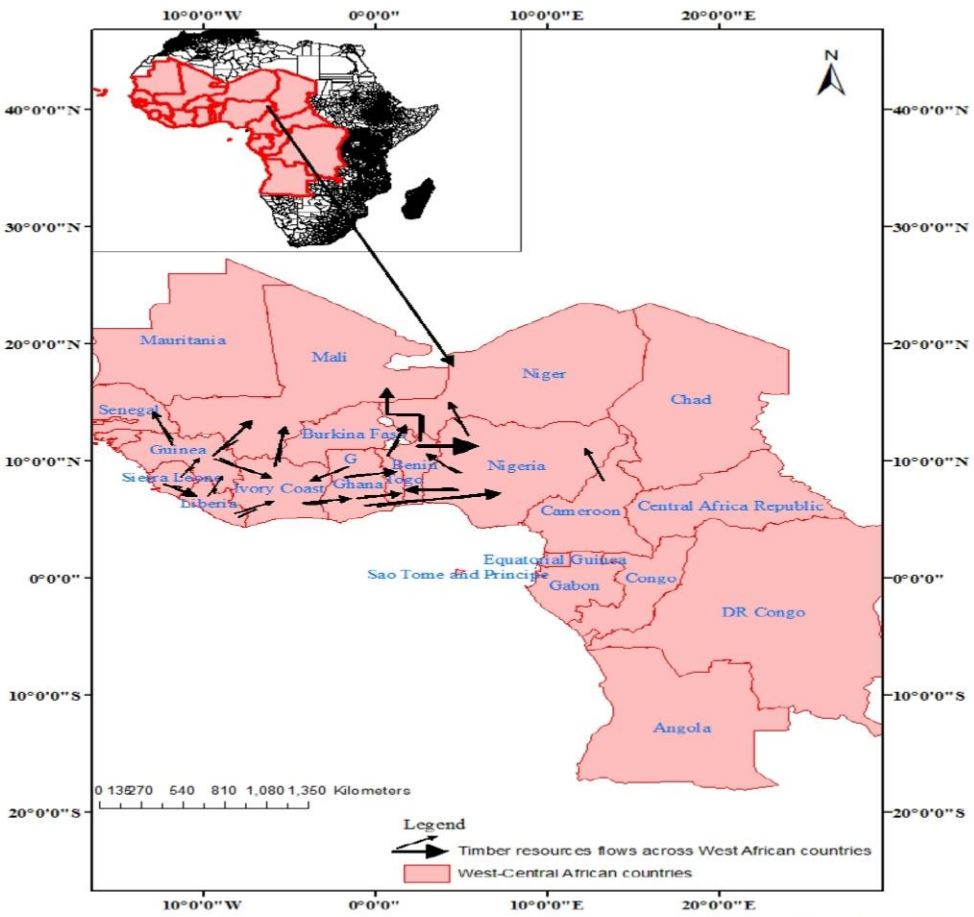
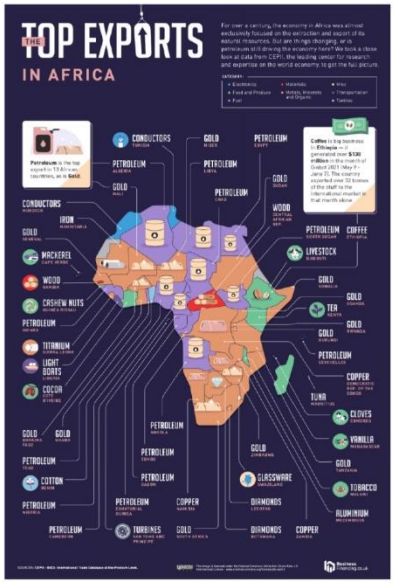
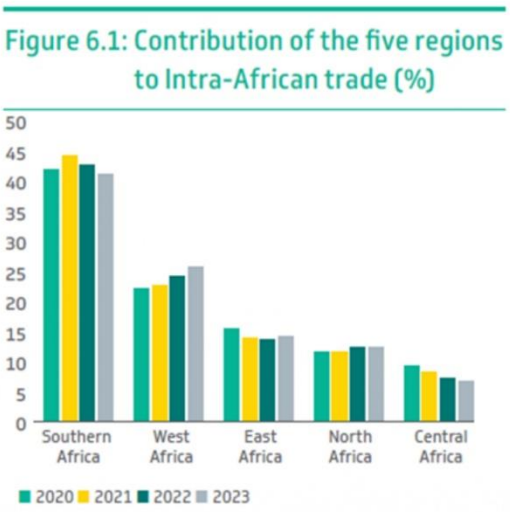
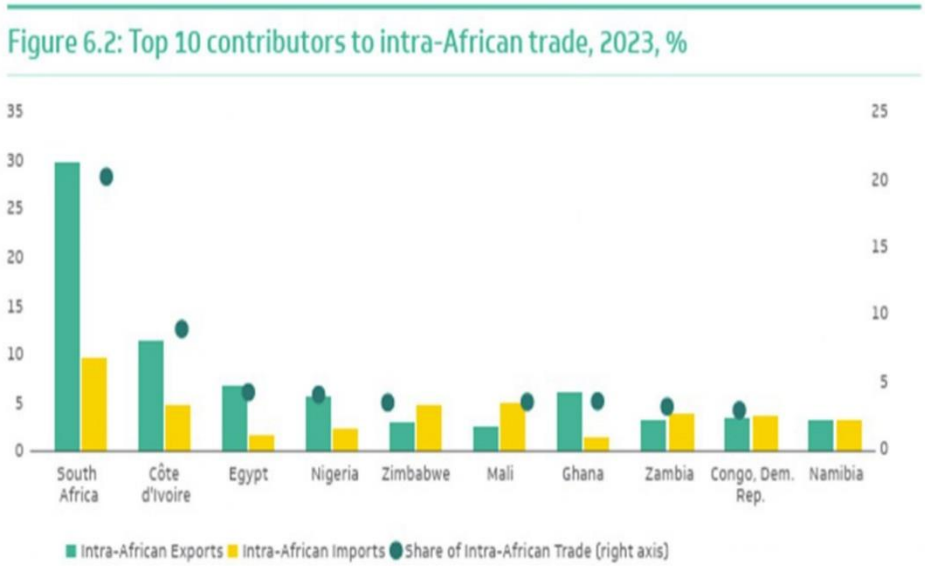


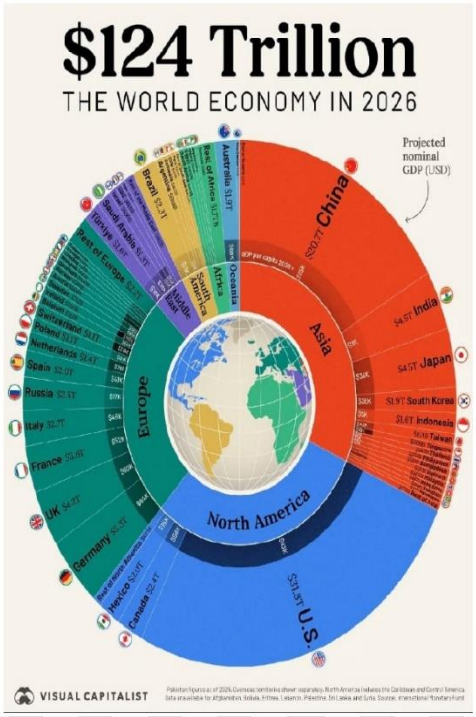
Figure 5: Timber trade routes within West Africa

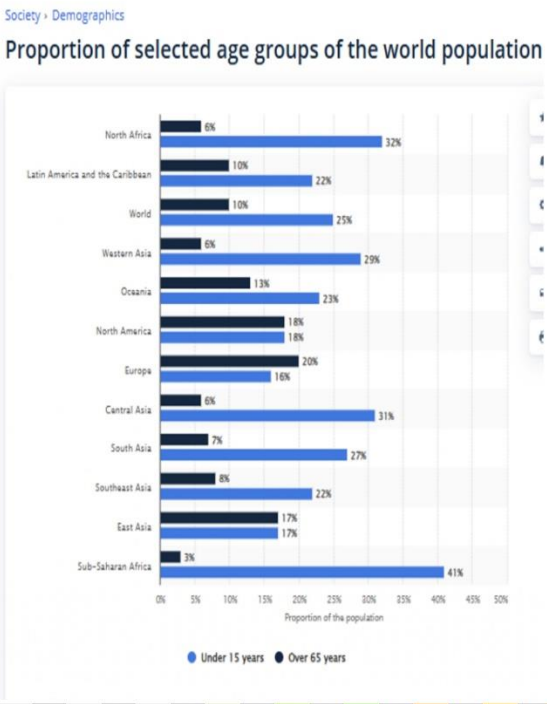

TOP EXPORTS
IN AFRICA


Figure 6.1: Contribution of the five regions to Intra-African trade (%)
50
45
40
35
30
25
20
15
10
5
0
Southern Africa
West Africa
East Africa
North Africa
Central Africa
2020 2021 2022 2023

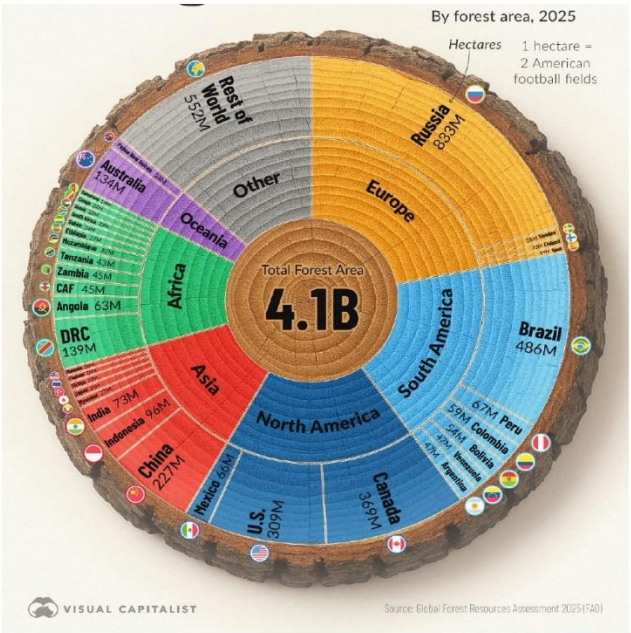

Figure 6.2: Top 10 contributors to intra-African trade, 2023, %
35
30
25
20
15
10
5
0
25
20
15
10
5
0
South Africa
Côte d'Ivoire
Egypt
Nigeria
Zimbabwe
Mali
Ghana
Zambia
Congo, Dem. Rep.
Namibia
Intra-African Exports
Intra-African Imports
Share of Intra-African Trade (right axis)
Sources: International Monetary Fund Direction of Trade Statistics, Afreximbank Research.

A Conundrum or Opportunity





Top 35 Countries with the Largest Forests



Understanding Conservation and it roles

Conservation is a controversial subject, depending on which side of the divide one is. It may be defined in several ways:

- As a continuing protection and development of natural resources such as soil, water, forest, wildlife, fish, energy, minerals and other materials in accordance with principles that ensure their optimum economic and social enjoyment.
- The pattern of natural resource use which fosters their maximum contribution to the sustained long term improvement to the quality of life of the majority of the people for the longest time.

Conservation...

May be defined as the optimum allocation of natural, human and cultural resources in the scheme of national development whereby economic and social security will be assured.

- It may be defined as the redistribution of natural resource use in the direction of the future where as depletion is the re-distribution of natural resource use in the direction of the present.

It may be defined as a wise use of natural resources to secure perpetual enjoyment by society.

Conservation may be defined as the optimum utilization of natural resources, consistent with the maintenance of a minimum set standard of quality of environment.

Problems in Resource Conservation

That the subject of conservation is controversial means there are problems. These include:

- ✓ Poverty - It is difficult for a poor society to conserve.
- ✓ Common property rights as a characteristic of natural resources. This causes a lot of problems. Everybody's property is nobody's property
- ✓ Market Imperfection.
- ✓ Ignorance and forces of custom of a society.

Some arguments against conservation

- Conservation ignores the role of technology and substitutes in increased consumption and development.
- Conservation involves an opportunity cost in terms of consumption denied of the present generation
- Better to consume now to create an affluent society that can ensure future prosperity. An argument in this direction is: can poor people give birth to rich children? In other words, if the present society is rich, the future is almost certainly bound to be rich
- There is inadequate economic information about future consumption possibilities and utility.

Arguments in favour of conservation

- The need to sustain a high living standard or material welfare for present and future generations.
- Preservation of High Quality environment.
- The need to provide for the future
- Protection of the Public Interest (Common property).

Overcoming the conundrum

i. Moving from supply chain to value chain

Timber trade has over the years been based on the supply of raw logs and/or rough-sawn logs (Plates 1 a, b, c and d). Some African governments have banned the export of unprocessed logs of indigenous species and rough-sawn lumber to protect supplies of round wood to the local market, which has been expanding fast because of increase in local purchasing power and expansion in the construction industry. However, much of this trade has not been properly controlled, so it is difficult to assess the volumes that are extracted and exported with any accuracy. The trade was also fraught with a lot of irregularities that did not make accounting easy. **The need to move business from supply chain to value chain is, therefore, an economic imperative to overcome the conundrum**

Plates 1a: A derelict sawmill in Ijebu Ode, Nigeria Plate 1b: Chainsaw milling in Cross River State in Nigeria





Plates 1c and d: Semi-processed wood and Teak logs ready for export





Unfortunately, teak plantations are apparently being devastated as a consequence of this trade. The economic implications of this include exportation of jobs, poor growth and development of wood-based industry and the ascendancy of chain saw milling/flitching, an environmentally and economically wasteful process.

ii. Forest-based Bioeconomy in practice

Opportunities in forest bioeconomy are limitless for Africa. Forest-based bioeconomy presents viable pathways for the conservation and sustainable use of natural resources, while simultaneously supporting communities, livelihoods and economic growth. Forest product value chains provide promising opportunities for upscaling the sustainable forest-based bioeconomy in Africa in such sectors as construction, manufacturing, services, agriculture, energy, and health among others. Upscaling the forest-based bioeconomy will require:

a. safeguarding any bioeconomy-related interventions against the potential creation of harm or negative impact;

b. implementing holistic enabling policies, including targeted incentives;

c. acknowledging the value of forests in all its functions;

d. putting local communities in the heart of any engagement, including gender aspects; and

e. engaging with youth to develop new and viable job opportunities.

Private investment in plantation establishment will bring efficiency into the enterprise, reduce fraud, and lead to appropriate pricing of products from such plantations. Such investments should be long term, targeting the youth for employment and wealth creation. It will also encourage industrial forestry, value addition and sustainable development.

In several parts of the world, plantation development is tending towards the private sector. Private forest ownership plays a significant role in Japan (59%), Europe (55%), North America (37%), and New Zealand (31%).

Suggested policies and strategies that can encourage private participation in forestry in Africa may include:

- ✓ Extension of legal recognition and state protection to private forest estates;
- ✓ Clearly stated policies indicating the direction in which the state wants management of private forests to proceed;

iv. Forest investment, Financing and private participation

Private participation is key, particularly in commercial plantation establishment. South Africa has demonstrtaed this commendably.

To increasing Africa's share in the global wood-based commodities trade, it will be ill-advised for governments to continue to invest in plantation development. Providing enabling environment for the private sector to thrive is considered more appropriate.

Experience over the years has indicated that the returns have been negative on investment in public plantation development. It is fraught with fraud right from the stages of planning, establishment, management to harvesting. It only benefits a few individuals who have little or no stake in such investment and enterprise.

iii. Deforestation-Free Forest-Based Value Chains Development

Forests are not just ecological assets but also resources that meaningfully contribute to:

- Employment opportunities and income increment
  - If structured well, forest-based value chains can generate decent green and scalable jobs, for the youth and poor especially in rural areas
    - Direct jobs – forestry, restoration, processing/industries, trade, , etc.
    - Indirect jobs – transport, logistics, equipment and service providers, certification and compliance services, etc.
- Rural transformation and national economic development
  - Vibrant forestry sector induces expansion of entrepreneurship and local services
- Sustainable land management and improved environmental services
  - Reducing deforestation helps conserve natural capital such as soil and water – key natural resources

➔Sustainably managed and effectively utilized forests help maintain and strengthen the interconnection between environmental and socioeconomic goals…



- ✓ Making specific pronouncements concerning land acquisition under Land Use Statutes/Laws for forest plantation establishment as against the general provisions for agriculture;
- ✓ Designing and implementation of a package of incentives for would-be investors in private forestry. These may include tax holidays, national merit awards among others.

Governments must move in the direction of empowering the private sector to own and embark on commercial and private forest plantation investment, with the public sector only playing monitoring and supervisory roles to enhance standards.

Summary of suggested pathways…

- **Decision on *what* to trade and *where*: segmentation of product (product types) & market (intra Africa, regional, global)**
- **Mapping the legality & sustainability *gateways* (what buyers check, the rules of the trade)**
- **Designing AfCFTA-ready supply chain (origin & documentation)**
- **Country-level movement & export controls: plan for permits**
- **Logistics & ports: move from forest to buyer efficiently**
- **Finance & risk: de-risk the trade**
- **Promote Innovation and Diversification**
- **Build Green Forest-Based Industries**
- **Strengthen Forest Governance and Land Tenure**
- **Enable Youth-Centered Green Employment**
- **Develop Market Systems and Certification**
- **Align Agriculture and Forestry**
- **Mobilize Finance for Green Value Chains**
- **Strengthen Data, Monitoring, and Innovation**
- **Build Partnerships – across sectors nationally and with relevant actors internationally**

Building Resilience for ecosystem conservation

- Why build resilience?
- Resilience becomes an issue when sustainability is challenged by change. Resilient systems deal with the disturbance or stress, the tendency to depart from normal, caused by change, by adapting in such a way that their basic structures and ways of functioning are retained. This is achieved through the possession of a capacity for learning and adjusting, and a capacity for self-organization (Okali, 2012).

Resilience...

- Building resilience requires us to have a working understanding of sustainability, the nature of change, vulnerability of systems to change, the meaning and desirable features of adaptation and the main attributes or characteristics of resilience
- Three main attributes characterize resilience:

(a) Buffer capacity

- Diversity of livelihood options;
- Raised human capital endowments
- Improved rights and access to livelihood resources
- Improved incomes
- Enhanced site specific knowledge;
- Policies that serve as incentives;
- A tendency towards stewardship, rather than just exploitation;
- Enhanced environmental benefits.

(b) Self Organization

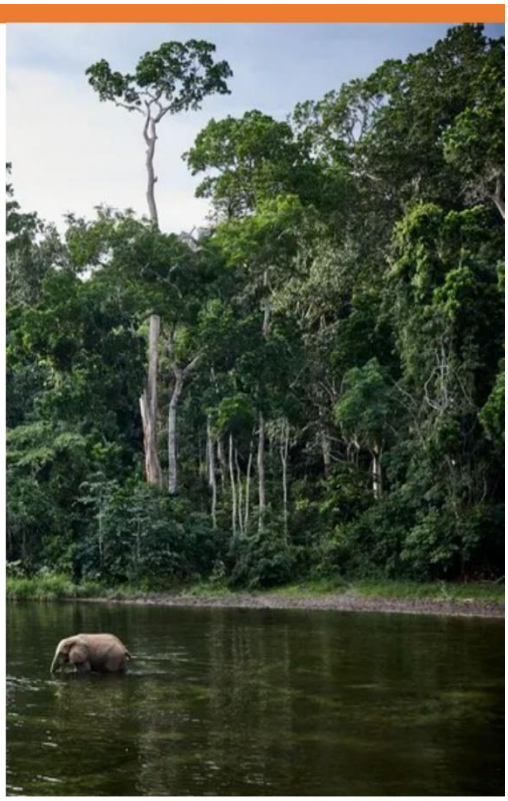
- Dependence on local resources;
- Cooperation and networking among components of the system;
- Ownership of resources;
- Degree of dependence on indigenous knowledge;
- Flexibility in decision making.

c. Increasing Adaptive Capacity:

- Opportunities for knowledge combination, promoted by existence of a variety of learning platforms
- Functioning feedback mechanisms: especially among stakeholders – farmers, extension officers, researchers, policymakers,
- Narrowing of power differentials
- Reliance on indigenous knowledge.

Actionable Recommendations

- **Governments:** Provide incentives for local forest production, processing industries and enforce sustainable forestry laws.
- **Private sector:** Invest in plantations, modern mills, furniture factories, and certification programmes.
- **Regional bodies:** Use AfCFTA to harmonize tariffs and standards and trust and confidence building.
- **International partners:** Support training, technology transfer, green financing, sincere and equitable partnership and cooperation for sustainable forest management and trade.



THANK YOU

www.afforum.org



GOODWILL MESSAGE BY THE DIRECTOR-GENERAL/CEO, FORESTRY RESEARCH INSTITUTE OF NIGERIA (FRIN), PROF. ZACHARIA BUBA YADUMA, AT THE 4TH ISTF INTERNATIONAL CONFERENCE THEMED "FOREST ECOSYSTEM CONSERVATION: A ROADMAP FOR RESILIENT ECONOMIES AND ENVIRONMENTAL SUSTAINABILITY" HELD AT OSUN STATE UNIVERSITY ON 19TH MAY, 2026

Protocols,

It gives me great pleasure to extend warm greetings to the organizers, distinguished participants, researchers, policymakers, development partners, students, and all stakeholders gathered here today for the 4th ISTF International Conference hosted by Osun State University.

The theme of this conference, *"Forest Ecosystem Conservation: A Roadmap for Resilient Economies and Environmental Sustainability,"* is particularly important, especially at a time when the world faces serious environmental challenges such as climate change, deforestation, flooding, and biodiversity loss.

Forests remain indispensable to human survival and national development. Beyond their ecological functions, forests contribute significantly to economic growth, climate regulation, food security, energy supply, livelihoods, and biodiversity preservation. Sustainable forest management is therefore not merely an environmental obligation but a strategic pathway toward building resilient economies and securing a sustainable future for generations yet unborn. As the apex forestry research institution in Nigeria, FRIN remains committed to advancing scientific research, innovation, capacity development, and evidence-based policy support to promote sustainable conservation and utilization of forest ecosystems. We recognize that achieving environmental sustainability requires strong collaboration among academic institutions, government agencies, local communities, international organizations, and the private sector.

I want to sincerely commend the International Society for Tropical Forestry (ISTF) and Osun State University for providing this important platform for intellectual exchange and interdisciplinary dialogue. I am confident that the discussions and ideas shared here will contribute greatly to sustainable development in Nigeria and beyond. I encourage participants to maximize this opportunity by engaging in productive discussions, sharing innovative ideas, and developing actionable strategies to enhance forest conservation, climate resilience, and sustainable economic development across Africa and beyond.

On behalf of the management and staff of FRIN, I wish you all a successful and fruitful conference.

Thank you, and God bless.

Prof. Zacharia Buba Yaduma
Director-General/CEO
Forestry Research Institute of Nigeria

FOREST POLICY AND GOVERNANCE FOR SUSTAINABLE FOREST MANAGEMENT TOWARDS THE NATION'S ECONOMIC DEVELOPMENT

Zira, B.D
Department of Forest Resources and Wildlife Management
Federal University of Agriculture, Mubi
zirabamidele@fuamb.edu.ng

A lead paper presented at the 2026 Annual Conference of the International Society of Tropical Foresters-Nigeria, ISTF
Date: 19th to 21st May, 2026.

Abstract
Nigeria's forestry sector remains significantly underutilized despite its vast natural endowment and potential contribution to economic diversification. With an estimated annual forest loss of approximately 400,000 hectares, Nigeria ranks among the countries with the highest deforestation rates globally. Paradoxically, the sector contributes less than 1% to Gross Domestic Product (GDP), while the country continues to export low-value raw timber and import high-value processed wood products. This study examines the structural inefficiencies, governance failures, and institutional constraints limiting the sector's performance. Anchored in green growth and natural capital theory, the paper reframes forests as strategic economic infrastructure. It proposes a three-pillar reform framework: fiscal transparency, expansion of the industrial value chain, and monetization of ecosystem services. The study concludes that with appropriate policy reforms, Nigeria's forestry sector could contribute between 5% and 7% of non-oil GDP within a decade while enhancing climate resilience and rural livelihoods.

Keywords: Sustainable Forest Management, Forest Governance, Green Economy, Nigeria, Natural Capital, Value Chain Development

1.0 Introduction
Nigeria is currently losing close to 400,000 hectares of forest annually, representing One of the fastest deforestation rates globally (Food and Agriculture Organization [FAO], 2020). Despite this vast natural resource base, the forestry sector contributes less than 1% to national GDP, reflecting a significant disconnect between resource endowment and economic performance (World Bank, 2021). Structural inefficiencies within the sector further exacerbate this paradox. Nigeria exports raw timber at relatively low prices while importing high-value processed wood products such as furniture, plywood, and paper. This pattern reinforces a primary commodity export trap, in which countries derive minimal value from their natural resources while depending on imports for finished goods (Sachs & Warner, 2001).

Additionally, Nigeria loses an estimated ₦200–300 billion annually due to illegal logging, weak revenue systems, and governance inefficiencies (Federal Ministry of Environment, 2022). These losses highlight systemic failures in monitoring, enforcement, and institutional coordination. Beyond economic implications, deforestation contributes significantly to climate vulnerability, including desertification in northern regions, flooding in southern zones, and declining agricultural productivity (NBS, 2023). Forest ecosystems provide essential services such as carbon

sequestration, soil protection, and watershed regulation, all of which are critical for sustainable development.

This paper, therefore, aims to:

i. examine the structural and governance challenges in Nigeria's forest sector;
ii. reframe forests as strategic economic assets within national development planning;
iii. propose a practical reform framework for achieving Sustainable Forest Management (SFM).

The central argument is that SFM must be repositioned as a strategic economic instrument, rather than a conservation obligation.

2.0 Conceptual and Theoretical Framework

This study is anchored in the interrelated frameworks of green growth, natural capital accounting, and resource governance. The concept of green growth posits that economic development can be pursued in a manner that simultaneously ensures environmental sustainability and resource conservation (OECD, 2011). It underscores the possibility of decoupling economic expansion from environmental degradation through efficient resource use and sustainable policy interventions. Natural capital theory further strengthens this perspective by viewing forests as valuable economic assets capable of generating both direct and indirect returns. Beyond timber production, forests provide critical ecosystem services such as carbon sequestration, biodiversity preservation, and watershed regulation, all of which have quantifiable economic value (Costanza *et al.,* 2014).

Empirical studies from countries including Indonesia, Brazil, and Ghana indicate that robust forest governance systems can significantly improve macroeconomic performance by increasing contributions to GDP, boosting export revenues, and generating employment opportunities (FAO, 2020; World Bank, 2021). For example, the adoption of advanced monitoring technologies, such as satellite-based surveillance in Brazil, has enhanced regulatory enforcement and contributed to a reduction in illegal deforestation (Nepstad *et al.*, 2014). In contrast, Nigeria's forestry sector continues to face significant challenges, including weak institutional capacity, low levels of value addition, and inadequate integration into broader national economic planning frameworks. These limitations hinder the sector's potential to contribute meaningfully to sustainable economic development.

3.0 State of Nigeria's Forest Sector

Nigeria's forest ecosystem has undergone a severe and continuous decline over the past decades. Forest cover, which was above 25% in the 1960s, has reduced sharply to about 10–12% in recent years, leaving an estimated 9.6 million hectares of forest land (FAO, 2020). This reduction is largely driven by agricultural expansion, rapid urbanization, infrastructure development, and households' heavy reliance on fuelwood as a major energy source. Energy dependence on forests remains particularly high in rural areas, where more than 70% of households rely on fuelwood for cooking and heating (International Energy Agency [IEA], 2022). This widespread dependence reflects persistent energy poverty and continues to exert unsustainable pressure on forest resources, contributing significantly to deforestation and forest degradation.

The forestry sector is also characterized by weak governance structures and a largely informal operational framework. It is estimated that over 80% of timber extraction occurs outside formal regulatory and monitoring systems (World Bank, 2021), leading to uncontrolled exploitation of forest resources, loss of government revenue, and limited enforcement of sustainable forest management practices. In addition, Nigeria spends more than ₦750 billion annually on the importation of wood-based products (National Bureau of Statistics [NBS], 2023), indicating a weak domestic capacity for wood processing and value addition.

The combined effect of these challenges has several important implications for national development, including:
i. Significant loss of potential public revenue;
ii. Continued exportation of low-value raw timber instead of processed wood products;
iii. Weak job Creation and limited rural employment opportunities;
iv. Progressive degradation and depletion of national natural capital.

4.0 Governance Failures and Institutional Constraints

Outdated legal frameworks, fragmented institutional arrangements, and weak enforcement capacity constrain Nigeria's forestry governance system. These structural weaknesses have significantly limited the effectiveness of sustainable forest management and regulatory compliance across the sector. Forest governance responsibilities are largely decentralized among the 36 states of the federation, resulting in fragmented policy implementation, inconsistent regulations, and weak coordination between federal and state forestry institutions (Federal Ministry of Environment, 2022). In practice, the Federal Department of Forestry has limited enforcement authority, which undermines its ability to ensure uniform national standards for forest conservation, timber harvesting, and trade regulation.

A major institutional gap is the absence of a functional national timber traceability system. This allows illegally harvested timber to circulate within formal markets with little or no accountability. In contrast, countries such as Indonesia have adopted robust timber legality verification and traceability systems that have significantly improved transparency, reduced illegal logging, and strengthened forest governance (FAO, 2020). In addition, several systemic constraints continue to weaken governance effectiveness in Nigeria’s forestry sector. These include:

i. corruption and rent-seeking behaviours that distort resource allocation and enforcement;
ii. inadequate and inconsistent funding for forestry institutions and conservation programs;
iii. limited technical and operational capacity among forestry personnel;
iv. Minimal inclusion of local communities in decision-making processes and benefit-sharing mechanisms.

Collectively, these governance failures undermine sustainable forest management, reduce sectoral efficiency, and significantly constrain revenue generation and long-term ecological sustainability.

5.0 Reframing Forests as Economic Infrastructure

Forests should be reconceptualized as strategic economic infrastructure rather than merely environmental assets, given their extensive and interlinked contributions across multiple sectors of the economy. This reframing is essential for repositioning forestry within national development planning and investment priorities.From an industrial perspective, forests serve as a foundational input base for key manufacturing subsectors, including construction, furniture production, pulp

and paper industries, and emerging bio-based materials. The availability and sustainable management of forest resources directly influence industrial output, import substitution potential, and overall value-chain competitiveness.

The forestry sector has significant capacity to create both direct and indirect jobs across its entire value chain. These include activities in forest establishment, harvesting, transportation, primary processing, secondary manufacturing, and marketing. When effectively managed, the sector can function as a major rural employment engine, particularly for youth and women in forest-adjacent communities. Ecologically, forests provide essential ecosystem services that underpin economic productivity in other sectors such as agriculture, energy, and water resource management. According to ecosystem valuation studies, these services, including carbon sequestration, soil conservation, water regulation, and biodiversity maintenance, constitute measurable components of natural capital that contribute significantly to long-term economic stability (Costanza *et al.,* 2014), particularly the work of Robert Costanza.

Furthermore, integrated land-use systems such as agroforestry enhance agricultural productivity, improve soil fertility, and increase resilience to climate variability. In addition, forest biomass is a viable, renewable energy source that can support Nigeria's transition toward cleaner, more diversified energy systems, thereby reducing pressure on fossil fuels and reliance on traditional fuelwood. Overall, forests should be recognized as multi-dimensional economic assets whose sustainable management can simultaneously drive industrial growth, rural development, environmental stability, and national economic transformation.

6.0 Reform Framework for Sustainable Forest Management

Transforming Nigeria’s forestry sector into a sustainable, revenue-generating, and climate-resilient economic system requires deep institutional, fiscal, and industrial reforms. The proposed framework is anchored on three mutually reinforcing pillars: fiscal transparency and governance reform, industrial and value chain expansion, and ecosystem service monetization. Together, these reforms aim to reposition forests as productive national assets rather than underutilized natural resources.

6.1 Fiscal Transparency and Revenue Reform

Weak accountability systems, fragmented collection processes, and significant revenue leakages at multiple administrative levels currently characterize forestry revenue administration in Nigeria. In many states, timber charges, logging fees, and royalty payments are still processed manually, creating opportunities for underreporting, misappropriation, and informal transactions. A major reform priority is the full digitization of forestry revenue systems. This includes developing integrated digital platforms for logging permits, transport documentation, stumpage fees, and licensing processes. Such systems should be directly linked to the national financial infrastructure to enable real-time monitoring and automatic revenue reconciliation.

A critical complementary reform is the integration of all forestry revenues into the Treasury Single Account (TSA) system. This would significantly reduce the fragmentation of public funds, improve transparency, and enhance fiscal discipline across federal and state forestry agencies. It would also strengthen audit trails and reduce opportunities for corruption and rent-seeking. In addition, the introduction of blockchain-based or barcode-enabled timber-tracking systems could further improve accountability by ensuring that every log is traceable from its forest origin to its

final market destination. When combined with enforcement mechanisms and inter-agency collaboration, these reforms could dramatically improve compliance levels.

Empirical projections indicate that improved governance and digitalization could increase annual forestry revenues from approximately ₦5 billion to between ₦50 billion and ₦ 80 billion. Beyond revenue gains, these reforms would also strengthen investor confidence and improve Nigeria's international credibility in sustainable forest governance.

6.2 Industrial Development and Value Chain Expansion

Nigeria's forestry sector remains heavily skewed toward primary production, with limited domestic processing capacity and low levels of value addition. At present, the country captures only about 10–15% of the total value of the forestry value chain. In contrast, the majority of value is lost through raw log exports and the importation of finished wood products. A central reform strategy is the gradual implementation of a phased restriction on raw log exports. This policy would incentivize domestic processing and encourage investment in downstream industries such as sawmilling, plywood production, furniture manufacturing, particleboard production, and the pulp and paper industry. Such a transition would enable Nigeria to shift from a raw material exporter to a value-added producer.

To support this transition, targeted industrial financing is essential. Development finance institutions, particularly the Bank of Industry, should be strengthened to provide concessional loans, credit guarantees, and long-term financing for forestry-based enterprises. Special credit windows for youth and women-led enterprises in the wood processing sector would also enhance inclusivity and employment generation. Furthermore, establishing dedicated forestry industrial clusters and wood-processing zones would significantly enhance efficiency and competitiveness. These clusters should be equipped with reliable electricity, road infrastructure, water supply, and waste management systems to reduce production costs and attract private sector investment.

In addition, strengthening technical training institutions and vocational programs in wood technology, forest engineering, and value-added manufacturing will be critical for building skilled human capital. Without skilled labour, industrial expansion will remain constrained regardless of financial investment. If effectively implemented, these reforms could significantly increase Nigeria’s retention of forestry value from the current 10–15% to over 50% within a medium-term horizon, while simultaneously creating thousands of direct and indirect jobs across rural and urban areas.

6.3 Ecosystem Service Monetization

Nigeria’s forest ecosystems provide a wide range of undervalued services, including carbon sequestration, biodiversity conservation, watershed protection, soil stabilization, and climate regulation. Despite their immense economic value, these services are largely excluded from formal national accounting systems and budgetary frameworks. A key reform direction is the development of functional Payment for Ecosystem Services (PES) schemes. Under this system, beneficiaries of ecosystem services such as hydropower operators, agricultural industries, and international carbon buyers would financially compensate communities and government agencies responsible for forest conservation.

In parallel, Nigeria must strategically position itself within global carbon markets. This requires establishing a national carbon registry capable of recording, verifying, and issuing carbon credits in accordance with international standards. Equally important is the development of robust Measurement, Reporting, and Verification (MRV) systems to ensure transparency and credibility in carbon accounting. Geospatial technologies, including satellite monitoring, remote sensing, and GIS-based forest inventory systems, should support these systems. Such technologies would enable real-time tracking of deforestation, forest regeneration, and changes in carbon stocks.

Community participation is also essential for success. Local communities should be formally integrated into carbon credit benefit-sharing arrangements to ensure equity, reduce conflict, and incentivize conservation. Without local ownership, ecosystem service monetization schemes are unlikely to be sustainable. According to World Bank estimates (2021), effective implementation of carbon markets and PES frameworks could generate between $150 million and $300 million annually by 2030. However, with strong governance, improved forest coverage, and expanded market access, actual revenues could exceed these projections over time.

7.0 Policy Roadmap

The successful transformation of Nigeria's forestry sector requires a clearly sequenced policy roadmap that aligns short-term stabilization measures with medium-term structural reforms and long-term strategic integration into national development planning. This phased approach ensures policy continuity, institutional strengthening, and sustained investment in the sector.

7.1 Short-Term Actions (0–2 Years)

The immediate priority is to address systemic inefficiencies, improve transparency, and establish a strong governance foundation for reform implementation. A key action is the full digitization of forestry administration systems. This includes electronic registration of logging permits, forest inventories, timber movement documentation, and royalty payment systems. Digital platforms will significantly reduce human interference in revenue collection processes, thereby minimizing corruption and improving data accuracy.

In addition, the enactment of a comprehensive Forest Reform Bill is essential. This legislation should modernize existing forestry laws, clearly define institutional mandates, strengthen enforcement mechanisms, and introduce penalties for illegal logging and non-compliance. The bill should also provide legal backing for sustainable forest management practices, private sector participation, and community-based forestry initiatives. Other short-term priorities include strengthening inter-agency coordination between federal and state forestry authorities, conducting a nationwide forest inventory update, and launching public awareness campaigns on sustainable forest use and energy alternatives to fuelwood.

7.2 Medium-Term Priorities (3–7 Years)

The medium-term phase focuses on building economic structures that enable value Creation, participation in climate finance, and industrial expansion. A major priority is establishing functional carbon markets and ecosystem service trading systems. This involves developing national frameworks for carbon pricing, certification, and credit trading, as well as establishing institutional mechanisms for monitoring, reporting, and verification (MRV). These systems will position Nigeria to access international climate finance and carbon offset markets.

In parallel, the Creation of dedicated forestry and green industrial development funds is critical. These funds should provide long-term financing for wood processing industries, reforestation projects, agroforestry enterprises, and biomass energy initiatives. Blended finance models combining public funding, private investment, and international development support will be particularly effective. During this phase, Nigeria should also develop forest-based industrial clusters and strengthen value chain linkages between primary producers and manufacturing industries. Investment in vocational and technical training institutions will be necessary to build a skilled workforce capable of supporting industrial expansion.

7.3 Long-Term Strategy (8–20 Years)

The long-term vision is to fully integrate forestry into Nigeria's national economic planning as a core pillar of the green economy and sustainable development agenda. This involves repositioning forests not only as environmental assets but as strategic economic infrastructure that contributes to GDP growth, employment Creation, climate resilience, and energy transition. Forestry should be embedded within national industrial, climate, and energy policy frameworks. At this stage, Nigeria should aim for a fully functional green economy system where forest ecosystems are sustainably managed, highly productive, and financially valued through multiple revenue streams, including timber, non-timber forest products, carbon credits, ecotourism, and ecosystem services.

Long-term success will also depend on strong institutional maturity, including autonomous forestry agencies, fully operational digital governance systems, and decentralized but coordinated forest management structures that empower local communities while maintaining national standards. Ultimately, the long-term objective is to achieve a resilient forestry sector that contributes significantly to economic diversification, rural development, and Nigeria's commitments to global climate and biodiversity goals.

8.0 Conclusion

Nigeria's forestry sector represents a substantial yet largely underutilized opportunity for national economic transformation. Despite its vast ecological and economic potential, the sector remains constrained by persistent governance weaknesses, institutional fragmentation, limited industrial capacity, and structural inefficiencies that limit optimal resource utilization and value Creation.

Sustainable Forest Management (SFM) must therefore be understood not only as an environmental responsibility but as a strategic economic imperative. When effectively implemented, SFM provides a pathway to strengthen natural capital, enhance fiscal revenues, expand industrial output, and improve rural livelihoods. It also offers critical co-benefits in climate change mitigation, biodiversity conservation, and ecosystem resilience. With comprehensive, well-coordinated reforms spanning governance modernization, industrial value chain expansion, fiscal transparency, and ecosystem service monetization, the forestry sector has the potential to contribute up to 7% to Nigeria's non-oil Gross Domestic Product. In addition, it can serve as a major source of employment generation, particularly in rural communities where alternative livelihood options remain limited.

Ultimately, the transition from a system characterized by forest depletion to One driven by sustainable forest-based development will require bold political commitment, institutional

strengthening, and sustained investment. A coordinated policy response across all levels of government, supported by the private sector and local communities, is essential for unlocking the full potential of Nigeria's forestry resources and securing long-term economic and environmental stability.

References

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., … Turner, R. K. (2014). Changes in the global value of ecosystem services. *Global Environmental Change*, 26, 152–158.

Food and Agriculture Organization (FAO). (2020). *Global Forest Resources Assessment 2020*. Rome: FAO.

Federal Ministry of Environment. (2022). *National Forest Policy Review Report*. Abuja, Nigeria.

International Energy Agency (IEA). (2022). *Africa Energy Outlook 2022*. Paris: IEA.
National Bureau of Statistics (NBS). (2023). *Nigeria Gross Domestic Product Report*. Abuja, Nigeria.

Nepstad, D., McGrath, D., Stickler, C., et al. (2014). Slowing Amazon deforestation through public policy and interventions. *Science*, 344(6188), 1118–1123.

OECD. (2011). *Towards Green Growth*. Paris: OECD Publishing.

Sachs, J. D., & Warner, A. M. (2001). The curse of natural resources. *European Economic Review*, 45(4–6), 827–838.

World Bank. (2021). *Forests, Trees, and Woodlands in Africa: Economic and Policy Perspectives*. Washington, DC: World Bank.

ISTF-NG 2026

SUSTAINABLE FOREST PRODUCTS DEVELOPMENT AND UTILISATION FOR ECONOMIC DEVELOPMENT IN NIGERIA

Olukayode Ogunsanwo, Ph.D. and Babajide Falemara, Ph.D.
Department of Forest Production and Products, Faculty of Renewable Natural Resources, University of Ibadan, Nigeria
Email: oy.ogunsanwo@gmail.com

A lead paper presented at the 2026 Annual Conference of the International Society of Tropical Foresters-Nigeria, ISTF
Date: 19th to 21st May, 2026.

Abstract

Sustainable development and utilization of forest products have become central to balancing economic growth with environmental integrity, particularly in forest-dependent regions such as Nigeria and across Africa. This paper synthesized current developments in sustainable forest management practices, efficient processing technologies, and inclusive governance systems to strengthen forest-based economies. It highlighted how reduced-impact logging, reforestation, and certification frameworks can support long-term resource availability. At the same time, life-cycle assessment and circularity approaches improve material efficiency and reduce environmental burdens across value chains. The role of non-timber forest products was also emphasized as a viable means of diversifying livelihoods without compromising forest structure. The paper identified persistent challenges, including deforestation, weak policy enforcement, low industrial efficiency, limited access to certification markets and inadequate investment in processing infrastructure. Addressing these constraints requires a strategic shift toward integrated forest management and stronger collaboration among industry, academia and government. The triple helix model is presented as a practical mechanism for bridging the gap between research and commercialization, enabling innovation, capacity building, and value addition. The paper concluded that a resilient forest-based economy will depend on coordinated investments, participatory governance, and sustained commitment to sustainability principles that align ecological conservation with socio-economic development. Policy recommendations for better utilisation and trade of forest products were proposed.

Keywords: Forest-based bioeconomy; Forest products; Forest resources; Innovation; Utilization

1.0 Introduction

Forests are a vital natural resource base, supplying timber and a wide range of non-timber forest products (NTFPs) such as fuelwood, foods, medicines, fibres, resins, gums, and other biologically derived materials. Beyond their direct economic value, forests also support biodiversity, carbon storage, soil protection, and watershed regulation. Their importance to livelihoods is profound, as more than 1.6 billion people globally depend on forest resources, including an estimated 90% of rural households in Africa. In Nigeria, forests remain central to rural survival, with about 80% of the rural economy relying on them for energy and income, even as deforestation continues at an

estimated rate of 3.5% per year (Dalu *et al*., 2021; Ahmed & Olaitan, 2024). Similarly, the Food and Agriculture Organization (FAO, 2015) reports that nearly One billion people depend heavily on forest extraction for income, while about one-fifth of the global population relies on forest resources to meet basic needs.

Despite this importance, forest resources are increasingly under pressure from population growth, urban expansion, and unsustainable harvesting practices. In many developing countries, the pace of deforestation has accelerated alongside the depletion of forest goods and the ecosystem services they provide. For instance, between 1990 and 2005, Nigeria lost about 36% of its primary forest cover, placing it among the ten countries with the highest deforestation rates globally (Nigeria Conservation Foundation, 2019). Projections are even more alarming, with warnings that forest land could be converted to grassland by 2046 if urgent action is not taken, leaving forest-dependent households without a secure livelihood base (NCF, 2019).

In recent years, growing attention has therefore shifted toward aligning forest product development and utilisation with the principles of sustainability, particularly in the context of climate change, biodiversity loss, and resource efficiency. A sustainable economy depends on the responsible use of natural resources in ways that reduce environmental harm while supporting social and economic well-being. From this perspective, forest products should not be viewed simply as commodities extracted from nature, but as part of a broader ecological system that sustains rural livelihoods, local economies, and forest resilience in line with the principle of sustainability (Sheppard *et al*., 2020).

This integrated understanding is especially relevant in Nigeria and across Africa, where forest products remain closely tied to food security, household income, and everyday subsistence. However, the development value of forest resources cannot be separated from conservation. Where harvesting is poorly regulated or access is weakly managed, the resulting pressure can erode the very benefits that communities depend on. The central challenge, therefore, is not whether forest products matter, but how to meet rising demand without compromising forest integrity (Ingalls *et al*., 2018; Arts *et al*., 2023).

Addressing this challenge requires innovative approaches to forest product processing, value addition, and utilisation that improve socio-economic outcomes while minimising environmental degradation. It also calls for sustainable forest management practices that preserve ecosystem resilience and productivity for future generations. In this way, forest product development can contribute meaningfully to a green economy while still maintaining ecological balance. This paper examined the contribution of forest products to economic development and environmental conservation, with particular attention to the opportunities, constraints, and sustainability implications for Nigeria and Africa at large.

2.0 Overview of Nigeria's forest and the global forest products trade

Nigeria's land area is about 923,763 km^2, with approximately 8% of the land as forests, and a growing stock of 936 million m^3 (FRA-Nigeria, 2020) across diverse and complex vegetation types within contiguous ecological zones (Figure 1).

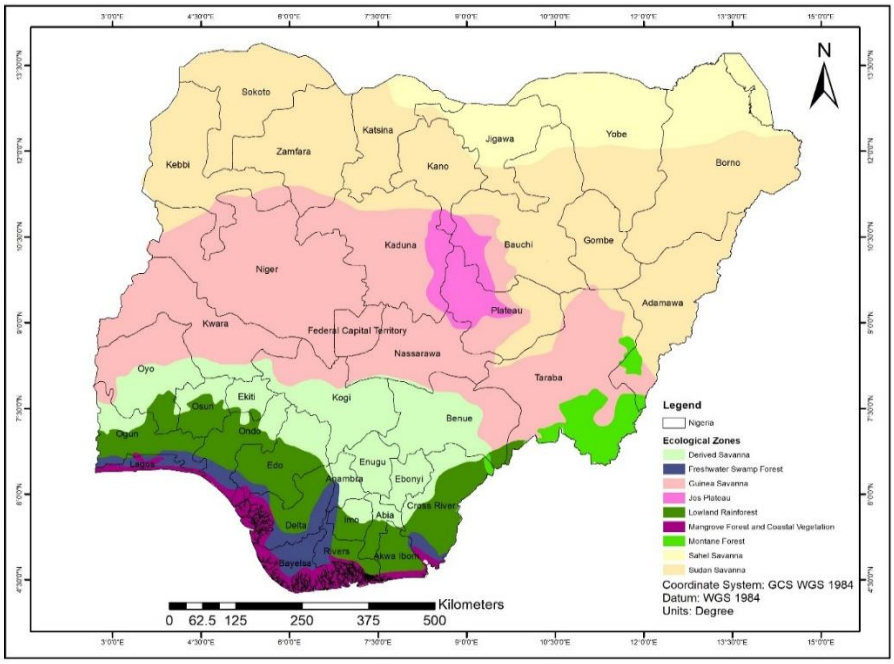


Figure 1: Map of Nigeria showing Vegetation zones

The forest industry contributes over USD 1.52 trillion annually to the global economy (Table 1). It supports more than 45 million jobs directly and indirectly through wood and non-wood products. Activities in the sector, including logging, pulp-composite panel products, paperboards, furniture, fuel woods, and wooden souvenirs, add significantly to GDP, with strong growth that is likely to triple by 2050. The formal forest sector directly contributes over USD 663 billion to global GDP, with pulp and paper responsible for the highest value (31%), followed by logging and solid wood products. The sector provides more than 18 million direct jobs and supports over 45 million jobs globally. Major components include pulp and paper (31%), forestry/logging (25%), solid wood products (25%), and furniture manufacturing (~20%). Asia (specifically East Asia) dominates value addition in most subsectors. Demand for sustainable wood is projected to double or triple by 2050 (FAO, 2024)

Table 1: Contributions of the Forest to the Global Economy

Region/ subregion	Forestry and logging		Solid wood products		Pulp and paper products		Furniture manufacturing		Total	
	Economic contribution									
	Direct	Total	Direct	Total	Direct	Total	Direct	Total	Direct	Total
	(USD million)									
Africa	13 457	45 301	2 170	7 007	2 651	8 725	4 191	11 598	22 468	48 296
Americas	39 679	92 050	18 398	55 038	31 702	90 184	15 413	39 454	105 192	257 275
Latin America and Caribbean	10 322	20 417	6 996	18 473	19 875	56 740	8 834	23 089	46 027	101 540
North America	29 356	71 632	11 402	36 565	11 827	33 445	6 579	16 365	59 165	155 735
Asia	81 474	126 558	88 984	364 562	108 045	373 477	59 452	181 749	337 955	765 307
Europe	30 505	59 534	47 188	132 381	58 741	158 485	48 818	112 529	185 252	423 109
Oceania	2 365	6 012	3 742	15 248	2 636	9 267	1 454	4 686	10 197	28 969
Grand total	167 480	329 455	160 482	574 236	203 775	640 139	129 328	350 016	661 064	1 522 957

Source: FAO (2024)

Nigeria has a long history of dependence on the utilisation and trade of forest products, both locally and internationally. By 1970, Southwest Nigeria alone earned over three million pounds from trade in timber products and other non-timber and non-wood products (Adebayo, 1971). The total export value for forest products in 2022 was USD $58.1 million. This includes "Other" wood products (41.6M), recovered paper (14.7M), and sawnwood (1.5M). Species usually preferred for export were *Milicia excelsa*, Iroko, Mahoganies (*Khaya ivorensis, Entandrophragma cylindricum*), *Afzelia africana, Nauclea didderrichii* and lately *Pterocarpus erinaceus,* which is now under CITES limitation. *Teak (Tectona grandis)* and Gmelina (*Gmelina arborea*) are the major timbers of commercial trade today. The volume of imports of forest products as of the second quarter of 2024 shows that raw material imports totaled ₦1,481.50 billion. This represents a 0.96% increase from ₦1,467.41 billion in the first quarter. In addition, the forest industry in Nigeria contributes approximately 2.5% to 3.0% to the Gross Domestic Product (GDP), acting as a crucial, albeit undervalued, sector. It supports the economy through timber production, providing employment for over 5 million people, supplying wood-based fuel to roughly 70% of households, and providing raw materials for the furniture, construction, and pharmaceutical industries.

Today, forest estates in Nigeria lack the capacity to support effective services and trade due to unregulated exploitation, illegal activities, and their inability to align with global environmental standards. The 400,000 ha deforestation rate and the lack of effective policy direction have contributed significantly to a low volume of trade in forest products.

3.0 Forest Products Classification and Utilization

Forest products are broadly categorized into timber-based and non-timber forest products (Figure 2). Forest products are utilized across a broad spectrum of sectors, including construction, energy, manufacturing, healthcare, and domestic applications. Timber products are typically classified into three stages based on their level of processing. Primary products, such as logs, roundwood, firewood, and pulpwood, are obtained directly from the forest. These are further transformed into secondary products, including lumber, plywood, paper, fuelwood/bioenergy (charcoal, briquette) through initial processing, and then tertiary products such as furniture and packaging, which are ready for end use. Lumber, for instance, consists of solid sawn wood cut from logs and widely

used in construction and furniture making. Pulp and paper products are fiber-based materials produced from processed wood chips.

In contrast, engineered wood products like plywood and particleboard are composites formed by bonding wood particles or veneers with adhesives, often offering enhanced strength and stability. Timber remains a primary material for construction and furniture production, for the paper industry, and as a renewable energy source in the form of fuelwood and charcoal. In addition, the 2022 classification and definitions of forest products have been updated to reflect ongoing innovation in the sector, including engineered wood products. This revised framework encompasses a broad range of materials across the value chain, from primary resources such as wood from forests and trees outside forest areas, bark, cork, and charcoal, to processed wood and paper products, as well as recovered paper and recyclable wood materials (FAO, 2022).

Non-timber forest products (NTFPs), on the other hand, encompass non-timber biological resource-derived goods obtained from forests. These products are obtained from plants, animals, and microorganisms, and include a wide range of items such as medicinal plants, fruits, nuts, fibres, spices, gums, resins, honey, mushrooms, and other wild resources (Table 2). They are sourced not only from natural forests but also from plantations, agroforestry systems, and trees outside forest areas, making them readily accessible to rural communities (Derebe & Alemu, 2023; Aiyeloja & Ajewole, 2006). They contribute significantly to livelihood and food security, healthcare, cultural practices, cottage industries, and sustainable economic development, particularly in developing regions. NTFPs are deeply embedded in rural livelihoods across Africa, contributing to food security, healthcare, and income diversification (Derebe & Alemu, 2023; Kurniasih *et al*., 2021). Their utilization supports local economies and provides income-generating opportunities for rural communities. Many NTFPs are collected from the wild and used locally within households and communities or traded within regional markets (Boyapati & Muthukumarappan, 2025; Hariharan *et al*., 2025). Roughly 77% of rural households across 24 developing countries rely on wild foods, underscoring the critical role of NTFPs in supporting subsistence and livelihoods (Asamoah *et al*., 2025).



Figure 2: Classification of Forest Products

Table 2. Categories of Non-Timber Forest Products (NTFPs)

Products		Description
Plant products	Food	Vegetal foodstuffs and beverages provided by fruits, nuts, seeds, and roots
	Fodder	Animal and bee fodder provided by leaves, fruits, etc.
	Medicines	Medicinal plants (e.g. leaves, bark, roots) used in traditional medicine and/or by pharmaceutical companies
	Perfumes and cosmetics	Aromatic plants provide essential (volatile) oils and other products used in cosmetics.
	Dying and tanning	Plant material (mainly bark and leaves) provides tannins, and other plant parts (especially leaves and fruits) are used as colorants.
	Utensils, handicrafts	Heterogeneous group of products including thatch, bamboo, rattan, wrapping leaves, fibres (e.g. Arouma, Bwa Flo, Silk cotton floss, Screw pine)
	Construction materials	Thatch, bamboo, fibres
	Ornamentals	Entire plants (e.g. orchids, ferns, philodendron) and parts of the plants (e.g. pots made from roots) are used for ornamental purposes.

	Exudates	Substances such as gums (water-soluble), resins (water-insoluble), and latex (milky or clear juice) are released from plants by exudation.
Animal products	Living animals	Mainly vertebrates, such as mammals, birds, and reptiles.
	Honey, beeswax	Products provided by bees
	Bushmeat	Meat provided by vertebrates, mainly mammals
	Other edible animal products	Mainly edible invertebrates such as insects (e.g. caterpillars), crabs and other secondary products of animals (e.g. eggs, nests)
	Hides, skins	Hide and skin of animals are used for various purposes.
	Medicine	Entire animals or parts of animals, such as various organs used for medicinal purposes (e.g. caterpillars, crab legs, snake oil)
	Colorants	Entire animals or parts of animals, such as various organs, are used as colorants.
	Other non-edible animal products	Bones used as tools

Source: Shiva and Verma (2002) and FAO (1995) cited in Ahenkan and Boon (2011).

Forest products are integral to both subsistence and commercial economies, highlighting the essential role of forest resources in both industrial applications and everyday life. The efficient and sustainable utilization of both timber and non-timber forest products is vital for minimizing waste, improving productivity, and preserving ecological balance. Beyond their environmental value, forest products also play a key role in economic development by supplying raw materials for industries, sustaining livelihoods, and contributing significantly to international trade. Their wide range of applications highlights a strong capacity to support inclusive economic growth when managed responsibly (Sangare *et al*., 2026).

The relevance of forest products becomes even more evident when considered within the framework of a sustainable or green economy. A green economy emphasises resource efficiency, reduced environmental impact, and improved human well-being (Loiseau *et al*., 2016). Forest products align closely with these goals, as they are renewable, widely accessible, and capable of supporting both formal and informal economic activities. A circular, sustainable forest product system represents a technology-driven model that integrates economic, environmental, and lifestyle considerations. It encompasses the planning, design, and management of resource use across the entire product life cycle, from cultivation and production to consumption, recovery, and recycling, to maximize ecosystem functions and human well-being (Figure 3). This approach relies on life cycle assessment as a key evaluation tool. It is grounded in the principle that natural systems operate through interdependence, where resources are used efficiently, energy consumption is minimized, and waste is reduced to the lowest possible level (Mao *et al*., 2025).

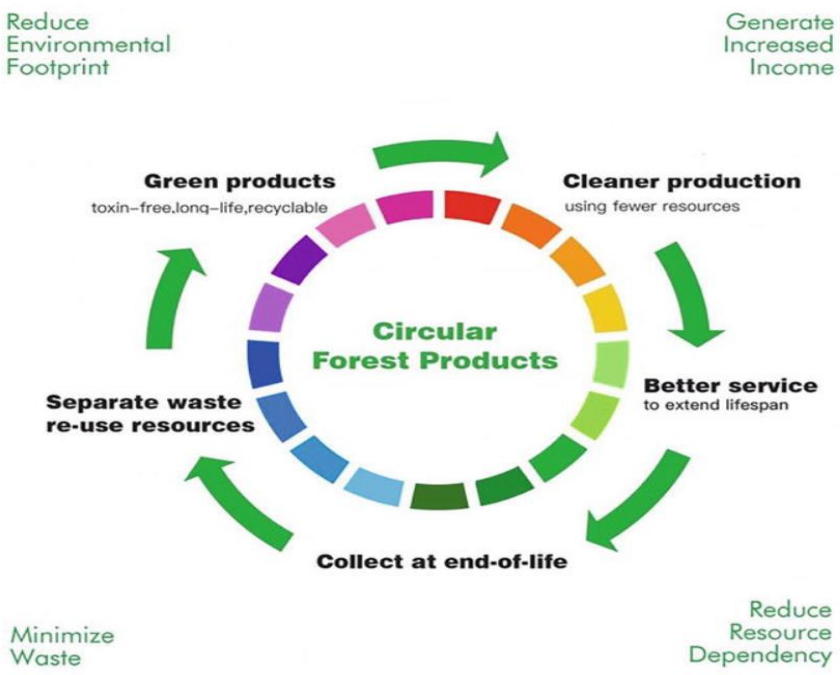


Figure 3: Concept of circular forest products
Source: Mao *et al*., (2025)

Closely linked to this is the concept of the forest-based bioeconomy, which promotes the use of renewable biological resources to replace fossil-based materials and energy sources. In principle, the bioeconomy offers a pathway to decarbonisation while fostering rural development. Forest biomass, whether derived from timber or non-timber sources, can support a wide range of applications, from bioenergy to bioproducts. Bioenergy offers a viable pathway toward greener energy systems, as it can meet energy demands while maintaining relatively low net carbon emissions across production and use, thereby supporting both economic and environmental goals. In addition, it enables the productive use of waste materials and improves land-use efficiency, contributing to a more sustainable transition toward green economic growth (Liu & Huang, 2024; Sohail *et al*., 2024).

However, rising demand for high-value forest products in urban markets is placing increasing pressure on rural resource bases, often pushing extraction beyond sustainable limits. This heightened exploitation accelerates forest degradation, deforestation and illegal logging**,** undermines biodiversity, and, in some instances, drives the conversion of natural forests into agroforestry systems (Boyapati & Muthukumarappan, 2025). Illegal logging presents serious challenges, threatening biodiversity and compromising supply chain integrity by allowing uncertified timber to enter legitimate markets. It is often linked to corruption and human rights violations, further complicating governance in the sector. Addressing these issues requires a combination of stronger regulatory enforcement, international cooperation, and the adoption of traceability systems to promote transparency and uphold ethical standards in forest management. In Nigeria, where forest resources are already under pressure, the transition to a bioeconomy must be accompanied by strong governance and sustainable management practices.

The principles of the circular economy further reinforce the sustainable utilisation of forest products. Circularity in forestry emphasises reuse, recycling, and cascading use, where materials are utilised sequentially to maximise value and minimise waste. For instance, wood can be used in construction, then repurposed into panels or fibre products, and finally converted into energy. Such cascading systems can improve resource efficiency and reduce environmental impacts, although their success depends on infrastructure, policy support, and market development (Lazaridou *et al*., 2021).

4.0 Forest Product Developments: Modern Developments and Innovations

The global forest sector is undergoing a paradigm shift, transitioning from extractive practices toward innovation-driven, value-oriented systems that integrate advanced materials, circular resource use, and diversified value chains. This evolution is driven by the urgent need for carbon-neutral materials and the advanced utilization of lignocellulosic biomass to address climate and economic challenges. However, in Nigeria, the forest sector is still dominated by primary extraction with minimal processing, resulting in low economic returns and high resource wastage.

4.1 Advances in Processing and Products Innovation

One of the breakthroughs in forest products development is the emergence of Engineered Wood Products (EWPs), such as cross-laminated timber (CLT) and glued-laminated timber (glulam), which have redefined the structural potential of wood in modern construction. These products enable the utilisation of smaller-dimension timber while delivering improved mechanical performance and dimensional stability, thereby enhancing resource efficiency and material competitiveness, while also acting as carbon sinks (Syahirah *et al*., 2025; Wang *et al*., 2024; Ekundayo *et al*., 2022; Arum *et al*., 2021).

Beyond its structural use, the industry is entering the realm of biorefining. Researchers are now extracting nanocellulose and lignin-based bioplastics from wood pulp, providing biodegradable alternatives to petroleum-based polymers. Biomass derived from wood and non-wood sources is increasingly being converted into bio-based materials, including bioplastics, bioactive compounds, high-value pharmaceuticals and biochemicals (Huang *et al*., 2025; Mandal *et al*., 2024). While these innovations offer promising pathways for reducing dependence on fossil resources, their sustainability outcomes depend on feedstock sourcing, processing efficiency, and lifecycle performance rather than technological novelty (Huang *et al*., 2025; Serna-Loaiza *et al*., 2019).

4.2 Value Addition in Timber and Non-Timber Forest Products (NTFPs)

The expansion of the forest value chain is critical for economic resilience. Rather than exporting raw wood or unprocessed non-wood materials, the stronger policy and industrial trend is toward processing, upgrading, branding, and market diversification (Laktuka *et al*., 2024; Aiyeloja & Ajewole, 2006)**.** The major emphasis is now on secondary and tertiary processing, transforming raw timber into finished products or precision-engineered furniture for global trade. This shift is strengthened by circular-economy thinking. In forestry, circularity is expressed through reuse, recycling, and cascading use (Figure 4), where wood and fibre are kept in service through successive applications before final energy recovery (Lazaridou *et al*., 2021).

Similarly, Non-Timber Forest Products (NTFPs), such as resins, essential oils, and medicinal extracts, are being integrated into standardised global supply chains. Value addition through specialised extraction and certification ensures these products command premium prices in

international markets, shifting the focus from volume-based extraction to value-based exports (Asamoah *et al*., 2023; Vantomme & Walter, 2003).

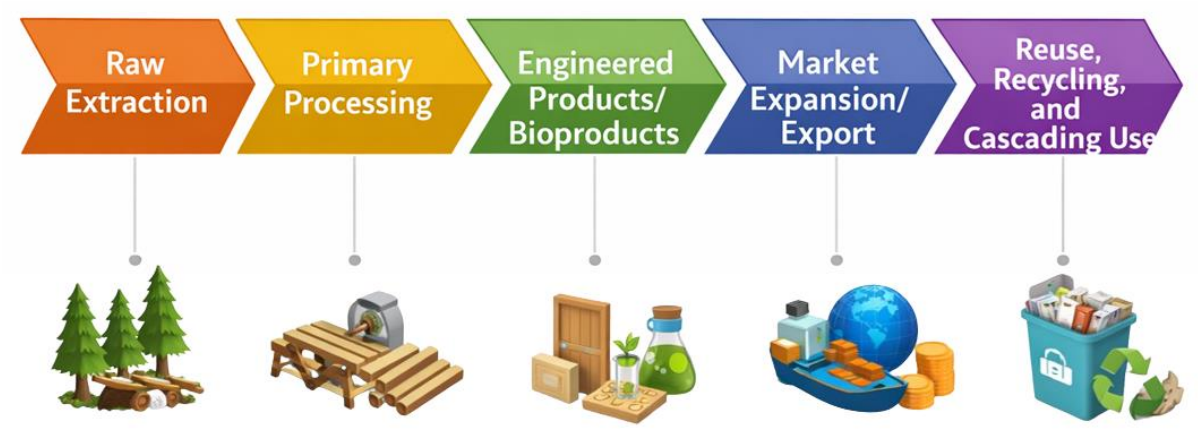


Figure 4: Forest Products value-chain progression

4.3 Emerging Technologies in Harvesting, Processing and Storage of Forest Products

Technological innovation is transforming forest harvesting, processing, and storage systems, particularly in reducing waste and improving precision across the lifecycle of forest products. The integration of digital tools such as Light Detection and Ranging (LiDAR) and "Forestry 4.0" tools enables precision harvesting, improved efficiency, traceability, and resource optimisation. This ensures that only the most suitable trees are taken while minimizing damage to the surrounding stand. These technologies can reduce operational losses, enhance decision-making, and support sustainable forest management when appropriately implemented (He *et al*., 2021). In addition, improved harvesting techniques and residue recovery systems are enabling more complete utilisation of forest biomass, reducing waste and increasing overall yield (Ghaffariyan, 2023).

A major advancement in wood processing technology is the adoption of Computer Numerical Control (CNC) systems. Unlike traditional hand tools or semi-automated machinery, CNC machines operate through computer-programmed instructions, enabling the production of highly precise and intricate designs with remarkable consistency. This level of automation not only improves accuracy but also enhances efficiency, enabling production scaling without compromising quality.CNC technology is particularly valued for its versatility across a wide range of applications. It allows manufacturers to cut and shape wood into boards, panels, and customized forms with ease, while also enabling detailed engraving and carving that add aesthetic value. In addition, CNC machines support drilling and slotting operations, which are critical for precise joinery in furniture production. They are equally useful in prototyping, allowing designers to quickly develop and refine new product concepts before transitioning to full-scale manufacturing. During processing, the use of advanced scanning technologies, artificial intelligence, and computer numerical control (CNC) machines maximizes the usable lumber volume from each log (Yao *et al*., 2024; Fredriksson & Broman, 2017).

In addition, proper drying is a crucial stage in wood processing, as inadequate moisture removal can lead to warping, cracking, or mould growth after production. Traditionally, timbers are usually air-dried by stacking in open spaces and relying on natural airflow. Although this method is

inexpensive, it is slow and highly dependent on weather conditions, often yielding uneven, unreliable results. Advances in drying technology have transformed this process, enabling manufacturers to produce more stable, consistent wood products that meet international quality standards. Modern technologies, such as automated kilndrying, vacuum drying, and thermal modification techniques, have improved the stability and durability of lesser-known wood species, allowing them to be stored and used in environments where they previously would not have been viable (Bak, 2025; Lyon *et al*., 2021). Techniques such as kiln drying and vacuum drying now define modern practice, offering greater control and efficiency. Kiln drying uses regulated heat and humidity to remove moisture evenly, while vacuum drying operates under reduced pressure to accelerate the process and achieve deeper, more uniform drying. These methods can shorten drying time from several months to just a few days, significantly improving production efficiency. Beyond speed, advanced drying enhances dimensional stability by minimizing shrinkage and deformation, improves durability by reducing the risk of decay and pest attack, and increases workability, making the wood easier to machine and finish. Ultimately, these benefits translate into higher-quality products with longer service life for end users (Lyon *et al*., 2021).

4.4 The Role of Research and Development (R&D) in Forest Product Developments

Research and development (R&D) serves as the engine for improving product quality. Through chemical modification (such as acetylation) and impregnation with eco-friendly bio-preservatives, research has enabled wood to resist decay and fire without the toxic environmental footprints of conventional synthetic treatments (Sandak *et al*., 2024). Advances in wood science, material testing, and processing technologies have enabled the standardisation and commercialisation of new forest products. In engineered wood systems, for example, factors such as adhesive type, spread rate, clamping pressure, wood density, processing conditions and surface condition are critical determinants of product quality and durability. These factors influence mechanical performance and long-term durability, making R&D central to reliable commercialization (Syahirah *et al*., 2025; Arum *et al*., 2021). Research and development support the adaptation of global innovations to local conditions, ensuring that technologies are both technically viable and contextually relevant, particularly in developing economies.

5.0 Environmental Significance and Resource Efficiency of Forest Products

Forest products occupy a central place in current environmental discourse because they link material use directly to ecosystem processes, particularly in the context of climate change mitigation and biodiversity conservation. Forest ecosystems function as major carbon sinks, while harvested wood products continue to store carbon over their service life, thereby extending sequestration beyond the forest itself (Bashmakov *et al*., 2022). Studies have shown that substituting wood for more energy-intensive materials, such as steel and concrete, can reduce lifecycle greenhouse gas emissions. However, the magnitude of this benefit depends on sustainable sourcing and efficient processing (Leskinen *et al*., 2018). Consequently, forest products contribute not only to carbon storage but also to broader climate-neutral development pathways. At the same time, the environmental value of forest products is closely tied to biodiversity outcomes. When forest products, particularly non-timber forest products (NTFPs), are managed sustainably, they can provide economic incentives for forest conservation and reduce the likelihood of land-use conversion (Asamoah *et al*., 2025).

Non-timber forest products (NTFPs) play vital roles in supporting rural livelihoods by creating income-generating opportunities, enhancing conservation, improving livelihoods and rural

development, particularly for communities located in or around forested areas (Table 3). For several households, forest resources form the backbone of their livelihoods. Through the harvesting, processing, and marketing of NTFPs, these communities can earn income and improve their standard of living (Asamoah *et al*., 2025; Adaaja *et al*., 2024; Jimoh *et al*., 2013). However, unsustainable extraction can have the opposite effect, accelerating degradation and biodiversity loss, underscoring the importance of governance and resource management.

Table 3. Resource Efficiency and Significance of Non-Timber Forest Products (NTFPs)

Category	Major Discoveries
Economic Contributions	The global trade in non-timber forest products (NTFPs) is estimated at USD 90 billion annually, with roughly one-third consumed locally. In countries such as Zambia and Tanzania, honey production has become a significant economic driver, with exports increasing by 20–30% each year since 2001.
Regional Importance	Across Central and West Africa, income from NTFPs can rival, and in some cases exceed, the earnings of salaried professionals such as school teachers. In the Democratic Republic of Congo, traders earn between USD 16 and 160 per week, while producers receive about half to three-quarters of that amount. In Nigeria, NTFP-based enterprises have expanded beyond local markets into international trade.
Specific NTFPs in Trade	The commercial value of wild mushrooms exceeds USD 2 billion annually. Similarly, the bushmeat trade across Africa is worth several billion dollars. n the Central African Republic, annual consumption alone is valued at approximately USD 16 million, accounting for over 1% of national GDP.
Market Integration	NTFPs also play an important role in both domestic and global markets, particularly in sectors such as herbal cosmetics, food, and traditional medicine. In Nepal, for instance, around 100 entrepreneurs handle over 42,000 tons of more than 100 NTFP products, generating about USD 26 million, with nearly 90% of exports destined for India.
Fuel and Energy	Energy needs in many developing countries are heavily supported by forest resources. In Nigeria, more than 70% of households rely on fuelwood, consuming about 27.5 million kg daily, thereby reducing dependence on costly alternatives. In Mozambique, the forestry sector contributes about 4% to GDP and supplies up to 80% of the nation's energy demand.
Medicinal and Food NTFPs	Traditional medicine remains a primary healthcare option for nearly 80% of Africa's population, with the global botanicals market valued at approximately USD 85 billion and growing at about 7% annually. South Africa alone has over 300,000 traditional healers who depend on NTFPs, while products like shea butter serve as key export commodities in countries such as Burkina Faso.

Bamboo and Rattan Trade	The global trade in bamboo and rattan surpassed USD 3.4 billion in 2019, highlighting their economic importance. China generates about USD 130 million annually from edible bamboo shoots, India's incense stick industry is valued at USD 400 million, and the Philippines has recorded significant exports of rattan furniture, reaching USD 123 million in earlier trade records.
NTFPs and Poverty Alleviation	Beyond trade, NTFPs contribute meaningfully to conservation, rural livelihoods, and economic resilience. In Nigeria, about 45% of households derive between 20.5% and 40.5% of their income from NTFPs, while a smaller proportion earns over 80% of their income from these resources.
Challenges in NTFP Valuation	Despite their importance, many NTFPs remain under-represented in national statistics due to the informal nature of their trade. In Sudan, between 10% and 50% of rural households depend on products such as gum, resin, and wax. In Ethiopia, gums and resins rank second only to livestock in economic significance, while foods from dry forests provide essential dietary supplements for local populations.

Adapted from Asamoah *et al*. (2025)

Similarly important is the role of forest products in advancing resource efficiency through circularity. The recycling of wood and paper products, alongside the growing use of biomass, allows materials to be utilised across multiple life cycles before final energy recovery, thereby maximising value while minimising waste (Lazaridou *et al*., 2021). This approach reduces pressure on primary forests by lowering demand for virgin raw materials and encourages the development of plantation forestry systems to meet industrial needs more sustainably. Efficient utilisation of forest biomass, including residues and by-products, can significantly reduce environmental burdens associated with disposal while improving overall system productivity (Leskinen *et al*., 2018). In reality, the environmental significance of forest products therefore lies not simply in their renewability, but in how they are managed, processed, and reused within integrated systems. When aligned with sustainable harvesting practices and strong institutional frameworks, forest products can simultaneously support climate mitigation, conserve biodiversity, and promote a more resource-efficient and circular economy.

6.0 Key Challenges in Forest Products Development and Utilization

Forest product development and utilization face a range of interconnected challenges that continue to constrain sustainability, value addition, and long-term sector growth.

1. **Deforestation, illegal logging, and biodiversity loss:** Unsustainable harvesting practices and weak controls over illegal logging accelerate forest degradation, resulting in biodiversity loss and the loss of ecosystem services. This undermines the resource base required for a continuous supply of forest products.

2. **Poor processing infrastructure and low investment:** Many developing regions, particularly Nigeria, lack modern processing facilities, limiting their ability to add value to raw materials. Low levels of investment further constrain innovation, efficiency, and competitiveness in forest-based industries.

3. **Weak governance and policy enforcement:** Although policies often exist, poor implementation, corruption, weak monitoring, inconsistent enforcement and limited institutional capacity reduce their effectiveness. This creates loopholes that enable illegal activities and unsustainable resource exploitation.

4. **Climate change and resource depletion:** Changing climate patterns, such as temperature and weather variation, increased droughts, fires, and pests, affect forest productivity, regeneration potential and health. Combined with overexploitation, this leads to declining forest resources and threatens future supply.

5. **Low industrial efficiency in developing regions:** A recurring challenge in forest-based industries is the gap between available raw material and the capacity to convert it efficiently into value-added products. Outdated technologies and inefficient production systems result in high material waste, low recovery rates, and reduced product quality, limiting the sector's overall productivity.

6. **Limited access to sustainable certification markets:** Many producers, especially smallholders, face challenges meeting certification requirements due to costs, technical barriers, and limited awareness, thereby restricting their access to premium international markets.

7.0 Strategies for Enhancing Sustainable Development and Utilization of Forest Products

Forest products are most sustainably used when harvesting, restoration, processing, and local governance are treated as a single entity rather than separate systems (Mao *et al*., 2025; Ogunsanwo & Adebayo, 2022; Tritsch *et al*., 2020). Achieving sustainable forest product utilization requires a combination of policy, technology, and community engagement. It focuses on balancing economic needs with ecological health through practices like selective harvesting, cultivating fast-growing species, and using certification standards to ensure long-term viability. It is geared towards transitioning from exploitative practices to a circular, sustainable bioeconomy, ensuring forests continue to provide resources for future generations.

Identified key strategies include:

1. **Harvest timber with reduced-impact logging, not conventional extraction:** Reduced-impact logging remains One of the strongest practical options for sustaining timber supply while limiting collateral damage to residual trees, soils, and carbon stocks. When harvest planning, directional felling, trained operators, and tighter control of extraction routes are applied, forests recover more slowly but more securely. For instance, in the Congo Basin, concessions operating under approved forest management plans also showed lower deforestation rates, although the benefits were not immediate (Tritsch *et al*., 2020).

2. **Plantation Development & Reforestation:** Planting fast-growing species, such as *Eucalyptus*, alleviates pressure on natural forests by providing a rapid supply of wood products (Mao *et al*., 2025; Ogunsanwo & Adebayo, 2022).

3. **Forest Certification and Legal Compliance:** Use certification as a verification tool, not as a substitute for good management. Implementing tracking systems such as the Forest Stewardship Council (FSC) and the Forest Law Enforcement, Governance and Trade (FLEGT) ensures that timber and non-wood products are sourced legally and sustainably, thereby reducing illegal deforestation (Ogunsanwo & Adebayo, 2022; Fajemirokun, 2021). For instance, in 2023, the Federal Ministry of Environment launched the Nigeria Timber Legality Standards (NTLS) to promote sustainable forest management and curb deforestation. The framework focuses on eliminating illegal logging, transport, and trade. It introduces a traceability system with registration and tracking codes to verify wood sources. The standards also strengthen export controls to ensure only legally sourced timber is traded while protecting biodiversity and revenue.

4. **Efficient Wood Processing & Residue Utilization:** Sustainability is not only about how trees are cut; it is also about how much usable material is recovered afterward. Studies have shown that reduced-impact logging combined with improved wood-processing technology can lower emissions while stabilizing timber production. However, reuse, recycling, and recovery offer the clearest long-term potential. In addition, logging and processing wood residues can convert them into secondary products, such as wood souvenirs, rather than letting them become waste. Wood offcuts, bark, sawdust, and so on should be treated as feedstock, not as an afterthought. Recovered timber can be channeled into panels, biomass energy and other secondary products, while energy recovery and recycling can reduce pressure on virgin raw material and improve material efficiency across the value chain (Falemara *et al*., 2025; Ogunsanwo *et al*., 2005).

5. **Triple Helix Collaboration:** A functional triple helix, linking industry, academia, and government, offers a practical route to advancing forest products development and utilization in Nigeria. Academic research outputs often fail to translate into market-ready innovations, largely because industry engagement is limited and institutional linkages are weak. Industries in Nigeria, in particular, are expected to transform research outputs and outcomes from academia into tangible products and innovations that could create opportunities for further validation and widespread commercialization. Bridging this divide is essential if scientific knowledge is to evolve into locally relevant technologies, strengthen domestic capacity, and stimulate a more competitive forest-based economy. Closing these gaps requires more than policy intent. Large industries must move beyond passive engagement and actively invest in research through sustained partnerships with universities and research institutes, creating a clear pathway from discovery to market. At the same time, the government must create an enabling environment through adequate research funding, fair and transparent commercialization frameworks, and standards that support product uptake. When these elements align, collaboration becomes a continuous pipeline, from discovery to processing and eventual commercialization, ensuring that forest product innovations are not confined to laboratories or bookshelves but developed into viable, market-driven solutions that strengthen both competitiveness and sustainability.

6. **Life Cycle Assessment (LCA):** LCA is best used to locate the main impact "hotspots" across the product chain, especially in manufacturing and end-of-life stages, so that recycling, reuse, and cascade use can be targeted where they deliver the greatest

environmental gain. Utilizing LCA tools, measures the environmental impact of forest products from extraction to disposal, while promoting recycling and the Creation of new bio-based products to extend the life cycle of materials **(**Sahoo *et al*., 2019). Life cycle assessment (LCA) evaluates a product's environmental impact across its entire life span, from raw material extraction and production (cradle-to-gate) to distribution, use, and final disposal (cradle-to-grave). Typically, roundwood is processed into high-value products, while forest residues are often left to decompose, burned, or used for low-value energy. However, both roundwood and residues can be utilized more efficiently across the value chain (Figure 5). As noted by Sahoo *et al*. (2019), wood is progressively transformed into a range of products, from conventional materials such as timber, plywood, oriented strandboard (OSB), particleboard, glulam, and laminated veneer lumber (LVL), to newer innovations like cross-laminated timber (CLT), dowel-laminated timber (DLT), nail-laminated timber (NLT), as well as mass-timber structures and advanced biomaterials such as nanocellulose.

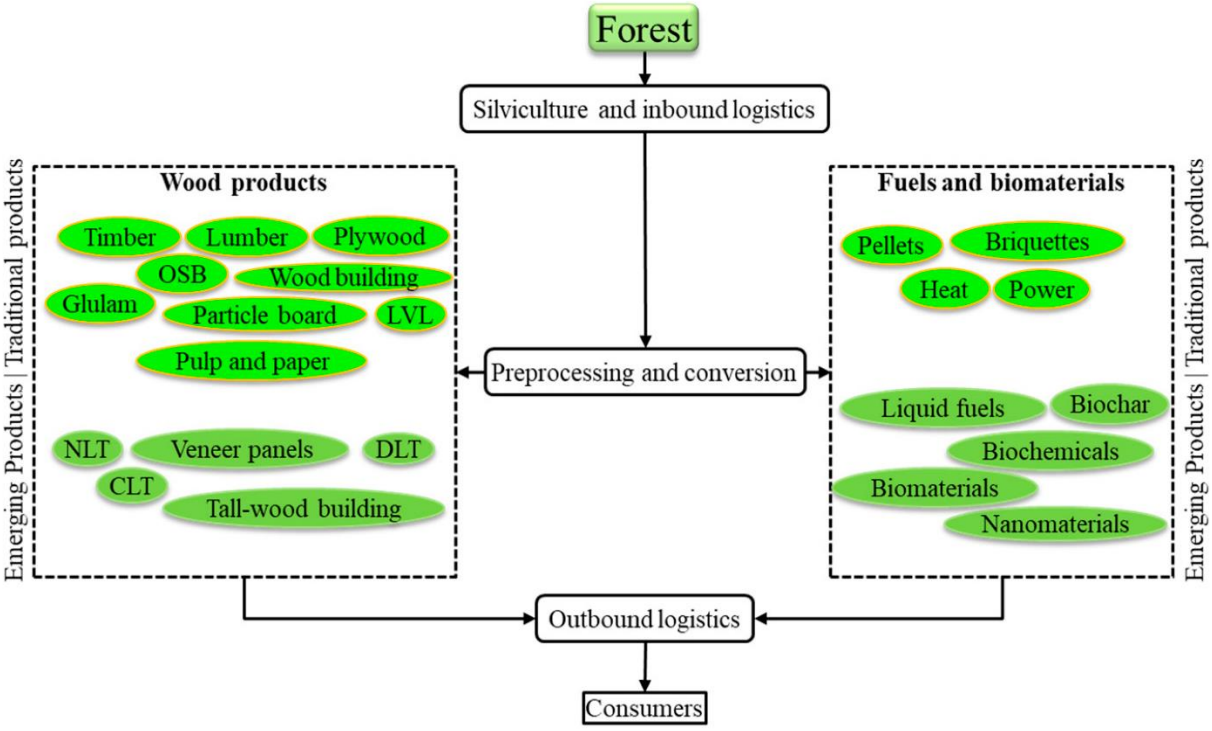


Figure 5: Supply Chain of forest-based products.
Source: Sahoo *et al*. (2019)

7. **Sustainable Management of NTFPs:** A practical sustainability strategy is to diversify income beyond timber by strengthening carefully managed NTFP harvesting, processing, and marketing. It requires encouraging the harvesting of NTFPs (such as nuts, medicinal plants, and rattan) by training local populations, which offers income without destroying forest structures. Well-regulated NTFP systems can support both income security and forest conservation if extraction levels remain ecologically bounded (Awe *et al*., 2011).

Transitioning to a sustainable forest-based economy in Nigeria and across Africa will require a deliberate shift from extraction to long-term value Creation. This begins with stronger forest

governance and firmer policy enforcement to curb illegal exploitation and promote responsible use, while also supporting value addition through better industrial processing so that more of the economic gains remain within local economies. At the same time, the sector should embrace renewable energy technologies to reduce dependence on fossil fuels and wood fuel, while lowering environmental pressure, alongside deeper community participation and fair benefit-sharing arrangements that give local people a real stake in conservation. Sustained investments in research, innovation, and capacity building are essential, as they can improve management practices, unlock new products, and strengthen technical skills. Public-private partnerships and international collaboration can further accelerate this transition by mobilizing finance, expertise, and market access for sustainable forest management and utilization.

8.0 Conclusion

Forest products are central to the sustainable development of Nigeria and Africa at large, offering significant economic, environmental, and social benefits. However, realizing this potential requires a shift from unsustainable exploitation to responsible management and utilization. By integrating sustainable forest management, technological innovation, and inclusive governance, forest products can serve as a cornerstone of a green economy while preserving the environment for future generations.

The sustainable development and utilization of forest products depend on treating forests not merely as repositories of timber, but as living economic and ecological systems that must be managed with care, efficiency, and long-term vision. Development will come from aligning sustainable forest management, improved processing technologies, life-cycle thinking, and the diversified use of timber and non-timber forest products with stronger governance and community participation. When forest resources are harvested responsibly, processed efficiently, and supported by inclusive local stewardship, they can continue to generate income, protect biodiversity, and sustain ecosystem services simultaneously.

Strong collaboration among industry, academia, and government can help close the funding, innovation, standardization, and commercialization gaps that continue to limit forest-based development in Nigeria and across Africa. Ultimately, a sustainable forest economy will depend on deliberate investment in research, value addition, policy enforcement, and equitable benefit-sharing, so that forest products contribute not only to industrial growth but also to environmental resilience and social well-being.

Recommendations

1. Effective Research: Research efforts should be intensified in forest product development. Government and Non-Governmental organizations should be encouraged to partner with Universities and Research institutes in developing ideas that could expand the frontiers of forest products development.
2. Valorisation of woodwaste: Stakeholders, particularly the government, should develop capacity in woodwaste management as part of local empowerment programmes, with the ultimate aim of improving efficiency in forest product utilisation.
3. Effective Forestry Extension and Environmental Education: Forestry and Environmental Education should be developed and institutionalised to inculcate the culture of sustainable

management of forest resources among forest user groups and other stakeholders in the forest industry value chain.

References

Adaaja, B. O., Akemien, N. N., Alawiye, M. A., Zaman, E. Y., Yahaya, U., & Khidir, H. Y. (2024). Economic and ecological sustainability of non-timber forest products (NTFPs) in Nigeria: A review. *FUDMA Journal of Sciences*, *8*(6), 196-204.

Ahenkan, A., & Boon, E. (2011). Non-timber forest products (NTFPs): Clearing the confusion in semantics. *Journal of Human Ecology*, *33*(1), 1–9.

Ahmed, Y. A., & Olaitan, R. A. (2024). The challenges of deforestation and management in Nigeria: Suggestions for improvement. *Ghana Journal of Geography*, *16*(1), 193–220.

Aiyeloja, A. A., & Ajewole, O. I. (2006). . Marketing non-timber forest products in Nigeria. A case study of Osun state. *Educational Research and Reviews, 1*(2), 52–58.

Arts, B., Behagel, J., De Koning, J., and van der Zon, M. (2023). *Community Forest Management: Weak States or Strong Communities? Politics and Governance, 11 (2), 336–345*.

Arum, C., Olofintuyi, I., & Ekundayo, O. O. (2021). Glulam beams: performance of PVA and PUR adhesives on bending strengths of locally selected Nigerian timber species. *Nigerian Journal of Technology*, *40*(3), 363-370.

Asamoah, O., Danquah, J. A., Bamwesigye, D., Verter, N., Acheampong, E., Boateng, C. M., ... and Pappinen, A. (2023). Perceptions of commercialisation and value addition of non-timber forest products in forest adjacent communities in Ghana. *Discover Sustainability*, *4*(1), 30.

Asamoah, O., Danquah, J.A., Bamwesigye, D., Akalibey, S., Appiah, M. & Pappinen, A. (2025). A systematic review of the potential of non-timber forest products to alleviate poverty. *Ecol. Front.* 45, 1123–1134.

Awe, F., Osadebe, C. O., Imoagene, E., Fashina, A. Y., Eniola, T. S., and Adeleke, E. O. (2011). Assessment of rural households' objectives for gathering non-timber forest products (NTFPs) in Kogi State, Nigeria. *African Journal of Environmental Science and Technology*, *5*(2), 143-148.

Bak, M. (2025). Improving the Physical Characteristics and Durability of Wood Through a Combined Modification Process Using Thermal Treatment and Wax Impregnation in One Step. *Forests*, 16(8), 1317.

Bashmakov, I. A., Nilsson, L. J., Acquaye, A., Bataille, C., Cullen, J. M., Fischedick, M., ... and Tanaka, K. (2022). Climate change 2022: Mitigation of climate change. Contribution of working group III to the sixth assessment report of the intergovernmental panel on climate change, chapter 11.

Boyapati, T., & Muthukumarappan, K. (2025). Non-timber forest products and the bioeconomy: Linking livelihood security and biodiversity conservation (2015–2025 trends). *Frontiers in Sustainable Food Systems*, *9*, 1714576.

Dalu, M. T., Gunter, A. W., Makatu, M., Dowo, G. M., Dondofema, F., & Dalu, T. (2021). Contribution of natural forest products to rural livelihoods at Mavunde and Sambandou Villages, Vhembe Biosphere Reserve, South Africa*: sustainability*, *13*(8), 4252.

Derebe, B., & Alemu, A. (2023). Non-timber forest product types and their income contribution to rural households in the Horn of Africa: a systematic review. *Forest Science and Technology*, *19*(3), 210–220. https://doi.org/10.1080/21580103.2023.2231963

Ekundayo, O. O., Arum, C., & Owoyemi, J. M. (2022). Bending strength evaluation of glulam beams made from selected Nigerian wood species. *International Journal of Engineering*, *35*(11), 2120-2129.

Fajemirokun, B. (2021). Making the case for reforms of forestry policy and law: Lessons and experiences from Nigeria. *Environmental Policy and Law*, *51*(5), 317-325.

Falemara B. C., Omole A. O., Ajayi B., Ogunsanwo O. Y., & Ogunbela A. A. (2025). Advancing Biomass Energy Development for Carbon Neutrality, Power Access, And Reduced Fossil Fuel Reliance in Nigeria's Clean Energy Transition: A Critical Review. In Akinyele, A.O., Omitoyin, S. A., Ige, P. O., Coker, O.M., Fasoro, O. A., and Ajiboye, A.O. (Eds). Renewable Natural Resources Management and Use: A path to sustainable development: Proceedings of the 1st Faculty of Renewable Natural Resources. Ibadan: 16-20 June, 2025, 656-678pp

FAO, (2022). *Classification of forest products 2022*. Rome. https://doi.org/10.4060/cb8216en

FAO. (2015). *Global Forest Resources Assessment (2015*). Food and Agriculture Organization of the United Nations: Rome, Italy, 2015; 56p.

FAO. (1995). Non-Wood Forest Products for Rural Income and Sustainable Forestry. Rome: FAO NWFPs 7.

Fredriksson, M., & Broman, O. (2017). Factors Affecting Volume Yield in a Forestry-Wood Value Chain: A Simulation Study Based on CT Scanning. In *Pro Ligno*. 13(4): 540-548.

Ghaffariyan, M.R. (2023). Short review of collecting technologies and methods in forest harvesting residues recovery. *Silva Balcanica*, *24*(1), 55–68.

Hariharan, S., Karpate, Y., Kainer, K.A., Karanth, K.K., & Vasudev, D. (2025). Drivers of spatial and temporal patterns of non-timber forest product extraction in southern India. *Glob. Ecol. Conserv.* 62:e03768.

He, Z., and Turner, P. (2021). A systematic review on technologies and Industry 4.0 in the forest supply chain: a framework identifying challenges and opportunities. *Logistics*, *5*(4), 88.

Huang, S., Dong, Q., Che, S., Li, R., and Tang, K.H.D. (2025). Bioplastics and biodegradable plastics: A review of recent advances, feasibility and cleaner production. *Science of The Total Environment*, *969*, 178911.

Ingalls, M.L., Meyfroidt, P., To, P.X., Kenney-Lazar, M., & Epprecht, M. (2018). The transboundary displacement of deforestation under REDD+: Problematic intersections between the trade of forest-risk commodities and land grabbing in the Mekong region. *Global environmental change*, *50*, 255–267.

Jimoh, S., Amusa, T., & Azeez, I. (2013). Population distribution and threats to sustainable management of selected non-timber forest products in tropical lowland rainforests of Southwestern Nigeria. Journal of Forest Research, 24(1), 75 – 82.

Kurniasih, H, Ford R.M., Keenan, R.J., and King, B. (2021). The evolution of community forestry through the growth of interlinked community institutions in Java, Indonesia. *World Develop.* 139:105319.

Laktuka, K., Kubule, A., Vamza, I., Rozakis, S., & Blumberga, D. (2024). Strategic pathways for a bioeconomy with high value-added products: Lessons learnt from the Latvian forest sector. *Biomass and Bioenergy*, *190*, 107400.

Lazaridou, D. C., Michailidis, A., & Trigkas, M. (2021). Exploring environmental and economic costs and benefits of a forest-based circular economy: A literature review. *Forests*, *12*(4), 436.

Leskinen, P., Cardellini, G., González-García, S., Hurmekoski, E., Sathre, R., Seppälä, J., ... and Verkerk, P. J. (2018). *Substitution effects of wood-based products in climate change mitigation* (Vol. 7). Joensuu: EFI.

Liu, Y. and Huang, Y. (2024). Assessing the interrelationship between fossil fuel resources and the biomass energy market for achieving a sustainable and green economy. *Resour. Policy. 88*, 104397.

Loiseau, E., Saikku, L., Antikainen, R., Droste, N., Hansjürgens, B., Pitkänen, K., ... and Thomsen, M. (2016). Green economy and related concepts: An overview. *Journal of Cleaner Production,* 139, 361-371.

Lyon, S., Bowe, S., & Wiemann, M. (2021). Understanding vacuum drying technologies for commercial lumber. *FPL-GTR-287*, *287*, 1–5.

Mandal, M., Roy, A., Mitra, D., & Sarkar, A. (2024). Possibilities and prospects of bioplastics production from agri-waste using bacterial communities: Finding a silver lining in waste management—*Current Research in Microbial Sciences*, *7*, 100274.

Mao, C., Lin, Y., Pan, Y., Qin, L., Cao, M., Huang, S., ... Wan, H. (2025). Green, sustainable, and circular forest products. In the *Wood industry: Impacts and benefits*. IntechOpen. https://doi.org/10.5772/intechopen.1007299

Nigeria Conservation Foundation. (2019). Green recovery Nigeria: towards a prosperous nation. Assessed on the 3rd of March 2025 from https://ncfnigeria.org/tag/green-recovery-nigeria/

Ogunsanwo, O. Y., & Adebayo, J. O. (2022). Sustainable utilization of wood and non-wood forest products for climate change mitigation. In *Proceedings of the 8th Biennial Conference of the Forests & Forest Products Society.* Forestry Research Institute of Nigeria. (pp. 365–371).

Ogunsanwo, O. Y., Aiyeloja, A. A., & Filani, G. S. (2005). Assessment of off-site waste associated with timber flitching in Ibadan. In *Proceedings of the 30th Annual Conference of the Forestry Association of Nigeria (FAN)* (pp. 345–353). Forestry Association of Nigeria.

Sahoo, K., Bergman, R., Alanya-Rosenbaum, S., Gu, H., & Liang, S. (2019). Life cycle assessment of forest-based products: A review: *Sustainability*, *11*(17), 4722.

Sandak, A., Gordobil, O., Poohphajai, F., & Herrera Diaz, R. (2024). Weathering of Wood Modified with Acetic Anhydride—Physical, Chemical, and Aesthetical Evaluation. *Forests*, *15*(7), 1097.

Sangare, A., Soropogui, Z., Soumaoro, G., Monemou, P., Magassouba, D., Camara, A., Sina, H., Adjanohoun, A. and Baba-Moussa, L. (2026).. Economic Importance of Non-Timber Forest Products Favored by the Local Populations of the Ziama Biosphere Reserve. *American Journal of Plant Sciences*, 17, 68-79.

Serna-Loaiza, S., Miltner, A., Miltner, M., & Friedl, A. (2019). A Review on the Feedstocks for the Sustainable Production of Bioactive Compounds in Biorefineries. *Sustainability*, *11*(23).

Sheppard, J.P., Chamberlain, J., Agúndez, D., Bhattacharya, P., Chirwa, P. W., Gontcharov, A., ... and Mutke, S. (2020). Sustainable forest management beyond the timber-oriented status quo: transitioning to co-production of timber and non-wood forest products—a global perspective. *Current Forestry Reports*, *6*(1), 26–40.

Shiva, M.P., & Verma, S.K. (2002). Approaches to Sustainable Forest Management and Biodiversity Conservation: With Pivotal Role of Non-timber Forest Products. Dehra Dun: Centre for Minor Forest Products, Valley Offset Printers.

Sohail, M. T., Li, W., & Sohail, S. (2024). Greening the economy: How forest-product trade and bioenergy shape the framework for green growth. *Forests*, *15*(11), 1960.

Syahirah, Y. A., Anwar, U. M. K., Sh, L., Ong, C. B., Asniza, M., & Paridah, M. T. (2025). The properties of Cross Laminated Timber (CLT): A review. *International Journal of Adhesion and Adhesives*, *138*, 103924.

Tritsch, I., Le Velly, G., Mertens, B., Meyfroidt, P., Sannier, C., Makak, J. S., and Houngbedji, K. (2020). Do forest-management plans and FSC certification help avoid deforestation in the Congo Basin?. *Ecological Economics*, *175*, 106660.

Vantomme, P., & Walter, S. (2003). Opportunities and challenges for nonwood forest products certification. In *Congress Proceedings XII, World Forestry Congress (WFC)* (pp. 21–28).

Wang, Q., Wang, Z., Feng, X., Zhao, Y., & Li, Z. (2024). Mechanical properties and probabilistic models of wood and engineered wood products: A review of green construction materials. *Case Studies in Construction Materials*, *21*, e03796.

Yao, K. C., Chen, D. C., Pan, C. H., & Lin, C. L. (2024). The development trends of computer numerical control (CNC) machine tool technology*: mathematics*, *12*(13), 1923.

ISTF-NIG 2026

ESTIMATING BENEFITS FROM THE NIGERIAN FORESTS: MARKET AND NON-MARKET VALUATIONS

Adetunji Lawrence Kehinde
Department of Agricultural Economics and Agribusiness Management
Osun State University, Osogbo
Email: kehindeal@uniosun.edu.ng
Tel: 08037860000

A lead paper presented at the 2026 Annual Conference of the International Society of Tropical Foresters-Nigeria, ISTF
Date: 19th to 21st May, 2026.

1.0 Introduction

I thank the organizers of the 4th International Society of Tropical Foresters (ISTF), Nigeria Chapter, for inviting me to present the paper titled "Estimating Benefit from the Nigerian Forests: The Market and Non-Market Valuations" at its international conference held at the College of Agriculture, Ejigbo campus, Osun State. I am honoured to deliver the lead paper at this event.

The Nigerian Forest estates represent One of Nigeria's strategic environmental assets. Its key products are timbers, Non-Timber Forest Products (NTFPs), and environmental services. Tangible products are traditionally included in Nigeria's Gross Domestic Product (GDP), accounting for 4.32% of the agriculture sector's GDP and 1.19% of the entire GDP (NBS 2025). In monetary terms, at 2019 constant prices, the forestry sub-sector contributed ₦2,631,374.14 million out of the ₦61,042,932.05 million contributed by the agriculture sector. The contributions omit the environmental services provided by the forest estates, which would result in a significantly higher estimate if included. Therefore, forest estates have mainly been viewed in terms of timber and NTFPs, so policy has always focused on widening the forest productive base by increasing plantation forestry and implementing sustainable forest management and strategies to diversify the economic contribution of forests. According to Larinde and Popoola (2008) and Kalu and Okojie (2009), as cited in Olajuyigbe (2018), these interventions would have a positive impact on the development of renewable resources and increase their contribution to GDP. However, this policy intervention, as noble as it appears, overlooks forests' ecological contributions and will continue to provide a flawed valuation of them.

Therefore, proper valuation of this asset is important as it has far-reaching implications for its use. It is commonplace nowadays to find indiscriminate deforestation by government and non-government actors for residential and industrial development, without a structured reforestation effort. This development is likely motivated by the inaccurate valuation and/or opportunity cost assigned to this resource by policymakers and other key stakeholders in the forestry sector. This paper redirects thinking on the need to prioritize the holistic value of forests by making the case for capturing the value of the environmental services they provide. This will, most importantly, help decide on the best land-use options when developmental pressures arise and help commit the forest to the best use and the greatest good. Economically, this involves critically considering its opportunity cost before committing to using it further.

This paper will provide a cursory review of the widely used methodology for market valuation of tangible forest products. It will focus on the Valuation of intangible products, known as environmental services. The contingent Valuation and stated preference methods will be discussed.

2.0 Timber and Non-timber Forest Products

The Nigerian Forest is diverse and spans the 6 agroecological zones of Nigeria. According to Olajuyigbe (2018), this extends from the mangrove swamp to the lowland rainforest in southern Nigeria, comprising the tropical forest found in the coastal area of Southwestern Nigeria to the open shrub and savanna woodlands on the low plateau, while the woodlands extend to the central part of Nigeria, in the semi-arid plains of the north and the highlands to the east. These ecological zones are diverse and important repositories of biodiversity, home to approximately 20,000 insect species, 7,895 plant species, 1,000 bird species, 247 mammal species, 123 reptile species, and 1,000 fish species. It is estimated that 172 plant, 17 mammal, 6 bird, and 13 amphibian species found in these vegetation types are threatened (IUCN 2004, Usman and Adefalu 2010 in Olajuyigbe, 2088).

Forests have contributed significantly to Nigeria's socioeconomic growth and development. They support the livelihoods of over 45 million people, providing subsistence and upholding traditional values. Many rural dwellers depend on non-timber forest products (NTFPs) and services for livelihood sustenance and additional income. Trading in NTFPs is an essential economic activity, with a complex web of market systems involving NTFP gatherers, producers, wholesalers, and retailers. The general populace obtains tangible products such as food, fodder, fuel, building materials and medicine, along with intangible products such as cultural symbols, traditional functions and ritual artifacts. In fact, non-timber products such as snails, mushrooms, chewing sticks, sponges, fruits, kola nuts, wild game, food wrapping leaves, medicinal plants, and wooden trays are very significant in the livelihoods of many urban and rural dwellers. Approximately 80% of Nigeria’s rural population engages in agro-forestry and agro-allied activities. In addition, rural and urban households obtain domestic energy from fuelwood and charcoal sourced from forests (Usman & Adefalu, 2010; Ajewole et al., 2013; Amusa et al., 2017).

2.1 Forest Non-Use Values

Important non-use and bequest values of the forest are expressed in terms of the environmental services provided by forests. Some of the environmental services include climate stabilization, carbon storage, protection of hydrological functions, and biodiversity conservation (Scherr et al., 2004; Adekunle et al., 2005). There are also cultural and social uses, but for the sake of this paper, they are summed up as environmental services.

2.1.1 Methodological Approaches

Some key methodological definitions/clarifications are provided below:

Benefits: The price people are willing to pay for an item, in the case of tangible and intangible items, as they respond to economic signals.

Revealed Preference: The study of individuals' choices to reveal the implied values that underlie their choices. Examples of revealed preference techniques include averting costs to avoid experiencing poor environmental quality or service, travel cost, inter-city wage differentials, etc.

Stated preference: This involves asking people to state the direct value they are willing to pay for a particular attribute or quality of the environment rather than do without it. The main example is the contingent Valuation.

2.2 Valuation of marketed goods and services: Market Valuation

These are the monetary values or prices assigned to forest products traded in the market. These prices result from the interaction between demand and supply. These are the prices that clear the markets for the different forest products, and the quantities are referred to as equilibrium quantities.

2.3 Valuation of non-marketed Environmental services: Direct Non-Market Valuation

A major service the forest provides is environmental services. This omission in the computation of the agriculture and forestry sector GDP significantly underestimates the contribution of forests and forest resources in Nigeria. Some of the environmental services include climate stabilization, carbon storage, protection of hydrological functions, and biodiversity conservation (Scherr et al., 2004; Adekunle et al., 2005). One of the best-known direct non-market Valuation and stated preference methods is the Contingent Valuation Method (CVM). This is a survey-based approach in which beneficiaries of environmental services are asked hypothetical questions to elicit their Willingness To Pay (WTP) or Willingness To Accept (WTA) for changes to environmental goods and services in contingent situations. According to Abdeta (2022), the main goal of any non-market valuation study is to provide an accurate estimate of the good/attribute's actual value.

In terms of empirical relevance, Abdeta (2022) in his systematic review of literature on willingness to pay for forest conservation in developing countries opined that CVM is used to develop financial incentive based instrument for (1) forest management programmes and payment of ecosystem (forest) services and (2) in a non-financial incentive programme to assess community's preference and willingness to pay for forest conservation activities. Abdeta (2022) further stated that applying WTP methodologies to estimate the conservation value of forests plays a very important role in providing an alternative source of finance for conservation programmes through public involvement, especially in developing countries, where government financing alone is inadequate due to budget constraints. Furthermore, the estimated value can be used in cost-benefit analysis of new projects and inform policy. CVM has been widely used in developed and developing countries and has produced very interesting results, clearly showing that people are willing to pay for environmental services provided by forests.

In a study to estimate WTP for environmental services by corporate organizations in Ogun State, Nigeria, Adekunle et al. (2005) used the contingent valuation method (CVM) to derive a monetary valuation of the environmental service functions of forest trees in the urban environment of the Federal University of Agriculture, Abeokuta (FUNAAB). The multistage random sampling procedure was used to select a sample of 48 out of the 75 registered students' corporate organizations, comprising academic, religious, and socio-cultural organizations and clubs. Data were collected through a well-structured questionnaire. The results show that 77% of the respondents were willing to pay (WTP) various amounts ranging from N5 to N1000 monthly. The overall mean WTP for the environmental services of UNAAB urban forest trees is N7,800 per month (US$1 = N140). The results showed that the respondents were aware of the forest's environmental value and were willing to pay for its maintenance.

Orowale et al. (2022) examined payment for forest ecosystem services through willingness-to-pay in the Oba Hills Forest Reserve, Osun State, Nigeria. The study assessed the socioeconomic characteristics of the respondents, willingness to pay (WTP), and factors that influenced the WTP for ecosystem services in Oba Hill forest reserve, Osun State. A pre-tested semi-structured questionnaire and interview guide were used to collect information from the respondents. A total of 100 respondents were randomly selected from the adjoining forest communities. Descriptive statistics were used to describe respondents' socioeconomic characteristics, and a choice experiment was used to assess Willingness-to-Pay (WTP) and the factors influencing it. D-Optimal design with a D-efficiency of 99.9% was developed for the choice experiment. A practical set of 9 choice sets, each with two product profiles and a status quo alternative, was obtained. Random-parameters Mixed Multinomial Logit (MIXL) and Generalized Multinomial Logit (G-MNL) models were used to estimate willingness-to-pay (WTP) and the factors influencing an individual's WTP for attributes of forest ecosystem services. Wildlife loss, soil fertility and cost attributes were significant at 0.1% significance level ($p \leq 0.001$). The mean WTP estimates for a household for increases in soil fertility, reductions in wildlife loss, and multiple important tree species were 8.60, 7.61, and 39.95 (Naira) per month, respectively. The study thus confirms that respondents were willing to pay for the forest's environmental services.

Bamwesigye et al (2020) investigated the WTP for existence value and sustainability in Uganda. They surveyed 203 respondents in selected towns and villages between 2018 and 2019. Field questionnaire interviews were conducted to assess Willingness to Pay (WTP) for forest existence. The WTP values ranged from 1 to 200 USD using the contingent valuation method (CVM). The cross-tabulation of the expressed preferences illustrates that 81.9% of the representative sample are willing to pay for forest existence value and sustainability. We concluded that the willingness to pay for forest existence significantly on prefesignificantly on preferences existence values and sustainability. The results equally express that the mean WTP in this region is 15 USD per year and that over 60% are willing to pay this amount. The socioeconomic results on determinants demonstrate heterogeneity, and over 90% of respondents are willing to pay for forest existence, conservation, and sustainability.

Finally, in a study by Ariyo et al. (2018) to investigate villagers' willingness to pay for conservation in Ibadan, Oyo State, Nigeria. Respondents were selected from villagers living at the perimeter fence of the International Institute of Tropical Agriculture (IITA) in Ibadan, Oyo State, Nigeria. The multistage sampling procedure was used to select 408 respondents, comprising farmers, hunters, herbalists, and herb sellers. They were interviewed using copies of well-structured questionnaires. Data were analyzed using descriptive statistics and the Logit regression model. The study showed that the majority of respondents were natives of the study area, were not educated or employed, had a monthly income of between 12,000 and 20,000 naira (US $33.38 to US $55.63), and lived within 1-9 km of the forest. The mean willingness to pay for forest conservation was ₦114. 38 (US $0.32) per household per month, and the total willingness to pay was ₦ 3, 461,024.42 (US $9, 627.32) per household per month. The study further revealed a significant relationship between respondents' socioeconomic characteristics and their willingness to pay for forest conservation. Variables such as gender, educational level, occupation, income and bid amounts had a significant effect on the willingness to pay for forest conservation. The study recommended assigning monetary values to the social, cultural, ecological, and economic services forests provide, so they can continue to provide these services sustainably. Also, the willingness to pay for forest conservation can serve as an alternative measure of displeasure with the conversion

of forests to other uses and as a supportive argument for the invaluable roles forests play in sustaining people's livelihoods.

3.0 Conclusion

The discussion thus far shows that the forest resources in Nigeria are undervalued, with disproportionate attention paid to tangible, marketed products, while the value of environmental services has been largely neglected. The contingent valuation method estimates the monetary value of environmental services by eliciting WTP. Therefore, for policy purposes, environmental Valuation will need to be computed for different ecological zones and aggregated centrally to obtain a national estimate of WTP, which will serve as a good proxy for the environmental contributions of the forest. Though corporate organizations pay a couple of environmental taxes, these will not suffice as a replacement. The government can therefore introduce an annual environmental service tax payable by every adult to support reforestation and forest conservation. Also, Environmental Impact Studies for developmental projects must be based on proper cost-benefit analysis, with the environmental services of the forest appropriately accounted for. When deciding whether to pursue alternative projects with different land use types, we must compare the benefits on both sides to ensure the forest estate is not sacrificed for less significant projects.

References

Abdeta, D. (2022). Willingness to Pay for Forest Conservation in Developing Countries: A Systematic Literature Review, Environmental and Sustainability Indicators, 16, 100201, https://www.sciencedirect.com/science/article/pii/S2665972722000332 Assessed 14/04/2026

Adekunle, M.F., Adedokun, M.O., & A.A. Adedoja (2006). Willingness to Pay for Environmental Service of Forest Trees by Cooperate Organisations (2006) Adekunle, Paper prepared for presentation at the Farm Management Association of Nigeria Conference, Jos, Nigeria, September 18-21, 2006.

Adekunle, M.F.; Momoh, S. and Agbaje, B.M. (2005). Pricing of urban forest environmental service functions at the Universitythe University of Agriculture, Abeokuta (UNAAB), Nigeria. Paper presented at the 2nd Annual Conference of the Nigeria Society of Environmental Management (NISEM). 5th – 8th Sept., 2005 UNAAB 30p.

Ariyo, O.C., Okojie, L.O., & O.M. Ariyo (2018). Villagers'. Villagers' willingness to pay for conservation in Ibadan, Oyo State, Nigeria. Asian Journal of Agricultural Extension, Economics & Sociology, (23) 1-14.

Bamwesigye, D, Hlavackova, P., Sujova, A., Fialova, J., & Kupec, P. (2020). Willingness to Pay for Forest Existence Value and Sustainability, *Sustainability* **2020**, *12*(3), 891; **https://doi.org/10.3390/su12030891**

IUCN. (2004). Red list of threatened species: a global assessment. International Union for Conservation of Nature. Available at https:/portals.iucn.org/library/node/9830.

Larinde, S.L. & Popoola, L. (2008). Socioeconomic assessment of secondary wood processing in Nigerian sawmills. *Journal of Agriculture, Forestry and the Social Sciences* 6: 146–156.

National Bureau of Statistics, Gross Domestic Product: Production, Income and Expenditure Approach Nigeria https://microdata.nigerianstat.gov.ng/index.php/catalog/147 Accessed 18/04/2026

Kalu, C. & Okojie, C.E.E. (2009). Economic contributions of forests in Nigeria: 1970-2000. *Research Journal of Social Sciences* 4: 69–73.

Orowale O. O., Oyerinde, O. V., & Olusola, J. A. (2022). Payment for Forest Ecosystem Services through Willingness to Pay in Oba Hill Forest Reserve, Osun State, Nigeria, XV World Forestry Congress, Building a green, Healthy and Resilient Future with Forest, held 2 – 6. May 2022, Coex Seoul. Republic of Korea. https://openknowledge.fao.org/server/api/core/bitstreams/71f44bd4-c16d-4239-a543-68609b940bca/content

Olajuyigbe, S. (2018). Forest perspectives: Green gold of Africa: Nigeria's forest, a depleted but resilient renewable resource, Irish Forestry (75). 92 – 112.

Scherr, S.; White, A.; Khare, A.; Inbar, M. and Moyan, A. (2004). For services rendered: The current status and future potential of markets for the ecosystem services provided by tropical forests. ITTO Technical Series No. 21 (2004) 69p

Usman, B.A. and Adefalu, L.L. 2010. Nigerian forestry, wildlife and protected areas: Status report. *Biodiversity* 11: 45–52.

ISTF-NIG 2026

POTENTIAL OF NON-TIMBER FOREST PRODUCTS IN FOREST CONSERVATION AND ECONOMIC DEVELOPMENT: A CASE STUDY OF HERBAL MEDICINE

Ibraheem O. Lawal, Ph.D

Provost, Federal College of Forestry, Ibadan

A lead paper presented at the 2026 Annual Conference of the International Society of Tropical Foresters-Nigeria, ISTF
Date: 19th to 21st May, 2026.

1.0 Understanding Non-Timber Forest Products

Non-timber forest products (NTFPs) are biological resources harvested from natural forests, plantations, and agroforestry systems that do not require tree felling. The Food and Agriculture Organization (FAO) defines NTFPs as goods of biological origin other than wood derived from forests, other wooded land, and trees outside forests (FAO, 2020). This definition encompasses an enormous diversity of products that have sustained human communities for millennia.

NTFPs can be categorized into several major groups based on their uses and characteristics. Medicinal plants are among the most valuable categories, providing raw materials for both traditional and modern pharmaceutical industries. Food products include wild fruits, nuts, mushrooms, edible leaves, and honey. Aromatic plants yield essential oils, resins, and gums used in perfumery, cosmetics, and industrial applications (Shanley *et al.*, 2020). Fiber-producing plants provide materials for textiles, basketry, and construction. Additionally, ornamental plants, dyeing and tanning materials, and various other products complete this diverse array.

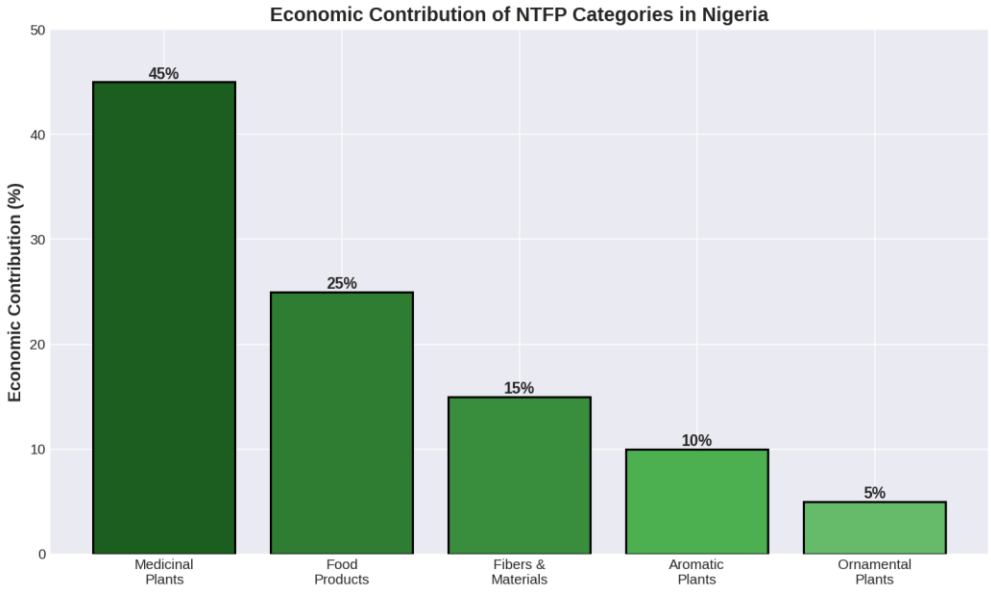


Figure 1: Economic Contribution of NTFP Categories in Nigeria

The significance of NTFPs extends beyond their material value. They represent a living connection to traditional knowledge systems, embodying centuries of accumulated wisdom about plant

properties and sustainable harvesting practices (Adepoju *et al.*, 2019). For many indigenous and local communities, NTFPs form the foundation of cultural identity, traditional medicine systems, and customary practices that have been transmitted across generations.

2.0 Economic Potential of the Herbal Medicine Trade

The global market for herbal medicine has experienced remarkable growth over the past two decades, with current estimates placing its value at over $150 billion annually (WHO, 2019). This expansion reflects increasing consumer preference for natural products, growing recognition of traditional medicine systems by mainstream healthcare, and rising health consciousness across populations worldwide. The World Health Organization reports that approximately 80% of the global population relies on herbal medicine for some aspect of primary healthcare (WHO, 2019).

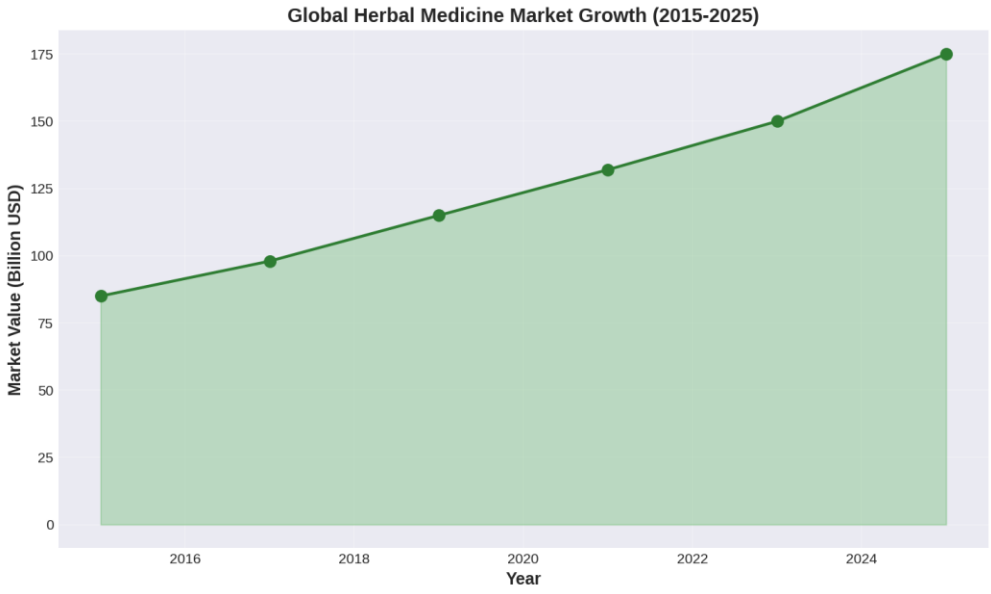


Figure 2: Global Herbal Medicine Market Growth (2015-2025)

In Nigeria and across Africa, the herbal medicine sector represents a substantial economic opportunity that remains largely untapped (Ndoye *et al.*, 2018). Millions of Nigerians derive their livelihoods from the collection, processing, and sale of medicinal plants. Traditional healers, herbalists, and medicinal plant traders form a complex value chain that extends from rural forest communities to urban markets. The sector provides employment opportunities that are particularly important in areas where formal employment is limited.

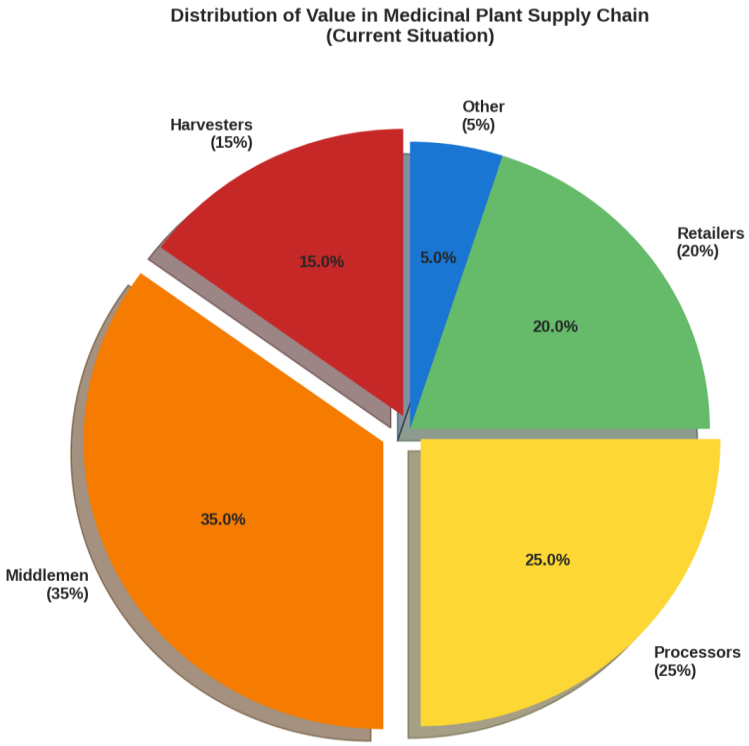


Figure 3: Distribution of Value in Medicinal Plant Supply Chain

The economic benefits of herbal medicine extend beyond direct trade. Value addition through processing, standardization, and product development creates opportunities for small and medium enterprises. The export potential of African medicinal plants to international markets represents another avenue for economic growth (World Bank, 2021). However, realizing this potential requires investment in quality control, certification systems, sustainable harvesting practices, and market development infrastructure.

Community-based enterprises focused on medicinal plant cultivation and sustainable harvesting have demonstrated impressive economic returns while contributing to forest conservation. These enterprises provide stable income for rural households, create employment opportunities for women and youth, and generate resources for community development (Adepoju *et al.*, 2019). When properly structured with equitable benefit-sharing mechanisms, they can significantly improve living standards in forest-adjacent communities while incentivizing forest protection.

3.0 Role of NTFPs in Forest Conservation Strategies

The integration of NTFP harvesting into forest conservation strategies exemplifies the sustainable development principle that economic value drives conservation (Laird *et al.*, 2010). When local communities derive tangible benefits from standing forests through NTFP collection, they develop vested interests in forest protection. This creates a powerful incentive structure that aligns conservation objectives with community welfare.

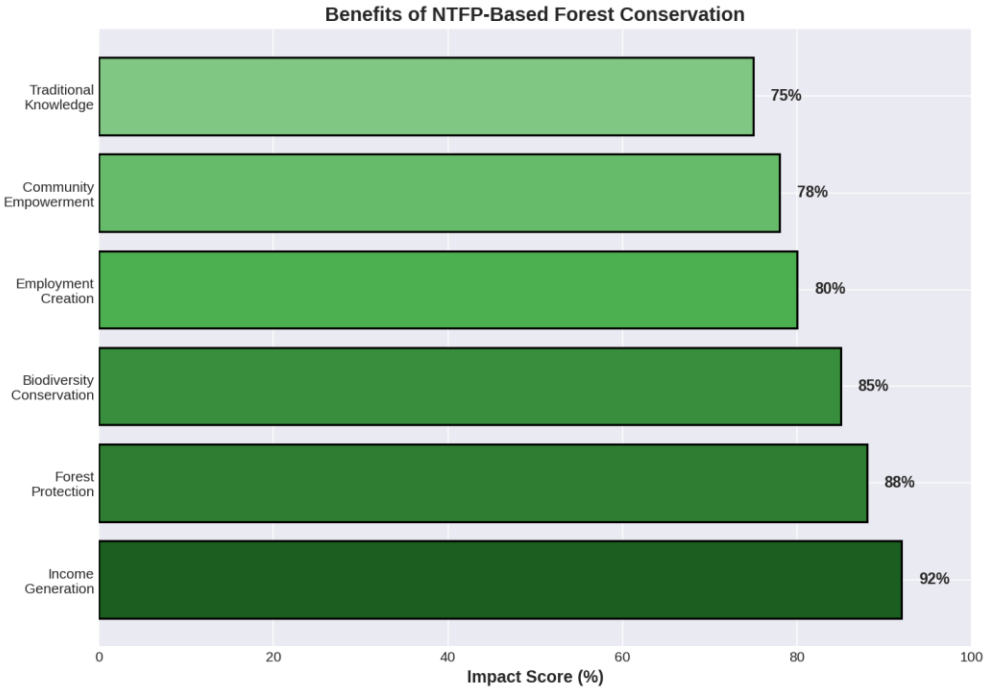


Figure 4: Benefits of NTFP-Based Forest Conservation

Traditional forest management systems developed by indigenous communities often incorporate a sophisticated understanding of sustainable harvesting practices. These systems typically include rotational harvesting, selective collection to ensure regeneration, and cultural practices that limit overexploitation (FAO, 2020). By recognizing and supporting these traditional management approaches, modern conservation strategies can benefit from accumulated traditional ecological knowledge while respecting community rights and customs.

The NTFP-conservation nexus also provides opportunities for innovative conservation financing. Payment for ecosystem services schemes that recognize the value of forest biodiversity conservation can be linked to sustainable NTFP harvesting rights (Shanley *et al.*, 2020). This creates financial flows that support both conservation and community livelihoods. Additionally, certification schemes for sustainably harvested NTFPs can command premium prices in international markets, further strengthening the economic case for conservation.

However, the relationship between NTFP harvesting and conservation is not automatically positive. Unsustainable harvesting practices, particularly commercial-scale collection for distant markets, can threaten forest health and biodiversity (Schippmann *et al.*, 2022). Successful integration requires careful management, monitoring of harvesting impacts, enforcement of sustainable practices, and equitable benefit distribution that maintains local support for conservation.

3.1 Case Studies of High-Value Medicinal Plants

Synsepalum dulcificum (Miracle Berry)



Scientific Name: Synsepalum dulcificum
Family: Sapotaceae
Common Names: Miracle berry, Miracle fruit
Active Compound: Miraculin

The miracle berry, indigenous to West African forests, exemplifies the economic potential of medicinal plants. This remarkable species contains miraculin, a glycoprotein that modifies taste perception, making sour foods taste sweet (Schippmann *et al.*, 2022). Beyond its novelty value, miracle berry has significant medical applications in managing taste disorders in cancer patients undergoing chemotherapy and in diabetes management as a natural sweetness enhancer without caloric content. The plant commands high prices in international markets, with dried berries fetching premium rates. Sustainable cultivation in agroforestry systems has proven economically viable while reducing pressure on wild populations (Adepoju *et al.*, 2019).

Garcinia kola (Bitter Kola)



Scientific Name: Garcina kola (Bitter Kola)

Family: Clusiaceae

Active Compound: Kolaviron

Uses: Respiratory ailments, Anti-inflammatory, Antimicrobial

Bitter kola is One of Africa's most valuable medicinal plants, with applications in treating respiratory ailments and inflammatory conditions, and as an antimicrobial agent. Scientific research has confirmed the presence of bioactive compounds, including kolaviron, which demonstrates hepatoprotective properties and potential in treating various liver conditions (Farombi *et al.*, 2005). The seeds command substantial prices in both local and export markets, creating strong economic incentives for cultivation. However, the species faces conservation challenges due to slow growth rates and overexploitation of wild populations, highlighting the need for cultivation programs and sustainable harvesting protocols (Schippmann *et al.*, 2022).

Hibiscus sabdariffa (Roselle)



Scientific Name: Hibiscus sabdariffa

Family: Malvaceae

Common Name: Roselle,Zobo

Active Compound:Anthocyanins,Polyphenols

Uses: Anti-hypertensive, Cardiovascular health, Antioxidant, Beverage Production

Roselle, widely cultivated across Nigeria, demonstrates the potential for medicinal plants to transition from wild collection to commercial cultivation. The plant's calyces are rich in anthocyanins, organic acids, and polyphenols, providing cardiovascular benefits, anti-hypertensive effects, and antioxidant properties (Odigie *et al.*, 2003). Commercial production of roselle extracts and beverages has created substantial economic opportunities, with well-established value chains connecting farmers to processors and markets. The crop provides income diversification for smallholder farmers and can be integrated into mixed farming systems (Ndoye *et al.*, 2018).

Vernonia amygdalina (Bitter Leaf)



Scientific Name: Vernonia amygalina
Family: Asteraceae
Common Name: Bitter leaf
Activ Compounds: Sesquiterpene lactones, Flavonoids
Uses: Diabetes management, Anti-hypertensive, Anti-malaria, Food vegetable

Bitter leaf exemplifies plants with dual use as both food and medicine, a common feature of West African traditional systems (Oluwalana & Adeola, 2002). The leaves are consumed as a vegetable and used to treat various ailments, including diabetes, hypertension, and digestive disorders. Phytochemical research has identified sesquiterpene lactones and flavonoids with antimalarial, antioxidant, and anti-inflammatory activities (Igoli *et al.*, 2005). The plant's easy cultivation and rapid growth make it suitable for small-scale production, providing regular income for rural households while meeting local demand for both food and medicine.

3.2 Challenges Facing Sustainable NTFP Harvesting

Despite the recognized potential of NTFPs for conservation and development, several challenges impede sustainable harvesting and equitable benefit distribution. Overexploitation driven by increasing market demand threatens many medicinal plant species (Schippmann *et al.*, 2022). Commercial collectors often employ destructive harvesting techniques that damage reproductive capacity or kill entire plants. The absence of reliable data on population sizes, regeneration rates, and sustainable harvest levels compounds these problems, making effective management difficult. Lack of secure land tenure and unclear access rights create disincentives for sustainable management (Laird *et al.*, 2010). When communities lack recognized rights to forest resources, they have little motivation to invest in conservation or sustainable harvesting practices. Conversely, outside actors may exploit resources without regard for long-term sustainability or local welfare. Resolving these tenure issues requires policy reforms that recognize customary rights while establishing clear frameworks for sustainable use.

Market-related challenges include price volatility, exploitation by intermediaries, and limited access to value-adding technologies. Harvesters often receive minimal compensation while intermediaries capture the majority of value in the supply chain (Ndoye *et al.*, 2018). Quality control and standardization issues limit access to premium markets, particularly for export. Building cooperative structures, improving market information systems, and supporting value addition at the community level can help address these challenges. Knowledge erosion represents another critical challenge. As younger generations migrate to urban areas and traditional knowledge transmission systems weaken, valuable information about medicinal plant identification, sustainable harvesting, and traditional preparation methods is being lost (WHO, 2019). Documentation of traditional knowledge, coupled with benefit-sharing arrangements that recognize knowledge holders' contributions, is essential for preserving this heritage while supporting conservation and development objectives.

3.3 Policy Frameworks and Stakeholder Engagement

Effective governance of NTFP resources requires comprehensive policy frameworks that address multiple dimensions, including conservation, sustainable use, equitable benefit sharing, and quality control (Laird *et al.*, 2010). National policies should recognize the economic importance of NTFPs while establishing clear guidelines for sustainable harvesting. Integration of NTFP management into broader forest policy, agricultural development strategies, and health sector planning is essential for coherent governance. Multi-stakeholder engagement is crucial for successful NTFP sector development. Local communities, traditional healers, commercial collectors, processors, traders, research institutions, and government agencies all have important roles and interests (FAO, 2020). Participatory approaches that include these diverse stakeholders in decision-making, planning, and implementation increase the legitimacy, effectiveness, and sustainability of NTFP initiatives. Platforms for dialogue and collaboration can help resolve conflicts, share knowledge, and coordinate activities.

Research institutions like the Forestry Research Institute of Nigeria (FRIN) play vital roles in generating knowledge about medicinal plants, developing sustainable harvesting protocols, and supporting domestication programs (Adepoju *et al.*, 2019). Strengthening links between research, policy, and practice ensures that management decisions are informed by scientific evidence while

remaining responsive to local contexts and traditional knowledge. Capacity building for all stakeholders, from harvesters to policymakers, is essential for effective sector development.

International frameworks, including the Convention on Biological Diversity, the Nagoya Protocol on Access and Benefit Sharing, and various trade agreements, provide important context for national NTFP policies (Shanley *et al.*, 2020). Compliance with these frameworks while advancing national interests requires careful policy design and implementation. Protection of traditional knowledge and fair benefit sharing from the commercialization of biodiversity are particularly important considerations.

4.0 Recommendations for Maximizing NTFP Potential

To fully realize the potential of herbal medicine and other NTFPs in forest conservation and economic development, several strategic interventions are recommended:

Strengthen Research and Development: Intensify research on medicinal plant biology, sustainable harvesting methods, cultivation techniques, and product development (Schippmann *et al.*, 2022). Establish comprehensive databases on the distribution, population dynamics, and sustainable harvest levels of NTFP species. Investigate value-addition opportunities and market requirements for various products.

Develop Sustainable Supply Chains: Support the development of transparent, equitable supply chains that ensure fair compensation for harvesters and communities while maintaining quality standards (Ndoye *et al.*, 2018). Promote cooperative structures and direct market linkages that reduce exploitation by intermediaries. Invest in value-adding infrastructure at the community level.

***Implement Certification and Quality Control Systems*:** Establish national standards for medicinal plant products covering quality, safety, and sustainability criteria (WHO, 2019). Develop certification schemes that verify sustainable harvesting practices and can command premium prices in markets. Support testing facilities and quality control infrastructure.

Secure Tenure and Access Rights: Reform policy and legal frameworks to recognize and protect community rights to forest resources and traditional knowledge (Laird *et al.*, 2010). Clarify access and benefit-sharing arrangements that incentivize conservation and sustainable use. Ensure fair representation of community interests in resource management decisions.

***Promote* Cultivation and Domestication:** Support programs for cultivating high-value medicinal plants in agroforestry systems, home gardens, and dedicated plantations (Adepoju *et al.*, 2019). Provide technical assistance, planting materials, and market support for cultivation initiatives. This reduces pressure on wild populations while creating stable supply sources and income opportunities.

***Build Capacity Across the Value Chain*:** Invest in training for sustainable harvesting, post-harvest handling, quality control, business management, and marketing (Shanley *et al.*, 2020). Strengthen the organizational capacity of community groups and cooperatives. Support knowledge exchange between traditional healers, scientists, and commercial operators.

Integrate Traditional Knowledge: Document and protect traditional knowledge about medicinal plants while ensuring that knowledge holders benefit from commercialization (WHO, 2019).

Develop frameworks for respectful collaboration between traditional medicine practitioners and modern healthcare systems. Support intergenerational knowledge transmission.

5.0 Conclusion

Non-timber forest products, particularly herbal medicine, represent a powerful convergence of conservation and development objectives. The sustainable utilization of these resources can generate significant economic benefits for forest-dependent communities while creating incentives for forest protection and biodiversity conservation (World Bank, 2021). Success requires moving beyond opportunistic extraction toward managed, sustainable production systems that balance economic returns with ecological integrity. The case of herbal medicine demonstrates both the potential and challenges of NTFP-based development. Growing global demand for natural products creates market opportunities, while traditional knowledge provides a foundation for sustainable use (WHO, 2019). However, realizing this potential requires addressing challenges of overexploitation, inequitable benefit distribution, quality control, and knowledge erosion through comprehensive, multi-stakeholder approaches.

As we move forward, we must recognize NTFPs not merely as extractive resources but as integral components of living forest ecosystems that require careful stewardship (FAO, 2020). Investment in research, policy reform, capacity building, and market development can transform the NTFP sector into a significant driver of sustainable development while strengthening the case for forest conservation. The path forward requires partnership among communities, government, researchers, and private sector actors, united in the vision of forests that sustain both nature and people.

References

Adepoju, A.A., Salau, A.S. & Oyewole, P.M. (2019). Socio-economic importance of non-timber forest products in rural livelihoods around Omo Forest Reserve, Nigeria. *Journal of Sustainable Forestry*, 38(4): 345-361.

FAO (2020). *The State of the World's Forests: Forest Biodiversity and People*. Food and Agriculture Organization of the United Nations, Rome.

Farombi, E.O; B.F. Adepoju, O.E., Ola-Davis, and G.O. Emerole (2005). Chemo-prevention of Latoxin BL Induced Genotoxicity and Hepatic Oxidative Damage in Rats by Kolavin, a natural biflavonoid of Garcinia kola Seeds. *European Journal of Cancer Prevention* 4(3): 207–214.

Igoli, J.O.; O.G., Ogaje, T.A. Tor-Anyin and N.P. Igoli (2005). Traditional Medicine Practice Among the Igede People of Nigeria: Part II. *African Journal of Traditional Complementary and Alternative Medicines*. Vol. 2:134-152.

Laird, S.A., McLain, R.J. & Wynberg, R.P. (2010). *Wild Product Governance: Finding Policies that Work for Non-Timber Forest Products*. Earthscan, London.

Ndoye, O., Ruiz Perez, M. & Eyebe, A. (2018). The Markets of Non-Timber Forest Products in the Humid Forest Zone of Cameroon. *Rural Development Forestry Network Paper 22c*, ODI, London.

Odigie, I. P., R. R. Ettarh & S. A. Adigun (2003). Chronic administration of aqueous extract of *Hibiscus sabdariffa* attenuates hypertension and reverses cardiac hypertrophy in 2K-1 C hypertensive rats. *J. Ethnopharmacol*., 86: 181–185.

Oluwalana S.A and O.A Adeola (2002). Indigenous uses of Vernonia amygdalina Del. In South Western Nigeria, In *The Ogun Journal of Agricultural Sciences. Published by the College of Agriculture. Sciences*, Olabisi Onabanjo University, Ago-Iwoye, Nigeria. 1: 177-185.

Schippmann, U., Leaman, D.J. & Cunningham, A.B. (2022). Impact of Cultivation and Gathering of Medicinal Plants on Biodiversity: Global Trends and Issues. In: Biodiversity and the Ecosystem Approach in Agriculture, Forestry and Fisheries, FAO, Rome.

Shanley, P., Pierce, A.R., Laird, S.A. & Guillen, A. (2020). *Tapping the Green Market: Certification and Management of Non-Timber Forest Products*. Earthscan, London.

WHO (2019). *WHO Global Report on Traditional and Complementary Medicine 2019*. World Health Organization, Geneva.

World Bank (2021). *Hidden Harvest: The Global Contribution of Capture Fisheries and Non-Timber Forest Products to Human Welfare*. World Bank, Washington DC.

ISTF-NIG 2026

INFORMATION AND COMMUNICATION TECHNOLOGY, ARTIFICIAL INTELLIGENCE AND THEIR IMPACTS ON FOREST ECOSYSTEMS

Evidence from Remote Sensing, LiDAR and UAS Research on Carbon Estimation

Dr. Omoyemeh Jennifer Ukachukwu
PhD, Forestry & Environmental Resources | NC State University
Senior Associate, Nature Based Solutions
Founder & Executive Director | Forest Regen Climate Initiative
drjenny@forestregenclimate.org

A lead paper presented at the 2026 Annual Conference of the International Society of Tropical Foresters-Nigeria, ISTF
Date: 19th to 21st May, 2026.

Background and Rationale

Forests cover approximately four billion hectares, nearly a third of the world's land surface and represent one of the most significant natural carbon sinks available to humanity. As the voluntary carbon market expands towards a projected valuation exceeding US$50 billion by 2030, the need for high-confidence, verifiable Measurement, Reporting, and Verification (MRV) data has never been more acute. Yet traditional field-based forest carbon inventory methods remain resource-intensive, spatially constrained, and fundamentally incapable of scaling to landscape or national levels without substantial technological augmentation. Information and Communication Technology (ICT) and Artificial Intelligence (AI) are transforming this paradigm. From airborne LiDAR and Unmanned Aerial Systems (UAS) to satellite platforms and AI-powered regression modelling, these tools offer a scalable, cost-effective path from plot-level measurement to landscape-level carbon accounting. This research demonstrates that low-cost, publicly available ICT tools; when paired with robust field validation and regression modelling, can generate scientifically defensible aboveground biomass estimates and quantify forest carbon sequestered. In Nigeria, three priority actions are recommended: investment in national established allometric equation databases; establishment of UAS and LiDAR monitoring programmes for forest plantations and REDD+ project areas; and integration of open-source remote sensing MRV pipelines into national forest inventory and carbon reporting frameworks. Realising the full potential of these technologies requires not only the tools themselves, but the trained workforce to deploy, validate, and iterate them — a challenge that demands sustained commitment to forest science education from the ground up.

TECHNICAL SESSIONS

SUB-THEME 1:
IMPROVING ECONOMIC BENEFITS FROM FORESTS: OPPORTUNITIES AND CHALLENGES

ISTF-NIG2026

DETERMINANTS OF GINGER (*Zingiber officinale*) PRODUCTION IN KAJURU LOCAL GOVERNMENT AREA OF KADUNA STATE, NIGERIA

[1]ARIYO, O. C., [1]BONI, P. G. and [2]ARIYO, M. O.

[1]Department of Entrepreneurship and Innovative Agriculture,
[2]Department of Horticulture and Landscape Technology,
[1,2]Federal College of Forestry Mechanization, Afaka, Kaduna, Kaduna State, Nigeria, Forestry Research Institute of Nigeria, Jericho Hills, Ibadan, Oyo State, Nigeria
**Corresponding Author: ask4ariyo@yahoo.com +2348033931981*

ABSTRACT

Ginger is an herbaceous spice crop, commercially grown extensively worldwide for its pungent aromatic rhizome. The study assesses factors affecting ginger (*Zingiber officinale*) production in the Kajuru Local Government Area of Kaduna State, Nigeria. A multi-stage sampling technique was used to select ninety-eight (98) ginger farmers. Data were collected with structured questionnaires and analyzed using descriptive statistics and a production function. The results revealed that the majority (72.45%) of the ginger producers were male, aged 21-40 years (72.45%), married (78.57%), and with a family size of 5-8 members (60.20%). (64.29%) had secondary school Education, (96.94%) had a farm size of 0.1-1.0 ha, and (43.87%) had 11-10 years of farming experience. The production model revealed that the coefficients of fertilizers, seeds (planting materials) and labour affect the output of ginger and were significant at the ($P< 0.05$) level of probability. These variables are very crucial to ginger output. The study concluded that fertilizers, planting materials (seeds), and labour variables affect ginger yield and recommends variable-input packages for ginger farmers at subsidized rates from government and non-governmental organizations.

Keywords: *Ginger, questionnaire, production function, Inputs-Output*

INTRODUCTION

Ginger (*Zingiber officinale*) is a rhizome; it contains numerous short, finger-like structures, or branches, that grow horizontally near the soil surface. It belongs to the order (Scitamineae) and to the family (*Zingiberaceae*). It is an herbaceous perennial root crop widely grown worldwide for its pungent, aromatic odour, making it an important export commodity in world trade (Ajibade & Dauda, 2005). The spiciness and pungency of ginger come from the principal compounds gingerol, shogaol, and zingerone (United Nations, 2012). According to Geekie (2010), ginger contains essential oils, namely, Oleoresin and Gingerol. The special characteristics of these oils make ginger a spice used in food to flavour curries, beverages, perfumes, and the medicinal industry (Yiljep *et al*., 2005).

Ginger was generally believed to have originated in Asia, where it was first cultivated and introduced to other parts of the world, including Nigeria. Ginger was introduced to Nigeria in 1927 (KADP, 2000; Nmadu & Marcus, 2013). The major producing areas in Nigeria include Kaduna,

Nasarawa, Sokoto, Zamfara, Akwa Ibom, Oyo, Abia, and Lagos states (Ibrahim *et al*., 2019a). Presently, Southern Kaduna is the largest producer of fresh ginger in Nigeria, particularly in Kachia, Jaba, Jama'a, and Kagarko Local Government Areas (Punch Newspapers, 2026; TheRadar, 2026). There are over 25 varieties of ginger grown worldwide; most have not been properly characterized (Ezeagu, 2016). Two commercial varieties of ginger are produced in Nigeria: the yellow ginger variety (UG 1), locally called "Tafin Giwa", with a bold yellow rhizome flesh, is stout with short internodes. The black ginger variety (UG 2), locally called "Yatsun Biri", has a dull-grey colour rhizome (Bokulo *et al*., 2015). The two varieties are higher in monoterpene and oil content, providing a stronger pungent odour and are always favoured for the manufacture of oils and oleoresins (KADP, 2000; Chukwu & Emehuite, 2003). However, the yellow variety of ginger is more popular than the black variety due to its higher yielding capacity and stronger pungency (Iwo *et al*., 2026).

The area under ginger cultivation in Nigeria is the largest in the world, but its contribution to global output is too low compared to other countries (Ibrahim *et al*., 2019a). This ranks her fifth in the world in production (National Bureau of Statistics, 2007). The reasons could be that most ginger production in Nigeria is undertaken by traditional and smallholder farmers who practice subsistence agriculture and use local technologies, resulting in low levels of ginger output. Besides, One of the problems faced by smallholder farmers was that the cultivation of the crop was not considered a business enterprise, and the profit-maximization motive was not adequately the focus. Several attempts have been made to increase ginger production in Nigeria since 1988, but these have not yielded the desired results (Shettima *et al*., 2017). There is high fluctuation of the yields and all efforts have not made any significant improvement in the income and standards of living of the famers (Food and Agricultural Organisation, 2024). However, FAO (2010) and Emmanuel (2008) stated that Nigeria has the capacity to enlarge the production of ginger in a medium to long term investment strategy that can develop into self-sufficient industry.

Nigerian ginger is highly valued and in high demand in international markets because it is used for the distillation of essential oils and the extraction of Oleoresin for flavouring and seasoning. There is a need, therefore, for farmers to increase ginger production from subsistence to commercial production levels. This will unlock its full potential to create employment opportunities, increase farmers' incomes, and stimulate economic growth and development, thereby increasing the country's Gross Domestic Product (GDP) and enhancing farmers' standard of living. In Nigeria, southern Kaduna remains the largest producer of newly harvested ginger; therefore, it is important to assess the factors affecting the input-output of ginger production in the study area. The objectives of the study are to describe the socio-economic characteristics of ginger farmers, ascertain the factors affecting ginger output, and identify the problems of ginger production in the study area.

Study Hypothesis

H_o: There is no significant difference between the output and inputs used in ginger production.

Methodology

Study Area

This study was conducted in Kajuru Local Government Area (LGA) of Kaduna state, Nigeria. The Local Government Area is located in southern Kaduna State, Nigeria. Its headquarters are located in Kajuru town. It is situated on longitude 9^0 59" N and 10^0 55" N and latitude 7^0 34" E and 8^0 13" E with an area of 2,464 km^2. It was formed out of the Chukum Local Government Area in March 1997. It has 10 wards: Maro, Idon, Kufana, Kajuru, Rimau, Afogo, Kallah, Tantatu, Buda, and Kasuwan Magani. Igabi LGA borders it to the north, Chikun LGA to the west, Kauru LGA to the east, Zangon Kataf LGA and Kachia LGA to the southwest and south, respectively. The local government has a population of 109,810, comprising 54,506 males and 55,304 females, according to the 2006 National Population and Housing Census (National Population Commission, 2009). The main indigenous group is the Adara. Others are Gbagyi and settlers such as Hausa, Fulani, Yoruba, Ikulu, and Igbo, among others, from different parts of the state and the country. The vegetation is of the Northern Guinea Savannah type, and the climate is marked by two distinct seasons: rainy and dry. The wet season started in the north from April while the dry spell continues from October-March and is typified by the hot and dry north eastern harmattan winds. The core job of the inhabitants of Kajuru is farming, which is mostly mixed cropping of maize, cocoyam, sorghum, potato, millet, pepper, cowpea, ginger, rice, sugarcane, and cassava. Rain-fed agriculture is mostly practiced in the area with little Fadama farming. Crop production is done manually on small, scattered pieces of land using crude implements such as hoes, cutlasses, knives, and axes. Large-scale farming is also practised, with few farmers engaged in tractor operations, which are visible along access roadsides.

Data Collection Methods

Data were collected using a well-structured questionnaire designed to capture the research objectives. The questionnaire consists of both open- and closed-ended questions, administered to respondents in their local language (Hausa) by personal interview. The respondents were interviewed individually and allowed to respond freely to the questions.

Techniques of Sampling

Three-stage sampling techniques were used for the research. The first stage was the purposive selection of five wards known for ginger production. The wards are Maro, Idon, Kufana, Tantatu and Kajuru. In the second stage, One village in each ward was selected due to a high concentration of ginger farmers and the volume of ginger produced. The chosen villages are Dogo Noma, Makyali, Unguwan Rana, Tantatu, and Buda. The third stage involves random selection of 30 and 20 respondents from Dogo noma and Makyali, and 25, 15, and 10 respondents from Unguwan rana, Tantatu, and Buda, respectively. Thus, a sample size of 100 respondents was used, but only 98 questionnaires were included in the final analysis.

Data Analysis

The data was analyzed using a production function model to determine the factors affecting ginger production. The socio-economic data were presented using descriptive statistics, such as frequency distributions, percentages, and tables.

Production Function Analysis

The production input variables affecting the outputs (yields) of ginger were subjected to production function analysis (Cobb-Douglas Production Function). The functional forms tried were three: linear, semi-log, and double-log. The best functional form was selected based on the the coefficient of multiple determination ()(R^2-value), F-statistics, t-values, a priori expectationsF-statistics, a prioriand the total number of significant variables. The implicit form of the model is as follows:
$Y= f (X_1, X_2, X_3, X_4, X_5, + \mu i)$

The model in its explicit functions is shown below:
Linear Function: $Y= \beta o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \mu i$
Semi-Log Function: $Y= \beta o + \beta_1 \log X_1 + \beta_2 \log X_2 + \beta_3 \log X_3 + \beta_4 \log X_4 + \beta_5 \log X_5 + \mu i$
Double Log Function: $\text{Log } Y= \beta o + \beta_1 \log X_1 + \beta_2 \log X_2 + \beta_3 \log X_3 + \beta_4 \log X_4 + \beta_5 \log X_5 + \mu i$
Where, X_1 = Farm size (hectares), X_2 = Fertilizer (kilograms), X_3 = Seed (bags), X_4 = Chemical (litters), X_5 = Labour (man-day), β_o = Constant term, β_1 to β_5= Regression coefficient or parameters, X_1 to X_5 = Independent or explanatory variables, μ_i = Error term or Random error, Y = Output (yield) in kilograms

Results and Discussion

Socio- Economic Characteristics of the Respondents

The socio-economic variables examined in this study are gender, age, marital status, family size, educational level, farm size and years of farming experience. The only institutional variable studied was the sources of finance for ginger production. The respondent's socio-economic characteristics in Table 1 showed that 72.45% of the ginger producers were male and 27.55% were female. This means that males are more into ginger farming than females. The reason could be that women play crucial roles in processing, while crop production requires effort and physical energy that men can provide. This aligns with recent findings showing that ginger production in Nigeria remains dominated by males due to the high labour and time demands of cultivation (Ibrahim *et al*., 2019b).

Age plays a very crucial role in agricultural production; it reveals the physical strength and vigour of the farmers. Younger farmers can withstand stress and invest additional time and effort in farming operations, which may lead to an increase in output. The majority (64.29%) of the respondents were in the 21-40 years age range, 31.63% were in the 41-60 years age range, and only 4.08% were in the 0-20 years age range. This indicates that younger farmers are more involved in ginger production than older adults. Table 1 further revealed that 78.57% of the ginger farmers are married, which may be linked to labour requirements in ginger production; only

21.43% are single. The production of ginger is labour-intensive; therefore, the family size of the respondents is crucial to ginger production, as it determines the availability of family labour. The majority (60.20%) of respondents have a family size of 5-8 members; 27.55% and 12.24% have family sizes of 1-4 and 9-12, respectively. This aligns with the findings of Olufemi and Kayode (2020), who stated that Nigeria's agricultural sector is dominated by smallholder farmers who rely heavily on human labour, primarily family labour, for farm operations.

The educational status showed that 64.29% of the respondents have secondary school Education, 26.53% have primary Education, and 9.18% have tertiary Education. This result corroborates the findings of Abdullahi and Abdullahi (2012), who asserted that formal Education makes it easier to adopt current technologies and enhances farm practices. In terms of farm size, the larger percentage (96.94%) of the ginger farmers have a farm area ranging from 0.1 to 1.0 hectares, while fewer respondents (3.06%) have farm areas between 1.1 and 2.0 hectares. The size of the farm, coupled with good management strategies, determines the outputs of ginger production. The sources of finance revealed that 77.55% of respondents sourced capital from personal savings, 18.37% from family and friends, and only 4.08% obtained a bank loan to finance their business. Acquisition of capital is vital to the growth of farm businesses, enabling them to increase yields and profits. A farmer's experience is crucial to agricultural production. The greater the farmer's experience, the greater the farmer's productive capacity. The respondents' experience in ginger production showed that 43.87% have 11-20 years of experience, 36.73% have 1-10 years, and 19.39% have 21-30 years. This indicates that the respondents have been involved in ginger production for a long time and have acquired extensive experience.

Table 1: Socio- economic characteristics of the respondents

Variable	Frequency	Percentage
Gender		
Male	71	72.45
Female	27	27.55
Age		
0-20	4	4.08
21-40	63	64.29
41-60	31	31.63
Marital status		
Single	21	21.43
Married	77	78.57
Family size		
1-4	27	27.55
5-8	59	60.20
9-12	12	12.24
Educational status		
Primary	26	26.53
Secondary	63	64.29
Tertiary	9	9.18
Farm size		
0.1 – 1.0	95	96.94
1.1 – 2.0	3	3.06

Sources of Finance		
Personal savings	76	77.55
Bank loan	4	4.08
Family and friends	18	18.37
Years of farming experience		
1-10	36	36.73
11-20	43	43.88
21-30	19	19.39

Source: Computed from Field Survey Data, 2020

Production Function Analysis

The input-output relationship was subjected to a production function analysis (Cobb-Douglas production function). The yield (output) of ginger was used as the dependent variable in the model, while the inputs used in ginger production formed the independent variables. The Cobb-Douglas production function is widely used in agricultural economics to estimate how inputs contribute to output under conditions of variable-factor productivity. It captures the elasticity of output with respect to each input and reflects diminishing marginal returns. Recent studies confirm its suitability for analyzing smallholder production systems in developing countries, where inputs vary widely in quality and quantity (Ogunniyi *et al*., 2023; Abojei *et al*., 2025).

The results presented in Table 2 showed that the coefficients for the variables were positively related to ginger, meaning that a rise in the variable's coefficient results in a unit increase in ginger output. Among the five variables in the production function analysis, only three were significant. The interpretation of individual variables used in the model showed a coefficient of farm size- X_1 (2.09) and t- values (0.19). Farm size has a positive but statistically insignificant effect on output. This suggests that simply expanding land area does not guarantee higher productivity; this may be due to land fragmentation, low mechanization, and suboptimal land management. Recent research in Nigeria confirms that land size often shows weak significance when input intensity is low (Abojei *et al*., 2025). The coefficient for the chemical used (X_4) (1.311) and the t-value (0.33) were also not significant. This may reflect inappropriate application, counterfeit agrochemicals, or poor timing issues widely documented in Nigerian agriculture. Recent reviews highlight that chemical inputs often fail to show significance when farmers lack training in proper usage (Gautam, 2024). However, the coefficient of fertilizer- X_2 (0.128) and t-value (2.98), seed- X_3 (0.232) and t-value (2.20) and labour- X_5 (0.343) and t- value (2.15) were significant at ($P< 0.05$) percent probability level. Fertilizer use significantly increases output, consistent with 2024–2026 findings that fertilizer remains One of the strongest determinants of crop productivity in African smallholder systems. Studies show that even modest increases in fertilizer application can substantially raise yields when combined with good agronomic practices (Gautam, 2024). Seed input is also significant, indicating that improved seed varieties or adequate seeding rates contribute meaningfully to output. This aligns with recent evidence that seed quality is a major driver of productivity gains in cassava, maize, and other staple crops (Abojei *et al*., 2025). Labour is significant, confirming the labour-intensive nature of smallholder agriculture. Studies from 2024–2025 show that labour availability, especially family labour, remains a key determinant of output in systems with limited mechanization (Abojei *et al*., 2025). The study by Danladi *et al*. (2017) on

the socio-economic assessment of ginger production in Jaba Local Government Area of Kaduna State, Nigeria, found that age, credit, and farm size were significantly associated with ginger production. Also, Ariyo *et al*. (2020) found the coefficients of fertilizer and farm size to be significant at (P< 0.001), labour (P< 0.05) and seeds (P< 0.10) in their study of the economics of yam production in Gboyin Local Government Area of Ekiti State, Nigeria.

In this study, labour had the highest impact coefficient of 0.343, followed by seed (0.232) and fertilizer (0.128). A One percent increase in labour, seeds and fertilizer use will increase ginger output by 0.343%, 0.232% and 0.128% respectively. The elasticities of production of the significant variables, when summed, show decreasing returns to scale (0.703 < 1). This means that proportionate increases in all inputs lead to less than proportionate increases in output. In practical terms, doubling all inputs would increase output by only about 70%. This is common in smallholder or resource-constrained production environments where inefficiencies, limited technology, or fixed factors (like land) restrict the ability to scale up.

The R^2 value of 0.6530 indicates that 65.30% of the variation in the output of ginger was explained by the variables (inputs) included in the model, while the residual 34.70% was due to the error term. This level of explanatory Power is consistent with contemporary agricultural production studies, which typically report R^2 values of 0.55-0.75 for Cobb–Douglas models (Dzarma *et al*., 2026). The adjusted R^2 of 0.537 suggests that the model remains robust even after adjusting for the number of predictors. The F-statistic of 3.82 indicated that the entire model was statistically significant (P< 0.01), indicating that the entire set of variables used in the model actually influenced ginger output. This aligns with recent findings that multiple inputs interact to influence productivity in smallholder farming systems (Ogunniyi *et al*., 2023). Based on this outcome, the null hypothesis that there is no significant relationship between the inputs used in ginger production and the output of ginger is rejected, and the alternative hypothesis is accepted.

Table 2: Estimate of Cobb-Douglas production function)

Variable	Regression coefficient	Standard error	T-values	Level of significance
Constant	51.10991	26.34248	1.94	
Farm size (X_1)	2.093482	11.12195	0.19	NS
Fertilizer (X_2)	0.128457	0.04315	2.98	0.05
Seed (X_3)	0.231568	0.10522	2.20	0.05
Chemical (X_4)	1.31147	3.936193	0.33	NS
Labor (X_5)	0.34268	0.15938	2.15	0.05
F- Statistics	3.82			0.01
R^2- square	0.6530			
Adjusted R^2- square	0.5370			

Source: Computed from field survey data, 2020

Constraints of Ginger Production in the Study Area

Agricultural production in Nigeria is facing a series of challenges, and ginger production is no exception. The problems facing ginger production in this study are presented in Table 3. Insecurity,

rampaging across the nation as a whole, occupied the 1st rank with 22.34%. This was followed by insufficient capital, having 19.24% and ranked 2nd. Bad ginger prices, scarcity of inputs, high labour costs, and poor storage facilities were ranked 3rd, 4th, 5th, and 6th, each with 16.84%, 12.03%, 9.97%, and 7.90%, respectively. Poor infrastructure and excessive transportation costs were ranked 7th and 8th, with 6.53% and 5.15%, respectively. This suggests that the major constraint of ginger production in the study area is insecurity.

Table 3: Distribution of constraints to ginger production in the study area

Farmer's constraints	Frequency*	Percentage	Rank
Insecurity	65	22.34	1st
Insufficient capital	56	19.24	2nd
Bad ginger prices	49	16.84	3rd
Scarcity of inputs	35	12.03	4th
High cost of labour	29	9.97	5th
Poor storage facilities	23	7.90	6th
Poor infrastructure	19	6.53	7th
Excessive transportation cost	15	5.15	8th
Total	**291**	**100.00**	

Source: Computed from field survey data, 2020 *Multiple responses

Conclusions

The study concludes that a greater number of ginger producers are male, married, aged 21- 40, and have a family size of 5-8 members. They had a secondary school Education and 11-20 years of experience in ginger production. The main source of finance for ginger production was personal savings. Besides, variables such as fertilizers, planting materials (seeds) and labour affect ginger production; proper management of these variables will increase ginger output. The constraints to ginger production were insecurity, insufficient capital, bad ginger prices, and scarcity of inputs. Others include high labour costs, poor storage facilities, poor infrastructure, and excessive transportation costs.

Recommendations

Based on the findings of the study, the following recommendations were offered:
The government should address insecurity to create a safe environment that allows ginger farmers to farm. The ginger farmers should form a cooperative society to pool their resources for bulk purchases of farm inputs. The government and non-governmental organizations should make farm inputs available to ginger farmers at subsidized rates to improve affordability. Institutions such as Universities, research institutes, and Engineering companies should research storage facilities for fresh and dried ginger to reduce the incidence of poor pricing, prevent them from selling their products at giveaway prices, and enable them to plan ginger sales during the off-season to earn more profits.

References

Abdullahi, A. N. & Abdullahi, I. (2012). Cowpea Marketing in Isa Local Government Area of Sokoto State, Nigeria. *Nigerian Journal of Farm Manag* (Formerly *FAMAN Journal*). 13(1): 80

Abojei, J. O., Aberji, D. O., Adaigho, D. & Emaziye, P. O. (2025). Technical efficiency of small-scale cassava farmers in Delta State using Cobb–Douglas stochastic frontier production function. *World Journal of Advanced Research and Reviews*, 25(3), 32–38.

Ajibade, L. K. and Dauda, Y. (2005). *Ginger Plant; Ginger Extension Pamphlet.* Bennard Ginger Company, Kafanchan, Nigeria. pp 145

Alabi, O. O. & Abdulazeez, I. (2018). Economics of Maize (Zea mays) Production in Igabi Local Government Area, Kaduna State, Nigeria. *Journal of Agricultural Faculty of Gaziosmanpasa University,* 35(3): 248–257. http://ziraatdergi.gop.edu.tr/Araştırma, doi:10.13002/jafag4434

Ariyo, O. C., Faleyimu, O. I. and Ariyo, M. O. (2013a). Economic analysis of small-scale forest-based mortar and pestles production in Kaduna Metropolis, Kaduna State, Nigeria. *Journal of Agricultural Research and Development*. Published by the Faculty of Agriculture, University of Ilorin, Kwara State. University of Ilorin 12(1):19-34. Available: www.ajol.com/index.php/jard

Ariyo, O. C., Ariyo, M O., Okelola, O. E., Omodona, S., Akesode, H. A., & Akanni, R. J. (2013b). Profitability analysis of plantain marketing in Kaduna Metropolis, Kaduna State, Nigeria. *Journal of Agriculture and Social Research*. Published by Agricultural Professionals of Nigeria (AgPRON) 13(1):21–30. Available: www.ajol.info/journals/jasr

Ariyo, O. C., Usman, M. B., Olorukooba, M. M., Olagunju, O. E., Oni, B. O., Suleiman, R., Adetunji, A. J. & Ariyo, M. O. (2020). Economics of Yam Production in Gboyin Local Government Area of Ekiti State, Nigeria, *Journal of Experimental Agriculture International* 42(4): 99–110, 2020; Article no. JEAI.57140; ISSN: 2457-0591

Ariyo, O.C. & Usman, M.B. (2020). Profitability Analysis of Fuel Wood Marketing in Igabi Local Government Area of Kaduna State, Nigeria. *Journal of Sustainable Environmental Management (JSEM)*, 12: 82–95. ISSN 2141- 0267.

Ariyo, O. C. (2023). Economic Analyses of Traditional Processing of African Locust Beans (*Parkia Biglobosa*) (Jacq.) Benth. Seeds in Kaduna Metropolis, Kaduna State, Nigeria. *Ethiopian Journal of Environmental Studies & Management* 16(4): 415–426, ISSN:1998-0507, doi: https://ejesm.org/doi/v16i4.2

Baiyegunhi Samm, L. J. & Fraser, G. C. H. (2009). Profitability in ginger production in three villages of Kaduna State, Nigeria. *Journal of Applied Sciences Research*. 5(10): 1685–1691.

Bokulo, N. H., Attahiru, K., Atiku, & Mohammed H. J. (2015). Impact of socio-economic factors on the adoption of ginger (*Zingiber officinale*) production technologies in Southern Kaduna State, Nigeria. *International Scholars Journals*, 3(2): 265–269. Frontiers of Agriculture and Food Technology ISSN 7295-2849 Available online at www.internationalscholarsjournals.org

Chukwu, G. O. & Emehuite, J. K. (2003). *Fertilizer efficiency and productivity of ginger on a hapilyariscol* in southern Nigeria. In M. O. Akoroda (editor), Root crops: the small processor and development of local food industries for market economy. Ibadan Polytechnic venture, Ibadan, Nigeria. pp198.

Danladi, E., Akinola, M. O., Banta, A. L., Makarau, S. B., & Ali, H. (2017). Socio-Economic Assessment of Ginger Production in Jaba Local Government Area of Kaduna State,

Nigeria, *Asian Journal of Agricultural Extension, Economics & Sociology 15(2): 1–11, Article no. AJAEES.28949, ISSN: 2320-7027*

Dzarma, E. D., Dagba, T. K. & Degla, G. (2026). Maize productivity optimization using Cobb–Douglas, CES, and hybrid models. In *Innovations and Interdisciplinary Solutions for Underserved Areas*. International Conference on Innovations and Interdisciplinary Solutions for Underserved Areas, 274–280.

Emmanuel, L. (2008). Technology and ginger farm performance—path of Production Efficiencies Overtime, *Agriculture Economics Journal,* 2:297-306.

Ezeagu, W. (2016). Ginger Export. A paper presented at the 3-daythe 3-day National Workshop on Massive Cassava and Ginger Production and Processing for Local industries and export, held at Fati Muazu Hall, National Center for Women Development, Abuja. January 13 2016.

FAO, (2024). Food and Agriculture Organization of the United Nations (FAO) retrieved on December 11 2015.

FAO. (2010). Production quantity of ginger worldwide, 1961-2009; 2010. Available: www.fao.Mongabay.com/g/5000-World+++/T

Gautam, S. (2024). Understanding the Cobb–Douglas production function in agricultural economics. *Journal of Technology & Innovation*, 4(2), 75–78.

Geekie, P. (2010). "Hub pages, Education and science," 1602 (online) available.

Ibrahim, M., Abdullahi, A., Yakubu, I. I., Yisa, K. M. (2019a). Assessment of the Adoption of Improved Ginger Production Technologies in Kajuru Local Government Area of Kaduna State, Nigeria. *Journal of Agriculture and Environment*, 15(2), 83-89 ISSN: 1595-465X (Print) 2695-236X (Online)

Ibrahim, H., Yusuf, O. J. and Nuhu, H. S. (2019b). *Socio-economic factors influencing ginger production in Kaduna State, Nigeria. Asian Journal of Agricultural Extension, Economics & Sociology*, 31(3), 1–9. https://doi.org/10.9734/ajaees/2019/v31i330132

Iwo, G. A., Amadi, C. O., Obok, E. E., Abua, M. N., Odor, E. O., Kwon-Ndung, H. E., Garba, A. and Idris, B. M. (2026). Multi-Environments Evaluation of Elite Mutant Lines of Improved Ginger for Yield Stability and Selection. *Asian Journal of Research in Crop Science*, 2026, 11 (2), 24-38.

KADP (Kaduna State Agricultural Development Project) (2000). Production of ginger: an extension guide. Kaduna State Agriculture Development Project, Kaduna. pp.18

NBS, (2007). National Bureau of Statistics 2007 Edition.

Nmadu, J. N. & Marcus, P. L. (2013). Efficiency of ginger production in selected local government areas of Kaduna State, Nigeria. *Journal of Food and Agricultural Economics*. 2013; 1(2):39-52.

National Population Commission (NPC). (2009). *2006 Population and Housing Census of the Federal Republic of Nigeria: Priority Tables (Volume II: Population Distribution by Sex, State, LGA & Senatorial District).* Abuja, Nigeria: National Population Commission. ISBN: 978-978-48732-5-6

Ogunniyi, A., Adebayo, O. & Olagunju, K. (2023). Input interactions and productivity outcomes among smallholder farmers in sub-Saharan Africa. *Journal of Agricultural Economics and Development,* 11(2), 145–160.

Olufemi, P.A. & Kayode, A.A. (2020). Pattern of Labor Use and Productivity Among Agricultural Households in Nigeria. In: Osabuohien, E.S. (eds) The Palgrave Handbook of Agricultural

and Rural Development in Africa. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-41513-6_9

Olukosi, J. O. & Ehrbbor, P. O. (2008). Introduction to Farm Management Economics, Principles and Application. Agitab Publisher Limited, Zaria. 2008; 62–73.

Punch Newspapers (2026). FG, Kaduna to build ₦40bn ginger processing hub in Kachia. Punch Nigeria, February 23

United Nations (2012). All Things About Ginger. Retrieved from www.Allthingsginger.co.uk. Retrieved on December 11 2015.

Yiljep, G.A, Fumen and Ajisegiri E.S.A (2005). The effects of peeling, spitting and drying on ginger quality and oil/oleoresin content. Agricultural engineering international: *The CIGR Ejournal*, vol VII (009): 1-8.

Shettima, B. G., Zira, B. D. & Bukar, U. (2017). Economic Analysis of Ginger Production in Kachia Local Government Area, Kaduna State, Nigeria. *ASUU Journal of Social Science*. *A Journal of Research and Development* 14(4) 1 & 2, pp. 58–66.

The Radar (2026). ₦40bn ginger processing hub set for Kaduna South to boost agro- industrialization, February 23.

ISTF-NIG 2026

RELATIONSHIP BETWEEN INPUT AND OUTPUT OF AGROFORESTRY FARMS IN ADAMAWA STATE, NIGERIA

[1]BONI, P. G., [2]YADUMA, Z. B [1*]ARIYO, O. C and [1]ARIYO, M. O

[1]Federal College of Forestry Mechanization, Afaka, Kaduna
[2]Forestry Research institute of Nigeria, Jericho, Ibadan, Oyo state
**Corresponding Author: ask4ariyo@yahoo.com +2348033931981*

Abstract

This study examined the relationship between input variables and agroforestry output in Adamawa State, Nigeria. A stratified and multistage random sampling technique was used to select 540 agroforestry farmers across three ecological zones: Northern Guinea Savanna, Southern Guinea Savanna, and Sudan Savanna. Data were collected using structured questionnaires, summarized with descriptive statistics, and analyzed using multiple regression and Analysis of Variance (ANOVA)**.** Results showed that agroforestry farmers were predominantly male (96.3%), within the 40–59-year age group (78%), and mostly married (93.7%). Majority (62.7%) had formal Education, 58.3% practiced agroforestry as their primary occupation, and 33.5% had 16–20 years of Experience. Nearly half (47.4%) cultivated 4–6 crops within the same agroforestry farm. ANOVA revealed a significant difference in output across ecological zones ($P < 0.05$), with the Southern Guinea Savanna (Ganye L.G.A.) recording the highest mean output (233.0 ± 232.1 kg). The double-log regression model showed that four variables significantly and positively influenced agroforestry output: agroforestry practices ($\beta = 1.166$; $P < 0.01$)**,** family size ($\beta = 0.214$; $P < 0.05$)**,** labour ($\beta = 0.080$; $P < 0.05$)**,** and farming experience ($\beta = 0.144$; $P < 0.05$)**.** These variables accounted for 79.6% of the variation in output ($R^2 = 0.796$), and the overall model was statistically significant at the 1% level. The study recommends strengthening farmer training on improved agroforestry practices, enhancing labour availability, and promoting experience-sharing platforms to improve productivity. Policies that support diversified agroforestry systems and labour-efficient management should be prioritized across ecological zones.

Keywords: Agroforestry, input-output relationship, ecological zone, yield variation

Introduction

Agriculture remains central to Nigeria's economy despite the dominance of the petroleum sector, contributing significantly to GDP, employment, and rural livelihoods (Ladipo, 2010; Udofia, 2007). However, agricultural productivity has stagnated in recent decades, widening the gap between domestic food supply and national demand and increasing reliance on food imports (FAO, 2015). This persistent productivity deficit underscores the need for sustainable land-use systems capable of improving yields while safeguarding the environment. Agroforestry has emerged as One of the most promising strategies for addressing land degradation, enhancing soil fertility, and improving rural livelihoods. Its ecological and socio-economic benefits, including biodiversity conservation, carbon sequestration, and diversified farm outputs, are well documented (Abdi *et al*., 2013; Akinwalere, 2017). Studies further show that agroforestry can increase crop yields,

restore degraded land, and generate additional income through fuelwood and non-timber products (Pretty *et al*., 2006; Orisakwe *et al*., 2011). These advantages make agroforestry a critical tool for climate resilience and poverty reduction in Nigeria.

However, despite its potential, agroforestry adoption and investment remain limited. FAO (2013) reports that agroforestry has not been adequately integrated into national land-use policies or rural development programmes. This policy gap persists even though agroforestry systems require long-term planning, substantial inputs, and careful management to achieve optimal productivity. Without clear economic assessments and evidence-based guidance, farmers and policymakers lack the information needed to scale up agroforestry effectively. Although previous studies highlight the ecological and livelihood benefits of agroforestry, there is limited empirical analysis of how input use, such as labour, land, and capital, interacts with output performance in real farming systems, particularly in northern Nigeria. This gap is critical because understanding input–output relationships is essential for improving productivity, guiding resource allocation, and informing policy interventions.

Materials and Methods

Study Area

Adamawa State lies between latitudes 70 ° and 11^0 N of the equator and longitudes 11° and 14° E of the Greenwich Meridian. The state is located in the North-Eastern part of Nigeria and shares boundaries with Taraba State to the South and West, Gombe State to the Northwest, and Borno State to the North (Figure 1). It also shares an international boundary with the Republic of Cameroon along its Eastern border. According to the 2006 national census, the state had a population of 3,175,950 and a land area of about 38,741km. Adamawa State is divided into twenty-one (21) Local Government Areas (Adebayo & Zemba, 2020). Agriculture is the major occupation of the inhabitants, while the major food crops cultivated include maize, sorghum, rice, groundnuts, cowpea, yams, cassava, sugarcane, and cotton. Major livestock reared are cattle, sheep, and goats (Adamawa State Economic Empowerment and Development Strategy, ADSEEDS, 2004). Adamawa experiences **a** unimodal rainfall pattern, ranging from 700 mm in the northwest **to** 1,600 mm in the south, with rainfall onset between April and May and cessation between September and November**.** The rainy season lasts 120–210 days, depending on location (Adebayo & Zemba, 2020). The major vegetation formations in the state are southern Guinea Savannah, Northern Guinea Savannah and Sudan Savannah, with additional open grass savanna and fringing riverine forests in valley areas (Akosim *et al*., 2020). Although the Upper Benue Basin falls within the Sudan Savanna, where dense woody vegetation would normally dominate, the landscape has been extensively converted into open farmland, retaining only scattered useful species such as *Vitellaria paradoxa*, *Ficus capensis*, *Parkia* spp., and *Adansonia digitata*, which farmers preserve for Shea butter and food (NCF, 2000).

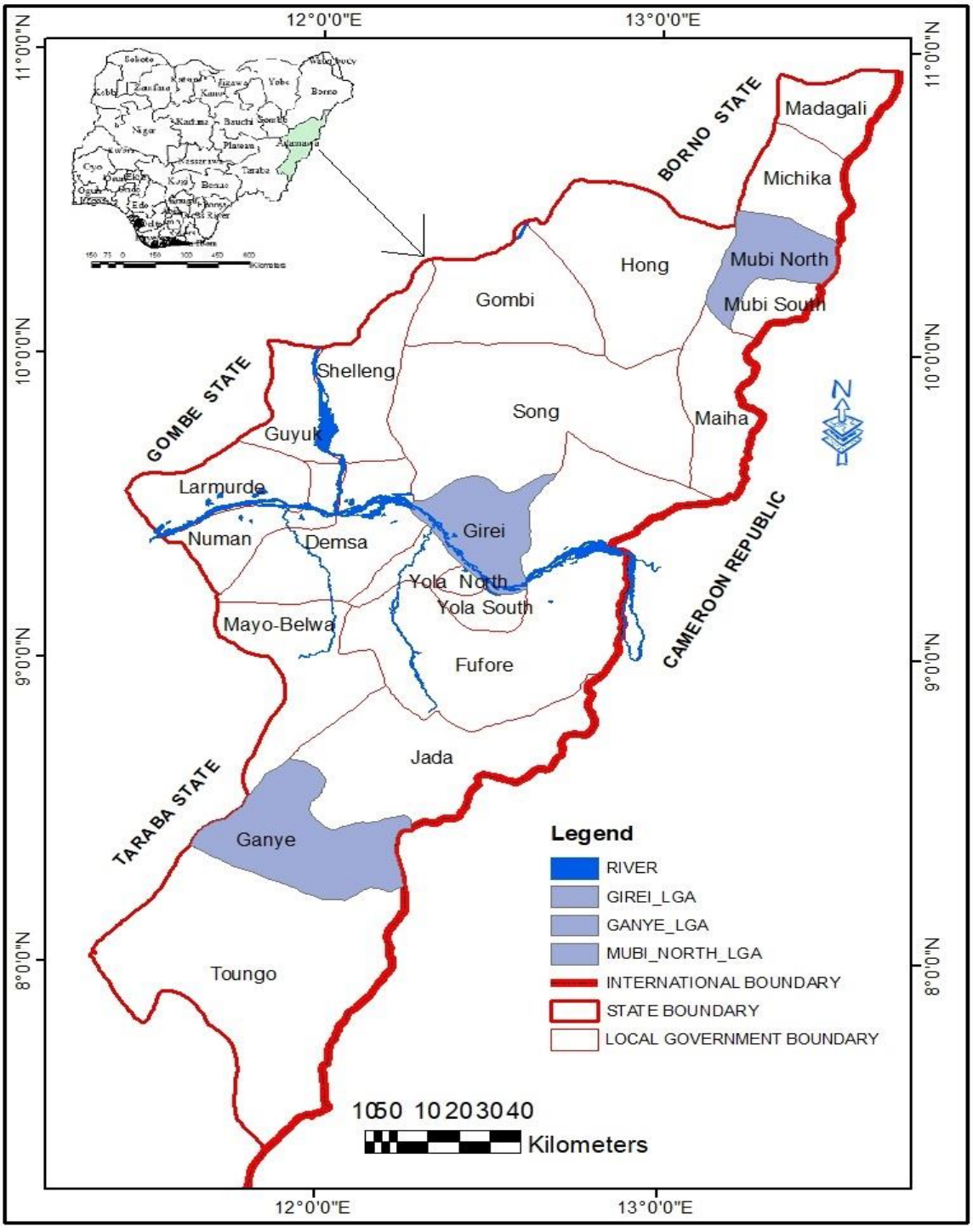


Figure 1: Map of Adamawa State showing the boundaries

Data Collection

Primary data were collected for this study using a well-structured questionnaire with open- and closed-ended questions administered to agroforestry farmers in the study area. The information elicited from the questionnaires included: socio-economic characteristics, income, Experience, farm size, labour, level of Education, family size, age, and land tenure system of the respondents.

Sampling techniques

The entire state was stratified into three ecological zones. In view of these, stratified and multistage random sampling techniques were employed in sampling the respondents. The entire state was stratified into three ecological types – Northern guinea savanna, Southern guinea savanna, and Sudan savanna. One Local Government Area was randomly selected from each ecological zone. Two council wards were selected from each Local Government Area, and two communities were selected from each council ward.

Data analysis

Descriptive statistics (tables, charts, and percentages), Analysis of Variance (ANOVA), and Multiple regression were used to achieve the desired objectives. ANOVA was used to compare outputs from agroforestry farms across the ecological zones G1, G2, and G3. The statistical model used was as follows:

$$Yij = \mu + Ti + eij$$

Where;

μ = the overall mean, Y_{ij} = the jth observations, T_i = the observations in each of the ecological zones, G1 = Northern guinea savanna (Girei L.G.A), G2 = Sudan savanna (Mubi North L.G.A), G3 = Southern guinea savanna (Ganye L.G.A)

Before applying ANOVA, the underlying assumptions were considered: normality of residuals, homogeneity of variances, and independence of observations. These assumptions ensure that differences detected among ecological zones reflect true variation rather than statistical artefacts.

Multiple regression was used to examine the relationship between agroforestry farms' input and output variables. The equation is shown below;

$$Y = F(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8)$$

Where**:**

Linear function as

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + \beta_8X_8 + \mu$$

Double-log function

$$\ln Y = l_n\beta_0 + \beta_1 l_n X_2 + \beta_2 l_n X_2 + \beta_3 l_n X_3 + \beta_4 l_n X_4 + \beta_5 l_n X_5 + \beta_6 l_n X_6 + \beta_7 l_n X_7 + \beta_8 l_n X_8 + U_1$$

Semi-log function

$$\ln Y = l_n\beta_0 + \beta_1 l_n X_2 + \beta_2 l_n X_2 + \beta_3 l_n X_3 + \beta_4 l_n X_4 + \beta_5 l_n X_5 + \beta_6 l_n X_6 + \beta_7 l_n X_7 + \beta_8 l_n X_8 + U_1$$

Exponential function

$$\ln Y = \beta_0 + \beta_1 X_2 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + U_1$$

Where;

X_1 = Age (Years), X_2 = Agroforestry practice (No.), X_3 = Level of Education (Years), X_4 = Family size (No.), X_5 = Land Area (Hectare), X_6 = Crop combination (No), X_7 = Labour (Man-days), X_8 = Experience in agroforestry practice (Years) and Y = Output from agroforestry farms (kg)

The final choice of functional form was based on statistical criteria, including goodness-of-fit, coefficient significance, and conformity with economic theory.

Results and Discussion

Gender

Table 1 shows that 96.3% of agroforestry farmers were males, while 3.7% were females. The analysis indicated that males participated more in agroforestry practice than their female counterparts.

Age distribution of respondents

Table 1 shows that the modal age of Agroforestry farmers falls between 50 and 59 years, which constitutes 56.7% of the total agroforestry farmers in the study area. It also revealed that the active agroforestry farmers are between the ages of 40-59 years, this range constitute 78% of the total agroforestry farmers in the study area, while 5.4%, 14%, and 2.6% fall within the bracket of 30-39 years, 60-69 years and 70 years and above, respectively. The mean age was 53.97.

Marital status

Table 1 indicates that 93.7% of the agroforestry farmers were married (506), while 3.9% were single and 2.4% were divorced. This shows that married couples were the most engaged in agroforestry.

Household size

The result shows that 47.4% of the agroforestry farmers had household sizes of a h,f 6-10, which constituted the highest percentage. At the same time, 44.6% had a family size ranging from 1 to 5. Farmers whose family sizes fall within the range of 11 - 15, 16 - 20 and ≥ 20 constituted 7.0%, 0.6% and 0.4%, respectively. The mean household size was 6.22.

Educational attainment

Table 1 revealed that 27.9% had no formal Education, while 9.1%, 31.9% and 22.6% had formal Education which constitute 62.7% of the total farmers in the study area.

Occupation

Table 1 shows that the largest percentage of respondents' occupations was farming: 58.3% were purely agroforestry farmers; 22.2% were farmers who also engaged in different forms of business; and 19.4% were civil servants who also practiced agroforestry as another form of income.

Farm Size of Agroforestry farmers

Table 1 indicates that the farmers cultivate the agroforestry farms. Those whose farmland size ranged from 1 to 5 ha constituted 44.6%, 47.4% had 6-10 ha and 7.0%, 0.6% and 0.4%, and 1.9% fell within the range of 11-15ha, 16-20ha and ≥ 20, respectively. The mean of agroforestry farm size was 2.72 ha.

Years of farming experience as an agroforestry farmer

Table 1 shows that 33.5% of the farmers had 16-20 years' experience, 27.6% had more than 20 years' Experience, and 25.4% had 11-15 years' experience. Only 3.5% and 10% of them had1-5 years and 6-10 years' Experience, respectively.

Table 1: Socio-Economic Characteristics of Respondents

Variables	Frequency	Percentage	Minimum	Maximum	Mean ($\bar{X}$)
Gender					
Male	520	96.3			
Female	20	3.7			
Total	540	100			
Age Range	Frequency	Percentage			
30-39	29	5.4			
40-49	115	21.3			
50-59	306	56.7			
60-69	76	14			
≥70	14	2.6			
Total	540	100	30	74	52.97
Marital status	Frequency	Percentage			
Married	506	93.7			
Single	21	3.9			
Divorce	13	2.4			
Total	540	100			
Family size	Frequency	Percentage			
1-5	241	44.6			
6-10	256	47.4			
11-15	38	7.0			
16-20	3	0.6			

ISTF-NIG 2026

≥20	2	0.4			
Total	540	100	2	14	6.22
Level of Education	Frequency	Percentage			
No formal	151	27.9			
Primary	49	9.1			
Secondary	172	31.9			
Tertiary	122	22.6			
Other specific	46	8.5			
Total	540	100			
Occupation	Frequency	Percentage			
Civil servant/farming	105	19.4			
Farming	315	58.3			
Business/farming	120	22.2			
Total	540	100			
Farm size (ha)	Frequency	Percentage			
1-5	210	38.9			
6-10	172	31.8			
11-15	85	15.7			
16-20	35	6.5			
≥20	28	5.2			
Others	10	1.9			
Total	540	100	1	21	2.72
Years of farming experience	Frequency	Percentage			
1 – 5	19	3.5			
6 – 10	54	10			
11 – 15	137	25.4			
16 – 20	181	33.5			
≥20	149	27.6			
Total	540	100	2	21	15.76

Source: Field Survey (2022)

Crop combinations on agroforestry farms

The results in Table 2 show a clear tendency toward high crop diversification among agroforestry farmers. Only 15.6% of respondents cultivated 2–4 crops on the same farmland, while 47.4% combined 4–6 crops, and 37.0% cultivated more than six crops. This pattern indicates that over 84% of farmers practice medium-to-high crop diversification, reflecting a deliberate strategy to optimize land productivity, manage risk, and enhance household food security. It was revealed that farmers who combine 4 to 6 or more crops have large farm areas and often lease out parts of their farms to other farmers. This suggests that crop combinations are shaped not only by ecological

suitability but also by landholding size, labour availability, and economic objectives. This aligns with recent studies showing that farmers with larger land areas are more likely to adopt complex agroforestry combinations because they can better manage spatial arrangements and labour demands (Mbow *et al*., 2023; Nair & Garrity, 2024). Crop combinations are tailored to landowners' needs, supporting the broader understanding that agroforestry systems are highly context-specific. Farmers often design combinations to maximize complementary interactions among species, improve soil fertility, and diversify income streams. Recent modelling work demonstrates that inter-species feedbacks in agroforestry systems can enhance emergent productivity, especially when multiple crops interact with trees to improve microclimate and nutrient cycling (Comolli & Fassola, 2026). However, the present findings differ from those of Ayodele *et al*. (2004), who argued that proximity between crops and trees may increase pest habitat, particularly in tree–cereal combinations that attract rodents, birds, and insects. More recent evidence suggests that while pest risks exist, diversified agroforestry systems often reduce overall pest pressure by supporting natural enemies and disrupting pest life cycles (Sileshi *et al*., 2022; Jamnadass *et al*., 2023**)**. Thus, the high level of crop diversification observed in this study may actually contribute to greater ecological resilience, contrary to earlier concerns. Furthermore, modern agroforestry research emphasizes that species-rich systems tend to enhance soil organic matter, reduce erosion, and improve water-use efficiency. These benefits are particularly relevant in savanna ecologies such as those represented by G1, G2, and G3 (Rana *et al*., 2026).

Table 2: Crop Combinations

Crop	Frequency	Percentage
2-4	84	15.6
4-6	256	47.4
≥ 6	200	37.0
Total	895	100

$\bar{X}$ = 2.96, Minimum = 2, Maximum = 6

Source: Field Survey (2022)

Production Function Analysis

Table 3 explanatory variables used were age (X_1), agroforestry practices (X_2), level of Education (X_3), family size (X_4), land area (X_5), crop combinations (X_6), labour (X_7) and experiences in agroforestry practices (X_8). Four functional forms were fitted into the model. These were linear, exponential, semi-log and double-log functions. The lead equation of the regression analysis, used as a proxy for determining the relationship between inputs and outputs of agroforestry farms, was chosen based on economic, econometric, and statistical criteria; hence, the double-log function was chosen as the lead equation. The model is presented thus:

Ln Y = 3.997*** + 0.05x1 + 1.166x2*** + 0.059x3 + 0.214x4**- 0.028x5 + 0.016x6 + 0.080x7** + 0.144x8** + μi
(19.666) (0.421) (31.067) (1.319) (2.326) (-1.233) (0.669) (2.326) (2.315)

The results revealed that four of the eight explanatory variables were significant and contributed positively to agroforestry yield. These are (X_2), (X_4), (X_7) and (X_8). The coefficient of multiple determinations (R^2) indicated that 79.6% of the variation in agroforestry yield was explained by

the variables included in the model, while the remaining 20.4% was due to random error. Consequently, the overall model is significant at the 1% level, as shown by the F-statistic. In the double logarithm function, the coefficients of the explanatory variables are elasticities; hence, a 1% increase in the significant variables' inputs would increase the output or agroforestry yield by the coefficient of these variables. The return to scale is the sum of the elasticities, which is either 1 or <1. Double-log was selected as the best fit because of the magniude of the coefficient of determination (R^2). Agroforestry practices (X_2): the coefficient is statistically significant at the 1% level; this implies that improving agroforestry practices will increase yield by 1.16%. Thus, a 10% increase in agroforestry practices will increase yield at 16.6%. The significance of family size (X_4) in agriculture hinges on the availability of a sufficient number of persons to accomplish various farm operations. However, the Table reveals that a 1% increase in the number of persons per household will increase agroforestry output by 0.24%. Thus, a 10% increase in family size would increase agroforestry yield by 2.14%.

Labour (X_7) agroforestry practices are labour-intensive, hence necessitating the hiring of labour. The coefficient of labour is positive and statistically significant at 5% level. Farming experience (X_8) is the active involvement of farmers in farming activities and exposure over time that leads to increased knowledge or skill. However, the coefficient for farming experience was positive and significant at the 5% level. A 1% increase in years of farming experience will increase agroforestry yield by 0.14%.

Table 3: Production Function Analysis

Variability	Linear	Exponential	Semi-log	Double-log
Constant	-64274.87	4.218	-224302.47	3.997
	(-2.286)**	(66.796)***	(-2.207)**	(19.666)***
X_1= Age	925.94	-0.002	106165.22	0.050
	(1.811)*	(-1.326)	(1.784)*	(0.421)
X_2=Agroforestry Practices	27562.49	0.101	226911.89	1.166
	(12.659)***	(24.724)***	912.081)***	(31.067)***
X_3= Level of Education	-535.15	0.101	18622.08	0.059
	(-0.151)	(1.264)	(0.833)	(1.319)
X_4= Family size	1724.77	0.003	19155.71	0.214
	(2.086)**	(1.382)	(1.995)**	(2.326)**
X_5= Land area	-3815.71	-0.001	-17842.97	-0.028
	(-1.612)	(-0.26)	(-1.597)	(-1.233)
X_6= Crop combination	1037.93	-0.007	3284.22	0.016
	(0.247)	(0.706)*	(0.276)	(0.669)
X_7= Labour	1082.72	0.005	3284.22	0.080
	(3.872)***	(7.344)***	(1.129)	(2.326)**
X_8= Experience in agroforestry practices	5961.64	0.002	16357.74	0.144
	(1.789)*	(1.945)*	(0.879)	(2.315)**
R^2	43.6%	76.8%	37.6%	79.6%
F-ratio	51.397	219.331	40.007	259.670
SE	70043.89	0.15726	73698.27	0.14721

*** Significant at 1%, ** Significant at 5%,
Source: Field Survey, 2022.

Output from agroforestry farms

Table 4 shows that southern guinea savannah G3 (Ganye L.G.A) had the highest mean of 233.0 ±232.1kg, followed by G2 (Mubi North L.G.A. representing Sudan savannah) with a mean of 224.4 ±169.5kg, while G1 (Gerei L. G.A. representing northern guinea savannah) had the least mean of 208.0 ± 149.9kg. Further comparison of the output in the three ecological zones using One-way analysis of variance (ANOVA) shows a significant difference ($p \leq 0.05$). The southern Guinea Savanna was ranked the best. There is a significant difference between the Southern Guinea Savannah and the Northern Guinea Savannah. This may be linked to the state's rainfall pattern. The Southern Guinea Savanna had a mean annual rainfall of 1100-1600mm, and rainfall lasts longer than in the Northern Guinea Savanna zones. This may be why outputs from Ganye are higher than those of the other zones. This agrees with Williams et al. (2010), who observed that rainfall can affect vegetation condition, agricultural production, and human livelihoods.

Table 4: Output of Agroforestry farms

Local Governments	Mean (output)
G1 = Gerei	208.0 ± 149.0kg a
G2 =Mubi North	2244.4 ± 169.5kg b
G3 = Ganye	233.0 ± 232.1kg b

Source: Field Survey (2022)

Conclusions

The study concludes that agroforestry farming in the study area is predominantly practiced by male farmers (96.3%)**,** with the majority (56.7%) belonging to the 50–59-year age group. The active farming population falls within the 40–59-year bracket, indicating that mature, economically active adults drive agroforestry in the region. Most farmers were married, had relatively large households of 6–10 members, and had formal Education, which may enhance their capacity to adopt and manage agroforestry innovations. The farmers typically cultivated four to six crops on their agroforestry farms and often leased portions of their farmland to other farmers, reflecting a diversified, economically adaptive land-use strategy. The analysis of agroforestry output across the three ecological zones revealed a significant difference ($p \leq 0.05$), with the Southern Guinea Savannah (G3- Ganye L.G.A.) recording the highest mean output. This superior performance is likely linked to the zone's favourable rainfall regime and longer growing season, which enhance interactions among tree crops and overall system productivity. Furthermore, key variables including agroforestry practices, family size, labour availability, and farmers' Experience were found to significantly and positively influence agroforestry output. Overall, the study concludes that socio-economic characteristics (such as labour, Experience, and household size) and agroforestry practices jointly determine agroforestry productivity.

Recommendations

The study recommends strengthening agroforestry productivity through targeted interventions that address both ecological and socio-economic factors. Since most agroforestry farmers are mature adults with formal Education, capacity-building programs should be expanded to improve their technical skills in tree–crop integration, soil fertility management, and climate-smart practices. Ecological differences in output, particularly the superior performance of the Southern Guinea Savannah, highlight the need for zone-specific agroforestry models, including drought-tolerant species and water-harvesting techniques in drier zones. Labour availability, family size, and farmer experience were significant determinants of output; therefore, labour-saving technologies, cooperative labour systems, and youth engagement initiatives should be promoted to reduce labour constraints. Farmers' existing practice of cultivating multiple crops should be supported by promoting diversified, market-oriented agroforestry enterprises.

References

Abdi, E., Fatahnia,F. M.D., A., A., K., A (2013). Effect of soya bean roasting and monensin on milk production and composition, and milk fatty acid profile in dairy cows. *Livest. sci*., 153 (1-3):73-80

Adamawa State Economic Empowerment and Development Strategy (ADSEED) (2004). Adamawa State planning commission, October 2004, ABTI press

Adebayo, A. A. and Zemba, A.A (2020) Climate in: Adebayo *et al* (eds) Adamawa State in Maps; Second Edition. Paraclete Publishers, Yola, Pp. 31 – 36.

Akinwalere, B. (2017). Determinant of Adoption of Agroforestry Practices among Farmers in Southwest Nigeria. *Journal of Applied Tropical Agriculture*, Vol. 22. 267-72

Akosim C., Tella, I.O., & Jatau, D.F (2020). *Vegetation and Forest. Resources* in: Adebayo *et al* (Eds) Adamawa State in Maps. Second Edition. Paraclete Publisher, Yola. Pp. 40 – 43.

Ayodele, I.A., Adegeye, A. O., & Akinyemi, A. (2004). Essentials of agroforestry. Second edition 2004, published by Frontline printing press, Mokola, Ibadan, Nigeria.

Comolli, L. R. & Fassola, H. F. (2026). Inter-species feedbacks drive emergent productivity in agroforestry systems: An agent-based analysis—*Frontiers in Agronomy*, 8, Article 1657465.

Food and Agriculture Organization (FAO) (2015) Agriculture growth in West Africa Market and Policy Derwerg (eds) Frank Hollinger (FAO) and John M. Stantz (Mechangan State University).

Food and Agriculture Organization (FAO). (2013). Advancing Agroforestry on the Policy Agenda: A guide for decision-makers, by Buttoud, G. in collaboration with Ajayi, O., Detlefsen, G., Place, F. & Torquebiau, E. Agroforestry Working Paper no. 1. Food and Agriculture Organization of the United Nations (FAO), Rome. Pp 37.

Jamnadass, R., Iiyama, M., Dawson, I. K., Tchoundjeu, Z., & Graudal, L. (2023). Agroforestry and biodiversity: Managing multifunctional landscapes for ecological resilience. *Agroforestry Systems, 97*, 455–472.

Ladipo, D. (2010). IITA research for development Nigeria; CENRAD/OGADEP, Agricultural Development programme, Unknown pagesolua.

Mbow, C., van Noordwijk, M. & Prabhu, R. (2023). Scaling agroforestry in sub-Saharan Africa: Opportunities and constraints. *Current Opinion in Environmental Sustainability*, 62, 101–112.

Nair, P. K. R. & Garrity, D. P. (2024). Advances in agroforestry: Integrating trees into sustainable farming systems. *Springer Nature*.

Orisakwe, L., & Ozioma, A. F. (2011). Adoption of improved Agroforestry Technology among contact farmers in Imo State, Nigeria, vol. 2, No.1, pp. 1-9

Pretty, J. N., Noble, A. D., Bossio, D., Dixon, J., Hine, R.E., Penning de Vries, F.W.T. and Morison, J.I.L. (2006). Resource-conserving agriculture increases yields in developing countries. *Environmental Science and Technology,* 40:1114-1119

Rana, P., Prakash, P. & Pathania, R. (2026). Synergizing nutrient management and mulching for onion cultivation under pomegranate-based agroforestry systems. *Agroforestry Systems*, 126.

Sileshi, G. W., Kuntashula, E., Matakala, P. & Mafongoya, P. L. (2022). Pest regulation in Diversified agroforestry systems: A synthesis of ecological mechanisms. *Ecological Applications, 32*(5), e2578.

Udofia S. I. (2007). Status of Homegarden in Akwa-Ibom State, Nigeria Ph.D Dissertation, Micheal Okpara University of Agriculture, Umudike, Abia State, Nigeria; Pp. 187

Williams, C. J. R., Kniveton, D. and Layberry. R. (2010) Assessment of climate models to reproduce rainfall variability and extremes over Southern Africa. *Theor. Appl. Climatol*. 99 (4), 9-27

ISTF-NIG 2026

FACTORS INFLUENCING AGROFORESTRY TECHNOLOGIES ADOPTION AMONG RURAL FARMERS IN KADUNA STATE, NIGERIA

[1]SIRAJO, A., [2]BONI, P.G., [2]MAIKANO, S., [1]AARON J.A.

[1]Department of Agricultural Technology, Federal College of Forestry Mechanisation, Afaka, Kaduna State
[2]Department of Forestry Technology, Federal College of Forestry Mechanisation, Afaka, Kaduna State
Correspondig Email: sidama90@gmail.com; +2348039685100

Abstract

The study examined the factors influencing the Adoption of agroforestry technologies among rural farmers in Kaduna State, Nigeria. Multi-stage, purposive and simple random sampling techniques were used to select 400 respondents. Data were collected and analyzed using a questionnaire and descriptive and inferential statistics, respectively. The results revealed that most respondents (76%) were male, and 58.6% were married, while 37.3% and 24.0% had secondary and tertiary Education, respectively. Most (82.0%) of the respondents had access to extension services. The results also reveal that respondents had an average age of 36 years, a household size of 5 persons, 10 years of farming experience, and a farm size of 10ha. Age ($P<0.05$), sex ($P<0.05$), access to extension ($P<0.05$), and educational level ($P<0.01$) were the factors that significantly influenced the Adoption of agroforestry technology. Destruction by humans and animals (97.51%), land ownership (76.52%), and policy and regulatory issues (73.76%) were the major constraints to agroforestry technology adoption in the study area and were ranked 1st, 2nd and 3rd, respectively. The study concluded that age, sex, educational level and income significantly influenced the Adoption of agroforestry technologies in the study area. Based on the study's findings, the following recommendations were made: to enhance the Adoption of agroforestry technologies, land-use policies should be enforced to protect agroforestry plots from encroachment and grazing. The government should implement agroforestry-friendly policies and strengthen extension services. Additionally, digital extension tools, awareness campaigns and educational programmes should be used to reach more farmers and promote the long-term benefits of agroforestry.

Keywords: Factors, Adoption, farmers, Agroforestry and Technologies

Introduction

Agriculture remains the primary livelihood source for rural communities in Nigeria, providing food, income and employment opportunities. However, challenges such as land degradation, deforestation, declining soil fertility, and climate change threaten agricultural productivity and sustainability. Agroforestry, which integrates trees and shrubs with crops and livestock on the same land, offers a viable solution to these challenges by enhancing soil fertility, conserving biodiversity and increasing farmers' resilience to climate variability (Nair, 2019). However, the level of Adoption and Adoption of these technologies among rural farmers varies across ecological zones due to differences in socio-economic conditions, policy support, and extension services (Ajayi *et al*., 2020). Adoption is a critical determinant, as farmers with better knowledge of agroforestry

benefits are more likely to incorporate such practices into their farming systems (Rahman *et al*., 2022). Despite the proven benefits of agroforestry, its Adoption among rural farmers in Kaduna State, Nigeria, remains relatively low, necessitating an investigation into the factors influencing its Adoption. Agroforestry technologies, which integrate trees and shrubs into agricultural landscapes, play a crucial role in enhancing environmental sustainability, improving soil fertility, and increasing farmers' resilience to climate change (Nair, 2021).

Despite the numerous advantages of agroforestry, its Adoption among rural farmers in Kaduna State remains low. This low adoption rate is attributed to multiple constraints, including inadequate awareness, limited access to extension services, financial constraints, insecure land tenure, and unfavourable policy frameworks. Studies have shown that farmers' socio-economic characteristics, perceptions, and institutional support significantly influence their adoption decisions (Ajayi *et al*., 2020; Place *et al*., 2021). However, there is limited empirical evidence on the factors influencing the Adoption of agroforestry among rural farmers in Kaduna State. It is against this background that the study seeks to find answers to the following research questions:

i. What are the socio-economic characteristics of the respondents in the study area?
ii. What are the factors influencing the Adoption of agroforestry technologies among respondents?
iii. What are the constraints to the Adoption of agroforestry technologies among respondents in the study area?

The study was conducted with a view to examining:

i. socio-economic characteristics of the respondents in the study area;
ii. factors influencing agroforestry technologies, Adoption among the respondents, and:
iii. constraints to the Adoption of agroforestry technologies among respondents in the study area

Methodology

The study was conducted in Kaduna State. The State is located between Longitude 6.0° E− 8.5° E and Latitude 9.5°N − 11.5° N of the Greenwich Meridian (Yusuf *et al,* 2020). It shares boundaries with the Federal Capital Territory to the South West, Niger State to the West, Zamfara State to the North West, Kano and Katsina States to the North, and Bauchi and Plateau States to the East. It lies within the savannah within the ecological zone. The climate is characterized by alternating wet and dry seasons. Kaduna State's vegetation consists of Northern Guinea Savannah in the North and Southern Guinea Savannah in the south. The State covers approximately 46,053 km². It receives an average of 5 months of rainfall, with an annual total of approximately 1,482mm. The annual temperature in Kaduna State ranges from 35°C to 36°C, and can drop to 10°C to 23°C during the harmattan period (Besar *et al*., 2020). The population of Kaduna as of 2021 was 89,032,200, based on a 2024 projection at a 3.0% growth rate (National Bureau of Statistics). Okra, pepper, maize, ginger, sorghum, rice, yams, cassava, millet, and tomatoes are grown in Kaduna State. Cattle, goats, sheep, rabbits, and poultry are reared (Balogun *et al*., 2020). Major economic activities in Kaduna State include farming and trading. The vegetation cover comprises indigenous forest species such as *Pakia biglobosa* (Dorawa), *Ceiba pentandra* (Silk Cotton), and *Adansonia*

digitata (African Baobab), as well as exotic species like *Azadirachta indica* (Neem), *Tectona grandis* (Teak), *Eucalyptus spp*., *Gmelina spp*., and *Pinus caribaea* (Pine) (Nguyen *et al*., 2020). Multi-stage, purposive, and simple random sampling techniques were used to select respondents. The State is divided into four Agricultural zones, namely: Lere, Maigana, Samaru and Birnin-Gwari. The first stage involves purposive selection of three (3) zones (Birnin-Gwari, Maigana, and Samaru) out of the four agricultural zones in the State due to the high level of agroforestry technologies activities in the area. In the second stage, three (3) Local Government Areas (LGAs) were randomly selected, namely Ikara, Igabi, and Sanga, each from One (1) of the selected zones. The third stage involved the systematic selection of three (3) Districts from each of the selected LGAs, making a total of nine (9) Districts. The fourth stage involved a random selection of two (2) communities from each of the selected districts, making a total of 18 communities. In the final stage, (35%) of the respondents were proportionately and randomly selected, making a total of 400 respondents drawn from the study area as the sample size for the study.
A structured questionnaire was used for data collection. A total of 400 questionnaires were administered to farmers by trained enumerators, and 362 were retrieved from the field and analyzed.

The data collected were analyzed using both descriptive and inferential statistics. Descriptive statistics such as frequency distributions, percentages, and means were employed to achieve objectives I, II, and III. While the binary logistic regression model was used to achieve objective III. The model is specified as:

$$Y1 = \alpha+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6+\beta_7X_7+\beta_8X_8+\beta_9X_9+\beta_{10}X_{10}+\beta_{11}X_{11} \ldots (1)$$

Yi = Dependent variable (decision to adopt agroforestry technologies or otherwise: Adoption = 1, No Adoption = 0)
X_1 = Age (years)
X_2 = Marital status (1= married, 2= single, 3= divorced, 4= widowed)
X_3 = Sex (1 = male, 2 = female)
X_4 = Level of Education (1 = primary, 2= secondary, 3= tertiary, 4= non-formal)
X_5 = Household size (number)
X_6 = Farming experience (years)
X_7 = Access to Market
X_8 = Cooperative membership
X_9 = Access to extension services (1= yes, 2= no)

Results and Discussion

Socio-economic characteristics of the respondents

The results in Table 1 showed that the majority (76%) of respondents were male. In comparison, females accounted for 24.0%, indicating that more males than females were involved in agroforestry farming in the study area. This implies that gender plays a significant role in decision-making and the Adoption of agroforestry. This is consistent with Zaca *et al.* (2023) and Jahan *et al*. (2022), who found that males constitute the majority of agroforestry adopters in South Africa. The result also showed that (58.6%) of the respondents were married, 23.2% were single, 6.4% were divorced, and 8.6% were widowed. This variable is important because having a spouse could increase a household's access to labour, which is necessary for agroforestry. The results corroborate

the findings of Bandi *et al*. (2022), who demonstrated a positive relationship between marital status and agroforestry adoption among farmers in the Luki Biosphere Reserve in the Democratic Republic of Congo.

Similarly, 37.3%, 24.0%, and 21.0% of the respondents had secondary Education, tertiary Education, and Quranic Education, respectively. The findings also showed that 11.9% and 5.8% of the respondents had primary and non-formal Education, respectively. This indicates that most respondents were literate and therefore more likely to understand the extension programmes easily and to have access to up-to-date agricultural technologies than illiterate farmers. This suggests that farmers with some formal or informal Education are more likely to understand the benefits of agroforestry than illiterate farmers. The results agreed with the reports by Bandi *et al*. (2022); Ibrahim *et al*. (2021); Kaua (2020); Kinyili *et al.* (2020), and Gebru *et al.* (2019) that more educated farmers make significant decisions regarding agroforestry adoption.

The results of respondents' access to extension services, as shown in Table 1, indicated that most (82.0%) had access, while 18.0% had no access. This indicates that respondents in the study had access to extension services, which could positively influence awareness and subsequently the Adoption of agroforestry technologies. This agrees with the findings of Admasu and Jenberu (2022) and Alabi *et al.* (2023) that access to extension services promotes the Adoption of sustainable agricultural practices in Southern Ethiopia and Smallholder farmers in Kaduna State, Nigeria, accordingly. The results further revealed that more than half (51.4%) of the respondents were in the 31-40 age bracket, with an average age of 36 years. The entries in the Table also revealed that 18.8%, 12.9%, 10.7%, and 6.1% were within the age ranges of 21-30, 41-50, 51-60, and 61+, respectively. This implies that the majority of the respondents fall within the active and productive age and are expected to be more receptive to agroforestry technologies. This finding is consistent with the reports of Zaca *et al*. (2023) and Beyene *et al.* (2019), who found that age affected the Adoption of agricultural technologies.

The results in Table 1 also showed that the majority (53.3%) of respondents had a household size of 6-10, with an average of 5 persons. The results showed that farmers' family size has a positive impact on the decision to adopt Agroforestry practices. Similarly, respondents with household sizes of 1-5, 11-15, and 16-20 persons accounted for 26.2%, 9.1%, and 7.5%, respectively. Only 3.9% of respondents had household sizes of 20 or more. This agrees with Ullah *et al.* (2023) and Zaca *et al.* (2023) that the family size of farmers has a positive impact on the decision to adopt Agroforestry practices in Bangladesh and KwaZulu- Natal province, South Africa, respectively. Similarly, 43.1% and 30.9% of the respondents had farming experience ranging between 21-25 years and 16-20 years, respectively. Furthermore, 4.9%, 8.6%, and 12.4% had farming experience of 1-5 years, 6-10 years, and less than 20 years, respectively, with an average of 10 years. This implies that farmers with more farming experience are more likely to adopt Agroforestry technologies than those with less farming experience. This could be due to older farmers' greater agroforestry experience. This is in line with Beshir et al. (2022), Doboch and Abiyo (2022), and Mahmood and Zubair (2020), who reported that farming experience is an encouraging factor in adopting Agroforestry technologies.

Table 1 further depicted that 38.9% and 29.8% of the respondents had farm sizes of 25 ha and above, and 21-25 ha, respectively, with an average farm size of 10ha. In addition, respondents with

farm sizes of 0.5-5 ha, 6-10 ha, and 11-15 ha accounted for 14.9%, 7.7%, and 5.8%, respectively. The distribution indicates that most respondents operated on relatively large farm holdings, which have implications for the Adoption of agroforestry technologies. The result concurred with the findings of Zaca *et al*. (2023) that farmers' landholdings have a positive impact on the decision to adopt agroforestry technologies in Kaduna State, Nigeria. Similarly, Tega and Bojago (2023) reported that large farm size hastens the adoption process.

Table 1: Distribution of Socio-economic Characteristics

Variable	Frequency	Percentage	Mean
Sex			
Male	275	76.0	
Female	87	24.0	
Marital status			
Married	212	58.6	
Single	84	23.2	
Divorced	23	6.4	
Widowed	31	11.8	
Educational level			
Non-formal	21	5.8	
Quranic	76	21.0	
Primary	43	11.9	
Secondary	135	37.3	
Tertiary	87	24.0	
Access to extension services			
Yes	297	82.0	
No	65	18.0	
Age (Years)			
21 – 30	68	18.8	
31 – 40	186	51.4	38.6
41 – 50	47	12.9	
51- 60	39	10.7	
61- Above	22	6.1	
Household Size			
1-5	95	26.2	
6-10	193	53.3	5.0
11-15	33	9.1	
16- 20	27	7.5	
Above 20	14	3.9	
Farming Experience (Years)			
1 – 5	18	4.9	
6 – 10	31	8.6	
11 – 15	45	12.4	

ISTF-NIG 2026

16 – 20	112	30.9	
21 – 25	156	43.1	10.2

Table 1: Cont'd

Variable	Frequency	Percentage	Mean
Farm Size (Ha)			
0.5 – 5	10	2.7	
6 – 10	21	5.8	
11 – 15	28	7.7	
16 – 20	54	14.9	
21 – 25	141	29.8	
Above 25	108	38.9	10.4
Distance to Market (km)			
0.5 – 5	163	45.0	
6 – 10	88	24.3	7.3
11 – 15	53	14.6	
16 – 20	32	8.8	
21 – 25	15	4.1	
Above 25	11	3.0	

Source: Field Survey, 2024

Factors Influencing Agroforestry Technologies Adoption

The results in Table 2 revealed the factors influencing the level of awareness of agroforestry technologies in the study area. The analysis used a binary logistic regression, as indicated by the presentation of coefficients, standard errors, p-values, and the pseudo-R-squared. The Chi-square value of 30.885 is statistically significant at the 10% level, indicating that the model as a whole fits the data better. The Pseudo R-squared of 0.0623 suggests that approximately 62.3% of the variation in the Adoption of agroforestry technologies is explained by the variables included in the model. While this may seem low, it is common in social science research where human behaviour is influenced by a set of variables, many of which may be unobserved. The results depicted that the coefficient of the level of Education is positive and statistically significant ($P<0.01$) in influencing the respondents' level of Adoption of agroforestry technologies. This implies that respondents with higher levels of Education showed greater awareness of agroforestry technologies. This aligns with Onuwa *et al*. (2023) and Giller *et al*. (2021), who found that Education enhances farmers' capacity to access, interpret, and adopt agricultural innovations. Educated farmers tend to interact more with extension systems and the media, thereby enhancing their knowledge.

The results also revealed that respondents' level of Adoption was significantly influenced by age ($P<0.05$), suggesting that as age increases, Adoption of agroforestry technologies also increases. This result agrees with the report by Oyawole *et al*. (2020), who found that older farmers tend to have more cumulative farming experience and stronger networks, which increase exposure to agricultural innovations. However, it confirmed that Tega *et al.* (2023), who argued that younger farmers were more likely to engage with modern technologies, especially via ICT platforms. This result further showed a significant ($P<0.1$) positive relationship between years of farming and the level of Adoption of agroforestry technologies. This result aligns with the report by Musa *et al*.

(2022), which found that prolonged engagement in agriculture increases familiarity with various land management techniques, including agroforestry. Experienced farmers are also more likely to recognize the long-term benefits of trees on farmland.

These further indicate that the coefficients are significant and significantly (P<0.05) influenced the Adoption of agroforestry technologies. Being male was positively associated with higher Adoption levels. This is consistent with Oluwole's (2020) report that men typically have greater access to extension agents, training programmes, and land ownership, which facilitates greater exposure to technologies. Coefficients for access to extension (P<0.05) and cooperative membership (P<0.05) were also positive and statistically significant at the 5% level, indicating that respondents with better access to extension services had higher levels of awareness. This aligns with Adefalu *et al.* (2021) and Dou *et al.* (2023), who found that timely and regular extension visits were critical for disseminating agroforestry knowledge. Extension agents serve as a bridge between research institutions and farmers, reinforcing best practices and innovations. The result revealed a significant positive association between cooperative membership and awareness. consistent agreement with Luo *et al.* (2022), who stated that farmers' cooperatives function as important channels for training, information dissemination, and technology.

Table 2: Factors Influencing Adoption of Agroforestry Technologies

Variable	Coefficient	Std. error	P-value
Age	0.028	0.01	003**
Marital Status	-0.015	0.145	0.21
Sex	0.122	0.425	0.02**
Level of Education	0.111	0.086	0.003***
Household Size	0.032	0.078	0.493
Farming Experience (Years)	0.005	0.042	0.1*
Access to Extension services	0.012	0.016	0.048**
Access to Market	0.031	0.508	0.727
Cooperative membership	0.003	0.047	0.025**
Constant	1.531		
Pseudo r-squared	0.0623		

Source: Field Survey, 2024 *** P<0.01, ** P<0.05, * P<0.1,

Constraints to Agroforestry Technologies Adoption of the Respondents

The result in Table 3 revealed that almost all (98.10%) of the respondents identified irregular or seasonal extension visits as a major constraint to the Adoption of agroforestry technologies. This implies that inconsistency in outreach and engagement by extension agents hampers the timely and effective dissemination of agroforestry information to rural farmers. This, therefore, disrupts the flow of knowledge and weakens farmers' capacity to understand and adopt agroforestry innovations. This finding aligns with Adefalu *et al*. (2021), who noted that a lack of regular contact with extension agents significantly hinders the spread of agroforestry technologies in rural communities in Kwara State. Similarly, Oyawole *et al*. (2020) reported that the shortage of skilled extension workers and inconsistent visitation schedules contributed to farmers' limited awareness and Adoption of agroforestry in Cross River State. Entries in Table 3 also revealed that most (96.96%) of the respondents reported that a low literacy level was a barrier to awareness. This indicates that many rural farmers may struggle to understand technical information about

agroforestry practices, particularly when it is disseminated in written materials or in languages they are not fluent in. Low literacy restricts their ability to read extension leaflets, interpret instructions on agroforestry models, or benefit from ICT-based agricultural tools. This finding aligns with the report of Zemarku *et al*. (2022), who stated that literacy is a foundational skill necessary for agricultural knowledge acquisition and innovation adoption. This constraint is also consistent with the report by Onuwa *et al*. (2021), which stated that low educational attainment limits farmers' ability to comprehend and apply information on agroforestry innovations in Plateau State. Similarly, Oyawole *et al*. (2020) reported that Education influenced farmers' Adoption of sustainable agricultural practices, with potential for climate-smart agriculture and food security among farm households in northern Nigeria. Hence, literacy plays an important role in the awareness and Adoption of agroforestry.

The result also shows that most respondents (92.82%) identified inadequate government or community awareness programmes as a constraint. This depicts the insufficiency of structured campaigns or sensitization initiatives by public institutions and community organizations to promote agroforestry technologies. Awareness Creation efforts appear to be either lacking in frequency, scope, or accessibility, thereby limiting farmers' exposure to the long-term benefits and practical applications of agroforestry. This is supported by Ibrahim *et al*. (2019), who reported that weak community mobilization, poor governmental awareness, and Adoption initiatives led to low adoption rates of conservation and agroforestry practices in Niger State. Furthermore, 81.77% of the respondents indicated that inadequate contact with NGOs or research institutions was a significant constraint. This implies a weak linkage between farmers and key stakeholders who could otherwise serve as sources of agroforestry innovations, training, and funding. This limited interaction deprives farmers of valuable demonstrations, pilot projects, and participatory learning opportunities. This result corresponds with findings by Isife and Madukwe (2005), who noted that limited contact with research and development institutions restricted access to relevant information, training, and improved technologies in southeastern Nigeria. More recently, Oluwole (2020) reported that institutional partnerships and collaborations continue to pose constraints on the Adoption of eco-friendly agricultural practices and their associated welfare impacts.

The result further indicated that 75.41% of the respondents cited inadequate training as a constraint. These reveal a gap in capacity-building efforts tailored specifically to awareness of agroforestry technology. This supports Flanagan *et al.* (2023), who stressed that continuous training and capacity-building initiatives are essential for extension officers and farmers to understand and implement agroforestry technologies effectively. Likewise, Giller *et al.* (2021) observed that the Adoption of conservation agriculture is highly knowledge- intensive, and farmers often face learning challenges and uncertainty, implying that information alone may not translate into effective implementation without practical experience. Only (17.95%) of the respondents indicated inadequate extension services in general as a constraint. This implies that while extension services exist in some form, their effectiveness is undermined more by irregular contact and seasonal operations than by total absence.

Table 3: Distribution of Respondents According to Constraints to Agroforestry Technologies Adoption (n=362)

Variables	Frequency	Percentage*	Rank
Irregular or seasonal extension visits	355	98.10	1st

Low literacy level among farmers	351	96.96	2nd
Inadequate government/community awareness programmes	336	92.82	3rd
Inadequate contact with NGOs or research institutions	296	81.77	4th
Poor access to information and communication tools	281	77.62	5th
Inadequate training	273	75.41	6th
Inadequate extension services	65	17.95	7th

Source: Field Survey, 2024 * Multiple responses

Conclusion and Recommendations

The study concluded that age, sex, access to extension and educational level significantly influenced the Adoption of agroforestry technologies in the study area. Based on the findings of the study, the following recommendations were made; More extension agents should be trained and deployed to rural areas to enhance farmers' knowledge and technical skills in agroforestry practices, while promoting the use of digital extension platforms, such as mobile applications and radio programs, to reach a larger number of farmers. Adoption campaigns and farmer Education programs should be intensified to address misconceptions about agroforestry technologies, emphasizing their long-term benefits. There should be more agroforestry-trained extension workers deployed to rural Kaduna. Radio, mobile apps, and community-based training programs should be strengthened to increase outreach. Support farmer associations to serve as information hubs for sharing agroforestry innovations. Enhance literacy and vocational agroforestry Education among rural women and youth.

References

Adefalu, L., Azeez, K., & Adeleke, O.A (2021). Assessment of extension agents' promotion strategy on sustainable agroforestry management practices in kwara State, Nigeria. *International journal of agricultural extension and social development*, 4(1) 206-211

Admasu, T. G., & Jenberu, A. A. (2022). The impacts of Apple-based agroforestry practices on the Livelihoods of smallholder farmers in Southern Ethiopia, *Trees, Forests and People 7* 100205. https://doi.org/10.1016/j.tfp.2022.100205.

Ajayi, O. C., Akinnifesi, F. K., Sileshi, G., & Chakeredza, S. (2007). Adoption of renewable soil fertility replenishment technologies in the southern African region: Lessons learnt and the way forward. *Natural Resources Forum* 31(4): 306–317s

Ajayi, O. C., Place, F. & Kwesiga, F. (2020). Impact of agroforestry-based soil fertility replenishment practices on people with low incomes in Zambia, *Asian Journal of Agriculture and Forestry* 108: 50-62

Alabi, O. O., Bayei, J. D. A., Jeremiah, S. (2023). Technical efficiency of agroforestry production technology among smallholder farmers in Kaduna State, Nigeria *Aust J Sci Technol 362–* 373

Ali, M. M., Islam, M. A., Islam, M. R., Dipto, S. S., & Bari, M. S. (2024). Assessing the cropland changes into agroforestry and its livelihood outcomes: Evidence from northern Bangladesh. *Trees, Forests and People*, 15 100497

Balogun, O. S., Usman, M. B., Ayodele, J. T., Aasa, O. S., & Anamayi, R. (2020). Fuelwood Consumption and Clean Cooking Fuel Poverty in Kaduna State, Nigeria: Implications for Sustainable Forest Management. *Journal of Forestry Research and Management*, 17(2): 148–158.

Bandi, M. M., Mahimba, M. B. Mbe, P. M. (2022). Adoption of agroforestry practices in and around the Luki Biosphere Reserve in the Democratic Republic of the Congo. *Sustainability* 14(16):9841.

Beyene, A. D., Mekonnen, A., Randall, B., & Deribe, R (2019). Household-level determinants of agroforestry practices Adoption in rural Ethiopia. *Forests, Trees and Livelihoods*, *28*(3): 194–213. https://doi. org/10.1080/14728028.2019.1620137

Besar, N. A., Suardi, H., Phua, M.-H., James, D., Bin Mokhtar, M & Ahmed, M. F (2020). Carbon Stock and Sequestration Potential of an Agroforestry System in Sabah, Malaysia. Forests, 11: 210-219

Beshir, M., Tadesse, M., Yimer, F., and Brüggemann, N (2022).. Factors affecting the Adoption and intensity of use of Tef-*Acacia decurrens* charcoal production agroforestry system in northwestern Ethiopia, *Sustainability* 14 **(**8) 4751

Doboch, D., & Abiyo, A. (2022). Assessing the contribution of agroforestry in sustaining the rural livelihoods and factors affecting their Adoption: The case of Hadero-Tunto District, South Ethiopia. *International Journal of Agroforestry and Silviculture*, 5**(**1): 122–135

Dou Y, Li Y, Li M, Chen X & Zhao X. (2023). The role of agroforestry in poverty alleviation: a case study from Nujiang prefecture, South-western China. *Sustainability* 15(5): 1–20

Flanagan, B, Boren – Alpizar, A, Wingenbach, G, Lawver. D, & Strong, R (2023). Evaluating agroforestry extension workers' technical and human relation competencies: A ranked discrepancy model needs assessment. Sustainability 15 (19) 14100

Gebru, B. M., Wang, S. W., Kim, S. J., & Lee, W. K (2019). Socio-ecological niche and factors affecting the Adoption of agroforestry practices across different agroecologies of Southern Tigray, Ethiopia. *Sustainability (Switzerland):***11**(13): 1–19.

Giller, K., Witter, E, Corbeels, M., & Tittonell, P. (2021). Understanding Adoption and impacts of conservation agriculture in Eastern and Southern Africa: A review

Ibrahim, Y., Mohammed, A., & Sani, B. (2021). Financial constraints and the Adoption of agroforestry in New Bussa, Nigeria *Journal of Rural Economics and Development* 14**(**2): 55-72

Isife, B., & Madukwe, M.C (2005). Constraints to farmers' effective participation in agricultural extension programmes of non-profit non- governmental organizations in Southern –Eastern Nigeria. *Global Approaches to Extension practice,* 1(1), 74-82

Jahan, H., Rahman, M. W., Islam, M. S., Rezwan-Al-Ramim, A., Tuhin, M. M. J. & Hossain, M. E. (2022). Adoption of agroforestry practices in Bangladesh as a climate change mitigation option: Investment, drivers, and SWOT analysis perspectives. *Environmental Challenges*, 7: 100-109

Kaua, C. G. (2020). Socio-economic factors affecting the Adoption of agroforestry practices in forest-adjacent communities: The case of Ndabibi Location, Nakuru. *East African Journal of Forestry and Agroforestry* 2**(**1): 59–67.

Kinyili, B. M., Ndunda, E. & Kitur, E. (2020). Trade-off between Agroforestry and Ecosystem Services among Smallholder Farmers in Machakos (Kenya). *Africa Environmental Review Journal*, 4**(**1): 1323

Luo, L, Qiao, D, Zhang, R, Luo, C, Fu, X., & Liu, Y (2022). Research on the influence of Education of farmers' cooperatives on the Adoption of green prevention and control technologies by members. International Journal of Environmental Research and Public Health, 19(10), 6255

Mahmood, M. I. & Zubair, M. (2020). Farmer's perceptions and factors influencing agroforestry practices in the Indus River Basin, Pakistan. *Small-Scale Forestry*, 19(1): 107–122.

Nair, P. K. R. (2019). Agroforestry: Trends, challenges, and prospects. *Agroforestry System* 95**(**4): 789–805.

Nair, P. R., Kumar, B. M & Nair, V. D. (2021). *Introduction to agroforestry: four decades of scientific developments* (p. 666). Cham: Springer

Nguyen, M. P., Vaast, P., & Pagella, T (2020). Sinclair, F. Local Knowledge about Ecosystem Services Provided by Trees in Coffee Agroforestry Practices in Northwest Vietnam. Land, 9, 486

Oluwale, S. (2020). Adoption decision and welfare impact of eco-friendly agricultural practices: Evidence from smallholder farmers in South- West Nigeria. Journal of Management Information and Decision Services, 23(5), 590-611

Onuwa, G.C, Mailumo, S., & Oyewole, S.O (2023). Socio-economic determinants of Adoption of maize production technologies among smallholder *Agriekonomika,* 12(1) 1-10

Oyawole, F., Dipeolu, A., Shittu, A., Obayelu, A., & Fbunmi, T.O (2020). Adoption of climate-smart agricultural practices and food security among farm households in northern Nigeria. *Open Agriculture*, 5 (1) 751-760

Place, A. P., Rodgers, L. V., Mundada, P., Smitham, B. M., Fitzpatrick, M., Leng, Z. and Houck, A.A (2021) Economic returns to households participating in different models of commercial tree plantations in Lao PDR. *International Forestry Review*, 22(1): 132-132.

Rahman, M. M., Islam, M. S., & Haque, M. E (2022). Awareness and Adoption of agroforestry practices among rural farmers in Bangladesh *Journal of Rural Development Studies*, **7**(2): 112-130

Tega, M and Bojago, E. (2023). Farmer's perceptions of agroforestry practices, contributions to rural household farm income, and their determinants in Sodo Zuria district, Southern Ethiopia. *International Journal of For Resources* 3**(**1): 202-215.

Ullah, A., Mishra, A. K., & Bavorova, M (2023). Agroforestry adoption decision in green growth initiative programs: Key lessons from the billion trees afforestation project (BTAP). *Environmental Management*, 71 (5): 950–964.

Yusuf, S. Oladele, O. N., Emeghara, U. U., Ishola, B. F., Ayodele, J. T., Awobona, T. A., & Olukotun, O (2020). Adoption of agroforestry practices by arable farmers in Igabi Local Government Area of Kaduna State, Nigeria. *Asian Journal of Research in Agriculture and Forestry*, 6(2): 28-37

Zaca, F. N., Ngidi, M. S. C., Chipfupa, U., Ojo, T. O., & Managa, L. R (2023). Factors influencing the uptake of agroforestry practices among rural households: Empirical evidence from the KwaZulu- Natal province, South Africa, *Forests*, 14 (10): 45-53

Zemarku, Z., Senapathy, M & Bojago, E. (2022). Determinants of Adoption of improved dairy Technologies: the case of O1a Woreda, Wolaita Zone, southern Ethiopia," *Advances in Agriculture*, 5(2): 19-22

SOCIO-ECONOMIC BENEFITS OF ONIGAMBARI FOREST RESERVE ON RURAL DWELLERS IN OLUYOLE LOCAL GOVERNMENT AREA, OYO STATE.

Odeyale, Olajumoke Celinah; Fadipe, Oluwasegun Babatunde and Adebayo, Ayodeji Gideon

Federal College of Forestry, Jericho, Ibadan, Oyo State, Nigeria
Corresponding author's email: jumoceline81@gmail.com/ 08036573330

Abstract

This study examined the socio-economic benefits of the Onigambari Forest Reserve on rural dwellers in Oluyole Local Government Area of Oyo State, Nigeria. Specifically, it assessed the prevailing economic activities, evaluated the perceived socio-economic impacts of the forest reserve, and identified constraints to sustainable forest-based livelihoods. A simple random sampling technique was used to select 127 respondents, of whom 107 completed questionnaires were collected and analyzed. Descriptive statistics and chi-square analysis were employed for data interpretation. The findings revealed that the majority of respondents were male (74.8%), married (86.9%), and within the economically active age group of 40–49 years. Farming, fuelwood gathering, grazing, fishing, and non-timber forest product (NTFP) collection were identified as the dominant economic activities, with grazing ranked highest. The study further showed that the forest reserve significantly contributes to rural livelihoods through income generation, employment opportunities, provision of raw materials, and improved standard of living. Chi-square analysis indicated that gender and educational status significantly influenced respondents' perception of socio-economic benefits. Despite these benefits, several constraints were identified, including land hunger, corruption, and inadequate government policies, which were ranked as major threats to sustainable forest management. The study concludes that while the Onigambari Forest Reserve plays a vital role in enhancing rural livelihoods, addressing institutional and environmental challenges is crucial for achieving sustainability.

Keywords: Socio-economic benefits, Rural dwellers, Forest, Forest reserve.

Introduction

Forest resources are fundamental pillars of rural livelihoods in developing nations, particularly within sub-Saharan Africa, where a significant portion of the population relies directly on natural ecosystems for survival and economic advancement. These ecosystems provide a diverse array of goods and services, including timber, fuelwood, medicinal plants, and various non-timber forest products (NTFPs), which are essential for household consumption and income generation (Arnold & Pérez, 2001). For many rural households, these resources act as a vital supplement to livelihoods, especially where formal employment is scarce (Vedeld *et al*., 2007). Furthermore, forests serve as an "economic safety net," providing critical alternative income during periods of agricultural failure or macroeconomic instability (Angelsen *et al*., 2014). The Food and Agriculture Organization (FAO, 2018) underscores that forests contribute significantly to rural development by bolstering food security and protecting the environment. In Nigeria, forest reserves have historically been established to balance ecosystem conservation with sustainable socio-economic utilization, providing rural populations with regulated access to resources while maintaining regional ecological stability (Aiyeloja & Ajewole, 2006). Communities near these reserves engage

in diverse activities, including farming, hunting, logging, and charcoal production (Arowosoge & Faleyimu, 2011). Empirical evidence suggests that forest-based ventures contribute substantially to the welfare of Nigerian rural households, often serving as a primary strategy for income diversification and poverty mitigation (Adepoju & Opadiran, 2021).

The forest reserves of Southwestern Nigeria are of particular strategic importance due to the high population density and the subsequent demand for natural resources. Within Oyo State, the Onigambari Forest Reserve, located in the Oluyole Local Government Area, supports numerous rural settlements where inhabitants rely heavily on fertile lands for farming (Oyetunji, 2019). Additionally, the extraction and marketing of fuelwood have emerged as profitable enterprises that significantly boost household liquidity in the host communities (Ayetan *et al*., 2021). Non-timber forest products (NTFPs) such as honey, mushrooms, and medicinal plants are a unique component of these livelihood strategies because they can often be harvested without compromising the forest's structural integrity (Arnold & Pérez, 2001). Research within Onigambari indicates that NTFP harvesting plays a transformative role in improving the living standards of rural dwellers by providing consistent cash flow (Oladipupo-Alade *et al*., 2021). Beyond direct extraction, the forest provides indirect ecosystem services, such as maintaining soil fertility and protecting watersheds, which are indispensable for local agricultural productivity (FAO, 2018).

Onigambari Forest Reserve is one of the largest forest reserves in Oyo State, covering about nine thousand hectares of land. The reserve consists of State-owned forest plantation, private forest plantation and federal experimental plots (Ayetan, 2017). Its strategic location within Oluyole Local Government Area, proximity to rural farming communities, and its ecological and economic significance to the surrounding population make it a particularly suitable site for investigating forest-based livelihoods and socio-economic dynamics. Despite these documented benefits, the rural communities surrounding the Onigambari Forest Reserve continue to face persistent poverty and developmental stagnation. While dwellers engage in farming, fuelwood extraction, and NTFP collection, the precise socio-economic impact of these activities has not been sufficiently quantified in existing literature. There is a notable gap in understanding how these dwellers perceive the influence of the forest on their well-being. Furthermore, several challenges hinder the optimization of these forest-based livelihoods, including limited access to credit facilities (Adepoju and Opadiran, 2021) and poor transportation infrastructure (Arowosoge and Faleyimu, 2011). Environmental pressures, such as climate variability and unsustainable harvesting practices, also threaten the long-term availability of these resources (Sunderland *et al*., 2017; Akinbile *et al*., 2018). Without addressing these systemic bottlenecks and understanding the dwellers' perspectives, sustainable forest management remains difficult to achieve. Consequently, this study seeks to investigate the prevailing economic activities being carried out in and around the Onigambari Forest Reserve, determine the perception of the socio-economic impact of these activities on forest dwellers, and examine the challenges militating against economic activities among rural dwellers in Oluyole Local Government Area.

Materials and Method

Study Area

Onigambari forest reserve was located in Oyo State with latitude 7 25’ and 7 55N and longitude 3 53’ and 3 9’E. The forest reserve which used to be part of the lowland rainforest, is now in the Guinea savanna and derived savanna zones. It covers a total land area of 13932.18 hectares

consisting of five zones: Mamu, Onigambari, Busogboro, Odo ona/Onipe and Olonde. The mean annual rainfall ranges between 1200mm to 1300mm (Uzokwe *et al.,* 2004).

Sampling Techniques and Size

The total population of household heads across the four communities: Gambari (600), Ibusogboro (532), Onipe (410), and Seriki (102), gave a total population of 1,644. Using the Yamane (1967) formula at a 95% confidence level and a 5% margin of error, a sample size of 127 respondents was determined, corresponding to approximately 7.7% sampling intensity. Respondents were selected from each community using proportionate random sampling to ensure adequate representation relative to community population size. Structured questionnaires were administered to the selected respondents; at the end of the exercise, 107 questionnaires were successfully retrieved, representing an 84% retrieval rate.

Method of Data Collection

Data for this study were collected from primary and secondary sources. The primary source was a well-structured questionnaire and interviews designed to capture socio-economic indicators. The secondary sources included relevant literature, research journals, and other publications.

Data Analysis

The data collected for this study were analyzed using both descriptive and inferential statistical methods. Descriptive statistics, such as frequency counts, percentages, and tables, were used to organize and present the data in a simple, understandable way. To test the research hypotheses, the Chi-square (χ^2) statistical test was applied. This test helped to determine whether there was any significant relationship between the variables under study. All hypotheses were tested at a 0.05 level of significance. In addition, mean ranking was used to analyze the data further. The mean values of the variables were calculated and used to rank them according to their importance. Variables with higher mean values were considered more significant and ranked accordingly.

Result and Discussion

Table 1 presents the socio-demographic characteristics of the respondents. The result indicated that 74.8% of the respondents were male, while 25.2% were female. This shows that there were more men than women in the free areas. This can be explained by the fact that men take up more difficult jobs to provide for their families. This also shows that men are more resilient to stress, allowing them to engage in more tedious work than their female counterparts. This aligns with Olawuyi *et al*.'s (20, 21) findings that men tend to handle stress better, allowing them to undertake more strenuous work than their female counterparts. The age distribution of the respondents revealed that the age group with the highest percentage was 40-49 years (47.7%), indicating that this age group participated more in the reserve's activities. They were followed by respondents aged 50-59 years, with 21.1%, while the lowest age group was 20-29 years, with 0.9%. This indicates that the majority of respondents remain active and able to participate in the sustainable management of the reserve. This was consistent with Díaz *et al*. (2018), who noted that the productive age for agricultural and forestry activities is typically 31-60 years. This result also revealed that 86.9% of the respondents were married, indicating that they have responsibilities for caring for and

providing for their families. This supported the findings of Olawuyi *et al*. (2021), who stated that a high percentage of the rural populations are married.

Furthermore, most respondents had secondary Education (46.7%), followed by primary Education (29.0%), while those with adult Education and no formal Education had the lowest scores, at 3.7% and 3.7%, respectively. This shows that formal Education is not a major requirement for forest-dependent communities. Still, their biggest concern is the easy, cheap, and readily available agricultural practices needed to sustain their livelihoods. This supported the findings of Falana *et al*. (2023), who found that formal Education is not critical for forest-dependent communities, as their main concern is affordable, easily accessible farming practices for sustaining their livelihoods.

Table 1: Socio-Economic Characteristics of the Respondents (N = 107)

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	80	74.8
	Female	27	25.2
Age (years)	20–29	1	0.9
	30–39	15	14
	40–49	51	47.7
	50–59	29	27.1
	Above 60	11	10.3
Marital Status	Single	8	7.5
	Married	93	86.9
	Divorced	3	2.8
	Widowed	3	2.8
Educational Status	No Formal Education	4	3.7
	Primary Education	31	29
	Secondary Education	50	46.7
	OND/NCE	10	9.3
	HND/BSc	8	7.5
	Adult Education	4	3.7
Household Size	Below 5	43	40.2
	6–10	41	38.3
	11–15	15	14
	Above 15	8	7.4
Occupation	Hunting	5	4.7
	Farming	16	15
	Artisan	12	11.2
	Civil Servant	22	20.6
	Trader	27	25.2
	NTFP Collector	17	15.9
	Loggers	3	2.8

	Timber Contractor	5	4.7
Work Experience (years)	Below 10	34	31.8
	10–20	38	35.5
	21–30	21	19.6
	31–40	12	11.2
	41–50	2	1.8

Source: Field Survey, 2024.

The prevailing economic activities in the study area are presented in Table 2, which range from the collection of shea butter and medicinal plant material to logging, hunting, farming, and fishing, among others. The respondents' decision was examined using major and minor prevailing factors; thus, the mean ranking shows that some economic activities in the study area are well placed and cherished by the respondents. This further revealed that grazing is ranked as the most important economic activity, with 2.50, followed by the collection of shea butter and fishing, ranked 2nd and 3rd, respectively. This result corroborates FAO (2008), which listed some of the benefits of forests, including promoting economic development and reducing poverty in society, such as fuelwood and other forest products, including fruits, vegetables, soup condiments, seeds, herbs, and wildlife.

Table 2: Economic activities in the study area (N = 107)

S/no	Economic Activities	Major n (%)	Minor n (%)	Not at all n (%)	Mean	Rank
1	Collection of shea butter	15 (14.0)	33 (30.8)	59 (55.1)	2.41	2nd
2	Collection of medicinal plants	31 (29.0)	70 (65.4)	6 (5.6)	1.77	7th
3	Logging	56 (52.3)	39 (36.4)	12 (11.2)	1.59	8th
4	Hunting	34 (31.8)	54 (50.5)	19 (17.8)	1.86	5th
5	Grazing	8 (7.5)	37 (34.6)	62 (57.6)	2.5	1st
6	Farming	76 (71.0)	24 (22.4)	7 (6.5)	1.36	10th
7	Fishing	12 (11.2)	70 (65.4)	25 (23.4)	2.12	3rd
8	Collection of wild vegetables	19 (17.8)	62 (57.9)	26 (24.3)	2.07	4th
9	Collection of snails	43 (40.2)	45 (42.1)	19 (17.8)	1.78	6th
10	Gathering of firewood	68 (63.6)	32 (29.9)	7 (6.5)	1.43	9th

Source: **Field survey, 2024.** *Values in parentheses represent percentages*

Socio-Economic activities influencing Onigambari Forest Reserves

Table 3 indicates that gender significantly influences socio-economic activities in the study area, with a chi-square of 26.25 (df=1) and a P-value of 0.00. Of the 107 respondents who perceived socio-economic influence, 98 indicated migration in and out of the community, improved social amenities (87), increased income (102), a source of employment (105), the provision of raw

materials (103), and an improved standard of living (105). Jimoh (2006) found that more than 85% of rural households in Africa depend on socio-economic activities in their areas. This demonstration shows that to maintain any sustainable management practice, special attention should be paid to conservation in these areas. Therefore, this supported the findings of Olawuyi *et al.* (2021), who stated that the application of good forest management practices unquestionably contributes to maintaining the value of forests as sources of timber and other forest products.

Table 3: Gender versus Perceived Socio-Economic Influence of Onigambari Forest Reserve (N = 107)

Socio-Economic Influence	Decision	Male (n)	Female (n)	Total (n)
Migration in and out of the community	Yes	73	25	98
	No	7	2	9
Improved social amenities	Yes	67	20	87
	No	13	7	20
Increase in income	Yes	78	24	102
	No	2	3	5
Source of employment	Yes	79	26	105
	No	1	1	2
Provision of raw materials	Yes	77	26	103
	No	3	1	4
Improved standard of living	Yes	79	26	105
	No	1	1	2

Source: **Field Survey, 2024.**

Table 4 indicates that Education of respondents significantly influenced socio-economic activities in the study area ($\chi^2 = 98.06$, df = 1, p = 0.00). Of the 107 respondents, the majority had a secondary school certificate as their highest educational qualification. This finding suggests that even at this level of Education, rural dwellers within the study area possess sufficient awareness to recognize how their educational background shapes their participation in socio-economic activities. This is consistent with the submission of Adegboye (2016), who established a significant relationship between Education and socio-economic status among rural dwellers in Nigeria ($\chi^2 = 94.09$, $p < 0.05$), noting that any improvement in educational attainment will correspondingly improve socio-economic status. Similarly, age, years of Education, and monthly income were found to be major socio-economic factors affecting livelihood activities among rural dwellers in southeast Nigeria (Nwibo *et al.*, 2014).

Table 4: Education versus Perceived Socio-Economic Influence of Onigambari Forest Reserve (n = 107)

Socio-Economic Influence	Decision	NFE	PE	SE	OND/NCE	HND/BSc	AE	Total
Migration	Yes	4	31	46	8	5	4	**98**
	No	0	0	4	2	3	0	**9**

Improved social amenities	Yes	3	25	41	7	7	4	**87**
	No	1	6	9	3	1	0	**20**
Increase in income	Yes	3	30	47	10	8	4	**102**
	No	1	1	3	0	0	0	**5**
Source of employment	Yes	4	30	49	10	8	4	**105**
	No	0	1	1	0	0	0	**2**
Provision of raw materials	Yes	4	30	48	10	7	4	**103**
	No	0	1	2	0	0	1	**4**
Improved standard of living	Yes	4	30	49	10	8	4	**105**
	No	0	1	1	0	0	0	**2**

Source: **Field Survey, 2024.**

Table 5 identified various constraints and classified them into major, minor, and non-constraints. The minor constraints are the lack of protective functions of forest resources, illegal settlements, illegal hunting, encroachment into reserves, and a lack of government policy, with 59.8, 58.9, 54.2, 44.9, and 42.1, respectively. At the same time, some of the respondents did not consider land hunger (62.6), corruption (54.2), lack of government policy (48.6), lack of illegal and institutional framework (46.7) and Illegal harvesting of forest products as constraints. However, generally, according to the mean ranking, land hunger, corruption, and the lack of government policy pose a major threat to sustainable forest management.

These findings align with existing literature. Encroachment into forest reserves has been widely attributed to population pressure, demand for fertile agricultural land, poverty, and weak political will, all of which reflect the issue of land hunger identified in this study (Areo *et al.,* 2024). Similarly, illegal logging in Nigeria has been linked to inconsistent forest policies, weak property rights, and corruption among enforcement officials, reinforcing the prominence of corruption and policy failure as major constraints. Furthermore, persistent challenges such as encroachment, illegal logging, and unsustainable exploitation of forest resources have been documented as systemic issues undermining forest management in Nigeria (Oruonye, 2017). The pervasive role of corruption in weakening enforcement mechanisms and enabling illicit timber harvesting further substantiates its significance as a critical barrier to sustainable forest governance.

Table 5: Sustainable forest management constraint

S/no	Constraints	Major n (%)	Minor n (%)	Not a constraint n (%)	Mean	Rank
1	Illegal hunting	17 (15.9)	58 (54.2)	32 (29.9)	2.14	7th
2	Illegal settlements	26 (24.3)	63 (58.9)	18 (16.8)	1.93	11th

3	Illegal logging	31 (29.0)	34 (31.8)	42 (39.3)	2.1	9th
4	Illegal harvesting of forest products	19 (17.8)	41 (38.3)	47 (43.9)	2.26	5th
5	Lack of protective function of forest resources	13 (12.1)	64 (59.8)	30 (28.0)	2.16	6th
6	Corruption	8 (7.5)	41 (38.3)	58 (54.2)	2.28	2nd
7	Land hunger	6 (5.6)	34 (31.8)	67 (62.6)	2.57	1st
8	Lack of government policy	10 (9.3)	45 (42.1)	52 (48.6)	2.39	3rd
9	Weak legal and institutional framework	12 (11.2)	45 (42.1)	50 (46.7)	2.36	4th
10	Lack of forest health and vitality	33 (30.8)	36 (33.6)	38 (35.5)	2.05	10th
11	Encroachment into the reserve	23 (21.5)	48 (44.9)	36 (33.6)	2.12	8th

Source: Field survey, 2024. *Values in parentheses represent percentages*

Conclusion

The study clearly demonstrates that the Onigambari Forest Reserve is a critical socio-economic asset to rural dwellers in Oluyole Local Government Area. It serves as a major source of livelihood through diverse economic activities, including farming, grazing, fuelwood collection, and the exploitation of non-timber forest products. These activities significantly contribute to income generation, employment Creation, and overall improvement in the standard of living of the rural population. The findings further highlight that socio-demographic factors, particularly gender and Education, play a significant role in shaping how rural dwellers perceive and utilize forest resources. However, the sustainability of these benefits is threatened by several constraints, notably land hunger, weak institutional frameworks, corruption, and inadequate government policies.

In essence, while the forest reserve continues to function as an economic safety net for rural households, its long-term viability depends on effective management strategies that balance resource utilization with conservation. Without addressing the identified challenges, the socio-economic benefits derived from the forest may not be sustained for future generations. The study recommends that the government strengthen forest policies and enforcement, while improving access to credit and rural infrastructure to support sustainable livelihoods. Also, community-based forest management and training on sustainable harvesting practices should be promoted to ensure long-term conservation and sustained socio-economic benefits.

References

Adegboye, M. A. (2016). Socio-economic status categories of rural dwellers in Northern Nigeria. *Asian Journal of Agricultural Extension, Economics & Sociology, 9*(3), 1–8.

Adepoju, A. O., & Opadiran, I. O. (2021). Participation in forest management practices and livelihood diversification among forest dwellers in Oyo State, Nigeria. *Turkish Journal of Agriculture – Food Science and Technology.* 9(12): 2087-2093. DOI: https://doi.org/10.24925/turjaf.v9i12.2087-2093.3699

Aiyeloja, A. A., & Ajewole, O. I. (2006). Non-timber forest products' marketing in Nigeria: A case study of Osun State. *Educational Research and Reviews*. 1(2): 52-58

Akinbile, L. A., Aminu, O. O., & Kolade, R. I. (2018). Perceived effects of climate change on forest-dependent livelihoods in Oyo State, Nigeria. *Journal of Agricultural Extension* (EJS). 22 (2): 169-179

Angelsen, A., Jagger, P., Babigumira, R., Belcher, B., Hogarth, N. J., Bauch, S., Börner, J., Smith-Hall, C. and Wunder, S. (2014). Environmental Income and Rural Livelihoods: A Global-Comparative Analysis. *World Development.* 64(1):12-28. doi: 10.1016/j.worlddev.2014.03.006.

Areo, O. S., Omole, A. O., Amoo-Onidundu, O. N., & Adejoba, A. L. (2024). Impact of illegal logging operation on Nigerian economy: A concise review. *Agriculture, Food, and Natural Resources Journal, 3*(2), 349–357. https://doi.org/10.5281/zenodo.14483423

Arnold, J. E. M., & Pérez, M. R. (2001). Can non-timber forest products match tropical forest conservation and development objectives? *Ecological Economics*. 39(3): 437–447.

Arowosoge, O. G. E., & Faleyimu, O. I. (2011). Status of forest policy implementation in Kaduna State, Nigeria. *Australian Journal of Basic and Applied Sciences, 5*(8), 995–1001.

Ayetan, G., A. S. Alli-Balogun, O. A. Fadele, & K. T. Layade. (2021). "Socio-Economic Benefit of Fuelwood Marketing on the Host Communities of Onigambari Forest Reserve, Nigeria". *Asian Journal of Research in Agriculture and Forestry.* 7(1):28–33. https://doi.org/10.9734/ajraf/2021/v7i130120.

Díaz, S., U. Pascual, M. Stenseke, B. Martín-López and R.T. Watson, Z. Molnár, R. Hill, Kai M. A. Chan, Ivar A. Baste, Kate A. Brauman, S. Polasky, A. Church, M. Lonsdale, A. Larigauderie, P. W. Leadley, Alexander P. E. van Oudenhoven, F. van der Plaat, M. Schröter, S. Lavorel, Y. Aumeeruddy-Thomas, E. Bukvareva, K. Davies, S. Demissew, G. Erpul, P. Failler, C. A. Guerra, C. L. Hewitt, H. Keune, S. Lindley, Y. Shirayama, 2018. Assessing nature's contributions to people: Recognizing culture and diverse sources of knowledge can improve assessments. Science. 359: 270-272.

Falana, A.R., F.F. Ojo-Fakuade, A.F. Joseph, F.T. Adelusi, O.O. Oke, M.A. Majolagbe & F.B. Adesokan (2023). Economic analysis of sawnwood marketing in Isokan Local Government Area, Osun State, Nigeria. *Journal of Applied Sciences and Environmental Management*. 27: 767–773.

Faleyimu, O.I. & Arowosoge, O.G.E. (2011). Status of forest policy implementation in Kaduna State, Nigeria. *Australian Journal of Basic and Applied Science,* 5(8): 995 – 1001

FAO (2018). The State of the World's Forests: Forest Pathways to Sustainable Development. Food and Agriculture Organization of the United Nations, Rome.

Nwibo, S. U., Mbam, B. N., & Neba, E. E. (2014). Socio-economic factors affecting the choice of livelihood activities among rural dwellers in southeast Nigeria. *Sky Journal of Agricultural Research, 3*(4), 60–66.

Oladipupo-Alade, E., Oyedele, M., Rufai, S., Adebisi-Fagbohungbe, T., Haastrup, N., Ganiyu, O., & Abdulazeez, F. (2021). Contributions of some non-timber forest products to household

income of rural dwellers in Onigambari Forest Reserve, Oyo State, Nigeria. *Journal of Applied Sciences and Environmental Management*. 25(9):1587–1590. https://doi.org/10.4314/jasem.v25i9.7

Olawuyi, E. B., O. C. Odeyale, B. H. Ugege & D.A. Adenuga (2021). Socio-economic analysis of non-timber forest products: A case of wrapping leaves in Oluwa Forest Reserve, Ondo State, Nigeria. *Agro-Science*. 20: 9–13.

Oyetunji, P. O. (2019). Entrepreneurial activities in rural forest communities in Nigeria: Case study of Onigambari Forest Area. *Research on Humanities and Social Sciences.* 9(11): 56-63.

Sunderland, T. C. H., Alida O'C., G. M., Lauren N., Giulia Rota N., Camilla W., Nur B. & Amy, I. (2017). Forests and livelihoods: Evidence from global comparative studies. World Development. 48-71

Uzokwe, V. E. N., Adejobi, A. O., & Olorundare, E. (2004). Taungya farming and poverty alleviation: the case of Onigambari forest reserve, Oyo State. *Bowen Journal of Agriculture, 1*(2), 202–211. https://doi.org/10.4314/bja.v1i2.41871

Vedeld, P., Angelsen, A., Bojö, J., Sjaastad, E., Berg, G. K. (2007). Forest environmental incomes and the rural poor. *Forest Policy and Economics.* 9 (7): 869-879. https://doi.org/10.1016/j.forpol.2006.05.008.

Yamane, T. (1967). *Statistics: An introductory analysis* (2nd ed.). Harper and Row.

ISTF-NIG 2026

CORRELATION BETWEEN CAUSES OF LAND USE CONFLICT AND SOCIO-ECONOMIC STATUS OF FOREST DWELLERS IN ONDO STATE, NIGERIA

[1*]Aluko, O.J, [2]Bobadoye, A., [1]Odeyale, O.C., and [1]Agbo-Adediran, A.O

[1]Federal College of Forestry, Ibadan, Oyo State, Nigeria
[2]Forestry Research Institute of Nigeria
Corresponding Email: juliwal2002@yahoo.com/08032878193

Abstract

This study examined the relationship between land use conflicts and the socio-economic status of forest dwellers in Oluwa Forest Reserve, Ondo State, Nigeria. The study assessed respondents' socio-economic characteristics, identified the dominant land-use activities, examined the causes of land-use conflicts, and determined the effects of these conflicts on household socio-economic wellbeing. A multistage sampling procedure was used to select respondents from three settlements located within and around the forest reserve. A total of 127 household heads were selected using a proportionate sampling technique, while primary data were collected through structured questionnaires and participatory rural appraisal methods. Descriptive statistics and Pearson Product-Moment Correlation were used for data analysis. The results showed that respondents had a mean age of 43 ± 7.6 years, indicating an economically active population dependent on land-based livelihoods. Staple crop production (94.0%), fruit marketing (91.9%), and non-timber forest product gathering (78.3%) were the dominant livelihood activities. The major causes of land use conflict included an increase in the number of people using land (Mean = 2.60), concessionaire activities (Mean = 2.51), and boundary disputes (Mean = 2.35). The socio-economic status index declined from 36.0 before conflict to 28.7 after conflict. Correlation analysis showed a significant negative relationship between causes of land-use conflict and socio-economic status after conflict ($r = -0.421$, $p < 0.01$). In contrast, socio-economic status before and after conflict showed a strong positive relationship ($r = 0.684$, $p < 0.01$). The study concluded that land use conflicts significantly reduced household welfare and livelihood sustainability.

Keywords: Land use conflict, socio-economic status, forest dwellers, livelihood outcomes, rural households.

Introduction

Land remains One of the most important natural resources upon which rural livelihoods depend, particularly in developing countries where a large proportion of the population relies directly on land-based activities such as farming, forestry, and the collection of non-timber forest products for survival. In Nigeria, and particularly in Ondo State, forest reserves serve as a major source of livelihood for rural households who depend on forest resources for food, income, fuelwood, and other socio-economic needs. However, increasing population pressure, agricultural expansion, logging, and competing land demands are intensifying land-use conflicts in many forest communities, thereby affecting the socio-economic status and livelihood outcomes of forest dwellers. Recent studies have shown that land remains a critical livelihood asset in rural Nigeria, and any threat to land access often translates directly into livelihood vulnerability and poverty

among rural households (World Bank, 2020). Land-use conflict has been widely recognized as a major challenge affecting rural development, natural resource sustainability, and household welfare in many developing countries. Studies have shown that changes in land use and land cover are primarily driven by agricultural expansion, settlement growth, and resource exploitation, all of which increase competition for limited land resources and often result in conflict among land users. In Nigeria and other parts of Africa, land-use conflicts have been linked to climate change, land scarcity, and weak land governance systems, which have intensified competition among farmers, pastoralists, and forest resource users (FAO, 2020). For instance, recent findings revealed that agricultural expansion remained a dominant driver of land use change in many forest regions of Nigeria, with significant implications for forest-dependent communities and the sustainability of forest ecosystems (FAO, 2017).

Similarly, land-use conflicts have been associated with negative livelihood outcomes, including reduced farm output, income loss, farmer displacement, and increased vulnerability to food insecurity among rural households. Evidence from recent studies in Nigeria indicated that recurring conflicts over land resources significantly reduced household income, agricultural productivity, and asset ownership among rural farmers and pastoralists (World Bank, 2020). In addition, land-related conflicts in Nigeria have contributed to internal displacement, food insecurity, and deterioration in rural welfare, thereby posing serious threats to rural livelihoods and human security (Adisa, 2012). These conflicts often disrupted farming activities, limited access to productive land, and forced households to adopt less productive livelihood strategies. In Ondo State specifically, rural households relied heavily on agriculture and forest resources as their primary means of livelihood, and land remained the most critical asset for production and income generation. However, increasing pressure on land due to population growth, land tenure issues, migrant farmers, and competing land uses has resulted in frequent conflicts among farmers, timber contractors, pastoralists, and government agencies. These conflicts had far-reaching implications for the socio-economic status of forest dwellers, often resulting in reduced access to land, crop destruction, income instability, and diversification of livelihoods into less productive activities. Land-use change and forest resource exploitation also contributed to environmental degradation and declining productivity, further worsening the socio-economic conditions of forest-dependent households (Azeez *et al.,* 2018).

Despite several studies on land use and forest resource management in Nigeria, few empirical studies have specifically examined the effects of land use conflicts on the socio-economic status of forest dwellers in Ondo State, using both descriptive and inferential statistical approaches. Therefore, this study was conducted to examine the socio-economic characteristics and livelihood activities of forest dwellers and to determine the relationship between land use conflicts and the socio-economic status of rural households in the study area.

Methodology

Study Area

The study was conducted in settlements within and around the Oluwa Forest Reserve in Ondo State, Nigeria. The reserve was situated within the state's high forest agroecological zone, characterized by dense tropical rainforest vegetation that supported both timber production and

diverse agricultural activities. Geographically, Oluwa Forest Reserve lies between approximately 6°35′–7°00′ North latitude and 4°30′–5°00′ East longitude, covering parts of Odigbo and Okitipupa Local Government Areas (Ayodele, 2021). The terrain of the reserve was predominantly undulating to gently rolling**,** with lowland rainforest landscapes interspersed with river valleys, seasonal streams, and well-drained sandy loam to lateritic soils suitable for tree crops and food crop cultivation (Madueke *et al*., 2021). The area experienced a humid tropical climate marked by high annual rainfall, dense canopy cover, and relatively high year-round temperatures, conditions that favored forest-based livelihoods and farming activities (Balogun *et al.,* 2020).

Sampling Procedure and Sampling Size

A multistage sampling procedure was used to select respondents for the study. In the first stage, Oluwa Forest Reserve was purposively selected due to the prevalence of land-use conflicts and the high level of livelihood activities among forest dwellers in the reserve. In the second stage, three settlements were selected from Oluwa Forest Reserve. Two settlements were selected from within the forest reserve, while One settlement within a 5km radius was selected from around the forest reserve. The selected settlements in Oluwa Forest Reserve were Makinde, Kangidi, and Onipetesi.

In the third stage, household listing and counting were conducted in the selected settlements using participatory rural appraisal techniques to obtain the study's sampling frame. Thereafter, a proportionate sampling technique was used to select respondents from each settlement. Fifty percent of the total households in each settlement were selected proportionately to the size of each settlement. The household heads constituted the unit of analysis for the study because they were responsible for livelihood decisions and land use activities within the household.

Table 1: Sampling Procedure for Oluwa Forest Reserve

Settlement	**Number of Selected Households**	**Households (50%)**	**Retrieved Questionnaires (n)**	**Percentage (%)**
Makinde (Within Reserve)	114	52	49	38.6
Kangidi (Within Reserve)	26	13	21	16.5
Onipetesi (Around Reserve)	122	61	61	48.0
Total	—	—	**127**	**100**

This table represents the distribution of households sampled from Oluwa Forest Reserve, showing the number of households in each settlement, the number selected using a 50% proportionate strategy, and the actual number of retrieved questionnaires.

Data Collection

Both primary and secondary data were utilized for the study. Primary data were collected using a structured questionnaire administered to the selected respondents. The secondary sources included relevant literature, research journals, and other publications on land-use conflicts in forest zones.

Data Analysis

Data Analysis of the Study

The data collected for the study were analyzed using both descriptive and inferential statistical techniques. Descriptive statistics, such as frequencies and percentages, were used to summarize responses and present patterns in the data. In contrast, inferential statistics, specifically the Pearson Product-Moment Correlation (PPMC), were used to assess the relationship between land-use conflicts and the socio-economic status of rural households in the study area.

Measurement of Variables

The variables used in the study were measured using structured scales adapted to reflect livelihood and conflict conditions within forest communities. Socio-economic status (SES), which served as the dependent variable, was measured using twelve livelihood indicators, including farm output level, household income stability, access to farmland, food security status, ability to meet household needs, ownership of productive assets, savings capacity, investment in farming activities, housing condition, Education expenditure capacity, healthcare access, and overall livelihood satisfaction. Each item was measured on a four-point Likert scale ranging from 1 = Very Low to 4 = High. Composite SES indices were generated for periods before and after land use conflict.

Causes of land use conflict were the independent variable. They were measured using respondents' perceptions of identified drivers, including population pressure, concessionaire activities, boundary disputes, government policy changes, land ownership structure, unauthorized land sales, and land hunger. Responses were rated using a three-point intensity scale, and mean scores were computed to determine the severity ranking of each conflict driver.

Model Specification

To examine the relationship between land use conflict and socio-economic status, the study adopted a correlation-based analytical model expressed functionally as:

SES=f (LUC)

Where:

- SES = Socio-economic status of forest dwellers
- LUC = Causes of land use conflict

The explicit econometric model was specified as:

$$SESi = \beta 0 + \beta 1 LUCi + \epsilon i$$

Where:

- SESi = socio-economic status index of the household
- β0 = constant term
- β1 = coefficient measuring the effect of land use conflict
- LUCi = land use conflict score
- ϵi = error term

The Pearson Product-Moment Correlation (PPMC) was used to determine the strength and direction of relationships among variables.

Result and Discussion

Socio-Economic Characteristics of Respondents

The socio-economic characteristics of respondents revealed important demographic patterns that shaped land-use interactions and livelihood vulnerability among forest dwellers in Oluwa Forest Reserve, as presented in Table 2. The mean age of respondents was 43 ± 7.6 years, with the majority (61.4%) falling between 31 and 50years. This indicated that most respondents were in the economically active age group, suggesting a high dependence on land-based livelihood activities, such as farming and forest resource extraction. The dominance of middle-aged household heads implied strong engagement in productive activities but also increased exposure to land competition and conflict pressures. Similar findings were reported by the World Bank (2020), which observed that economically active rural populations depend heavily on land resources, making them particularly vulnerable to disruptions in land access. Educational attainment showed that 40.9% of respondents possessed secondary Education, while only 17.3% attained tertiary Education. This moderate level of Education suggested limited access to alternative employment opportunities outside agriculture, thereby reinforcing dependence on forest land. Previous studies noted that low educational diversification often constrained livelihood adaptation strategies in forest communities experiencing land conflicts (FAO, 2017). The gender distribution indicated male dominance (78.3%), reflecting traditional land ownership and decision-making systems prevalent in rural Nigeria, where men typically controlled land resources and agricultural decisions. The high proportion of married respondents (84.9%) and households with 5–8 members (51.3%) further suggested significant household responsibilities, increasing pressure on land resources for food and income generation. These findings supported Uzeh et al. (2008), who argued that household population has a significant influence on farming practices, intensification, and increased competition for land. The nearly equal distribution between indigenes (53.5%) and non-indigenes (46.5%) also implied potential tenure-related tensions, as migrant farmers often faced insecure land rights, a factor widely linked to rural land conflicts in Nigeria (Alder Wily, 2017).

Table 2: Socio-Economic Characteristics of Respondents in the Study Area (n = 127)

Variable	Category	Frequency	Percentage (%)
Age (Years)	≤ 30	18	14.2

Variable	Category	Frequency	Percentage (%)
	31 – 40	36	28.3
	41 – 50	42	33.1
	51 – 60	21	16.5
	> 60	10	7.9
	Mean Age = 43 ± 7.6 years	—	—
Educational Status	No formal Education	19	15.0
	Primary Education	34	26.8
	Secondary Education	52	40.9
	Tertiary Education	22	17.3
Sex	Male	99	78.3
	Female	28	21.7
Marital Status	Single	3	2.7
	Married	108	84.9
	Divorced	6	4.8
	Widowed	10	7.7
Indigene Status	Indigene	68	53.5
	Non-indigene	59	46.5
Household Size	1–4 persons	45	35.2
	5–8 persons	65	51.3
	≥ 9 persons	17	13.4

Table 3 shows that staple crop production was the dominant land use activity, practiced by 94.0% of respondents. This confirmed that subsistence and semi-commercial agriculture remained the backbone of rural livelihoods within the forest reserve. Fruit marketing (91.9%) and non-timber forest product (NTFP) gathering (78.3%) also constituted major livelihood activities, demonstrating the multifunctional dependence of households on forest ecosystems. The high involvement in cocoa farming (72.0%) highlighted the importance of plantation agriculture as a major source of income. However, plantation expansion often required long-term land occupation, which potentially intensified competition over land resources. FAO (2017) noted that agricultural commercialization and plantation agriculture were key drivers of land use change and conflict in Nigeria's forest zones. Non-farm land-related activities (64.5%) suggested emerging livelihood diversification strategies, possibly adopted as coping mechanisms against declining agricultural productivity caused by land disputes. Studies have shown that rural households diversify livelihoods when land access becomes uncertain or contested (Loison, 2015). Overall, the findings demonstrated that heavy reliance on land-based activities increased vulnerability to land use conflicts and socio-economic instability.

Table 3: Land Use Activities in the Study Area

Land Use / Existing Land Use Activities	**Percent (%)**	**Frequency (n = 127)**
Staple crop production (cassava, yam, maize, plantain, cocoyam, etc.)	94.0	119
Fruit marketing	91.9	117
Gathering and marketing of Non-Timber Forest Products	78.3	99
Cocoa farming (plantation agriculture)	72.0	91
Non-farm land-related activities	64.5	82

The findings in Table 4 revealed that several structural and socio-economic factors contributed to land-use conflicts in the study area. The increase in the number of people using available land recorded the highest mean score ($\bar{x}$ = 2.60), indicating that population pressure constituted the most significant driver of conflict. This outcome suggested that growing rural populations intensified competition over limited land resources, particularly in forest-fringe communities where agricultural expansion remained the primary livelihood strategy. Similar observations were reported by Boone (2019), who noted that rising demographic pressure in sub-Saharan Africa heightened disputes over land access and tenure rights as households sought to secure productive land for survival. Concessionaire activities ranked second ($\bar{x}$ = 2.51), reflecting tensions between local communities and external actors granted land-use rights by government authorities. The finding implied that commercial exploitation of forest resources often restricted traditional access to farmland and forest products. Alden Wily's (2017) studies demonstrated that concessions allocated without adequate community participation frequently sparked disputes due to perceived exclusion and the loss of customary rights.

Boundary disputes ($\bar{x}$ = 2.35) also emerged as a major cause of conflict. The absence of clearly demarcated land boundaries and overlapping customary claims likely encouraged disagreements among households and neighbouring communities. Research conducted by Fenske (2014) showed that weak land documentation systems in rural Africa increased uncertainty over property rights, thereby escalating interpersonal and communal conflicts. Government policy changes ranked fourth ($\bar{x}$ = 2.28), suggesting that shifts in land administration or forest governance regulations disrupted existing land-use arrangements. Policy reforms that altered access rights or imposed conservation restrictions often generated resistance among rural users whose livelihoods depended on land resources. This aligned with findings by the Food and Agriculture Organization (FAO, 2022), which reported that poorly communicated land reforms frequently triggered disputes when local stakeholders perceived policies as threatening their economic security. The land ownership structure ($\bar{x}$ = 2.25) further contributed to conflicts, indicating that plural tenure systems combining customary and statutory arrangements created ambiguity regarding ownership and authority. According to the United Nations Environment Programme (UNEP, 2023), overlapping governance systems often lead to competing claims over land, particularly when traditional institutions and formal legal frameworks operate simultaneously.

Conversely, unauthorized land sales ($\bar{x}$ = 1.55) and land hunger ($\bar{x}$ = 1.46) recorded relatively low mean scores, suggesting that although these factors existed, they were less prominent drivers of

disputes within the study area. This finding implied that conflicts were driven more by institutional and demographic pressures than by individual speculative activities. Similar conclusions were reached by the World Bank (2024), which emphasized that structural governance challenges, rather than isolated illegal transactions, were the dominant causes of rural land conflicts in developing economies.

Table 4: Causes of Land Use Conflict in the Study Area

Causes of Conflict	Mean Score	Rank
Increase in the number of people using the land	2.60	1st
Concessionaire activities	2.51	2nd
Boundary disputes	2.35	3rd
Government policy changes	2.28	4th
Land ownership structure	2.25	5th
Unauthorized land sales	1.55	Low
Land hunger	1.46	Low

The comparison of socio-economic status (SES) indicators before and after land use conflicts, as presented in Table 5, revealed a consistent decline across all livelihood dimensions. Farm output decreased from a mean score of 3.21 to 2.48, indicating reduced agricultural productivity following conflicts. This decline likely resulted from restricted land access, crop destruction, and disrupted farming cycles. World Bank report (2020) similarly reported that land conflicts significantly reduced farm productivity and household welfare in rural Nigeria. Access to farmland experienced the greatest decline (Mean Difference = −0.94), confirming land accessibility as the most severely affected livelihood asset. Reduced access translated into lower food security (−0.76), weakened income stability (−0.74), and diminished ability to meet household needs (−0.79). These outcomes demonstrated how land conflicts directly undermined rural livelihood sustainability.

Financial resilience indicators also deteriorated substantially, including savings capacity (−0.83) and investment in farming activities (−0.83). The decline suggested that households shifted from accumulation to survival strategies, limiting long-term economic growth. Declining housing conditions, Education expenditure capacity, and healthcare access further reflected broader welfare deterioration. The grand mean SES index declined from 36.0 before conflict to 28.7 after conflict, confirming an overall reduction in socio-economic wellbeing among forest dwellers. This supported the assertion by FAO (2017 that persistent land conflicts contributed to rural poverty, vulnerability, and declining human welfare indicators.

Table 5: Socio-Economic Status (SES) Items of Respondents Before and After Land Use Conflicts in the Study Area (n = 127)

S/N	Socio-Economic Status Indicators	Mean Score Before Conflict	Mean Score After Conflict	Mean Difference	Decision (Effect)
1	Farm output level	3.21	2.48	−0.73	Decreased

S/N	Socio-Economic Status Indicators	Mean Score Before Conflict	Mean Score After Conflict	Mean Difference	Decision (Effect)
2	Household income stability	3.05	2.31	−0.74	Decreased
3	Access to farmland	3.34	2.40	−0.94	Decreased
4	Food security status	3.12	2.36	−0.76	Decreased
5	Ability to meet household needs	3.08	2.29	−0.79	Decreased
6	Ownership of productive assets	2.96	2.41	−0.55	Decreased
7	Savings capacity	2.88	2.05	−0.83	Decreased
8	Investment in farming activities	3.10	2.27	−0.83	Decreased
9	Standard of housing condition	2.85	2.39	−0.46	Decreased
10	Ability to pay children's school expenses	3.18	2.52	−0.66	Decreased
11	Access to healthcare services	2.97	2.33	−0.64	Decreased
12	Overall livelihood satisfaction	3.06	2.22	−0.84	Decreased
Grand Mean (SES Index)		**36.0**	**28.7**	**−7.3**	**SES Declined**

The Pearson Product-Moment Correlation analysis examined the relationship between the causes of land-use conflict and the socio-economic status (SES) of forest dwellers before and after conflict. The results, as presented in Table 6, revealed important insights into how conflict drivers influenced livelihood wellbeing in Oluwa Forest Reserve. The analysis showed a weak negative relationship between causes of land use conflict and socio-economic status before conflict ($r = -0.118$), which was not statistically significant. This indicated that before the emergence or escalation of conflicts, the identified drivers, such as population pressure, concessionaire activities, boundary disputes, and policy changes, had minimal direct influence on household welfare conditions. At that stage, respondents still maintained relatively stable livelihood systems supported by adequate access to farmland and forest resources.

However, a strong, statistically significant negative relationship was observed between causes of land-use conflict and socio-economic status after conflict ($r = -0.421$, $p < 0.01$). This finding implied that as the intensity and frequency of conflict increased, the socio-economic wellbeing of forest dwellers declined considerably. The result confirmed that structural conflict drivers translated into reduced livelihood performance, including lower farm output, unstable income, declining savings capacity, and reduced access to productive land, as earlier reflected in the SES comparison analysis. The findings further showed a strong positive relationship between socio-economic status before and after conflict ($r = 0.684$, $p < 0.01$). This suggested that households with

relatively better welfare conditions before conflicts still retained some level of resilience afterward, although their socio-economic conditions generally deteriorated. The persistence of this relationship indicated that pre-conflict livelihood strength influenced rural households' post-conflict recovery capacity.

Table 6: Pearson Product-Moment Correlation Between Causes of Land Use Conflict and Socio-Economic Status (SES) Before and After Conflict (n = 127)

Variables	Causes of Land Use Conflict	SES Before Conflict	SES After Conflict
Causes of Land Use Conflict	1.000	−0.118	−0.421**
SES Before Conflict	−0.118	1.000	0.684**
SES After Conflict	−0.421**	0.684**	1.000

p < 0.01 (2-tailed)

Conclusion

The study concluded that land use conflicts significantly contributed to the declining socio-economic status of forest dwellers in Oluwa Forest Reserve. The dominance of land-based livelihoods left households vulnerable when access to land became contested. Population pressure, concessionaire operations, and boundary disputes emerged as the principal drivers of conflicts within the study area. Empirical evidence showed that socio-economic wellbeing deteriorated considerably after conflicts, as reflected in reduced farm output, declining income stability, weakened savings capacity, and limited access to farmland. The significant negative correlation between conflict causes and post-conflict socio-economic status confirmed that increased land disputes directly translated into a decline in livelihoods. Although households with stronger pre-conflict welfare conditions demonstrated some resilience, overall socio-economic outcomes worsened across the communities. The findings, therefore, established land governance challenges as a critical determinant of rural poverty and livelihood instability in forest-dependent environments.

Recommendations

Based on the findings, the study recommended that government agencies strengthen land tenure security by implementing clear land demarcation and transparent land administration systems in forest reserve communities. Community-based conflict resolution committees involving traditional leaders, government institutions, and land users should be established to promote participatory dispute management. Policies regulating concessionaire activities should incorporate livelihood protection measures to ensure that forest-dependent households retain equitable access to productive land. Furthermore, livelihood diversification programmes and agricultural support services should be introduced to reduce excessive dependence on forest land resources. Finally, continuous stakeholder engagement and awareness programmes were necessary to promote sustainable land use planning and prevent recurring conflicts in forest reserve areas.

References

Adisa, R. S. (2012). Land use conflict between farmers and herders – Implications for agricultural and rural development in Nigeria. *Rural Development–Contemporary Issues and Practices*, 99–108.

Azeez, I. O., Oladele, O. I., & Adekunle, V. A. J. (2018). Forest resource use and livelihood strategies among rural households in Nigeria. *Journal of Sustainable Forestry*, 37(6), 601–615. https://doi.org/10.1080/10549811.2018.1471856

Ayodele, I. A. (2021). Forest reserve management and rural livelihood systems in southwestern Nigeria. *Nigerian Journal of Forestry*, 51(1), 45–56.

Balogun, A. L., Adewale, B. A., & Adesina, F. A. (2020). Climate variability and its effects on forest ecosystems in southern Nigeria. *Environmental Monitoring and Assessment*, 192(3), 1–12. https://doi.org/10.1007/s10661-020-8150-2

Boone, C. (2019). *Property and political order in Africa: Land rights and the structure of politics*. Cambridge University Press.

Fenske, J. (2014). Land tenure and investment incentives: Evidence from West Africa. *Journal of Development Economics*, 109, 138–153. https://doi.org/10.1016/j.jdeveco.2014.03.001

Food and Agriculture Organization of the United Nations. (2017). *The state of food and agriculture: Leveraging food systems for inclusive rural transformation*. FAO.

Food and Agriculture Organization of the United Nations. (2020). *Land tenure and rural development in Africa*. FAO.

Food and Agriculture Organization of the United Nations. (2022). *Guidelines on the responsible governance of tenure of land, fisheries and forests*. FAO.

Loison, S. A. (2015). Rural livelihood diversification in sub-Saharan Africa: A literature review. *Journal of Development Studies*, 51(9), 1125–1138. https://doi.org/10.1080/00220388.2015.1046445

Madueke, M. C., Oke, D. O., & Adekunle, V. A. J. (2021). Land use dynamics and forest cover change in southwestern Nigeria. *Environmental Management*, 67(2), 345–356.

Uzeh, R. E., Oboh, V. U., & Ogidan, I. O. (2008). Determinants of farm size and productivity among rural farmers in Nigeria. *Journal of Agricultural Extension*, 12(2), 45–52.

Liz Alden Wily (2017). *Customary tenure: A key to enabling sustainable development*. Land Tenure Journal, 1, 1–23.

United Nations Environment Programme. (2023). *Global environment outlook: Land and resource governance report*. UNEP.

World Bank. (2020). *Land governance assessment framework: Identifying and monitoring good practice in the land sector*. World Bank Publications.

AGROFORESTRY: A TOOL FOR ENHANCING SMALLHOLDER FARMERS IN ODEDA LOCAL GOVERNMENT AREA, OGUN STATE, NIGERIA

[1]Ugege B.H., [2]Kolade,. R.I,. [1]Kareem A.T ., [1]Marizu J. T and [1]Iselobhor, F.A.

[1]Federal College of Forestry, Ibadan, Oyo State, Nigeria
[2]Forestry Research Institute of Nigeria
Corresponding Email: bukolasfavour@yahoo.com

Abstract

This study investigates the impact of agroforestry on enhancing the income of smallholder farmers in Odeda Local Government Area, Ogun State, Nigeria. Agroforestry, integrating trees and shrubs with crops and/or livestock, is a sustainable land-use system with significant economic and environmental potential. Data were collected from 80 purposively selected smallholder farmers using structured interviews and questionnaires focusing on farm size, agroforestry practices, and income levels. Descriptive statistics and budgetary analysis, including a benefit-cost ratio (BCR) calculated at a 15% discount rate over ten years, were employed to analyze the data. Findings indicate that most farmers operated on 1–2 hectares and predominantly practiced taungya agroforestry, with 86% having over 5 years of experience. The total income from agroforestry was ₦148,984,967.90, against a total cost of ₦123,015,035.00, yielding a BCR of 1.21, demonstrating a positive financial impact. However, advanced agroforestry systems such as alley cropping, silvopasture, and forest farming were absent, suggesting untapped potential for further income enhancement. Innovations like climate-smart agroforestry and improved tree genetics could further boost profitability and sustainability. The study recommends increased awareness, better land access, and investment in research to optimize agroforestry's socio-economic benefits for smallholder farmers.

Keywords: Agroforestry Systems, Smallholder Farmers, Income Enhancement, Sustainability

Introduction

Agroforestry has emerged as a sustainable land-use system in response to increasing anthropogenic pressures and environmental degradation (FAO,2020). It integrates trees and shrubs with crops and/or livestock on the same land unit, offering a holistic approach to land management. Globally, nearly half of agricultural land has at least 10% tree cover, highlighting the widespread adoption of agroforestry and its critical role in rural livelihoods (FAO, 2020). The agroforestry system contributes to farmers' resilience by diversifying income sources and enabling year-round harvesting of multiple products. Social benefits include the provision of fuelwood, medicinal plants, and culturally significant species, while economic benefits encompass income generation, food production, fodder supply, and raw materials for cottage industries. Environmentally, agroforestry helps combat erosion, improve soil fertility, and mitigate the effects of climate change (Adeola & Adetumi, 2015).

Despite these known advantages, empirical data on the income impact of agroforestry, especially in specific local contexts, remain limited. This may be because measuring income in rural settings is complex due to informal economies, multiple income streams, and seasonal variability.

Population pressure and land scarcity further constrain adoption (Sheikh et al., 2021). Nevertheless, agroforestry has the potential to enhance food security, increase household income, and contribute to environmental sustainability (FAO, 2011). This study, therefore, investigates the impact of agroforestry on the income of smallholder farmers in Odeda Local Government Area, Ogun State, Nigeria, aiming to provide evidence-based strategies to optimize its socio-economic benefits.

Methodology

Study Area

The study was conducted in Odeda Local Government Area (LGA) of Ogun State, located in southwestern Nigeria. The area lies between latitude 7°13′N and 7°30′N and longitude 3°11′E and 3°46′E (Figure 1). Odeda LGA covers approximately 1,263 km² and has a projected population of about 186,300 people. The climate of the area is characterized by a tropical wet and dry climate with two distinct seasons: the rainy season (April–October) and the dry season (November–March). Agriculture is the dominant occupation of the inhabitants, with most farmers engaged in smallholder farming systems involving crops such as cassava, maize, vegetables, and tree crops.(*Chiaka et al,2022)* The ecological conditions of the area are suitable for agroforestry practices, as farmers traditionally integrate trees with crops through systems such as taungya farming, boundary planting, and home gardens. These farming systems provide both ecological and economic benefits to rural households.

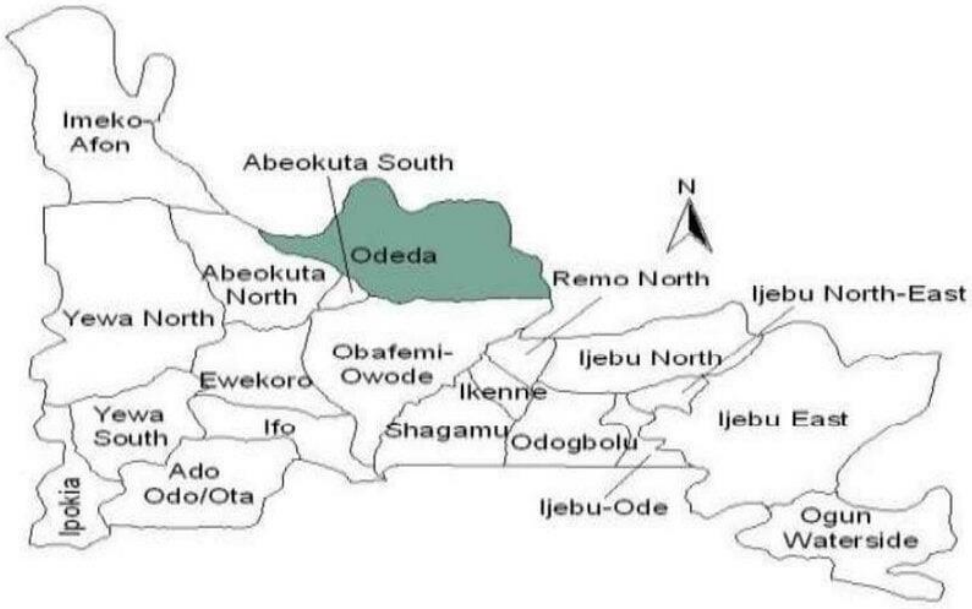


Figure 1: Map of Odeda Local Government Area, Ogun State, Nigeria

Research Design

The study adopted a cross-sectional survey design to collect information from farmers practicing agroforestry in the study area. This design allowed the researchers to obtain relevant socio-economic and farm-level data from respondents at a single point in time.

Sampling Procedure

A multistage sampling procedure was used in selecting respondents for the study. In the first stage, Odeda Local Government Area was purposively selected due to its significant agricultural activities and the presence of agroforestry practices among smallholder farmers. In the second stage, two communities, Ilugun and Olosan, were selected based on their prominence in farming activities and accessibility. In the final stage, 80 smallholder farmers practicing agroforestry were selected for the study.

Of the 80 questionnaires administered, 25% were distributed in Ilugun and 75% in Olosan. The respondents were selected based on their involvement in agroforestry practices and willingness to participate in the study.

Method of Data Collection

Both primary and secondary data were used in this study. Primary data were collected through structured questionnaires and interview schedules administered directly to the selected farmers. The questionnaire was designed to obtain detailed information on respondents' socio-economic characteristics, farm size, types of agroforestry practices adopted, farming experience, production costs, and income from agroforestry activities.

Secondary data were obtained from the relevant literature, including journal articles, government reports, textbooks, and conference proceedings, on agroforestry practices and smallholder farming systems.

Method of Data Analysis

The data collected were analyzed using descriptive statistics and budgetary analytical techniques.

Descriptive statistics, including frequency distributions, percentages, and mean values, were used to describe the socio-economic characteristics of respondents, farm sizes, and the agroforestry practices adopted by farmers.

Budgetary analysis was used to evaluate the profitability of agroforestry practices among farmers in the study area. The analysis involved estimating the present value of benefits and costs over 10 years at a 15% discount rate. The discount rate was adopted to reflect the opportunity cost of capital in agricultural investments.

The discount factor was calculated as follows.

formula:

$$Discount\ Factor = \frac{1}{(1+r)\text{^}n}$$

It is derived from the theory of **Time Value of Money**,

Where:

r = discount rate (15%)

n = number of years

The benefit–cost ratio (BCR) was calculated to determine the profitability of agroforestry investments using the following expression: As reported by Boardman et al. (2018)

BCR = Present Value of Benefits / Present Value of Costs

Where:

BCR > 1 indicates that the investment is profitable

BCR = 1 indicates break-even

BCR < 1 indicates that the investment is not profitable

Econometric Model

To further examine the factors influencing farmers' income from agroforestry practices, a multiple regression model was specified. The regression model was used to estimate the relationship between farmers' income and selected socio-economic characteristics.

The functional form of the model is expressed as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \varepsilon$$

Where:

Y = Annual income from agroforestry (₦)

X1 = Age of farmer (years)

X2 = Household size (number of persons)

X3 = Level of Education (years of schooling)

X4 = Farm size (hectares)

X5 = Farming experience (years)

β0 = Constant term

β1–β5 = Regression coefficients

ε = Error term

The model was estimated using Ordinary Least Squares (OLS).

Result and Discussion

Socio-economic Characteristics of Agroforestry Farmers

The socio-economic characteristics of farmers engaged in agroforestry in Odeda Local Government Area, Ogun State, are presented in Table 1. These variables provide important insight into how demographic and social factors may influence agricultural behavior and the adoption of sustainable practices. The results show that 53.75% of respondents were male and 46.25% were female, indicating a slight male dominance in agroforestry participation in the area. This observation aligns with the findings of Anthony et al. (2021), who reported that farming activities in rural Nigeria are often male-dominated due to the physically demanding nature of farm operations. Cultural and traditional roles may also limit female participation, particularly in land-intensive ventures like agroforestry. The average Age of the respondents was 48 years, with about 61% under 50, suggesting that a majority are still in their economically active years. This demographic structure is favorable for agricultural productivity, as younger and middle-aged farmers are generally more receptive to innovation and sustainable practices. It also aligns with Umunna et al. (2018), who emphasized that a younger farming population is essential to ensuring food security by enhancing labor availability and fostering openness to training.

Regarding marital status, 82.50% of respondents were married. This implies a high level of social responsibility and household stability, which can influence decision-making in farm investment and long-term land management. It further suggests that agroforestry may serve as a vital livelihood strategy supporting household needs. Regarding educational attainment, the table shows that 68.75% of respondents had no more than secondary Education. While basic Education is beneficial for interpreting extension advice and adopting innovations, the relatively low level of tertiary Education may limit advanced understanding of complex agroforestry practices. However, the fact that most respondents have at least secondary Education is encouraging, as it can facilitate participation in training and extension programs, as highlighted by Yusuf et al. (2015). Together, these socio-economic indicators reflect a relatively active, moderately educated, and experienced farming population.

Table 1. Socio-characteristics of the Respondents

Variable	Frequency	Percentage	Mean
GENDER OF RESPONDENTS			
SEX			
Male	43	53.75	
Female	37	46.25	
TOTAL	**80**	**100**	
AGE OF RESPONDENTS			
Less than or equal to 40	17	21.25	
41-50	32	40.00	
51-60	21	26.25	
61-70	9	11.25	
Above 70	18	1.25	
TOTAL	**80**	**100**	
Mean			**48.45**
MARITAL STATUS OF RESPONDENTS			
Single	2	2.50	
Married	66	82.5	
Separated	2	2.50	
Divorced	2	2.50	
Widowed	8	10.00	
Total			
Mean	**80**	**100.00**	

HOUSEHOLD SIZE OF RESPONDENTS			
1-5	71	88.75	
6-10	9	11.25	
Total	**80**	**100**	
Mean			**3.86**
EDUCATIONAL QUALIFICATION OF RESPONDENTS			
No Formal Education	11	13.75	
Primary Education	18	22.50	
Secondary Education	37	46.25	
Tertiary Education	14	17.50	
Total	**80**	**100**	
MAIN OCCUPATION OF RESPONDENTS			
Farming	36	43.75	
Civil Service	25	31.25	
Artisanship	3	3.75	
Total	**80**	**100**	

Field survey 2024

The pie chart (Figure 2) illustrates the distribution of respondents by farm size within the study area. Farm size is a critical factor influencing the scale of agricultural production, resource use efficiency, and the potential for agroforestry adoption. The chart reveals that the majority of farmers (71%) operate on farm sizes ranging between 1 and 2 hectares, indicating a predominance of smallholder farming in the area. This finding is consistent with the structure of Nigeria's agricultural sector, which is predominantly small-scale farming, as noted by the FAO (2018). Smallholders often face limitations in mechanization, capital investment, and access to formal markets, which can affect their capacity to scale up agroforestry practices. A smaller proportion, 26%, cultivate between 3 and 4 hectares, representing medium-scale farmers. These individuals may have greater access to inputs and extension services and could serve as early adopters and influencers of sustainable practices, such as agroforestry.

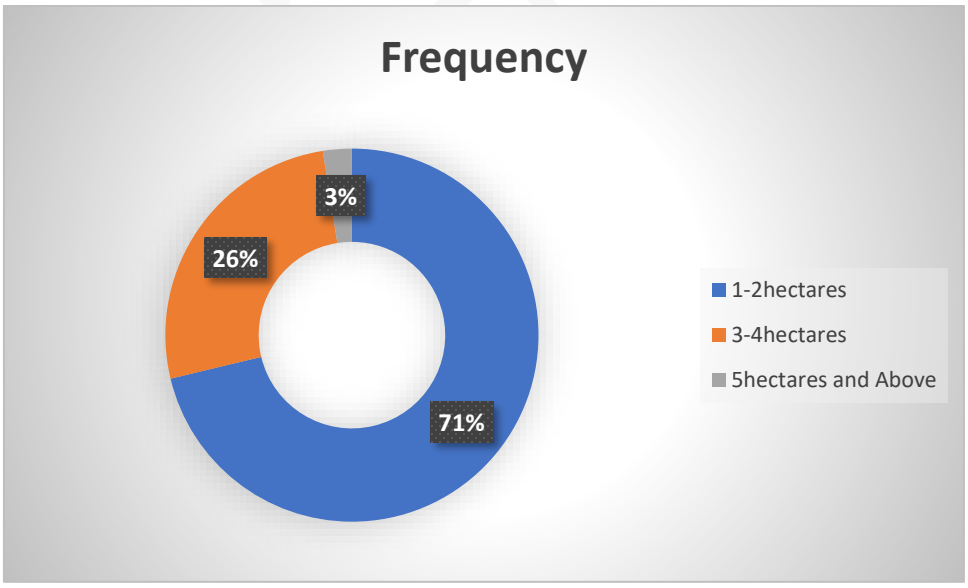


Figure 2: Farm Size of Respondents

Types of Agroforestry Practices Adopted by Respondents

The agroforestry practices adopted by farmers in the study area (Table 2) included a variety of approaches to integrating trees, crops, and livestock into farming systems. Understanding the distribution of these practices is essential for tailoring extension and policy efforts that promote sustainable land use. The most widely practiced form of agroforestry was Taungya, adopted by 33.75% of respondents. Taungya involves integrating crops with forest trees. Its popularity may be attributed to its dual benefits of producing food and improving climatic conditions, while also enhancing soil structure and reducing erosion. Multipurpose trees and shrubs were the second most common practice, adopted by 28.75% of respondents. These species are valued for their multiple uses—such as fodder, firewood, fruits, and improved soil fertility. The relatively high adoption rate underscores the recognition of trees as integral to household livelihood strategies, supporting findings by Babalola et al. (2022) that multipurpose trees enhance both food security and ecological resilience. Boundary planting, reported by 25% of respondents, involves planting trees or shrubs along farm boundaries. This practice provides protective functions (such as serving as windbreaks and demarcating farm boundaries) and may also offer additional products, such as fruits or poles. Its moderate adoption rate reflects the dual utility and space-efficiency of the practice, especially for smallholder farmers. Home gardens were practiced by 10% of respondents. These are typically small-scale, intensively managed plots near dwellings that combine trees, crops, and sometimes animals. The least adopted practice was windbreaks, with only 2.5% of respondents using this method. This low uptake may reflect limited awareness or the perception that wind damage is not a significant threat in the study area. However, windbreaks offer long-term benefits in improving microclimates, protecting crops, and reducing evapotranspiration, which may need to be emphasized in future extension efforts. Overall, the observed diversity of agroforestry practices indicates a growing awareness among farmers of sustainable land-use strategies. However, the dominance of Taungya and multipurpose species suggests that productivity and utility are key drivers of adoption. Promotion strategies should therefore focus on scaling up high-impact practices while raising awareness of the long-term ecological benefits of less widely adopted systems, such as windbreaks.

Table 2. Type of Agroforestry Practices

Agroforestry	Frequency	Percentage %
Home gardens	8	10
Taungya	27	33.75
Boundary Planting	20	25
Multipurpose trees/shrubs	23	28.75
Windbreaks	2	2.50
Total	**80**	**100**

Field Survey 2024

The number of years the respondents have been engaged in agroforestry practices is presented in Figure 3. From the figure, it can be seen that the majority (86%) of respondents had no more than

5 years' experience in agroforestry. In comparison, only 4% had more than 10 years' experience in agroforestry practices in the study area. This suggests that most participants are younger and less experienced in agroforestry. The small proportion (4%) of respondents with more than 10 years of experience suggests that long-term expertise in agroforestry is limited**,** which may affect the depth of knowledge and skills, and possibly the productivity or efficiency of agroforestry practices in the area.

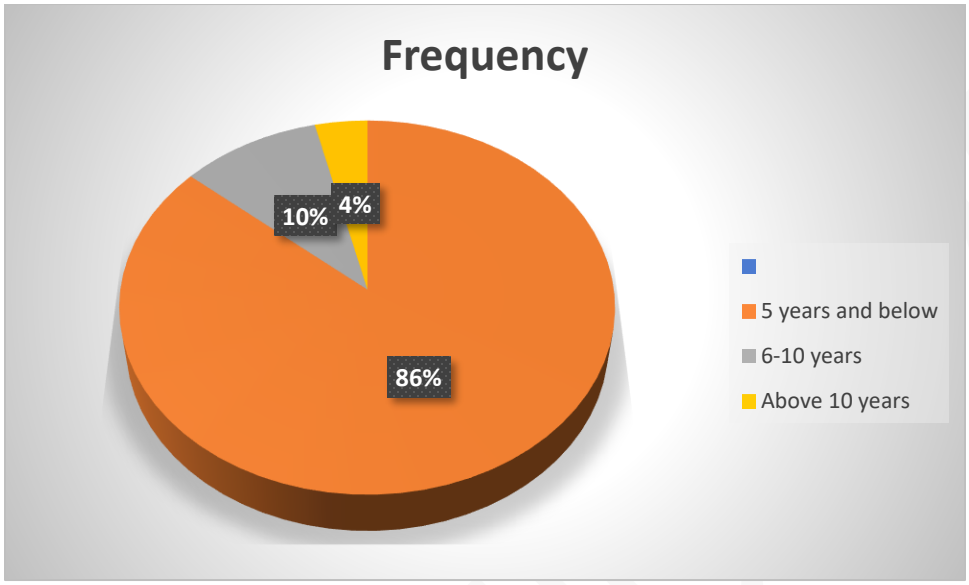


Figure 3: Agroforestry Practice Experience

Cost and Returns Analysis

The study used the Benefit-Cost Ratio (BCR) approach to determine the costs and benefits accruing to agroforestry farmers in the study area over a period of 10 years. A 15% discount rate was used to compute the discount factor, based on the Central Bank of Nigeria's current official interest rate. At various points in recent years, the CBN maintained or adjusted the MPR around 15–27%, providing a basis for selecting a 15% discount rate in investment appraisals. The results are summarized in Table 3.

Table 3: Cost and Returns to Agroforestry Farmers ₦

YRS	DISCOUNT FACTORS(15%)	TOTAL BENEFIT	PRESENT VALUE OF BENEFIT	TOTAL COST	PRESENT VALUE OF **COST**
1	0.870	36770400	31,990,248	17,415,000	15,151,050
2	0.756	18730750	14,160,447	9775000	7,389,900
3	0.658	34,458,050	22,673,396.90	16250000	10,692,500
4	0.572	20910000	11,960,520	10815000	6,186,180
5	0.432	38000000	18,886,000	17580000	8,737,260
6	0.432	22370000	9,663,840	12860000	5,555,520

7	0.376	35225000	13,244,600	16615000	6,247,240
8	0.327	22470000	7,347,690	12830000	4,195,410
9	0.284	36755000	10,438,420	16825000	4,778,300
10	0.247	34898000	8,619,806	16525000	4,081675
TOTAL			148,984,967.90		123,015,035

Field survey 2024

The results show a cumulative Present Value of Benefits (PVB) of ₦148,984,968 and a Present Value of Costs (PVC) of ₦123,015,035 over the 10 years. From these values, two key economic indicators were derived:

Net Present Value (NPV) $NPV = PVB - PVC$

= ₦148,984,968 − ₦123,015,035 = ₦25,969,933

The positive NPV indicates that agroforestry is a profitable investment over the 10-year horizon.

Benefit-Cost Ratio (BCR):

BCR = 148,984,967.90 / 123,015,035 = 1.21

A BCR greater than 1.0 indicates that the benefits of agroforestry exceed its costs, making it an economically efficient venture. The year-by-year analysis revealed that Years 1, 3, 5, and 7 recorded higher total benefits, likely associated with peak yields or harvesting periods of economically valuable tree and crop components. Although costs in these years were also relatively high, the net benefits remained favorable. The declining trend in the present values over time reflects the time value of money, reinforcing the importance of early returns in long-term agroforestry investments. The findings support integrating agroforestry practices as a sustainable land-use and income-generating strategy, particularly in rural areas. The dual benefits of food production and ecological services (e.g., improved soil structure and reduced erosion), coupled with economic profitability, highlight agroforestry as a viable pathway to both livelihood improvement and environmental conservation (Manono & Mwami, 2026).

Constraints Faced by Agroforestry Respondents

The major constraints encountered by agroforestry farmers in the study area. The responses were ranked by frequency and percentage of mentions among respondents.

Table 4: Constraints Faced by Respondents

Constraint	Frequency	Percentage (%)	Rank
Long gestation period of trees	21	26.25	1st
Illegal felling of trees	20	25.00	2nd
Lack of planting materials	15	18.75	3rd
Competition between arable crops and trees	14	17.50	4th

Constraint	Frequency	Percentage (%)	Rank
Inadequate land for tree planting	10	12.50	5th

Field survey 2024

The results reveal that the long gestation period of trees was the most cited constraint by respondents, accounting for 26.25% of the responses. This highlights farmers' reluctance to adopt or expand agroforestry practices due to the delayed economic returns from tree crops. Many farmers, particularly those dependent on short-term income, may be discouraged by the years it takes for trees to become productive or harvestable. This aligns with Youp et al. (2025), who stated that many farmers focus on short-term income to cover immediate needs and lack the resources to invest in tree seedlings. The illegal felling of trees was identified as the second most pressing issue (25.00%). This suggests weak enforcement of forest regulations and insecurity over tree tenure. When farmers fear that their trees may be harvested unlawfully, they may be less motivated to invest in long-term agroforestry practices (Amare et al., 2019). The lack of planting materials (18.75%) ranked third, indicating that the availability of quality seedlings or tree species is a significant barrier. This challenge could hinder the diversification and sustainability of agroforestry systems, especially if farmers lack access to improved or fast-growing varieties. Competition between arable crops and trees was mentioned by 17.5% of respondents. This indicates a concern about spatial and resource competition, such as sunlight, nutrients, or water, which may negatively impact crop yields, particularly in the early stages of tree growth when canopy management is not yet effective. Finally, inadequate land for tree planting ranked lowest at 12.5%, although it remains a noteworthy issue. Land scarcity could stem from small farm sizes, competing land uses, or land tenure constraints. It may also reflect prioritization of short-term arable farming over long-term forestry investments, especially in densely populated rural areas.

Conclusion and Recommendations

The study demonstrates that agroforestry is a financially viable and environmentally beneficial land-use system for smallholder farmers in Odeda Local Government Area, Ogun State, Nigeria. The benefit-cost ratio of 1.21 confirms its profitability. The most commonly practiced system was the taungya method. To enhance agroforestry adoption and maximize its benefits, the study recommends a multifaceted approach. This includes promoting awareness through targeted campaigns and extension services to educate farmers about agroforestry methods and their advantages, securing land tenure by providing legal and institutional support to ensure long-term land access for smallholder farmers, and investing in research and innovation to develop improved tree species and context-specific agroforestry models. Additionally, adopting climate-resilient practices will support adaptation to climate change, while strengthening partnerships among government agencies, NGOs, researchers, and farmer groups will provide essential technical and material support. Finally, offering incentives such as subsidies, tax relief, and financial programs will encourage farmers to embrace agroforestry practices.

References

Adeola, R.G., & Adetunbi, S.I. (2015). Farmers' Perception of Sustainable Agriculture in Southwestern Nigeria: Implications for Rural Economy. *International Journal of Applied*

Agricultural and Apicultural Research, 11(1&2), 86-92. https://www.ajol.info/index.php/ijaaar/article/view/141579

Amare, D., Wondie, M., Mekuria, W. & Darr, D. (2019). Agroforestry of Smallholder Farmers in Ethiopia: Practices and Benefits. *Small-scale Forestry* **18**, 39–56 (2019). https://doi.org/10.1007/s11842-018-9405-6

Anthony, L., Alabi, O.O., Ebukiba, S.E., and Gamba, V. (2021). Economic Determinants of Rice Marketing Decisions among Smallholder Rural Farming Households, Federal Capital Territory, Nigeria. *International Journal of Agriculture, Forestry and Life Sciences*, 5(1), 29-44. https://dergipark.org.tr/en/pub/ijafls/issue/60445/845040

Babalola, F.D., Yetunde, O.R., & Paxie, W.C. (2022). Towards the Transformation of Agricultural Landscapes: Determination of Agroforestry Tree Species Producing Beneficial Ecosystem Services to Local Farmers in Nigeria. *XV World Forestry Congress*.

Chiaka, J. C., Zhen, L., Yunfeng, H., Xiao, Y., Muhirwa, F., & Lang, T. (2022). *Smallholder farmers' contribution to food production in Nigeria*. Frontiers in Nutrition, 9, 916678.https://doi.org/10.3389/fnut.2022.916678

FAO. (2011). *Making Integrated Food-Energy Systems Work for People and Climate: An Overview*. FAO Environment and Natural Resource Management Working Paper 45. Written by A. Bogdanski, O. Dubois, C. Jamieson, & R. Krell. Rome.

FAO. (2018). *The State of Food and Agriculture 2018: Migration, Agriculture and Rural Development*. Food and Agriculture Organization of the United Nations, Rome.

FAO (2020). *Agroforestry*. Rome: Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/agroforestry/about-agroforestry/faqs/en/

Manono, B. O., & Mwami, B. (2026). Agroforestry and soil health: A review of impacts and potential for sustainable agriculture. Earth, 7(1), 31.

Sheikh, R., Islam, M.A., Sharmin, A., Biswas, R., & Kumar, J. (2021). Sustainable Agroforestry Practice in Jessore District of Bangladesh. *European Journal of Agriculture and Food Sciences*, 3(1), 1-10. https://doi.org/10.24018/ejfood.2021.3.1.150

Umunna M.O, Ibrahim, A.O., and Adebayo O.O. (2018). Youth Participation in Agriculture and its implications for food security in Nigeria. Nigerian Journal of Agricultural Extension, 19(2) 45-52

Youp, D., Ubacht, J., van Andel, E., & Keledorme, L.A. (2025). Exploring the Transition to Agroforestry for Smallholder Farmers: A Feasibility Study for the Ashanti Region of Ghana. *Frontiers in Sustainable Food Systems*, January 2025. https://doi.org/10.3389/fsufs.2024.1493753

Yusuf, O,.Omonona,B.T and salman K.K(2015); Determinants of farmers participation in Agricultural extension training programmes in Nigeria. Journal of Agricultural Extension 19(2),45-56.

Zomer, R.J., Neufeldt, H., Xu, J., Ahrends, A., Bossio, D., Trabucco, A., van Noordwijk, M., & Wang, M. (2016). Global Tree Cover and Biomass Carbon on Agricultural Land: The Contribution of Agroforestry to Global and National Carbon Budgets. *Scientific Reports*, 6, 29987. https://doi.org/10.1038/srep29987

ISTF-NIG 2026

SUB-THEME 2:
LAND USE AND LAND COVER CHANGE: IMPACTS ON FOREST LANDSCAPE DEGRADATION

CHANGING LANDSCAPES, CHANGING FORESTS: EVIDENCE OF LAND USE DYNAMICS AND FOREST DEGRADATION IN SELECTED NIGERIAN FOREST LANDSCAPES

Ofordu, C.S.

Meteorology Section, Environmental Modeling and Biometrics Department, Forestry Research Institute of Nigeria, Jericho, Ibadan, Nigeria
Correspododing Email: csosudiala@yahoo.co.uk; +2348034087545

Abstract

Land use and land cover change (LULCC) remains a primary driver of forest landscape degradation in selected forested regions of Nigeria, with significant consequences for biodiversity, ecosystem services, and sustainable development. Rapid population growth, agricultural expansion, urbanization, infrastructure development, and unsustainable resource extraction have transformed forested landscapes across these ecological zones. This study synthesizes evidence from existing literature, national forest assessments, and selected case studies to examine patterns and trends of LULCC and their effects on forest degradation. Findings indicate that conversion of forest land to agriculture and built-up areas has resulted in habitat fragmentation, declining forest cover, soil degradation, and reduced forest productivity. Socio-economic drivers, coupled with weak institutional and policy frameworks, exacerbate these impacts. Comparisons with developed countries reveal similar pressures from urbanization and infrastructure expansion, though effective governance and policy enforcement often mitigate forest loss in these contexts. The study underscores the need for integrated land-use planning, strengthened forest governance, and adoption of sustainable landscape management strategies that balance economic development with environmental conservation. These insights provide actionable guidance for mitigating forest degradation and promoting resilient, sustainable forest landscapes in these selected regions.

Keywords: Degradation; forests, landscape; land cover dynamics; land use change; sustainable development

Introduction

Forest landscapes are living systems. They supply wood, store carbon, support wildlife, regulate water and weather, and provide livelihoods for millions. However, globally, forests are changing rapidly because humans alter the land beneath them. This change, known as land use and land cover change (LULCC), is a primary driver of forest degradation, affecting ecosystem health and the services forests provide. These pressures occur in both countries with strong environmental laws and those still developing their governance frameworks.

In Nigeria's forested regions, pressures are intense. Satellite data and GIS show that dense forest cover is shrinking, fragmenting, and being replaced by farmland, bare land, and built-up areas as communities expand and economic activities intensify. For instance, in parts of Taraba State, forest cover declined by more than 30% between 2006 and 2018, while in Oba Hills Forest Reserve, Osun State, forest cover fell by nearly 43% over 36 years (Ologunde *et al*., 2025). These trends reflect how land use decisions reshape landscapes over decades. Similar patterns are observed in

other key forested regions across the country, driven largely by agricultural expansion and resource extraction. These regional patterns mirror broader global trends. For instance, in Europe and North America, land use has also transformed forest landscapes, though dominant pressures differ. Approximately 80% of European land has been shaped by agriculture, infrastructure, and settlement, and land conversion continues to push into green semi-natural areas. Intensive land use in these regions contributes to declines in vegetation productivity, lower biomass accumulation, and threats to ecosystem services such as biodiversity maintenance and climate regulation. Even with protective frameworks and afforestation incentives, urban expansion and infrastructure development fragment habitats and alter landscape function, indicating that economic growth often outpaces conservation measures.

Comparing Nigerian forested regions with developed countries highlights both similarities and differences in how LULCC drives forest change. In Nigeria, rural and frontier agriculture remains a major driver and weak enforcement of land regulations, coupled with high dependence on forest resources, exacerbates degradation. In contrast, urbanization and agricultural intensity dominate land transformation in much of Europe, with reforestation programs sometimes increasing forest cover while semi-natural habitats may decline. Despite these differences, two broad patterns emerge. First, human demand for land, whether for crops, housing, or infrastructure, consistently reshapes forests, regardless of a country's development status. Second, the effectiveness of governance, institutions, and land-use planning strongly influences whether these pressures lead to sustainable outcomes or to degradation. In Nigeria, policy frameworks often struggle to keep pace with land demands, while in developed contexts, governance mechanisms can mitigate loss, even as pressures persist from urban and economic expansion.

Understanding forest degradation through LULCC requires placing local evidence from Nigeria's forested regions within a wider global context. This comparative perspective clarifies the scale and direction of change while highlighting universal challenges, such as balancing development needs with ecosystem sustainability. Drawing from local case studies and international evidence, this study examines the patterns, drivers, and consequences of LULCC in selected Nigerian forest landscapes. It explores lessons to strengthen policy and management responses. The study adopts a conceptual framework linking human drivers, ecological pressures, and potential management strategies.

Conceptual Framework / Theoretical Background

Forests do not exist in isolation; they are part of complex landscapes shaped by natural processes and human actions. When people change the land for farming, roads, or settlements, forests respond- shrinking, fragmenting, or losing the ability to provide critical ecosystem services like clean water, carbon storage, and wildlife habitat. Understanding these changes requires a framework that links drivers, pressures, state of the forest, impacts, and responses, commonly referred to as the DPSIR framework (Driver-Pressure-State-Impact-Response). *Drivers* are the underlying causes of land-use change. In Nigeria's forested regions, population growth, economic development, and the need for food and housing drive farmers and developers to convert forest land (Alegbeleye *et al*., 2024). Globally, developed countries face similar pressures, though urbanization and infrastructure development often outweigh rural agricultural drivers (European Environment Agency, 2024).

Pressures are the direct human activities that alter the land. Examples include deforestation for crops, illegal logging, mining, and urban expansion. Shifting cultivation, smallholder farm expansion, and unregulated logging create immediate pressures (Ologunde *et al*., 2025). In Europe, conversion of green spaces and forested land to urban and industrial uses exerts similar pressures, but is often managed through zoning and planning regulations (EEA, 2022). *State* refers to the condition of the forest itself, measured by forest cover, fragmentation, species richness, soil health, and carbon stocks. In some Nigerian reserves, forest cover has declined sharply over the past decades, with remaining patches highly fragmented (Adeyemi & Ayinde, 2022). In contrast, forests in developed countries may retain higher overall cover but often lose ecological complexity due to urban and agricultural pressures.

Impacts are the consequences of these changes, including biodiversity loss, soil degradation, reduced forest productivity, and diminished ecosystem services. In Nigeria's forested regions, soil erosion and declining productivity threaten local livelihoods (Ikyaagba *et al*., 2023). Developed countries also experience impacts such as declining habitat connectivity and localized loss of ecosystem services, despite stronger environmental regulations. *Responses* are the actions taken to mitigate degradation. In Nigeria, policy interventions and community-based forest management are increasing but remain under-resourced. Lessons from Europe demonstrate that integrated land-use planning, zoning enforcement, and restoration programs can maintain forest cover and ecosystem services even under economic pressures (EEA, 2024). Building on this framework, the study employs a desk-based approach that integrates literature review, national assessments, and selected case studies to examine patterns of forest degradation without requiring new field surveys.



Figure 1: Conceptual framework showing how land use dynamics drive forest degradation and potential management responses in Nigeria.

Methods / Approach

This study adopts a desk-based evidence synthesis approach to examine how land-use and land-cover change contribute to forest degradation in selected forested regions of Nigeria. Rather than relying on new field surveys, the methodology integrates information from published scientific literature, national forest assessment reports, remote sensing datasets, and targeted case studies to develop a comprehensive understanding of forest landscape dynamics. A structured review of peer-reviewed journal articles, government reports, and publications from international organizations was conducted to document trends in forest cover change, land use dynamics, and associated ecological and socio-economic implications. Particular attention was given to studies conducted within Nigeria's major ecological zones, including the rainforest, derived savanna, and montane forest regions. To place the Nigerian experience within a global context, relevant studies from developed countries, especially in Europe and North America, were also reviewed. These international examples provide comparative insights into how similar land use pressures have been managed under different governance and institutional frameworks. Sources were selected based on relevance, scientific credibility, and publication within the defined study period (2000 - 2020) to ensure that the analysis reflects current patterns and policy realities.

In addition to literature sources, national forest assessment data and satellite-based forest monitoring reports were examined to quantify changes in forest cover, levels of fragmentation, and major land conversion trends over time. These datasets provide an objective basis for identifying long-term patterns of forest loss and degradation without requiring primary data collection. Remote sensing products and national reports supported qualitative interpretations and strengthened the reliability of findings. To complement the regional-level analysis, selected case studies were used as illustrative examples of how land use change operates in specific forested areas. Forest reserves such as Oba Hills Forest Reserve and landscapes in Taraba State were examined to highlight distinct patterns of agricultural expansion, settlement growth, and resource extraction. These case studies were chosen to reflect differences in ecological conditions, land-use intensity, and management regimes, allowing comparisons across multiple forest types and contexts in Nigeria. A comparative analysis contrasted observed patterns in Nigerian forested regions with documented land-use and forest-management trends in developed countries. This approach identifies both universal drivers of forest change, such as urban expansion and agricultural demand, and context-specific factors, including governance effectiveness, enforcement capacity, and land-use planning systems. The comparative perspective strengthens the study's international relevance and supports broader policy lessons.

Data were analyzed using a combination of qualitative synthesis and basic quantitative interpretation. Qualitative analysis identified recurring themes related to drivers of land use change, forms of forest degradation, and institutional challenges. Quantitative data from national assessments and remote sensing reports were organized into summary tables and trend descriptions showing changes in forest cover, rates of land conversion, and spatial patterns of degradation over time. Where time-series data were available, trends were examined to determine whether forest loss and degradation were accelerating or stabilizing in specific regions. This approach has certain limitations. Because no primary field surveys were conducted, findings depend on the quality, resolution, and coverage of existing datasets and published studies. Some satellite products have

relatively coarse spatial resolution and may underestimate small-scale forest degradation or localized land conversion. Comparisons with developed countries are illustrative rather than directly equivalent, as differences in governance, reporting standards, and ecological conditions may influence outcomes. Despite these constraints, the combined use of literature, national data, and case studies provides a robust, integrative framework for understanding land-use dynamics and forest degradation in Nigeria's forested regions.

Results / Findings

Analysis of national forest assessments and remote sensing studies indicates that forested areas in Nigeria have experienced a sustained decline from 1980 to 2020. Dense forest cover in southern Nigeria has been particularly affected, with increasing fragmentation observed in ecologically sensitive regions such as Cross River and Ondo States (Ologunde *et al*., 2025; FAO, 2020). In northern Nigeria, savanna and woodland ecosystems are progressively converted into agricultural land, resulting in declining soil quality and reduced rates of forest regeneration (Geist & Lambin, 2002; Ayanlade *et al*., 2018). Across these regions, annual deforestation rates are estimated to range between 0.5% and 1.2%, depending on forest type and local pressures, reflecting persistent human-driven impacts from both subsistence and commercial land uses (FAO, 2020; Global Forest Watch, 2023). Agricultural expansion remains the dominant form of land conversion. Shifting cultivation and permanent crop farming continue to replace forested landscapes, especially in regions with high population growth and limited alternative livelihoods. Urbanization has intensified land-use change, as rapidly growing cities such as Lagos and Abuja expand into formerly forested areas, creating peri-urban landscapes characterized by mixed residential, industrial, and agricultural land uses (Seto *et al*., 2012; Akinyemi, 2021). These trends illustrate how demographic pressure and economic development interact to reshape forest landscapes at multiple spatial scales within Nigeria.

When compared with developed countries, historical patterns of forest loss due to agriculture and urban growth show similarities. In Europe and North America, large-scale deforestation occurred during earlier phases of industrialization and agricultural expansion. Over the last two decades, several countries have experienced partial forest recovery driven by strong policy frameworks, reforestation programs, and integrated land-use planning. For example, forest cover in France and Germany increased by approximately 5-8% between 2000 and 2020 due to afforestation and sustainable forest management initiatives (European Environment Agency, 2022; Hansen *et al*., 2013). Despite this recovery, habitat fragmentation remains a concern in urbanizing regions. In contrast, Nigerian forested regions have experienced limited recovery, largely due to weak enforcement of land-use policies, continued dependence on forest resources, and high pressure from subsistence agriculture.

Table 1. Comparative summary of drivers, impacts, and management responses of land use change on forest landscapes in Nigerian forested regions and developed countries

Category	Nigerian Forested Regions	Developed Countries	Notes / Interpretation
Primary Drivers	Rapid population growth, subsistence and commercial agriculture,	Urbanization, industrial development, and intensive mechanized agriculture	Land conversion is human-driven in both contexts, but livelihood dependence dominates in Nigerian forested regions, while economic

	urban expansion, fuel wood and timber demand		and industrial drivers dominate in developed countries
Policy and Governance	Weak enforcement of forest laws, unclear land tenure, and limited technical and financial capacity	Strong environmental regulations, land-use zoning, incentives for conservation, and effective monitoring systems	Governance capacity strongly determines the scale and reversibility of forest degradation.
Forest Cover Trends	Rapid decline in tropical rainforest and savanna patches, increasing fragmentation	Mixed trends: stabilization or net forest gain in some regions due to reforestation, but fragmentation persists near cities	Reforestation programs in developed countries partially offset historical losses; Nigerian forests, by contrast, largely lack comparable investment.
Socio-economic Pressure	High dependence on forests for livelihoods, food production, and household energy	Low dependence on forests for subsistence; forests mainly serve recreational, commercial, and ecological functions	Economic necessity accelerates forest clearing in Nigerian forested areas
Major Pressures on Forests	Agricultural expansion, grazing, logging, mining, and urban encroachment	Urban expansion, transport infrastructure, and agricultural intensification	Pressures differ in form but lead to similar habitat modification
Impacts on Forest Ecosystems	Habitat loss, biodiversity decline, soil erosion, reduced carbon stocks, and lowered forest productivity.	Habitat fragmentation, loss of semi-natural landscapes, reduced ecosystem connectivity, and localized carbon stock decline	Impacts in Nigerian forested regions are often more severe and harder to reverse.
Management Responses	Community-based forest management, selective protection, and small-scale reforestation projects	Green belts, afforestation and reforestation programs, protected areas, and landscape-level planning	Developed countries generally have greater institutional and financial capacity to implement responses.

Source: *Author's synthesis based on FAO (2020), European Environment Agency (2022, 2024), Geist & Lambin (2002), Seto et al. (2012), and Global Forest Watch (2023).*

The observed land-use and land-cover change patterns in Nigerian forested areas have produced substantial ecological consequences. Habitat fragmentation has left remaining forest patches isolated, reducing connectivity for wildlife movement and genetic exchange (Foley *et al*., 2005; Laurance *et al*., 2014). Declining forest cover has weakened ecosystem services, particularly water regulation, soil fertility maintenance, and carbon storage. Continuous cultivation on previously forested land has accelerated soil erosion and nutrient depletion, further constraining forest regeneration (Lambin *et al*., 2003; Ayanlade *et al*., 2018). Reduced forest productivity has limited the availability of timber and non-timber forest products, increasing pressure on remaining forest resources. Comparable impacts are observed in developed countries, particularly in peri-urban and agricultural landscapes, though mitigation strategies such as green belts, landscape restoration programs, and biodiversity corridors help maintain ecosystem function and stabilize forests (European Environment Agency, 2024; Pauleit *et al*., 2017).

Multiple drivers shape forest degradation in Nigerian forested regions. Socio-economic pressures, including rapid population growth, poverty, and reliance on forest resources, encourage forest clearance for agriculture and settlement (Geist & Lambin, 2002; FAO, 2020). Policy and governance gaps, including weak enforcement of forest protection laws and unclear land tenure,

create conditions for unregulated land conversion (Ostrom, 2010; Akinyemi, 2021). Infrastructure development, such as roads, housing, and mining, fragments forest landscapes and increases human accessibility to previously intact areas. Globally, developed countries face similar pressures, but stronger institutional frameworks, land-use zoning, and long-term planning reduce uncontrolled forest loss (European Environment Agency, 2022; Seto *et al*., 2012).

Case studies illustrate the site-specific nature of degradation. In Oba Hills Forest Reserve, Osun State, forest cover declined by approximately 43% between 1980 and 2016, driven mainly by agricultural expansion and grazing pressure, compounded by local reliance on fuel wood and timber (Adeyemi & Ayinde, 2022). In Taraba State, shifting cultivation and small-scale farming reduced forest cover by over 30% between 2006 and 2018, with limited government intervention (Abba *et al*., 2021). These examples demonstrate that while forest loss varies across ecological zones, human pressure combined with weak governance consistently drives degradation. Overall, the results reveal that land use and land cover change in Nigerian forested regions mirror early development trajectories observed in developed countries, but without comparable levels of policy control and restoration investment. This contrast underscores the importance of integrating land-use planning, governance reform, and landscape restoration to prevent long-term ecological decline in these critical forest landscapes.

Discussion

This study confirms that land-use and land-cover change are dominant drivers of forest degradation in Nigerian forested regions, with agricultural expansion, urban growth, and infrastructure development reshaping forest landscapes across ecological zones. Patterns of forest loss and fragmentation in sites such as Oba Hills Forest Reserve (southern rainforest) and Taraba State forests (derived savanna) are consistent with previous findings (Adeyemi & Ayinde, 2022; Abba *et al*., 2021), demonstrating that forest degradation in Nigeria is a widespread transformation driven by demographic and economic pressures. The comparative perspective in Table 1 highlights key similarities and differences between Nigerian forests and those in developed countries. In Nigerian forested regions, population growth and dependence on forests for livelihoods intensify deforestation and land conversion. Forests are primarily cleared to meet immediate needs for food, fuelwood, and income, linking land-use change closely to household survival strategies.

In contrast, developed countries experience land conversion mainly through urbanization, industrial development, and agricultural intensification, but strong governance structures, land-use zoning, and reforestation programs have enabled partial forest recovery in several regions of Europe and North America (European Environment Agency, 2022; 2024). This comparison demonstrates that while human demand for land is a universal driver of forest change, the outcomes depend largely on institutional capacity and policy effectiveness. The ecological and socio-economic consequences of forest degradation in Nigerian forests are severe. Habitat fragmentation reduces biodiversity and disrupts ecological connectivity, while soil degradation undermines agricultural productivity and increases vulnerability to erosion and flooding. Declining forest carbon stocks further contribute to climate change, linking local land use decisions to global environmental risks (Foley *et al*., 2005; Lambin *et al*., 2003). These impacts directly affect rural

livelihoods that rely on forest resources for food, medicine, and energy, reinforcing cycles of poverty and environmental decline.

Similar issues of habitat fragmentation and ecosystem service loss are observed in peri-urban and intensively farmed landscapes of developed countries, yet restoration programs, protected areas, and landscape planning approaches help limit long-term damage (Pauleit *et al*., 2017; European Environment Agency, 2024). The key distinction lies in recovery capacity and adaptive management, which remain limited in Nigeria. Lessons from international experience are directly relevant: integrated land-use planning effectively balances agricultural production, urban expansion, and forest conservation; strategic zoning and spatial planning reduce conflicts between development and conservation; and long-term monitoring discourages illegal forest conversion (Seto *et al*., 2012; European Environment Agency, 2022). Community participation is also critical, as incentives for sustainable land management improve compliance and encourage stewardship of forest resources. Restoration and reforestation initiatives further demonstrate that degraded landscapes can regain ecological function over time when supported by consistent investment and institutional commitment. Table 1 reinforces the central conclusion: unmanaged human pressure leads to forest degradation regardless of geography, but policy responses and management strategies can significantly alter outcomes. Nigeria's forest degradation is not inevitable; it reflects gaps in governance, planning, and investment. Strengthening these areas, while adapting international best practices to local ecological and social realities, offers a pathway toward more resilient forested landscapes and sustainable development.

Policy and Management Implications

The findings indicate that forest degradation in Nigerian ecological zones, particularly the southern rainforest, derived savanna, and montane forests, extends beyond biodiversity loss, directly affecting climate regulation, hydrological processes, and broader landscape functioning. Conversion of forested areas into agricultural fields and built-up land alters evapotranspiration rates, soil moisture dynamics, and surface energy balance, influencing local rainfall patterns and microclimates (Foley *et al*., 2005; Lambin et al., 2003). These dynamics underscore the need for land-use strategies that integrate forest conservation with climate-informed planning and predictive environmental modeling. Strengthening governance is fundamental to reducing forest loss across ecological zones. Clear land tenure arrangements, consistent enforcement of forest protection laws, and alignment between land-use policies and regional development plans can significantly limit uncontrolled deforestation. Evidence from developed countries shows that strong institutional frameworks, spatial zoning, and long-term land-use planning are effective in stabilizing forest cover even under high development pressure (European Environment Agency, 2022; Seto *et al*., 2012). In contrast, inconsistent enforcement and limited technical capacity in Nigeria's forested regions continue to undermine conservation efforts, highlighting the need for institutional reform supported by reliable environmental data systems.

Beyond regulatory measures, modern environmental modeling offers opportunities for proactive and targeted forest management. Integration of remote sensing, geographic information systems, and biometric analyses enables the identification of forest degradation hotspots, the prediction of future land-use scenarios, and the assessment of potential climatic and ecological impacts (Hansen *et al*., 2013; Global Forest Watch, 2023). These data-driven approaches support early intervention

strategies, enabling policymakers to prioritize high-risk forested areas and optimize resource allocation for conservation and restoration initiatives. Community engagement remains critical, particularly in regions where livelihoods depend heavily on forest resources. Modeling tools can complement participatory forest management by identifying the most vulnerable zones to anthropogenic pressures and guiding decisions on sustainable harvesting, agroforestry practices, and reforestation schemes (Ostrom, 2010; Geist & Lambin, 2002). Restoration programs should target landscapes with the greatest potential to enhance microclimate regulation, improve soil stability, and increase carbon sequestration, thereby delivering both ecological and socio-economic benefits. International experience demonstrates that reforestation and landscape restoration programs can successfully rebuild degraded ecosystems when supported by long-term policy commitment and adequate investment (European Environment Agency, 2024).

Overall, policy responses must shift from reactive forest protection toward integrated, predictive, and climate-sensitive land management. By embedding environmental modeling within decision-making, forest managers in southern rainforest, derived savanna, and montane forest zones can adopt adaptive strategies that balance development pressures with long-term ecosystem sustainability.

Conclusion

This study demonstrates that forest degradation in selected Nigerian ecological zones is closely linked to land-use and land-cover change, with wide-ranging implications for ecological integrity, climate systems, and landscape processes. Deforestation and fragmentation disrupt hydrological cycles, alter microclimates, and degrade soil quality, highlighting the critical interplay between forest management and predictive environmental modeling. Comparisons with developed countries show that while land-use pressure is a global phenomenon, the severity and reversibility of forest degradation depend largely on governance capacity, planning systems, and the application of data-driven management strategies. For Nigerian forested regions, sustaining landscapes requires coordinated approaches that integrate effective policy enforcement, community participation, and investment in restoration guided by high-resolution predictive models. Linking land-use change datasets with climate and hydrological models can anticipate shifts in rainfall, temperature, and ecosystem services, enabling interventions that are environmentally robust and socially acceptable. Future research should focus on developing dynamic, spatially explicit models that capture interactions between human activities, forest ecosystems, and climate processes. Strengthening monitoring systems and improving access to spatial and biometric data will enhance adaptive management and policy effectiveness. With sustained political commitment and strategic use of environmental modeling tools, Nigeria's forest landscapes can be conserved and restored, ensuring they continue to deliver essential ecological, climatic, and socio-economic benefits for current and future generations.

References

Abba, A., Mohammed, M., & Abdullahi, S. (2021). Spatio-temporal analysis of forest cover change in Taraba State, Nigeria, using remote sensing and GIS. *Environmental Monitoring and Assessment*, 193(4), 1–15.

Abba, U. J., Adewuyi, T., Bakoji, Y. M., Mohammed, B. B., Umar, A. A., Abdullahi, I., & Isa, M. S. (2021). GIS and remote sensing analysis of the impact of land use and land cover change

on forest degradation: Evidence from the central part of Taraba State, Nigeria. *Geography, Environment and Earth Science International*, 25(11), 14–26.

Adeyemi, A. A., & Ayinde, M. O. (2022). Evaluation of land use and land cover changes in Oba Hills Forest Reserve, Osun State, Nigeria. *Forestist*, 72(2), 137-148. https://forestist.org/en/evaluation-of-land-use-and-land-cover-changes-in-oba-hills-forest-reserve-osun-state-nigeria-132717

Adeyemi, O., & Ayinde, I. A. (2022). Land use change and forest degradation in Oba Hills Forest Reserve, Osun State, Nigeria. *Environmental Management*, 305, 114-128.

Afforestation. (2026). In *Wikipedia*. https://en.wikipedia.org/wiki/Afforestation

Akinyemi, F. O. (2021). Land use change and urban expansion in Nigeria: Implications for forest ecosystems. *Land Use Policy*, 104, 105–118.

Alegbeleye, O. M., Rotimi, Y. O., Shomide, P., Oyediran, A., & Ogundipe, O. (2024). Land use land cover (LULC) analysis in Nigeria: a systematic review of data, methods, and platforms with prospects—*Bulletin of the National Research Centre*, 48, 123.

Ayanlade, A., Radeny, M., & Morton, J. (2018). Comparing smallholder farmers' perceptions of climate change with meteorological data: A case study from Nigeria. *Weather and Climate*, 19, 1–12.

European Environment Agency. (2022). Forests of Europe: State and trends 2000-2020. Copenhagen: EEA.

European Environment Agency. (2022). Impact of land use on vegetation productivity in Europe. https://www.eea.europa.eu/en/analysis/indicators/impact-of-land-use-on

European Environment Agency. (2024). Land use in Europe: Patterns and trends. https://www.eea.europa.eu/en/topics/in-depth/land-use

European Environment Agency. (2024). Urban sprawl and ecosystem services in Europe. Copenhagen: EEA.

FAO. (2020). Global Forest Resources Assessment (2020). Nigeria country report. Rome: Food and Agriculture Organization of the United Nations.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., … Snyder, P. K. (2005). Global consequences of land use. *Science*, 309(5734), 570–574.

Geist, H. J., & Lambin, E. F. (2002). Proximate causes and underlying driving forces of tropical deforestation. *BioScience*, 52(2), 143–150.

Global Forest Watch. (2023). *Forest loss in Nigeria: Trends and drivers*. Washington, DC: World Resources Institute.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., … Townshend, J. R. G. (2013). High-resolution global maps of 21st-century forest cover change. *Science*, 342(6160), 850–853.

Ikyaagba, E. T., Jande, J. A., & Abiem, M. K. (2023). Effects of land use and land cover change on Tse Gavar Forest Reserve, Benue State, Nigeria. *East African Journal of Forestry and Agroforestry*, 6(1), 1–14. https://journals.eanso.org/index.php/eajfa/article/view/127

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, 28, 205–241.

Laurance, W. F., Sloan, S., Weng, L., & Sayer, J. A. (2014). A global strategy for road building. *Nature,* 513, 229–232.

Ologunde, O. H., Kelani, M. O., Biru, M. K., Olayemi, A. B., & Nunes, M. R. (2025). Land use and land cover changes: A case study in Nigeria. *Land*, 14(2), 389. https://www.mdpi.com/2073-445X/14/2/389

Ologunde, A. O., Adeyemi, O., & Salami, A. T. (2025). Forest fragmentation and land use change in southern Nigeria: Evidence from satellite observations. *Environmental Research Letters*, 20(2), 1-12.

Ostrom, E. (2010). Beyond markets and states: Polycentric governance of complex economic systems. *American Economic Review*, 100(3), 641-672.

Pauleit, S., Zölch, T., Hansen, R., Randrup, T. B., & Konijnendijk van den Bosch, C. (2017). Urban green infrastructure and ecosystem services. *Landscape and Urban Planning*, 157, 1-8.

Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030. *Proceedings of the National Academy of Sciences*, 109(40), 83–88.

ISTF-NIG 2026

PHYTO-EXTRACTION OF POTENTIAL TOXIC ELEMENTS FROM GOLD MINE CONTAMINATED SOIL USING *Terminalia superba* ENGL. DIELS

OYEDIJO, Olanrewaju Segun, *OLORUNNIBE, Victor Niyi, OLAJUYIGBE, Samuel Olalekan

Department of Forest Production and Product, Faculty of Renewable Natural Resources, University of Ibadan, Nigeria.

**Corresponding Email: victor_niyi@yahoo.com*

Abstract

Anthropogenic activities such as mining, agricultural practices, and construction have introduced Potential Toxic elements (PTEs), which act as pollutants to the soil. This pollutant degrades the soil and, by extension, affects the ecosystem and biological organisms. This study aimed to assess the phytoremediation potential of *Terminalia superba*, an indigenous tree, for PTE-contaminated soil. Control and PTEs soil samples were obtained from the Nursery Garden and a gold mining site in Ilesha, Osun State, respectively. Metal analysis of soil samples was done before and after transplanting using standard analytical procedures. Six-month-old *T. superba* seedlings raised in the nursery were transplanted into polythene pots filled with either clean (control) or contaminated (gold-mined) soil. Seedling survival and growth were measured. Transfer factor and bioaccumulation potential were also studied. The collected data were analyzed using descriptive statistics and a t-test. Results showed a decrease in the concentration of the PTEs (Zn and Pb) in the soil and survival of all transplanted seedlings at the end of the study. Plant height for seedlings transplanted into the control soil was 45.20±8.41cm, while those transplanted into contaminated soil were 45.20±5.36 cm at the end of the study. For the plants' collar diameter, seedlings in the control soil had the highest mean of 2.42±0.38 cm, while those in the contaminated soil had the lowest mean of 2.06±0.43 cm. There was no difference in the number of leaves for seedlings transplanted on the control (16.40±3.21) and the contaminated (16.20±2.30) soil at the end of the study. Results on transfer factors showed that Zinc (3.09) had the highest transfer factor value, while Pb (2.04) had the lowest; for bioaccumulation factors, Pb (0.13) had the highest, while Zn (0.034) had the lowest. It can be concluded that *T. superba* reduces Zn and Pb concentrations in soil, with high transfer and bioaccumulation factors. *Terminalia superba* is strongly recommended as a candidate indigenous tree for phytoremediation of PTE-contaminated soils.

Keywords: Phytoextraction, Ilesha, Gold mine, Degradation, Indigenous trees

Introduction

Soil is a basic support system that enables vital ecosystems to support food production and biodiversity conservation for human activities (Johnston *et al.,* 2018). However, it loses its potential to provide these services when it becomes contaminated with pollutants. Anthropogenic activities, such as agriculture, timber harvesting, livestock, and mining, are major drivers of a nation's economic development, but also raise global environmental concerns (Biswas & Biswas, 2018; Salvarrey *et al*., 2014). Activities from industrial processes, metalliferous ore mining and smelting, electroplating, production of fuel and energy, and the use of fertilizers and pesticides are

also sources of concern (Pegah, 2023). Mining is a critical source of deposition of potentially toxic elements (PTEs), such as lead (Pb) and Zinc (Zn), in soils (Nwhogha *et al.,* 2018). Mining is under scrutiny for causing significant environmental changes, including elevated concentrations of toxic metals in soil, posing threats to biodiversity and human health (Marrugo-Madrid *et al*., 2021; Biswas & Biswas, 2018; FAO/WHO, 2018). Mining activities are known to elevate PTEs concentrations, often exceeding permissible levels (Sahoo *et al*., 2018; WHO, 1996). Additionally, these elements play no essential role in organism development and are therefore non-essential metals (Lata & Asthana, 2018). Soil pollution with toxic elements is a serious environmental problem, especially in gold mining areas. Zinc and Lead are PTEs that make soils less fertile and do not support plant growth (Amadi *et al*., 2017; Uchendu *et al*., 2020). Gold mining is increasing, and most mine sites are operated illegally, using chemicals and heavy machinery (Surukite *et al*., 2023). Consequently, the use of environmentally unfriendly substances in this process and poor waste management pollute the environment and contaminate the soil (Adepoju & Adebayo, 2016). This activity results in loss of arable land, thereby endangering food security and agricultural production.

The soil remediation methods employed have proven expensive, difficult, and unsustainable. Therefore, low-cost technologies such as phytoremediation have been suggested as effective and sustainable methods (Chukwuka *et al.,* 2019). According to Guo *et al.* (2023), there is an alarming rate of lead contamination in agricultural soils in mining areas of Nigeria. Phytoremediation, a cost-effective, eco-friendly approach, holds great potential for the rehabilitation of PTE-polluted soils. Several plants, including *Populus nigra*, *Terminalia ivorensis,* and *Vigna unguiculata,* have been screened for their potential to rehabilitate polluted soils and groundwater. Similarly, native tree species have been reported to have strong affinities for environmental conditions in their localities, with promising phytoremediation potential (Alghamdi & El-Zohri, 2024). They are less affected due to their adaptive nature and role in interaction with important microorganisms, which aid in soil rehabilitation (Lance *et al*., 2020). Some plants can immobilize pollutants and convert metals into soluble forms, thereby reducing the risk to the ecosystem (Ali *et al.,* 2013; Chukwuma *et al.,* 2019).

Terminalia superba Engl. Diels, an indigenous tree species native to Nigeria, has shown phytoremediation capabilities for crude oil-contaminated soils (Olajuyigbe & Aruwajoye, 2014). The tree can thrive in various environments and accumulate heavy metals from soil (Bansah & Addoh, 2016). *Terminalia superba* is an indigenous tree species with great potential for high biomass production, a deep rooting system, and the ability to adapt to adverse environmental conditions, making it an important alternative in tropical environments for phytoremediation interventions (Kaba *et al*., 2020). Nevertheless, very limited information is available on the potential of *T. superba* to remediate soils contaminated with PTEs, such as Zinc and lead, on gold mining sites. Therefore, this study aims to investigate the potential of *T. superba* to phytoextract PTEs, such as Zinc and lead, from polluted soil retrieved from a gold mining site in Ilesha, Osun State, Nigeria.

Materials and Method

Study Area

The experiment was conducted at the Nursery section, Department of Forest Production and Products, University of Ibadan, Nigeria, situated between latitudes 7.4494º N to 7.4491°N and longitudes 3.8967º E to 3.8972°E. The temperature ranges between 19ºC and 34ºC, with a mean annual temperature of 26ºC. It has a bimodal rainfall pattern, with an annual average of 2500 mm. The rainfall peak is in June and September, and the lengthy rainy season lasts from March to early November (Christiana *et al*., 2013).

Contaminated soil was collected from a gold mining site located at Ilesha, Osun State, Nigeria. The site has a point coordinate of latitudes 7.5840^0 N to 7.5839^0 N and longitudes 4.7119^0 E to 4.7122^0 E. The area is 360-400 m above sea level with an annual rainfall of 1600 - 2000 mm.

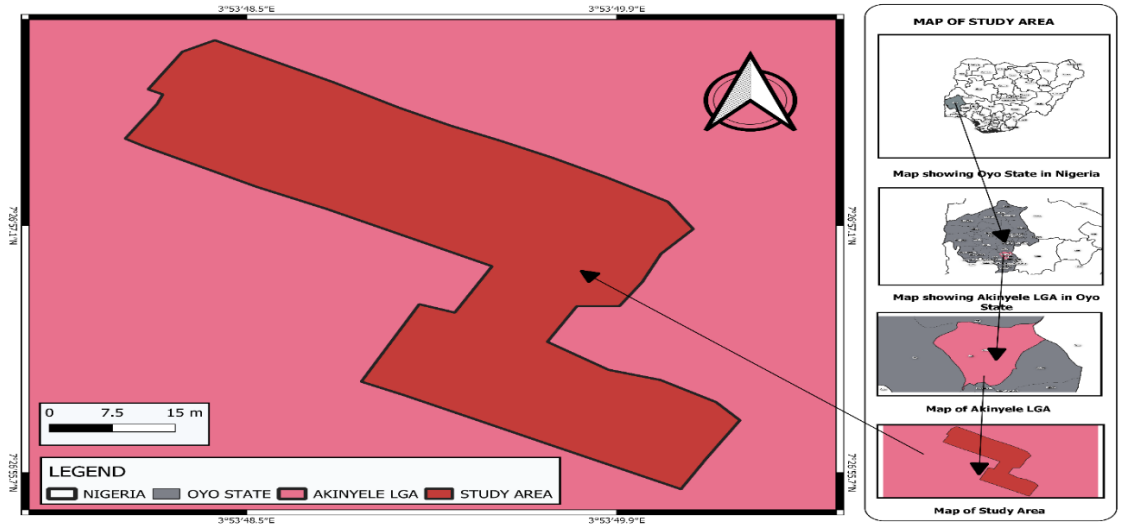


Figure 1: Map showing the study area at the University of Ibadan campus (Source: field survey, 2025)

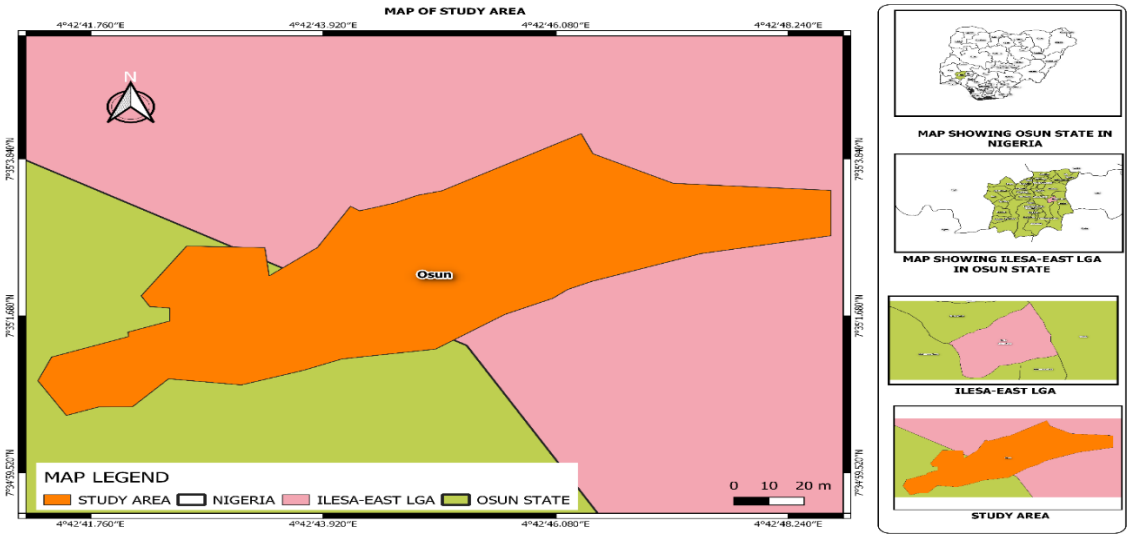


Figure 2: Map showing the site of gold mining in Ilesha, Osun State (Source: field survey, 2025)

Collection of Soil Samples and Experimental Site

Contaminated soil samples were randomly collected at 20m intervals along a 1000m transect from the mining area at Ilesha, Osun State, Nigeria. Debris was removed from the sampling area, and then the top 15 cm of soil was collected. Different soil samples were collected in polyethylene bags, then combined and mixed to create a single representative sample. The non-contaminated used for the control study was obtained from the Nursery section of the Department of Forest Production and Products.

Soil Sample Preparation and Digestion

The contaminated nursery soil samples were sent to the laboratory for metal analysis before planting to determine PTE levels. The method used for the metal analysis followed the procedures employed by Oladele *et al*. (2016).

Experimental Design and Treatments

Soil sample composite, sieved in a 2mm mesh sieve, was filled to the brim into twenty-five (25) polythene pots (size:20cm x 15cm) while the non-contaminated soil collected from the nursery was filled into five (5) polythene pots of the same dimension (this serves as the control). The polythene pots were placed on a level platform to prevent nutrient and metal leaching, and the experiment was arranged in a Completely Randomized Design (CRD).

Nursery Practice and Transplanting

Terminalia superba seeds collected from a healthy mother tree at the University of Ibadan campus were used for this study. Germinated seedlings were transplanted into the prepared polytene pots filled with clean soil and left for 6 months to stabilize. The six-month-old *T. superba seedlings* were transplanted into each prepared polythene pot filled with the soil composite and monitored for 14 weeks. A total of 30 seedlings of uniform growth were used in the study: 25 for the contaminated treatment, 5 for the control. All seedlings were watered daily in the morning.

Measurement of Growth Parameters

Survival: This was done by counting the number of growing seedlings transplanted
Plant height: Plant height was measured from the ground to the top with a ruler in centimetres.
Collar diameter: measured using a vernier calliper.
Number of leaves: The total number of leaves per seedling was counted for each treatment and recorded.
The experimental setup was allowed to stabilize for two weeks before assessment.

Metal Analysis in a Plant

The solution produced by dry ashing the plant sample at 550°C and dissolving the ash in distilled deionized water in a flask was used to analyze the heavy metal components of the sample. With the use of an atomic absorption spectrophotometer (Buck Scientific Model 200A), all the metals (Zn and Pb) were examined. For soil samples, the same process was repeated (Oluwole et al., 2020).

Determination of Transfer Factor (TF)

The term describes the transfer of metal from the soil to the plant body: the "heavy metal Transfer factor" (TF), also known as the accumulation factor (AF) or Bioconcentration factor (BCF). According to Surukite *et al*. (2023), this was computed by dividing the plant's heavy metal content by the corresponding soil concentration.

Transfer Factor (TF) = Conc. HM in the aerial part of the plant / Conc. HM in the Soil

Statistical Analysis

The collected data were analyzed using descriptive statistics and a t-test. The least significant difference (LSD) test was used to determine whether the means of the treatments differed.

Results

Results showed that *Terminalia superba* seedlings transplanted into the control soil and the contaminated soil survived throughout the study. The presence of PTEs (Pb and Zn) did not cause plant death at the start or end of the study (Table 1).

Table 1: Survival of *Terminalia superba* seedlings on PTE-contaminated soil

		Survived seedlings	Total seedlings
	Control	5	5
	Contaminated	25	25
Total		30	30

The plant height recorded for the control and the contaminated soil was the same at 2 weeks after planting (2WAT), with mean values of 29.28±8.66 cm and 29.26±4.39 cm, respectively. Similarly, there was no difference in the mean plant height at the end of the study. Plant height for seedlings transplanted into the control soil had a mean of 45.20±8.41cm, while those transplanted into contaminated soil had a mean of 45.20±5.36 cm (Table 2).

For Collar diameter at 2WAT, plants transplanted into the Control soil had a mean of 0.88±0.22 cm, while those transplanted into the contaminated soil had a mean of 0.82±0.16 cm. Results showed increases in the mean collar diameter of plants transplanted into control and contaminated soil over the weeks. However, at 16WAT, plants on the control soil had the highest mean value of

2.42±0.38cm, while those on the contaminated soil had the lowest mean value of 2.06±0.43 cm (Table 2).

Results in Table 2 for the number of leaves showed that *T. superba* seedlings transplanted into contaminated soil at 2WAT had the highest mean of 9.20±2.26, while the lowest was recorded for seedlings transplanted into the control soil (6.80±0.22). The number of leaves increased with time (i.e., as the week progressed). At 16 WAT, the mean number of leaves for plants grown on control and contaminated soil was 16.40±3.21 and 16.20±2.30, respectively.

Table 2: Growth response of *Terminalia superba* seedlings on PTE-contaminated soil

Weeks	Plant Height (cm)		Collar Diameter (cm)		Numbers of Leaves	
	Control	**Conta.**	**Control**	**Conta.**	**Control**	**Conta.**
2WAT	29.28±8.66	29.26±4.39	0.88±0.22	0.82±0.16	6.80±1.64	9.20±2.26
4WAT	31.26±9.59	33.08±4.91	1.10±0.18	1.15±0.21	8.60±0.55	10.40±2.82
6WAT	34.34±11.0	35.38±5.42	1.48±0.18	1.37±0.21	10.00±0.00	11.76±2.92
8WAT	39.44±9.32	38.43±5.69	1.68±0.25	1.50±0.26	11.00±2.23	12.92±2.30
10WAT	41.44±9.36	41.75±5.38	1.92±0.30	1.63±0.90	12.00±1.87	13.72±2.25
12WAT	41.26±8.97	42.95±5.02	2.10±0.31	1.75±0.30	13.20±2.38	14.80±2.00
14WAT	43.38±9.01	44.19±5.31	2.24±0.29	1.90±0.36	15.20±2.86	15.28±2.23
16WAT	45.20±8.41	45.00±5.36	2.42±0.38	2.06±0.43	16.40±3.21	16.20±2.30

Mean ± SD, WAT (weeks after transplanting)

Results in Table 3 show the heavy metal analysis of the soil samples used before and after the study. It reveals that the PTEs, such as Zn and Pb, decreased progressively in soil after remediation in both control and polluted soils. There was a high percentage of Zinc and lead concentration in the contaminated soil when compared to the control.

Table 3: Potential Toxic Element analysis of the soil before and after remediation

	Control		**Contaminated**	
	Conc. at 2WAT	**Conc.at 16WAT**	**Conc.at 2WAT**	**Conc.at 16WAT**
Zn (Mg/kg)	0.72±0.37	0.08±0.022	1.44±0.077	1.11±0.072
Pb (Mg/Kg)	0.14±0.063	0.14±0.72	0.30±0.29	0.16±0.21

Mean ± SD, WAT (Weeks after Transplanting)

Results of the T-test showed that *T. superba* seedlings significantly affected the heavy metal concentrations in the contaminated soil at 16WAT. There was a significant difference in the PTEs concentration between the two treatment means (Table 4).

Table 4: Paired Samples T-test

	Paired diff.	**T**	**P-value**
Zn conc. at 2WAT -16WAT	0.35	10.36	0.000*
Pb conc. at 2WAT– 16WAT	0.17	9.38	0.000*

**=Significant at 5% probability level*

Figure 3 shows the PTEs transfer factor phytoremediation potential of *T. superba*. The result showed that Zn (3.09) had the highest transfer factor, while Pb (2.04) had the lowest.

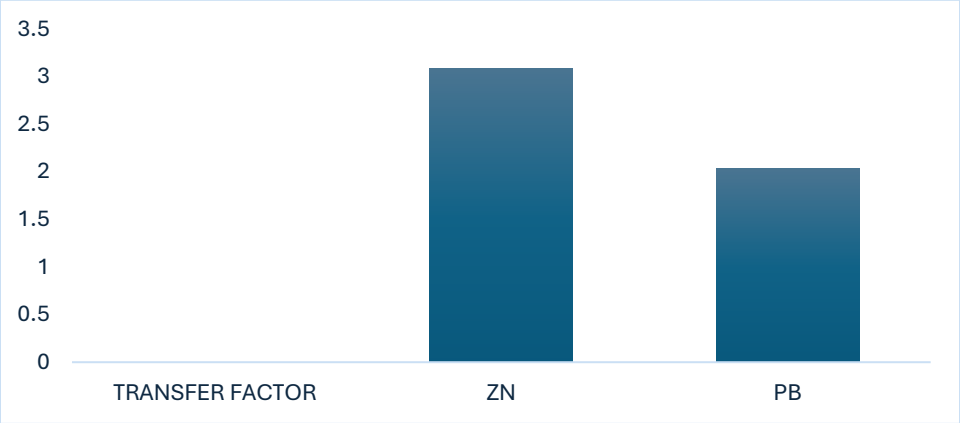


Figure 3: Transfer factors of *Terminalia superba* seedlings on PTE-contaminated soil

Figure 4 shows the PTEs' bioconcentration factors and phytoremediation potential of *T. superba*. The results revealed that Pb (0.13) had the highest transfer factor, while Zn (0.034) had the least metal bioaccumulation factor.

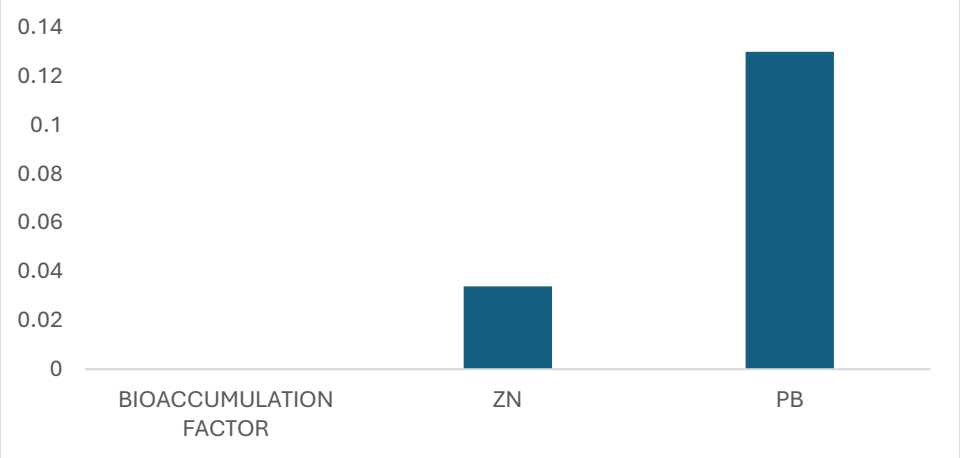


Figure 4: Bioaccumulation factors of *Terminalia superba* seedlings on soil with PTEs

Discussion

In this study, the phytoremediation potential of *T. superba* seedlings planted in contaminated PTE-polluted soil was evaluated and compared with that of seedlings planted in the control soil. It was observed that *T. superba* seedlings planted in the control soil and the contaminated soil performed well morphologically, except for collar diameter, which was larger in the control soil than in the contaminated soil during the study. This could be due to the presence of PTEs in the contaminated soil. It has been reported that soil rich in heavy metals creates a barrier to water absorption, reduces aeration, and impedes the free flow of water into the soil, thereby blocking oxygen from reaching the soil. This corroborates the reports of Anyalogbu *et al*. (2017), who observed reductions in

morphometric parameters such as plant height, leaf length, leaf breadth, and plant girth, indicating the phytoremediation potential of *Talinum triangulare* in heavy-metal- and hydrocarbon-contaminated soil. From the soil metal analysis results, there was a reduction in the concentrations of Zinc and lead at the end of the study. The reduction in the concentration of these metals corroborates the findings of Puga *et al*. (2015) and Oladele *et al*. (2018), who reported similar results using *Vigna ungulanta*.

This reduction has been attributed to the translocation of metals from the soil to the roots. Additionally, this study documents that Zn (Zn) has the highest transfer factor, while Lead (Pb) has the least. This implies that Zn is highly mobile and moves more rapidly from the soil to the plant and its parts. This could be due to metal-specific properties and plant affinities for metal mobilization (Cristaldi *et al*., 2017; Wang *et al*., 2017). Furthermore, in this study, lead (Pb) has the highest bioaccumulation potential for PTEs compared to Zinc. This corresponds with the findings of Anyalogbu *et al*. (2017), who reported higher bioaccumulation and uptake rates of heavy metals in *Talinum triangulare* cultivated in heavy-metal-contaminated soil. This could be attributed to metal-specific properties, plant affinities for metal mobilization, and soil properties (Cristaldi *et al.*, 2017; Wang *et al*., 2017).

Conclusion

It could be concluded that the *Terminalia superba* plant can phytoextract heavy metals from PTE-contaminated soil. This is evident in this study, as contaminated soil could not hinder the growth and survival of *T. superba* seedlings. It also reduced the concentration of this metal in the PTE-contaminated soil. It is recommended that *T. superba* exhibit phytoremediation capabilities, making it an excellent candidate tree for remediating contaminated soils. The plant's survival indicates that it can grow well on PTE-contaminated soil.

References

Adepoju, M. A., & Adebayo, A. A. (2016)**.** Environmental impacts of artisanal gold mining in southwestern Nigeria: A study of Ilesa. *Journal of Sustainable Development in Africa* 18 2: 23–35.

Alghamdi, S., & El-Zohri, M. (2024). Phytoremediation characterization of heavy metals by some native plants at anthropogenically polluted sites in Jeddah, Saudi Arabia. *Resources* 13 7: 98.

Ali, H., Khan, E., & Sajad, M. A. (2013). Phytoremediation of heavy metals: Concepts and applications. *Chemosphere,* 91(7):869–881. https:// doi. org/ 10. 1016/j. chemo sphere. 2013. 01. 075

Amadi, A., Ebieme, E., Musa, A., Olashinde, P., Ameh, I. & Shuaibu, A. (2017). Utility of Pollution Indices in the Assessment of Soil Quality around the Madaga Gold Mining Site, Niger State, North-Central Nigeria*. Ife Journal of Science* 19 2: 417.

Anyalogbu, E. A. A., Anadi, C. C., Nweje-Anyalowu, P. C. & Nnoli, M. C. (2017). Use of waterleaf (*Talinum triangulare*) in remediation of soil exposed to heavy metals: A green technology approach. *World Journal of Pharmaceutical and Life Sciences*, 3(9) 48–53.

Bansah, K. & Addoh, W. (2016). Phytoremediation potential of plants grown on reclaimed spoil lands. *Ghana Mining Journal* 16.1, 68.

Biswas, S., & Biswas, A. (2018). Impact of Mining on Forests and Their Biological Diversity at Kirandul Iron Ore Mines, Dantewada, South Bastar, Chhattisgarh: A Case Study. J Environ Sci Studi 1(1):16. https:// doi. org/ 10. 20849/ jess. v1i1. 420

Christiana, E. O., & Amanambu, A. N. (2013). Climate change and rainfall series variability in Ibadan, Nigeria. *International Journal of Engineering and Technology* 3 1: 82–88.

Chukwuka, K. S., Odebode, S. O., & Adama, O. M. (2019). Heavy metal contamination in aquatic ecosystems of Nigeria: Impacts on fish populations and human health risks. *Environmental Toxicology and Chemistry* 38 2: 405–414.

Chukwuma, C.C., Ikewychi, J.C. & Monanu, M.O. (2019). Removal of Hydrocarbons from Crude Oil Contaminated Agricultural Soil by Phytoremediation Using *Mariscuc alternifolius* and *Fimbristylis ferruginea. European Journal of Biological Research* 9 1: 34–44.

Cristaldi, A., Conti, G. O., Jho, E. H., Zuccarello, P., Grasso, A. and Copat, C. (2017). Phytoremediation of contaminated soils by heavy metals and PAHs. A brief review. Environ. Technol. Innov. 8: 309–326.

FAO/WHO (2018) Safety evaluation of certain contaminants in food: prepared by the eighty-third meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). In: WHO food additives series, No. 74; FAO JECFA Monographs 19 bis (Series 74, Vol 74). https:// iris. who. int/ handle/ 10665/ 276868

Guo, Z., Yang, J., Li, K., Shi, J., Peng, Y., Sarkodie, E., & Jiang, L. (2023). Leaching behaviour of As and Pb in Lead–Zinc mining waste rock under mine drainage and rainwater. *Toxics* 11 11: 943.

Johnston, A. S. A., Sibly, R. M. & Thorbek, P. (2018). Forecasting the effects of tillage and soil warming on earthworm populations. *Journal of Applied Ecology* 55.3 1498-1509.

Kaba, J., Otu-Nyanteh, A., & Abunyewa, A. (2020). The role of shade trees in influencing farmers' adoption of cocoa agroforestry systems: insight from the semi-deciduous rain forest agroecological zone of Ghana. Njas. *Wageningen Journal of Life Sciences* 92 1: 1–7.

Lance, R., Butler, A., Jung, C., & Lindsay, D. (2020). Multiple stressors in multiple species: effects of different rdx soil concentrations and differential water-resourcing on rdx fate, plant health, and plant survival. *Plos One* 15(8)

Lata, S. and Asthana, S. (2018). Biologically essential and non-essential elements that cause toxicity in the environment. J Environ Anal Toxicol 8 2 :2–5. https:// doi. org/ 10. 4172/ 2161- 0525. 10005 57

Marrugo-Madrid, S., Turull, M., Montes, G. E., Pico, M. V., Marrugo-Negrete, J. L., and Díez, S. (2021). Phytoremediation of mercury in soils impacted by gold mining: a case-study of Colombia. In: Bioremediation for environmental sustainability: toxicity, mechanisms of contaminants degradation, detoxification and challenges, pp 145–160. https:// doi. org/ 10. 1016/ B978-0- 12–820524- 2. 00007-9

Nwhogha, J.S., Mmeremikwu, I.A., Anedo, E.O., Osodoke, V.E., and Ano, A.O. (2018). Effect of Artisanal Mineral Mining on Heavy Metals Content and Chemical Properties of Soils of Ameka Mining Area in Abakaliki, Ebonyi State. *The Nigerian Agricultural Journal* 48.2. with

Oladele, E. O., Adewumi, O. O., Taiwo, I. A., & Odeigah, P. G. C. (2018). Removal of Pb and Zn from Soil using cowpea (*Vigna unguiculata)* and maize (*Zea mays*) plants. *Journal of Applied Sciences and Environmental Management*, 22(3), 432–438.

Oladele, E.O., Odeigah, P.G.C., Taiwo, I.A., & Yahaya, T. (2016). Remediative potential of bambara nut on Pb and Zn-polluted soils. Ife J. Sci. 18(2), 483–491.

Olajuyigbe, S. O., & Aruwajoye, D. A. (2014). Phytoremediation of diesel oil-contaminated soil using seedlings of two tropical hardwood species (*Khaya senegalensis* and *Terminalia superba*). *International Journal of Scientific and Engineering Research 5* 6: 1067–1078

Pegah Kharazian. (2023). Investigation on revegetation/phytoremediation of Campo Pisano abandoned mine area. *Universita Degli Studi Di Cagliari* 13.

Puga, A. P., Abreu, C., Melo, L. C. A & Beesley, L. (2015). Biochar application to a contaminated soil reduces the availability and plant uptake of Zinc, lead and cadmium. *Journal of Environmental Management*, 159 86-93.

Sahoo HB, Gandre DK, Das PK, Karim MA, Bhuyan GC (2018). Geochemical mapping of heavy metals around the Sukinda-Bhuban area in Jajpur and Dhenkanal districts of Odisha, India. Environ Earth Sci 77(2):77–34. https:// doi. org/ 10. 1007/ s12665- 017–7208-2

Salvarrey AVB, Kotzian CB, Spies MR, Braun B (2014). The influence of natural and anthropogenic environmental variables on the structure and spatial distribution of macroinvertebrate communities along a longitudinal gradient in southern Brazilian streams. J Insect Sci 14:1–23. https:// doi. org/ 10. 1673/ 031. 014. 13

Surukite, O., Mautin, O., Qudus, U., Racheal, O., Sesi, K. & Fatimah, M. (2023). Assessment of the phytoremediation potential of heavy metal contaminated soil using *Vigna unguiculata* L. (Walp). The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 22, 199–209.

Uchendu, U., Biose, E. & Ubuoh, E. (2020). Assessment of heavy metal concentration in soil impacted by mining overburden in Enyigba, Abakaliki, Ebonyi State, Nigeria. *Journal of Applied Sciences and Environmental Management* 24 7: 1169–1173.

Wang, L., Ji, B., Hu, Y., Liu, R. & Sun, W. (2017). A review on in situ phytoremediation of mine tailings. *Chemosphere* 184 594–600.

WHO (1996) WHO permissible limits for heavy metals in plant and soil. https://www.omics online. org/articles- images/ 2161- 0525-5- 334- t011. Html. Accessed Feb., 2026

Yoon, J., Cao, X., Zhou, Q., & Ma, L. Q. (2006). Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. Science of the Total Environment, 368(2-3), 456–464.

THE IMPERATIVE OF URBAN TREE PLANTING FOR BEAUTIFICATION AND CLIMATE AMELIORATION IN NIGERIAN CITIES

***OBADIMU Olusegun Olusola[1], and OLOWOYO Felix Babatunde[2]**

[1]Forestry Research Institute of Nigeria, PMB 5054, Jericho Hill, Ibadan, Nigeria
[2]Federal College of Forest Resources Management, Ishiagu, Ebonyi State
Corresponding Author's e-mail: obadolusola@gmail.com; 08034309571

Abstract

Nigeria faces the problem of unprecedented urbanization. This has led to severe environmental challenges, including urban heat, air pollution, loss of urban trees, and more. Urban tree planting is also facing multiple challenges, including inadequate funding, limited public awareness, rapid urban expansion, poor maintenance practices, and a lack of comprehensive urban policies. This article examined the critical importance of urban tree planting for beautification and climate amelioration in Nigerian cities. The article asserted that urban forestry can reduce temperatures, improve air quality, enhance property values, and mitigate climate change impacts; however, there has been no seriousness on the part of the government and urban dwellers to incorporate trees and ensure their proliferation in urban centres. The article therefore suggested that, in the long term, tree planting should be incorporated into urban planning and development. There should be commitment that goes beyond political rhetoric, coupled with institutional reforms that promote community engagement in tree planting. The paper concluded that by improving city aesthetics, mitigating urban heat, and enhancing air quality through tree planting, Nigerian cities become more resilient to the growing pressure on the quality of the environment and climate change.

Keywords*: urban forestry, climate change mitigation, urban heat island, green infrastructure, Nigeria, urban beautification, ecosystem services*

Introduction

Nigeria is experiencing One of the most rapid rates of urbanization globally, with urban populations projected to reach 60% of the total population by 2030 (United Nations, 2018). This demographic shift, while indicative of economic transformation, has engendered profound environmental challenges, including the expansion of informal settlements, infrastructure deficits, and the systematic degradation of urban ecosystems. The replacement of vegetated surfaces with impervious materials has intensified the urban heat island (UHI) effect, increased cooling energy consumption, and compromised the aesthetic and ecological quality of Nigerian cities. Urban tree planting emerges as a multifunctional strategy, capable of simultaneously addressing beautification objectives and climate amelioration imperatives. Unlike conventional infrastructural interventions, trees provide ecosystem services that accrue over time, offering cost-effective solutions to urban environmental challenges. Recent scholarship has increasingly recognized urban forestry as a critical component of climate adaptation strategies in developing countries, particularly given limited financial resources for technological solutions (Ale *et al.,* 2024). This paper argues that integrating tree planting into urban planning is an essential strategy for sustainable urban development in Nigeria. The review proceeds by examining the environmental and aesthetic benefits of urban trees, assessing current implementation challenges, and proposing recommendations for scaling urban forestry initiatives.

The Environmental Imperative: Climate Amelioration through Urban Forestry

Mitigation of Urban Heat Islands

The urban heat island effect is One of the most pressing environmental challenges in Nigerian cities, where surface temperatures in built-up areas can exceed those in surrounding rural areas by 3–5°C (Li *et al*., 2022). This thermal differential elevates energy demand for air conditioning, exacerbates heat-related morbidity and mortality, and compromises urban livability. Empirical research across African cities demonstrates that urban green spaces can reduce surface temperatures by 2–3°C in densely populated areas, with cooling effects extending up to 1.7 kilometres from vegetated sites (Ngulani & Shackleton, 2020; Ale *et al*., 2024). In Lagos, vertical greening systems have demonstrated temperature reductions of up to 5°C in areas where they have been implemented, while also providing food security benefits through urban agriculture (Africa Climate Insights, 2024). Similarly, studies in Enugu Metropolis reveal that 58% of farming households have adopted urban tree planting as a climate change mitigation strategy, recognizing benefits such as wind protection, improved soil, and temperature regulation (Apeh *et al.,* 2023). The above indicates the potential for urban forestry to function as a decentralized, adaptive cooling infrastructure that requires minimal maintenance compared to mechanical cooling systems.

Carbon Sequestration and Air Quality Improvement

Urban forests contribute substantially to climate change mitigation by sequestering carbon. Mature urban trees in Sub-Saharan Africa can sequester between 22 and 45 kilograms of carbon annually, with cumulative impacts significant at the municipal scale (Ale *et al*., 2024). Beyond carbon storage, trees function as biological filters, removing particulate matter and gaseous pollutants from the atmosphere. In Nigerian cities, where vehicular emissions and industrial activities contribute to poor air quality, establishing urban tree corridors along major roadways could significantly reduce respiratory disease burdens. According to Ikudayisi *et al*. (2021), vegetation can serve as a natural filter, releasing oxygen while absorbing pollutants—a function particularly vital for public health in densely populated urban centres. The integration of tree planting into urban beautification strategies thus yields dual benefits: aesthetic enhancement and the provision of critical ecosystem services that technological infrastructure cannot replicate cost-effectively.

Urban Beautification and Socio-Ecological Benefits

Aesthetic Enhancement and Property Values

The beautification dimension of urban tree planting extends beyond superficial aesthetics to encompass the Creation of livable, psychologically restorative environments. Urban green spaces provide recreational opportunities, improve mental health outcomes, and enhance social cohesion—factors increasingly recognized as essential components of sustainable urban development (Oluwadare, 2025). In Nigerian cities, where public spaces are often poorly maintained or encroached upon, strategic tree planting can transform degraded landscapes into valued community assets (Adegun, 2017; Mensah, 2014). It has been observed that properties adjacent to well-maintained urban forests command premium prices, suggesting that tree-planting initiatives can generate economic returns through enhanced land values. Ngulani and Shackleton

(2020) also reported that the shade and evaporative cooling provided by urban trees reduce building energy costs, with potential annual savings of approximately $532 per household in comparable African contexts.

Trees in urban areas play a significant role in reducing building energy costs through various mechanisms, such as

(i) Shade Provision: trees provide shade for buildings, especially during hot summer months. By blocking direct sunlight, trees help lower indoor temperatures, reducing the need for air conditioning and lowering energy consumption.
(ii) Cooling Effect: The process of transpiration, whereby trees release moisture into the air, can cool the surrounding environment. This natural cooling effect can lower ambient temperatures in urban areas, further reducing reliance on energy-intensive cooling systems.
(iii) Windbreaks: Strategically planted trees can act as windbreaks, reducing the impact of cold winds on buildings in the winter. This protection can reduce heating costs by minimizing heat loss from structures.
(iv) Energy Efficiency Improvement: The presence of trees can improve the overall energy efficiency of a neighbourhood or city. By promoting cooler environments, trees reduce the heat island effect common in urban areas, thereby lowering overall energy demand for residential and commercial buildings.
(v) Aesthetic Value and Property Value Increase: Trees enhance the aesthetic appeal of urban areas, often leading to higher property values. While this is not a direct reduction in energy costs, increased property values can enhance economic viability and investment in energy-efficient upgrades.
(vi) Urban Planning and Design: Incorporating trees into urban planning and landscape design can lead to more energy-efficient building placements and designs. Thoughtful landscaping can optimize natural heating and cooling, thereby reducing energy costs.
(vii) Carbon Sequestration and Air Quality: Though more indirect, trees help improve air quality and sequester carbon dioxide, contributing to a healthier environment. Improved air quality can enhance public health, potentially reducing healthcare costs associated with pollution. (Akbari *et al*., 2001; McPherson *et al.,* 2008).

Psychological Well-being and Community Engagement

The psychological benefits of urban greenery are well-documented, with exposure to natural environments associated with reduced stress, improved cognitive function, and enhanced overall well-being. In Nigerian urban contexts, where rapid development often outpaces the provision of recreational facilities, street trees and neighbourhood green spaces provide accessible opportunities for nature contact. Furthermore, community-based tree-planting initiatives foster social capital and environmental stewardship, creating avenues for citizen participation and decision-making (Fisher *et al*., 2016; Moskell, 2012; Breyer & Mohr, 2023).

Current Challenges and Barriers in the Nigerian Context

Despite the documented benefits of urban forestry, Nigerian cities face significant implementation barriers. Research indicates that while some municipalities possess green space policies, enforcement is often weak or non-existent (Ale *et al.,* 2024). The absence of comprehensive urban

greening master plans results in ad hoc, unsustainable tree-planting initiatives that fail to achieve systemic impact. Institutional fragmentation between Federal, State, and Local Governments further complicates coordinated urban forestry management.

According to Ikudayisi *et al*. (2021), high levels of poverty and inequality limit investment in green infrastructure, as resources are often directed toward addressing immediate economic challenges rather than long-term environmental sustainability. Cultural perceptions that undervalue urban greenery create additional obstacles, as many communities prioritize infrastructure development over environmental conservation. This mindset, coupled with limited public awareness regarding the benefits of green infrastructure, impedes the mainstreaming of urban forestry in development agendas. The financing of urban forestry remains critically under-addressed in the academic literature, with only 2% of reviewed studies examining sustainable funding mechanisms (Ale *et al.,* 2024). Nigerian cities typically lack dedicated budgets for tree planting and maintenance, resulting in high tree mortality and the failure of urban greening initiatives to reach maturity. The absence of public-private partnership models for urban forestry further constrains resource mobilization.

Urban Tree Planting: The Way Forward

Integration of Green Infrastructure into Urban Planning

For Nigerian cities to realize the benefits of urban tree planting, green infrastructure must be formally integrated into urban planning frameworks. This requires developing urban greening master plans that specify tree cover targets, species selection criteria, and maintenance protocols. Planning regulations should mandate the inclusion of green spaces in new developments, with requirements for tree-lined streets and neighbourhood parks modelled on successful initiatives, just as initiated in Accra and Johannesburg (Africa Climate Insights, 2024).

Strengthening Policy Enforcement and Institutional Coordination

Effective urban forestry necessitates robust institutional frameworks with clear mandates for implementation and enforcement. Concerned governments at various levels should establish dedicated urban forestry units with technical expertise in arboriculture and landscape management. Legal instruments for protecting existing urban trees during infrastructure development must be strengthened and consistently applied.

Community Engagement and Public Awareness

Overcoming cultural barriers requires targeted interventions that demonstrate the tangible benefits of urban trees to local communities. Participatory tree planting programs, school-based environmental Education, and community stewardship models can shift public attitudes toward valuing green spaces. This submission aligns with the work of Apeh *et al*. (2023) in Enugu State, where tree planting involved engaging residents as active participants rather than passive beneficiaries, leading to higher adoption rates and the long-term maintenance of the trees.

Innovative Financing Mechanisms

The challenge of scaling urban tree planting initiatives often hinges on securing adequate funding. Traditional funding, such as governmental budgets and philanthropic donations, always falls short of meeting the need for expansive planting initiatives. To address this gap, we need to adopt

innovative financial approaches that engage communities and enhance sustainability. Therefore, for a sustainable urban tree planting, the following financial mechanisms are proffered:

(a) Raising of Green bonds to generate capital for environmental initiatives. These bonds will be used to attract investors who are interested in sustainable projects that yield both financial returns and positive environmental outcomes. For instance, a city can issue green bonds specifically earmarked for urban forestry initiatives, allowing residents to partake in the ownership of their community's green future. By coupling financial returns with ecological benefits, green bonds foster a deeper connection between citizens and their urban forests.

(b) Payment for Ecosystem Services (PES) to incentivize landowners or municipalities to maintain and grow trees in exchange for financial compensation derived from the ecological benefits provided by those trees. For example, a city may partner with local businesses that benefit from improved air quality and shade, offering tax incentives or grants in return for their contributions to urban tree-planting efforts. This encourages collaboration among various stakeholders.

(c) Community Engagement to allow community members to contribute directly in small amounts to a common fund designated for tree planting projects they believe in. This allows grassroots movements to flourish, helps generate a sense of ownership over local green spaces, builds community solidarity, and promotes environmental consciousness, thereby creating a more invested and united urban populace.

(d). Initiation of corporate Sponsorship and Eco-Partnerships, which permit local companies to sponsor tree planting events as part of their corporate outreach strategies, thereby enhancing their brand image while contributing to their community. These partnerships can be structured through agreements that include naming rights for parks or trees, public recognition in marketing materials, or co-branded community events. By aligning corporate interests with community goals, sustainable funding becomes a shared endeavour that enriches both the ecological landscape and the social fabric of the city.

Conclusion

As Nigerian cities continue to expand under mounting climate pressure, the role of urban greenery, particularly through tree planting, becomes even more critical. What is required now is a deliberate shift in mindset and action. City planners, policymakers, and local communities must move beyond recognition to absolute commitment, embedding tree planting and green infrastructure into urban planning frameworks, governance systems, and everyday civic practice. In doing so, Nigeria can nurture cities that are not only more attractive but also healthier, more inclusive, and more resilient in the face of a changing climate. Ultimately, the journey toward sustainable urban tree planting must be a collective One, drawing on the strengths, passion, and resources of the entire community to ensure that green spaces flourish for generations to come.

References

Adegun, O.B. (2017). Urban green infrastructure in Nigeria: Issues, challenges and prospects. *Sustainable Cities and Society*, 35: 1 – 10

Africa Climate Insights. (2024). Africa's cities innovate to beat the heat. https://africaclimateinsights.org/africas-cities-innovate-to-beat-the-heat/ Accessed March, 2026.

Akbari, H., Pomerantz, M. & Taha, H. (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas, *Solar Energy*, 70(3): 295 – 310.

Ale, S., Adjonou, K., Segla, K. N., Komi, K., Zoungrana, J. B. B., Aholou, C., and Kokou, K. (2024). Urban forestry in Sub-Saharan Africa. *Sustainability,* 17(1): 24. https://doi.org/10.3390/su17010024

Apeh, C. C., Agbugba, I. K. & Mdoda, L. (2023). Assessing the determinants of adopting urban tree planting as a climate change mitigation strategy in Enugu Metropolis, Nigeria. *Sustainability,* 15(16): 12224. https://doi.org/10.3390/su151612224

Breyer, B., & Mohr, C. (2023). Advancing social equity in urban tree planting: Lessons learned from an integrative review of the literature. *Urban Forestry & Urban Greening*, 89: 128116

Fisher, D.R., Svendsen, E.S., & Connolly, J.J.T. (2016). *Urban environmental stewardship and civic engagement: How planting trees strengthens the roots of democracy*. Routledge.

Ikudayisi, A. E., Morakinyo, T. E., & Olusoga, O. O. (2021). Urban green infrastructure in Nigeria: A review. *Scientific African*, 14, e01044. https://doi.org/10.1016/j.sciaf.2021.e01044

Li, X., Stringer, L. C. & Dallimer, M. (2022). The impacts of urbanization and climate change on the urban thermal environment in Africa. *Climate*, 10(11): 164. https://doi.org/10.3390/cli10110164

McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., & Xiao, Q. (2008). Urban tree database for energy and environmental benefits assessment. *Urban Forestry and Urban Greening*, 7(4): 123 – 135.

Mensah, C.A. (2014). Urban green spaces in Africa: Nature and challenges. *International Journal of Ecosystem*, 4(1): 1 – 11

Moskell, C. (2012). *Towards sustainable urban forest governance: Strategies for stakeholder engagement in tree planting and stewardship* (Master's thesis, Cornell University). http://hdl.handle.net/1813/29267

Ngulani, M., & Shackleton, C. M. (2020). Assessment of the contribution of urban greenery to the micro-climate in Bulawayo, Zimbabwe. *Urban Forestry and Urban Greening*, 55: 126839.

Oluwadare, D. M. (2025). Urban resilience through green infrastructure: Mitigating the urban heat island (UHI) effect. *International Journal of Renewable Energy and Environmental Sustainability,* 10(4):1–7. https://doi.org/10.5281/zenodo.17426818

United Nations, Department of Economic and Social Affairs, Population Division. (2018). *World urbanization prospects*: *The 2018 revision*. United Nations. 103 p. Accessed, February 2026.

FOREST DEGRADATION IN NIGERIA: CONSERVATION CHALLENGES, RESPONSES, AND PATHWAYS FORWARD

***Oyetunji, P. O.[1], Ibironke, Y. T.[1] and Akinyemi, G. O.[1]**

[1] *Onigambari Research Station, Forestry Research Institute of Nigeria, Ibadan, Nigeria*
**Corresponding Email: oyetunjisiji@yahoo.com*

Abstract

Forest degradation poses a critical threat to Nigeria's environmental sustainability, biodiversity conservation, and rural livelihoods. This paper examines the drivers, challenges, and conservation responses to forest degradation in Nigeria, and proposes strategic pathways for sustainable forest management. The study identifies agricultural expansion, illegal logging, fuelwood extraction, population growth, poverty, weak governance, land tenure insecurity, and market pressures as key contributors to forest degradation across Nigeria's diverse ecological zones. Major conservation challenges include inadequate policy implementation, institutional weaknesses, chronic underfunding of forestry programs, insufficient technical capacity, limited baseline data, and insecurity in forest areas. Despite these obstacles, Nigeria has implemented various conservation interventions, including national forest policies, protected area systems, afforestation initiatives, and other community-based engagements. However, many of these efforts have achieved limited success due to poor enforcement, political instability, inadequate local participation, and funding constraints. This research proposes critical pathways forward, including comprehensive policy and governance reforms, improved monitoring systems utilizing modern technologies, enhanced community participation and empowerment, cross-sectoral collaboration, climate change adaptation strategies, and strengthened regional and international cooperation. Effective forest conservation in Nigeria requires integrated approaches that address both the environmental and socioeconomic dimensions of forest degradation, while ensuring inclusive governance and sustainable resource management.

Keywords: forest degradation, deforestation, sustainable forest management

Introduction

Forest resources refer to the biotic and abiotic components of forest ecosystems that meet human requirements and promote environmental health, comprising Timber and Non–Timber Forest Products (NTFPs). These resources include wood, fruits, nuts, medicinal plants, and various ecosystem services such as carbon sequestration and habitat provision (Bonan, 2008; Smith *et al*., 2012; FAO, 2020). The utilization of Nigeria's forest resources is in many folds, which include the supply of wood fuel for domestic cooking and heating in rural and urban poor areas; pole-sizing for housing, fencing, and furniture; construction and joinery; weaving fibers for baskets, nets, and furnishings; and special medicinal trees for drugs, incense, and carving (Aribisala, 1993; Oriola, 2009). Other uses include watershed protection to manage runoff, storage, and soil nutrient management; atmospheric regulation, which happens when solar heat is absorbed in evapotranspiration; and CO_2 sequestration. Trees as a forest resource also serve in erosion control, restoring degraded landscapes, stabilizing dunes, providing shelter belts, and maintaining soil

nutrients and structure in land banks. Pulpwood for newsprint, papers and boards, containers, textiles, veneer logs for plywood and furniture, sawn timber for lumber, furniture, joinery and construction, transmission poles, etc., are among the forest resources that are required in industries and for export. (Ayeni, 2013). The main product of a forest ecosystem is trees, and their production is determined by the nature and size of the forest (Babulo *et al.*, 2009). A forest ecosystem includes abiotic components (air, sunlight, moisture, and Soil) and biotic components (producers, consumers, and decomposers).

Why Forest Degradation is a Critical Issue in Nigeria

Between 1981 and 1994, Nigeria lost 3.7 million hectares of its forests, and it is estimated that less than 4% of the country's rainforest cover is left (Buba *et al*., 2020). Forest degradation in Nigeria is an urgent environmental and socioeconomic issue due to its adverse impacts on biodiversity, climate stability, and human livelihoods. This crucial issue is caused by several interrelated variables, corroborated by data from Nigerian and foreign sources, as well as internal information. Local dwellers' dependence on forest resources for energy and livelihood is another significant cause. Fuelwood and charcoal remain the principal domestic energy sources for heating and cooking in many parts of Nigeria. Because of this over-reliance on forest biomass, trees have been harvested excessively, contributing to the gradual degradation of forest ecosystems. In addition, rural communities rely on forests for non-timber forest products, including nuts, fruits, and medicinal plants, which places more pressure on forest resources in the absence of sustainable management practices (Arnold & Pérez, 2001; Shackleton & Pandey, 2014).

The degradation of Nigeria's forests has significant impacts on the environment and on humans. The ability of degraded forests to provide crucial ecosystem services, including carbon storage, soil fertility maintenance, and water management, is reduced. Increased soil erosion, decreased agricultural output, biodiversity loss, and increased susceptibility to climate change can result from this. Furthermore, millions of people who directly rely on forests for their livelihoods are at risk due to the loss of forest resources (Hansen *et al*., 2013). The combined consequences of population pressure, dependency on forest resources, poor governance, and environmental change have made forest degradation a serious problem in Nigeria. Adopting sustainable forest management techniques, enhancing environmental regulations, and fortifying institutional structures are necessary to address this issue and guarantee long-term conservation and sustainable use of forest resources.

Conceptual Framework

The Concept of Forest Degradation

Forest degradation is the alteration of the condition of the forest resulting in a change (as opposed to loss) or reduction in the coverage without necessarily a loss from its original condition, but a negative change to its structure (loss of biodiversity or a decrease in biomass) that diminishes its capacity to generate services and products (Tovar, 2009). Forest degradation occurs when forest ecosystems lose their capacity to provide important goods and services to people and nature (IUCN, 2021). Oyediji and Adenika (2022) note that forest degradation is a process that negatively affects a forest's characteristics, leading to a decline in the value and production of its goods and services. According to Korom *et al.* (2022), forest degradation extends beyond the biophysical to

include social conditions, with implications for canopy cover, stand structure, and aboveground biomass. By collecting consistent forest inventory data and monitoring changes in forest biomass and structure, national forest monitoring systems can be used to measure and assess forest degradation (Tavani *et al*., 2009).

Deforestation and Forest Degradation

While both deforestation and forest degradation have negative impacts on forests, the degree and kind of impacts vary (FAO, 2000). Olagunju (2015) mentions that deforestation is the conversion of forested areas to non–forested land for several purposes, primarily agricultural, industrial, and urbanization, while degradation results from disturbances that cause changes in forest attributes, leading to a reduced productive capacity of the forest.

Table 1 – Differences Between Forest Degradation and Deforestation

Aspect	***Deforestation***	***Forest Degradation***
Definition	*Conversion of forest land to non-forest land use*	*Reduction in forest quality or canopy cover while the remaining forest*
Forest Area	*Decreases permanently or long-term*	*Usually remains the same*
Impact	*Complete loss of the forest ecosystem*	*Partial damage to forest structure and functions*
Examples	*Clearing forests for farming or urban development*	*Selective logging, repeated fires, and overgrazing*

Source: FAO, 2000

Linkages between forest degradation, livelihoods, and environmental stability

Nigeria's forests are under stress due to several factors, including increased agricultural production, population growth, and a high reliance on fuelwood for energy (FAO, 2020). Northeastern Nigeria, including Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe, is particularly susceptible to forest degradation due to its semi-arid Sahelian climate, extreme poverty, and prolonged conflicts among farmers, herders, and Boko Haram. Socioeconomic issues have rendered this area even more dependent on forest resources. For example, forests in Northeastern Nigeria, where many rural people are poor, provide vital resources such as food, fuelwood, and medicinal plants (Zahradeen *et al.*, 2019). Additionally, many displaced individuals in Nigeria, particularly in the northern region of Nigeria, have been forced to rely mostly on forests for shelter and basic needs due to insurgencies and violent conflicts, which have accelerated the degradation of forests (Baba, 2021). In Northeastern Nigeria, forest degradation has severe environmental and socioeconomic implications. Local food security and livelihoods are directly threatened by the ongoing loss of forest cover, which increases soil erosion, lowers agricultural productivity, and impacts water availability (Zahradeen *et al.*, 2019).

Ecological services like soil fertility, nitrogen cycling, and climate regulation are adversely affected by forest destruction. The forest's capacity to store carbon and control regional climate conditions is reduced when vegetation is removed. Additionally, it reduces soil fertility and exposes it to erosion, further reducing surrounding agricultural output. (Lambin *et al.*, 2003). Forest degradation in northeastern Nigeria has serious environmental and socioeconomic implications. Local food security and livelihoods are directly threatened by the ongoing loss of forest cover, which exacerbates soil erosion, reduces agricultural productivity, and alters water

availability, thereby posing a direct threat to local food security and livelihoods (Zahradeen *et al.*, 2019).

In Nigeria, socioeconomic factors, including poverty, rapid population growth, and rising demand for land and forest products, are also strongly linked to forest degradation. Recognizing that so many rural communities depend on trees for food, energy, and revenue, forest resources are continuously exploited. However, if the area remains designated as forest, this pressure eventually leads to the depletion of forest biomass and the degradation of forest ecosystems (Geist & Lambin, 2002). Nigeria's forest degradation has consequences that extend beyond environmental impacts. Degraded forests lack the capacity to maintain water cycles, regulate the climate, and prevent soil erosion. The availability of timber and non-timber forest products, which sustain rural livelihoods and national economic activity, is also impacted by the decline in forest quality. Thus, understanding forest degradation is crucial for establishing conservation policies and sustainable forest management plans in Nigeria (Hosonuma *et al.*, 2012; Lambin *et al.*, 2003).

Overview of Nigeria's Forest Governance Structure

Nigeria's forestry regulations evolved over the years, originating in 1890 with the Forestry Ordinance, which established forest reserves (Ujor, 2018). With the implementation of the Forestry Ordinance and the establishment of a forestry service headed by forest conservators, the first forest reserve was established in 1901 (Imasuen, 2013). The colonial government laid the foundation in 1956 with the passage of the Forestry Act, which included provisions for both the establishment and protection of forests. It outlined penalties for violations and created protected zones (Esavwede & Abijogun, 2022). It was passed during the colonial era with the goals of creating forest reserves, regulating the demand for forest resources, and promoting sustainable forestry practices. Despite efforts at reforestation, there are issues with enforcement and coordination across government levels. In addition, the National Forest Policy 2020 is based on 30 components encompassing the seven internationally recognized components for sustainable forest management and raising the percentage of forest cover from 6% to 25% by 2030 (Global Forest Goals, 2024).

Drivers and Patterns Of Forest Degradation In Nigeria

Direct drivers of forest degradation

- **Agricultural expansion and shifting cultivation**

Significant environmental impacts, such as biodiversity loss, soil erosion, and decreased carbon sequestration capacity, have resulted from the conversion of forested areas to farmlands, especially near riverbanks and fertile zones, as well as logging motivated mainly by agricultural expansion, including wood extraction and displacement related to conflict (Yaro *et al*., 2025). In Nasarawa State's Odu local government area in North Central Nigeria, agriculture has also contributed to changes in the forest. Since the 1970s, residents in this area have relied solely on farming and forest resources for their livelihoods. (Chunwate *et.al*. 2025).

- **Logging and timber extraction (legal and illegal)**

According to the Environmental Investment Agency's (EIA) 2017 report, over 1.4 million illegal rosewood logs from Nigeria, worth US$300 million, were shipped to China, revealing the largest timber-smuggling operation in history. Nigeria's deforestation rate is primarily driven by illegal logging in the country's southwest and south-south forest belts (Adediran *et al*., 2016).

- **Fuelwood collection and charcoal production**

The extraction of biomass in the form of forest products, such as fuelwood, timber, and fodder, alters wildlife habitat and constitutes One of the most important threats to forests and wildlife (Shaanker *et al*., 2004). Due to unsustainable logging to produce fuelwood and charcoal, areas near Nigerian communities exhibited signs of forest degradation (Yaro *et al.*, 2025).

- **Mining activities**

Mining is a profitable activity that encourages development, which may lead to population increase and the subsequent loss of forests. It is also extremely destructive and intensive (Mather, 2001; Sands, 2005). Petroleum exploration, exploitation, and oil spills are currently destroying forests in Nigeria (Akachuku, 2007). In Nigeria, the mining of various minerals, including coal, barite, and tin, has scarred the landscape and destroyed forests.

Indirect drivers of forest degradation

- **Population growth and demographic pressures**

In general, FAO and international organizations believe that poverty and population expansion are the primary drivers of forest loss and that they can help address the issue by promoting development and reducing population growth. On the other hand, the World Rainforest Movement and numerous other NGOs maintain that the majority of forest loss is directly caused by unrestrained development and the excessive consumption patterns of wealthy industrialized nations (Sambe *et al*., 2018). Nigeria's unemployment rate is closely linked to its growing population; the lack of employment opportunities drives young people in rural areas to engage in illegal forest activities as a means of subsistence. (Owolabi, 2019).

- **Poverty and livelihood insecurity**

Poverty is an indirect driver of change: "People expand agricultural land in the Forest Reserve of Nasarawa State, North Central Nigeria, to get their livelihood because they have no good way of getting food or money to survive." This is One of the main causes of changes in the forest reserves. "Poverty is a significant driver of changes in the forest reserve," emphasized a community leader in Doma, Nasarawa State. To meet their financial needs and maintain their way of life, people exploit this forest, often removing portions of it to access and use its resources (Chunwate *et al*., 2025).

- **Weak governance and institutional failures**

Illegal logging of forest trees and poor government policies are the main causes of forest cover loss. Inadequate regulations seriously threaten the forest industry and the base of forest resources

in Nigeria, and at times lead to unrestricted exploitation or illegal logging. This stems from the State Forest Department's inability to demonstrate political influence when granting timber permits and regulating the scale of felling cycles and theft to meet minimum girth felling limits. (Owolabi, 2019).

The socio-political environment, particularly the insurgency in northeastern Nigeria, significantly shaped the socioeconomic and conflict dynamics of forest exploitation. Communities' greater dependence on forest resources for survival due to displacement underscores the need for integrated environmental and humanitarian initiatives. Inadequate community involvement and weak enforcement of forest conservation laws have led to the unsustainable use of forest resources. (Yaro *et al.*, 2025)

- **Land tenure insecurity**

One of the main factors influencing deforestation and forest degradation is the lack of property rights or land rights. (Labin *et al*., 2018) Cultivators around the forest frontier are forced to cut down more forests to survive, as they often lack land titles and are displaced by others who acquire tenure over the areas they inhabit (Deacon, 1999). In general, poorly defined tenure is harmful to both people and forests because unclear and insecure property rights may make it harder for financial institutions and land users to adopt sustainable land-use practices that limit deforestation (Motel, 2009). Insecure property rights encourage forest destruction. by providing landowners the opportunity to remove forests, cultivate crops, and construct buildings in an effort to claim land (Araujo, 2009).

- **Market demands and economic factors**

A temporary rise in commodity prices tends to raise expectations of future prices, increasing the likelihood that land will be cleared and converted to agriculture (Angelsen, 1995; Sunderlin, 2000). Several development initiatives have failed because they have, intentionally or unintentionally, supported the development of those who already own land, authority, influence, and political clout. The rural poor become even more isolated, and as a result, pressure on the forests increases. Also, there is no encouragement for low-income farm households or commercial loggers to consider how their activities affect the environment. According to Panayotou (1990), such unaccounted costs result in economic failures, including local market failures, policy failures, and global appropriation failures.

- **Cultural and social practices**

Over the years, many of our traditional forest management regions have maintained yields of many products (such as the myth of the "Evil Forest"). However, they have recently faced degradation and economic pressure. (Owolabi, 2019)

Forest Conservation Challenges In Nigeria

There have been several obstacles affecting conservation efforts in Nigeria. According to Salamatu *et al*. (2023), the peculiar and prevailing social, political, and economic realities, which have stifled

commensurate development relative to the human resource base, make the realization of appropriate conservation outcomes difficult.

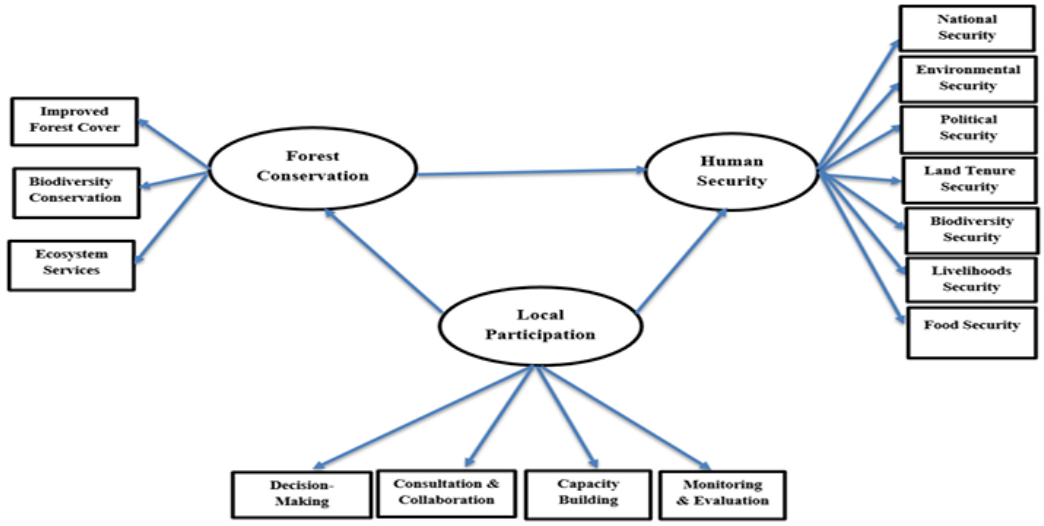


Figure 1 – Conceptual Framework for Forest Conservation

Source: Ebire *et al.* (2025)

- **Policy and Governance Challenges**

Weak government policies, governance problems, and implementation issues have undermined conservation effectiveness in Nigeria. Okoye and Ogu (2025) note that among the environmental challenges facing Nigeria are non–implementable laws and policies, as well as a weak and uncoordinated institutional framework. Existing forestry laws, including various state laws, are largely outdated and ineffective (Idehen & Bello, 2025). Forest degradation has continued because regulatory enforcement has been weak. Overlapping mandates among regulatory agencies, institutions, and personnel have prevented forest governance from having a consistent impact. Issues of jurisdiction, especially between federal and state agencies, have contributed to inefficiencies in government institutions' ability to address conservation challenges in Nigeria. The uncoordinated land-use policy has been a major contributor to the environmental degradation of the country (Usman & Adefalu, 2010).

- **Financial and Resource Constraints**

Chronic underfunding of forestry institutions has remained a structural constraint limiting their effectiveness and forest conservation programs. According to Ayeni (2013), funding constraints have not been the reason for the lack of use of remotely sensed data in forestry management in the past. A paucity of funds from all levels of government has affected wildlife conservation in Nigeria negatively (Adewumi *et al.*, 2018). The persistent inadequate funding of the forestry subsector affects afforestation initiatives, strains research and limits the efforts of the already strained personnel. Olukwu – Kalu *et al.* (2022) allude that the quality of public spending on forestry in Nigeria is dismal and neglected.

- **Socioeconomic and Livelihood Pressures**

According to Ayeni (2013), several challenges facing conservation efforts include a widening communication gap between the forestry industry and landowners, as well as a high level of poverty among the rural populace. Forest conservation issues have been stressed by the marginalization of local communities (Ebire *et al.,* 2025). There is an existing gap in public awareness on conservation and environmental Education in Nigeria. Rural communities depend on forest resources for their survival and livelihoods, which can affect any conservation efforts. According to Ahmed and Oruonye (2017), infringement of forest reserves and violations of protected area boundaries have a greater impact on the local economy, as they threaten the conservation of forest resources and the diversity found in such areas. The lack of stakeholder engagement, collaboration and coordination between government agencies, the private sector, civil societies, and local communities have negatively affected the implementation of sustainable forest management practices (Areo *et al.*, 2023)

- **Technical and Knowledge Gaps**

Technical and knowledge challenges have also strained forest conservation efforts in Nigeria. Despite the growth of advanced technologies like artificial intelligence, it has seen minimal use in forestry in Nigeria. The knowledge gap also makes it difficult to know the required information on biodiversity in Nigeria and deforestation trends. The absence of reliable, broad data on forestry impedes research, prevents data-driven decision-making and policy-making, and hinders the development of effective conservation strategies.

- **Climate Change**

According to Areo *et al.* (2023), changing climate patterns are affecting forest conservation strategies in Nigeria. Biodiversity loss, forest fires, and deforestation make implementing sustainable forest management practices an uphill task. Climate change and environmental degradation are significant challenges facing Nigeria's environmental governance (Okoye & Ogu, 2025).

- **Insecurity**

Insecurity in Nigeria has been on the rise in recent years, with forests being a hub for kidnappings, banditry and other vices. The prevalence of forest crime has been on the rise due to governance, corruption, and illegality in the forest sector, especially in sub-Saharan Africa, including Nigeria (Ahmed & Oruonye, 2017). Security challenges involving forests have made accessing forest resources, collecting data and implementing strategies very difficult.

Conservation Responses and Interventions

Forest conservation worldwide has been motivated by a wide variety of societal and cultural values, including their roles as key constituents of the landscape, their potential to mitigate climate change, and their importance in preserving biodiversity (Arevalo & Ladle, 2016). Several intervention efforts have been deployed by the Nigerian government and other national planners to conserve the country's forest resources, especially given the pressure they face.

- **Natural Forest Policies and Legal Frameworks**

The federal and state governments of Nigeria have been tasked with developing forest policies, given forests' importance to the country's economy, welfare, and population. Ekakitie and Enakireru (2024) mention that forest legislation provides the structural framework within which forest policies are set and, in turn, reflects their objectives and priorities. The constitution of the Federal Republic of Nigeria acknowledges the significance of the environment in its chapter II, which addresses the Fundamental Objectives and Directive Principles of State Policy. Section 20 therein states that 'The state shall protect and improve the environment and safeguard the water, air, and land, forest and wildlife in Nigeria' (Ganiyu, 2024). According to Idehen and Bello (2025), this began with the enactment of a Forestry Law in 1938, and in 1956, the Forestry Act, promulgated by the colonial government, aimed to regulate the exploitation of forest resources, establish forest reserves, and promote sustainable forestry practices. Sobere (2024) identifies several governmental legal actions, such as the National Environmental Standards and Regulatory Enforcement Agency Act (2007), the Nigerian Urban and Regional Planning Act (1992), and the Environmental Impact Assessment Act. These frameworks and government policies provide the basis for the Creation of national parks, forest reserves, research institutions, government agencies, and conservation programs. Despite extensive forest policies and legislation, these laws have generally been ineffective due to corruption, lack of political will, poor enforcement, and underfunding of regulatory institutions.

- **Protected Areas and Forest Reserve Systems**

In a bid to address forest degradation and implement sustainable forest management strategies, the federal and state governments have created national parks and forest reserves. Protected areas and forest reserves in Nigeria cover about 107,527 km^2 and have been designated for conservation, management, and propagation of wild animals comprising 1,160 constituted forest reserves, including 6 national parks, 20 game and wildlife sanctuaries, 13 proposed game reserves/wildlife sanctuaries and 8 strict nature reserves (Ayeni, 2013). According to Ekakitie and Enakireru (2024), there are 8 national parks in Nigeria namely Chad Basin National Park, Cross River National Park, Gashaka – Gumti National Park, Kainji Lake National Park, Kamuku National Park, Okomu National Park, Old Oyo National Park and Yankari National Park.



Figure 2 – National Parks in Nigeria

Source: Adaeze *et al.*, (2018)

Forest reserves that were once managed for sustainable timber production have now become highly fragmented and degraded (Ebire *et al.*, 2025). Olukwu-Kalu *et al.* (2022) affirm this, stating that forests in Abia State have been excessively exploited without significantly enhancing their growth, structure, stock, or species density. Many of these protected areas have suffered neglect,ct turning into crime hotspots and at the mercy of poachers and illegal tree fellers.

- **Afforestation and Reforestation Initiatives**

Different government administrations have flagged numerous schemes aimed at afforestation. Many afforestation and reforestation strategies have been implemented in collaboration with private and international organizations, including the United Nations (UN), the World Bank, and the Food and Agriculture Organization (FAO).

In 1977, the Nigerian government established the National Committee on Arid Zone Afforestation Project (AZAP) to develop a suitable afforestation program to reduce desertification and improve human livelihoods (Gbadebo, 2022). According to Medugu *et al.* (2009), in collaboration with the World Bank, the Nigerian government embarked on an initial Forestry I program (1979 - 1986) with very little success before attempting the Forestry II program (1987 – 1996). Presently, at the national level, the Great Green Wall project is on course, a regional initiative in Africa to address desertification more coherently (Ibrahim & Muhammad, 2015). This endeavor largely focuses on

the worst-affected states, including Adamawa, Borno, Yobe, Bauchi, and Gombe in the northeast and Kano, Katsina, Jigawa, Sokoto and Zamfara in the northwest (Geidam & Mohamad, 2022).

According to Geidam and Mohamad (2022), the Boko Haram insurgency has been the major obstacle to afforestation in Northern Nigeria. Gwatiyap *et al.* (2022) add that the challenges associated with afforestation and reforestation in Nigeria include poor seedling quality, drought, accelerated land degradation, and increasing demand for fuelwood. Many afforestation programs also suffer from political instability, underfunding and a lack of local participation.

- **Community-Based Forest Management Approaches**

Local communities play an integral part in sustainable forest management in Nigeria. According to Azeez and Ajayi (2022), people's role in maintaining forest biodiversity is very important, requiring a delicate balance and positive perceptions and attitudes. Even though many rural communities have relied on forests for their survival, traditional institutions have developed methods to protect biodiversity through matrilineal cults, age groups, sacred groves, and even clan elders (William, 2025). Local communities possess extraordinary knowledge of how to manage forests, utilize them sustainably, and have wildlife adapted to a wide range of conditions (Bisong *et al.*, 2016). The failure of many afforestation efforts has been attributed to the lack of inclusion of indigenous rural communities.

- **The Role of Non-Governmental Organizations (NGOs) and the International Community**

The scourge of forest degradation has become a global issue, thus emphasizing the need for international partnerships and NGOs. Funding for forestry development and forest management in Nigeria relies entirely on annual allocations and occasional donations, so ultimately NGOs (Olon ukwu – Kalu, Riki and Agbeja, 2022). According to Sobere (2024), the contemporary international forest regime consists of substantial soft laws (non – binding) as well as international and regional treaties, including the United Nations Conference for Environment and Development (UNCED), 1992 Convention on Biological Diversity (CBD), International Tropical Timber Agreement (ITTA) 2006, Agency 21, etc. Ekakitie and Enakireru (2024) note that Nigeria is a signatory to conventions on environmental protection, including, but not limited to, the following.

- The Convention on the Prevention of Marine Pollution by Dumping of Waste and other Matters (1973)
- The International Convention for the Prevention of Pollution of the Sea by Oil (1954)
- The Basel Convention on the Control of Transboundary Movement of Hazardous Waste and Its Disposal

Despite significant funding to the forestry subsector from the private sector, there is very little information on the extent of contributions from private investment by institutional investors, commercial banks, NGOs, and the philanthropy sector (Olukwu-Kalu, Riki and Agbeja, 2022). According to Olunusi *et al.* (2025), efforts to introduce Payment for Ecosystem Services (PES) policies in Nigeria, such as REDD+ projects, have faced significant implementation challenges and, without legal backing and long-term financing, have failed to gain traction in the conservation landscape.

Forestry Conservation Pathways Forward For Nigeria

With forest conservation identified as critical to preserving biodiversity, protecting livelihoods, and mitigating climate change, there are important pathways for the Nigerian government and other national planners to pursue.

- **Policy and Governance Reforms**

There is a need to review a forestry country's forestry laws to ensure they are current, enforceable, and practical. According to Idehen and Bello (2025), urgent steps are required to enact a comprehensive National Forestry Act incorporating existing state forestry laws to unify forest management and conservation. Sobere (2024) advocates that the Land Use Act be amended to integrate environmental conservation issues, including forestry protection, biodiversity conservation, drought, and desertification control. Beyond creating laws, there is a need to implement them by demonstrating the required political will and establishing appropriate institutional frameworks. The government and other national planners must fund regulatory institutions and agencies to enable them to have the tools and personnel needed for thefor the enforcement of laws.

- **Improved Monitoring and Data Systems**

The Nigerian government can invest in data and information management systems to promote the collection, analysis, and dissemination of data and information on forest resources and forest management (Areo *et al.*, 2023). Technologies such as artificial intelligence (AI), big data analytics, and the internet of things (IoT) can be used to improve forest management in Niger, particularly in mapping, tracking anthropogenic activities, administration, and forest conservation (Oyetunji *et al.*, 2024). Addressing data scarcity by encouraging research, investing in personnel, and promoting transparency to support forest conservation efforts.

- **Community Participation, Empowerment and Governance**

Communities should be stakeholders in forest management and actively promote sustainable practices in the forests around them (Idehen & Bello, 2025). Educating local communities around forests about conservation will help reduce pressure on forests, especially from new settlements (Oyediji & Adenika, 2022). According to Aro *et al.* (2023), this can be done through public outreach campaigns, training and capacity-building programs, and the development of educational materials that highlight the importance of sustainable forest management practices. Inclusiveness is important because it enables broad-based participation in local public decision-making to sustain forest management with economic objectives (Arifalo, 2024). It is pertinent that the Nigerian government reduce poverty levels, particularly in rural areas, to relieve the pressure on forest resources for livelihoods, survival, and energy.

- **Cross – section collaboration and Integration**

Forest conservation in Nigeria requires stronger collaboration across multiple sectors, levels of government (local, state, te and federal), and agencies and institutions. Integrating forest conservation goals into national development planning can help address these pressures. William

(2025) advocates for the Creation of a conservation task force across all states, formed from the Integration of government agencies, individuals, local communities, and NGOs. Strengthening coordination among federal, state, and local governments, as well as collaboration with the private sector, civil society organizations, and academic institutions, can improve policy coherence, enhance conservation outcomes, and reduce overlapping mandates.

- **Climate Change Adaptation and Mitigation Strategies**

The Nigerian government can develop and implement climate-smart forestry programs such as afforestation and reforestation, the development of climate-resilient forest management strategies, and the Integration of climate change considerations into forest policies and plans (Areo *et al.*, 2023). These strategies can also support Nigeria's commitments to global climate agreements and strengthen long-term environmental sustainability.

- **Regional and International Cooperation**

Nigeria can coordinate their forest management strategies across multiple countries, ensuring effectiveness and efficiency. While Nigeria partners with many international organizations on climate change, there is a need for greater participation and cooperation. According to Anwadike (2020), the government needs to ratify the remaining conventions and treaties in biodiversity conservation. Strengthening partnerships with regional bodies, international organizations and development agencies can also provide access to technical expertise, financial resources and knowledge-sharing platforms that support sustainable forest management.

Conclusion and Recommendations

Effective forest conservation in Nigeria requires a comprehensive, coordinated approach that addresses the structural challenges facing the forestry subsector. Strengthening policy and governance frameworks should be a priority, particularly through the review of existing forestry laws and the development of a comprehensive national forestry policy that harmonizes federal and state regulations. Equally important is improving institutional capacity through adequate funding, stronger enforcement mechanisms, and the development of technical expertise within regulatory agencies. Investments in monitoring systems, data collection, and emerging technologies can significantly improve the management of forest resources by enabling data-driven decision-making and better tracking of deforestation and illegal activities.

Another critical recommendation is to promote community-based forest management and inclusive governance. Rural communities depend heavily on forest resources for their livelihoods, making their inclusion essential for sustainable conservation outcomes. The Nigerian government should strengthen public awareness campaigns, provide environmental Education, and create livelihood alternatives that reduce pressure on forest ecosystems. Encouraging collaboration among government agencies, private-sector actors, civil society organizations, and international partners can also foster more integrated and effective conservation strategies. Regional and international cooperation will remain vital for providing technical assistance, financial support, and knowledge exchange to address transboundary environmental challenges such as desertification and climate change.

In conclusion, forests play a vital role in maintaining biodiversity, regulating climate, and supporting livelihoods in Nigeria. Despite numerous conservation initiatives and policy frameworks, the effectiveness of forest conservation efforts has been constrained by governance challenges, limited funding, socioeconomic pressures, and weak institutional coordination. Addressing these challenges requires a renewed commitment to sustainable forest management that integrates policy reform, community participation, technological innovation, and international cooperation. By adopting a more coordinated and inclusive approach to forest governance, Nigeria can better protect its forest resources and ensure their sustainability for future generations.

References

Adaeze, J. E., Abubakar, A., & Jatau, D. F. (2018). Ethnobotany among the Gashaka inhabitants of Gashaka Gumti National Park, Taraba State, Nigeria. *Journal of Forestry, Wildlife and Environment, 10*(4), 17–23.

Adediran, D. I., Okunola, R. A., & Akindutire, A. F. (2016). Criminality: Illegal logging of woods in Nigeria's Southwest forest belt—*African Journal of Criminology and Justice Studies (AJCJS), 9*(1).

Adewumi, A. A., Idowu, E. O., & Oyeniran, B. H. (2018). Issues, challenges and strategies of wildlife conservation in Nigeria. *International Journal of Life Sciences Research, 6*(2), 37–44.

Ahmed, Y. M., & Oruonye, E. D. (2017). Challenges in enforcing forestry legislation in Taraba State, Nigeria. *International Journal of Geography and Geology, 6*(3), 48–57.

Akachuku, A. C. (2007). Disappearing forests: The consequences and challenges of sustainable development in Nigeria. In *Proceedings of the 31st Annual Conference of the Forestry Association of Nigeria*, Makurdi, Benue State, Nigeria (pp. 48–61).

Angelsen, A. (1995). Shifting cultivation and deforestation: A study from Indonesia. *World Development, 23*, 1713–1729.

Anwadike, B. C. (2020). Biodiversity conservation in Nigeria: Perception, challenges and possible remedies. *Current Investigations in Agriculture and Current Research, 8*(4), 1109–1115.

Araujo, C., Bonjean, C. A., Combes, J. L., Motel, P. C., & Reis, E. J. (2009). Property rights and deforestation in the Brazilian Amazon. *Ecological Economics, 68*(8), 2461–2468.

Areo, O. S., Omole, A. O., Ajidele, F. A., Adejoba, A. L., & Odebunmi, G. F. (2023). Modern forest operation techniques in Nigeria: Challenges and solutions. *Australian Journal of Science and Technology, 7*(2), 76–82.

Aribisala, O. A. (1993). *Raw materials revolution and impact on industrialization in Nigeria.* Mednet Publications Ltd.

Arifalo, S. F. (2024). Assessment of community participation in forest conservation in Ondo State, Nigeria. *African Journal of Agriculture and Food Science, 7*(3), 39–55.

Arnold, J. E. M., & Pérez, M. R. (2001). Can non-timber forest products match tropical forest conservation and development objectives? *Ecological Economics, 39*(3), 437–447.

Ayeni, A. O. (2013). Forestry in Nigeria: A brief historical overview, phases of development and present challenges—African Association of Remote Sensing of the Environment (AARSE) Special Publication.

Azeez, I. O., & Ajayi, R. A. (2022). Knowledge perceptions and attitudes toward forest conservation practices in Southwestern Nigeria. *XV World Forestry Congress*, Seoul, Korea.

Baba, A. (2021). Deforestation in conflict-affected regions of Nigeria: Impacts and Policy Responses. *Journal of Environmental Studies, 34*(4), 113-128

Babulo, B., Muys, B., Nega, F., Tollens, E., Nyssen, J., Deckers, J., & Mathijs, E. (2009). The economic contribution of forest resource use to rural livelihoods in Tigray, Northern Ethiopia. *Forest Policy and Economics, 11*, 109–117.

Bisong, T. L., Ogbonna, K. L., & Kyari, I. U. (2017). Effect of community participation in forest conservation in the Ikom Agricultural Zone of Cross River State. *Global Journal of Agricultural Sciences, 16*, 31–35.

Bonan, G. B. (2008). Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science, 320*(5882), 1444–1449.

Buba, F. N., Gajere, E. N. & Ngum, F. F. (2020). Assessing the Correlation Between Forest Degradation and Climate Variability in the Oluwa Forest Reserve, Ondo State, Nigeria. *American Journal of Climate Change, 9*, 371-390

Chunwate, B. T., Marchant, R. A., Jew, E. K. K., & Stringer, L. C. (2025). Understanding local perspectives on the trajectory and drivers of change in gazetted reserves in Nasarawa State, North Central Nigeria*: land, 14*(7), 1450.

Deacon, R. T. (1999). Deforestation and ownership: Evidence from historical accounts and contemporary data. *Land Economics, 75*, 341–359.

Ebire, M. O., Adeniyi, I. A., & Agbonifo, J. (2025). Forest conservation and human security: A qualitative study of forest reserves in Ondo State, Nigeria. *NIU Journal of Social Sciences, 11*(3), 25–36.

Ekakitie, G. W., & Enakireru, E. O. (2024). Redressing the challenges of unsustainable utilization of forestry resources in Nigeria. *Journal of Law and Sustainable Development, 12*(12), 1–28.

Esavwede, J. P., & Abijogun, O. M. (2022). Nigeria without oil: A call for a paradigm shift to forest laws as a tool for harnessing forest resources in Nigeria. *Journal of Legal, Ethical and Regulatory Issues, 25*(6), 1–9.

Food and Agriculture Organization of the United Nations. (2000). *Global forest resources assessment 2000: Main report.* Rome: FAO.

Food and Agriculture Organization of the United Nations. (2002). *Second expert meeting on harmonizing forest-related definitions for use by various stakeholders.* Rome: FAO.

Food and Agriculture Organization. (2005). *Global forest resources assessment 2005: Terms and definitions.* FAO.

Food and Agriculture Organization of the United Nations. (2009). *State of the world's forests 2009.* Rome: FAO.

FAO. (2010). *Global forest resources assessment 2010: Terms and definitions.*

FAO. (2010). *Challenges and opportunities for carbon sequestration in grassland systems.*

FAO. (2011). *State of the world's forests 2011.*

FAO. (2012). *Livestock and landscape.*

Ganiyu, Y. (2024). An appraisal of the legal and policy framework on the conservation of biodiversity in Nigeria: Challenges and way forward. *LexScripto, 1*(1).

Geidam, A., & Mohamad, L. Z. (2022). Factors affecting afforestation program in Nigeria: Building a conceptual framework. *International Journal of Academic Research in Business and Social Sciences, 12*(12), 1444–1452.

Geist, H. J., & Lambin, E. F. (2002). Proximate causes and underlying driving forces of tropical deforestation. *BioScience, 52*(2), 143–150.

Gwatiyap, J. K., Ikyaagba, E. T., & Soba, T. M. (2023). Challenges of the afforestation programme in Kaduna State, Nigeria. *Journal of Research in Forestry, Wildlife & Environment, 15*(1), 9–19.

Hansen, M. C., Potapov, P. V., Moore, R., et al. (2013). High-resolution global maps of 21st-century forest cover change. *Science, 342*(6160), 850–853.

Hosonuma, N., Herold, M., De Sy, V., De Fries, R., Brockhaus, M., Verchot, L., Angelsen, A., & Romijn, E. (2012). An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters, 7*(4), 044009.

Ibrahim, K. M., & Muhammad, S. I. (2015). A review of afforestation efforts in Nigeria. *International Journal of Advanced Research in Engineering and Applied Sciences, 4*(12), 24–37.

Idehen, S. O., & Bello, J. B. (2025). A review of forestry laws in Nigeria: How effective? *International Journal of Law, 11*(4), 43–48.

Imasuen, O. I., Oshodi, J. N., & Onyeobi, T. U. S. (2013). Protected areas for environmental sustainability in Nigeria. *Journal of Applied Sciences and Environmental Management, 17*(1)

IUCN (2021). Deforestation and Forest Degradation. International Union for Conservation of Nature (IUCN) Issue Brief, February 2021

Korom, A., Syukur, S. M., Jawan, A., Suratman, M. N., Jalloh. M. B., Jamian, M. & Latif, Z. A. (2022). Understanding Forest Degradation – A Review of Forest Structure Indicators. *Borneo Akademika, 6*(1), 115-125

Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources, 28*, 205–241.

Mather, A. S. (2001). Recent Asian forest transitions in relation to forest transition theory. *International Forestry Review, 9*(1), 491–502.

Medugu, N. I., Majid, M. R., & Foziah, J. (2009). The role of the afforestation programme in combating desertification in Nigeria. *IJCCSM, 2*(1), 35–47.

Motel, P. C., Pirard, R., & Combes, J. L. (2009). A methodology to estimate the impacts of domestic policies on deforestation. *Ecological Economics, 68*(3), 680–691.

Ogunrinola, O. F., Ogunwale, T. O., Oyetola, S. O., & Salami, K. D. (2023). Tree species diversity status and contributors to forest degradation in Shasha Forest Reserve, Nigeria.

Oke, R. A. (2019). Challenges facing forest production value addition and implications on economic development. *World News of Natural Sciences, 25*, 130–140.

Okoye, A. T., & Ogu, O. A. (2025). Challenges and opportunities of environmental governance in 21st-century Nigeria. *IJLTEMAS, 14*(6), 1060–1065.

Olagunju, T. E. (2015). Impacts of Human-Induced Deforestation, Forest Degradation and Fragmentation on Food Security. *New York Science Journal, 8*(1), 4 - 16

Olukwu-Kalu, D. C., Riki, J. T. B., & Agbeja, B. O. (2022). Appraisal of challenges to sustainable forest management in Abia State, Nigeria. *European Journal of Environment and Earth Sciences, 4*(2), 73–77.

Olunusi, B. O., Yusuf, A., Salihu, S. S., Moradeyo, S. O., Onubi, M. O., Fagbote, Y. J., & Thomas, J. (2025). Adapting global forest conservation strategies for Nigeria's sustainable development. *RUN Journal of Management, 2*(3), 123–133.

Oriola, E. O. (2009). Forestry for sustainable development in Nigeria. *International Journal of African Studies, 1*, 11–16.

Oruonye, E. D., Bashir, B. M., Anger, R. T., & Ahmed, Y. M. (2024). An assessment of forest degradation in Taraba Central Zone, Nigeria. *Discovery Nature, 1*(2).

Owolabi Saka-rasaq, O. (2019). Forest loss in Nigeria: The impact on climate and people from illegal forest activities and government negligence: *Bachelor's Thesis, Novia University of Applied Sciences*.

Oyediji, O. T., & Adenika, O. A. (2022). Forest degradation and deforestation in Nigeria: Poverty link. *Journal of Multidisciplinary Research and Analysis, 5*(10), 2837–2844.

Oyetunji, P. O., Akinyemi, G. O., Murtala, M. O. & Oyediji, O. T. (2024). The Role of Big Data in Promoting Forestry Research in Nigeria. Proceedings of the 2nd ISTF-NIGERIA International Conference, Forestry Research Institute of Nigeria (FRIN), Ibadan, Oyo State, Nigeria

Panayotou, T. (1990). The economics of environmental degradation: Problems, causes and responses. Harvard Institute for International Development.

Sands, R. (2005). Forestry in a global context. CABI Publishing, Wallingford, United Kingdom (UK).

Shaanker, R. U., Ganeshaiah, K. N., Rao, M. N., & Aravind, N. A. (2004). Ecological consequences of forest use. *Conservation and Society, 2*(2), 347–363.

Shackleton, S., & Pandey, A. (2014). Positioning non-timber forest products on the development agenda. *Forest Policy and Economics, 38*, 1–7.

Smith, P., Ashmore, M. R., Black, H. I. J., Burgess, P. J., Evans, C. D., Quine, T. A., Thomson, A. M., Hicks, K., & Orr, H. G. (2012). The role of ecosystems and their management in regulating climate and environmental quality. *Journal of Applied Ecology, 50*(4), 812–829.

Sobere, N. U. (2024). Impact of deforestation on biodiversity conservation in Nigeria and the legal response. *East African Journal of Law, Policy and Globalization, 2*(1), 27–53.

Sunderlin, W. D., Resosudarmo, I. A. P., Rianto, E., & Angelsen, A. (2000). The effect of Indonesia's economic crisis on small farmers and natural forest cover. CIFOR Occasional Paper No. 28.

Tavani, R., Saket, M., Piazza, M., Branthomme, A., & Altrell, D. (2009). Measuring and monitoring forest degradation through national forest monitoring assessment. FAO.

Tovar, C. L. M. (2009). Analysis of the Normalized Differential Vegetation Index for the Detection of Degradation of Forest Coverage in Mexico, 2000-2009. Forest Resources Assessment Working Paper 173: Case Studies on Measuring and Assessing Forest Degradation.

Ujor, G. C. (2018). The forest policies of Nigeria: A cursory analysis. *Nigerian Agricultural Policy Research Journal, 5*(1).

Usman, B. A., & Adefalu, L. L. (2010). Nigerian forestry, wildlife and protected areas: Status report.

William, J. V. (2025). Assessing Nigeria's efforts in biodiversity conservation. *Scientific Reports in Life Sciences, 6*(1), 85–98.

Yaro, H., Aliyu, N., Babayo, J. A., Atang, I., Ezekiel, E., Jimmy, D., & Flourish, O. A. (2025). Examining deforestation and forest degradation in Northeastern Nigeria. *International Journal of Scientific Research and Modern Technology, 4*(3), 43–53.

Zahradeen, M., Ahmed, A., & Babangida, A. (2019). Forest resource degradation in Northern Nigeria: Causes, impacts and mitigation. *Sustainable Development Journal, 17*(3), 56–72.

CHALLENGES FACING PRIVATE FORESTRY ESTABLISHMENTS IN NIGERIA

***[1]Alagbada O. R. and [2]Ayeni A. E.**

[1]Forestry Research Institute of Nigeria, Ibadan, Oyo State, Nigeria
[2]Federal College of Forest Resources Management, Ebonyi State, Nigeria
Corresponding Email: olanrewajuar@gmail.com;+2348095182231

Abstract

Nigerian private forestry development has significant potential to advance environmental sustainability, economic growth, and sustainable development. This is an emerging concept in Nigeria and is yet to be fully established as in other countries. This study examines the emerging role of private forestry in Nigeria as a pathway to sustainable development, environmental conservation, and economic growth. With over 90% of forest resources controlled by government plantations that fall short of meeting the rising demand for timber and forest products, a significant supply gap has created opportunities for private-sector participation. The paper highlights the increasing interest in private forestry as a viable solution for sustainable resource management and poverty reduction. However, its expansion is constrained by challenges such as complex land tenure systems, limited land access, inadequate infrastructure, and insufficient processing facilities. Despite these barriers, early successes and growing awareness indicate strong potential for the sector. The study concludes that targeted policy reforms, improved infrastructure, and streamlined land access are essential to unlock the full benefits of private forestry for present and future generations.

Keywords: Private forestry, sustainable development, wood products, challenges, Land ownership

Introduction

Private forestry refers to forest management practices undertaken by private entities to generate economic returns while achieving environmental and social benefits. These practices often include investments in projects related to afforestation, reforestation, and sustainable forest management. The national forest estate in Nigeria is currently estimated at 9.6 million hectares, representing less than 10% of the country's total landmass, and is delineated within roughly 445 gazetted forest reserves. (FAO, 2020). These forests provide various ecological, economic, and social benefits, including timber and non-timber forest products, biodiversity conservation, carbon sequestration, watershed protection, climate regulation, and cultural heritage.

Unfortunately, the nation's forest resources have been susceptible to deterioration, deforestation, and depletion due to various human activities, including agricultural expansion, logging, mining, infrastructure development, and natural disasters such asdisasterssuch as wildfires and climate change. (Iwuchukwu *et al.,* 2023). Private forestry development can play a critical role in addressing the challenges facing Nigeria's forest resources and in maximizing their potential for sustainable development (Ogunwale *et al*., 2020). Some benefits of private forestry development in Nigeria include economic benefits such as creating employment opportunities, generating income for local communities, reducing dependence on imported forest products, and contributing to the country's Gross Domestic Product (GDP) (National Bureau of Statistics, 2021).

Additionally, private forestry development can help conserve biodiversity and ecosystems and mitigate climate change (World Bank, 2021). It serves as a carbon sink, helping reduce greenhouse gas emissions and combat global warming. Private forestry development promotes community development, social inclusion, and the preservation of cultural heritage (FAO, 2015). However, this sector faces several challenges, including inadequate policy and institutional frameworks, limited access to finance, insufficient technical skills and knowledge, limited market linkages, and inadequate infrastructure (Ayodele, 2020). Government, businesses, commercial entities, civil society, and local communities must work together to promote sustainable forest management practices, boost market access, improve value addition, and foster innovation and technology transfer to meet these problems.

The role of private forestry development in Nigeria is important in planting, maintaining, and ethically exploiting for economic gain. Both the government and private forestry sectors, which account for 10.8% of the nation's total land area, indicate that Nigeria's forest resources have been severely degraded by deforestation, other human activities, and natural disasters. The persistent reduction of the national forest estate relative to the 25% benchmark indicates a critical failure to maintain historical forest levels, necessitating urgent, sustainable management interventions. To address the issues affecting Nigeria's forest resources and to maximize their potential for sustainable development, private-sector participation is essential. Private forestry development can play a significant role in boosting export revenue and lessening reliance on imported forest products; creating employment opportunities, generating income for local communities, and contributing to the country's Gross Domestic Product (GDP) (Ajayi *et al*., 2018). Private forestry development also has important environmental benefits, including carbon sequestration that further reduces greenhouse gas emissions and combats global warming.

Forests can protect watersheds, regulate water cycles, and prevent soil erosion, enhancing the resilience of ecosystems and communities to climate change and natural disasters. They also contribute to biodiversity conservation, social benefits, and ecosystems (Akindele *et al*., 2020). The Forest provides traditional medicine, food, fuelwood, and other essential services to local communities, especially in rural areas. The participation of local communities in forest management enhances decision-making, reduces conflicts, and promotes social cohesion (Adetoro *et al*., 2019). Private forestry development in Nigeria may have advantages, but it also faces several difficulties. These difficulties include deficient institutional and policy frameworks, limited financial access, insufficient technical expertise and knowledge, limited market connections, and deficient infrastructure. Addressing these challenges requires concerted efforts by the government, private sector, civil society, and local communities to promote sustainable forest management practices, enhance value addition, increase market access, and promote innovation and technology transfer (FAO,2018).

Importance Of Private Forestry Establishment In Nigeria

Private forestry is vital to Nigeria's economic, social, and environmental sustainability (FAO, 2020). In Nigeria, private forestry refers to the growing, managing, and harvesting of trees on privately owned land. Private forestry manages forested land owned by individuals, private companies, or non-governmental organizations (NGOs) for economic or social benefits. (Akinbowale *et al*., 2019). The importance of private forestry in Nigeria is multifaceted, encompassing ecological, economic, and social benefits such as job Creation, timber production, and environmental conservation, among others. Ecologically, private forestry can help combat

climate change, conserve biodiversity, and protect watersheds, while socially, it can help reduce poverty and promote community development (Popoola *et al.,*2019).

Economically, private forestry can provide a source of income and create job opportunities in various areas, including plantation establishment, maintenance, management, logging, transportation, and processing of forest products; all of these require labour to drive the economic phases (Areo *et al*.,2023). Job Creation is essential to economic growth and development in any country. In Nigeria, where unemployment is a significant issue. With the significant level of unemployment in Nigeria today (FAO, 2020), the establishment of private forestry can help reduce poverty and promote rural development through jobjob Creation, thereby improving the livelihoods of many people and the country's economy as a whole. Forest management requires labor activities such as weed control, pruning, thinning, and pest management, as well as employment opportunities, to improve the host communities where private forestry is established. In addition, private forestry creates jobs in the logging sector, which involves felling and extracting trees for processing. Skilled and unskilled labour is required for the sawmilling and processing of timber into finished products, including furniture, paper, and other forest products.

Private forestry can also help reduce pressure on natural forests, which are often overexploited for timber and non-timber forest products. However, the potential of private forestry in Nigeria has not been fully exploited. The lack of policy support and incentives, inadequate funding, and a weak regulatory framework are among the challenges facing the private forestry sector in Nigeria (Popoola et al., 2019). The government must provide policy support and incentives to encourage private investment in the forestry sector. This could include tax breaks, access to credit facilities, and other incentives to promote sustainable forest management.

Timber Production: Timber production is an essential component of Nigeria's forestry sector, and private forestry plays a crucial role in meeting the demand for timber and other forest products. Private forestry is becoming increasingly important in Nigeria, offering opportunities for sustainable forest management and timber production. However, the country's forestry sector faces significant challenges, including deforestation, illegal logging, and inadequate infrastructure. One of the key benefits of private forests is that they help reduce pressure on natural forests, which are rapidly being depleted by illegal logging and deforestation. Private forest owners can meet the demand for timber without relying on natural forests. This helps protect natural ecosystems, which are essential for maintaining biodiversity and regulating Earth's climate.

Income Generation: Private forestry provides economic benefits, including timber, non-timber forest products (NTFPs), and ecosystem services, which can be harnessed to generate income for individuals, communities, and the country as a whole (Ogunwusi *et al*., 2017). Timber is a valuable forest resource in Nigeria and a major economic contributor. Various timber species, such as Mahogany, Obeche, and Teak, are in high demand for furniture, construction, and other industries. Thus, privately owned forests can generate income (TimbAdekunle, 2020).

Non-timber forest products (NTFPs) are another critical resource for income generation. NTFPs, such as fruits, nuts, spices, and medicinal plants, have high demand in local and international markets and can provide a significant source of income for forest communities, especially in private forestry (Onyekwelu *et al*., 2018). Carbon sinks provided by the private Forest can be monetized and used to generate income. For instance, forest carbon credits can be sold in international markets to generate income for owners and managers (Oluwole *et al*., 2017). A

successful agroforestry practice is achieved through private forestry rather than government-driven forestry, with benefits including conservation, biodiversity conservation, and food security. It can also generate income for farmers by selling agroforestry products, such as fruits, nuts, and timber (Olawuyi *et al*., 2019).

Rural Economic Development: Rural economic development is an important driver of global economic growth, and Nigeria is no exception. According to a World Bank report, 60% of Nigerians live in rural areas, underscoring the critical role of rural microdevelopment in reducing poverty and promoting sustainable economic growth (World Bank, 2021). Private forestry is One way to promote rural economic development in Nigeria. Its establishment contributes significantly to rural economic development in Nigeria by creating jobs, generating income, and increasing economic activities (Nigeria Forestry Service, 2021). Furthermore, it can stimulate the demand for goods and services, such as transportation, equipment, and supplies, in areas where it is established. The establishment of private forestry further drives the establishment of forest-based industries, such as sawmills and pulp and paper mills.

Mitigating Climate Change: Private forestry has the potential to play a significant role in mitigating climate change, given the country's rich forest resources (World Bank, 2021). Trees absorb carbon dioxide during photosynthesis and store it in their biomass, thereby reducing atmospheric carbon dioxide levels. This leads to a reduction in gas emissions, which are One of the primary causes of climate change. Deforestation and forest degradation result in the loss of carbon stored in forests. Private. Private forestry can help reduce deforestation and forest degradation, thus preserving that carbon.

Environmental Benefits: Nigeria has recently experienced rapid deforestation and environmental degradation. The importance of private forestry lies in its potential to provide a range of environmental benefits, which include:

Biodiversity conservation: by providing habitats for a range of plant and animal species, creating wildlife corridors, and protecting important habitats, as alternatives.

Soil conservation: stabilizing soil structures and reducing the impact of rainfall on the soil surface, maintaining forest cover on private lands, and reducing soil erosion and sedimentation in water bodies.

Water conservation: private forests contribute to water conservation by regulating and improving water quality. Evapo-transpiration from private forestry complements that provided by natural forest cover, thus further protecting wetlands in the proxy.

Climate resilience: private forestry can help to build climate resilience by providing a buffer against the impacts of climate change, such as extreme weather events and changes in temperature and precipitation patterns. It regulates microclimates and reduces the risk of soil erosion and landslides.

Challenges Facing Private Forestry Development In Nigeria

Private forestry development in Nigeria faces several challenges that have hindered the sector's growth. Some of the key challenges include:

Lack of Investment: Forestry is a crucial sector in Nigeria, contributing significantly to the country's economy and providing employment for many people. The private forestry sector in Nigeria faces a significant challenge in attracting investment, which has hindered its growth and negatively impacted its contribution to the country's economy. The absence of a supportive policy framework is One of the main reasons for Nigeria's lack of investment in private forestry (Achalu, 2020). Nigeria lacks a policy framework that encourages private investment in forestry, making it difficult for private investors to assess the potential returns. As a result, other financial institutions are unwilling to lend to projects in the sector without a clear policy framework, and because of the sector's long-term investment yields (National Forestry Service, 2021). The high cost of doing business in Nigeria is another reason for the country's lack of investment in private forestry.

Nigeria is known for its challenging business environment, characterized by high input costs, infrastructure deficits, and regulatory barriers. These factors make it difficult for private investors to establish and maintain forestry operations that require significant capital investment and long-term planning, and there is a low level of awareness regarding the profits from private forestry (Achalu, 2020). This, in turn, affects operational profitability as transportation costs rise, thereby limiting market access for forestry products.

Private forestry development in Nigeria faces financial challenges (Ajao, 2019; Olaoye *et al*., 2020). The lack of access to credit and finance further makes it challenging for private investors to engage in sustainable forestry practices and promote private forestry development (Adekunle *et al*., 2020). Although there are various sources of funding for private forestry businesses, such as government grants and loans, international donor support, and private-sector investment, accessing these funds is often difficult due to bureaucratic red tape and limited awareness of available opportunities (Adewumi *et al*., 2020). Many private investors lack the necessary knowledge and skills to engage in sustainable forestry practices, and there is also a shortage of trained professionals in the forestry sector, making it difficult to attract and retain skilled workers (World Bank, 2016).

In addition, the lack of a well-developed forestry financing system in Nigeria has also hindered the growth of private forestry businesses. A limited number of financial institutions offer forestry financing, and those that do have not been tailored to meet the specific needs of the forestry sector (Adegboyega & Ajao, 2019). This has led to a lack of financing options for private forestry businesses, often resulting in a funding gap that hampers the growth and sustainability of their operations. The high cost of inputs required for forestry operations, such as seedlings, fertilizers, and equipment, also poses a significant challenge for private forestry businesses. Without access to affordable financing, many private forestry businesses cannot invest in the necessary inputs for their operations, leading to reduced productivity and lower profitability (Olaoye *et al*., 2020).

Inadequate Policies and Regulations: Private forestry development in Nigeria faces several challenges, including inadequate policies and regulations, deforestation, unsustainable logging practices, and poor forest management (Ar, 2023). An example is the Land tenure laws, both at the federal and state levels, which govern land ownership and use in Nigeria. Amending these laws to provide clear and secure land tenure for private forestry projects would encourage investment and long-term planning by private entities.

The country's forest resources are being depleted at an alarming rate due to these challenges, and demand for forest products such as timber and fuelwood is high, driven by a large population (National Forestry Service, 2021).

One of the major challenges facing private forestry development in Nigeria is the lack of clear and effective policies and regulations. Nigeria's forest policies and regulations are fragmented and often contradictory, which leads to confusion and uncertainty for private forestry investors. Additionally, the regulatory frameworks are poorly enforced, leading to widespread illegal logging and other unsustainable practices. Moreover, the government does not provide adequate support for private forestry investors (World Bank, 2016).

Limited Market Access: Market access is critical for any business, including forestry, as it enables businesses to sell their products to consumers and generate revenue (World Bank, 2020). However, limited market access creates significant barriers to entry for small and medium-sized forest owners in private forestry, hindering their effective participation in the forestry sector (FAO, 2020). In Nigeria, several factors limit private forestry (Private Forestry Service, 2021).

Firstly, Nigeria's forestry sector is dominated by large forest concessions owned and managed by the government or large multinational companies. (Areo *et al*.,2023). These large-scale operations benefit from established supply chains and distribution networks, enabling them to reach domestic and international markets with their products (Mwaura, 2020).

Secondly, the lack of infrastructure, such as roads, railways, and ports, limits the transportation of forest products from remote areas to urban centers where demand is high. This lack of infrastructure increases transportation costs, making it difficult for small and medium-sized forest owners to compete with larger operations (Ogunjobi *et al*., 2021).

Thirdly, establishing a processing unit is capital-intensive, and it is the capacity of private forest owners to process their products. Thus, they are forced to sell raw material rather than finished or semi-finished products to larger companies with the resources to add value (Fapohunda *et al*., 2020).

Fourthly, lack of access to finance to scale up their operations on a sustainable basis is another significant challenge limiting their ability to invest in processing facilities, transportation, and other critical aspects of forestry development (Adeniyi *et al*., 2021). To overcome the challenge of limited market access, there is a need for increased investment in infrastructure and processing facilities, especially in rural areas where most private forest owners operate (FAO, 2020). Another approach is encouraging partnerships between small and large forest owners to share resources and leverage each other's strengths. Such partnerships can help small forest owners access established supply chains and distribution networks while allowing larger companies to source raw materials from small-scale forest owners (World Bank, 2020).

Lack of Access to Land: Inadequate infrastructure and a shortage of skilled personnel hinder private forestry development in Nigeria. Nigeria, with over 2,00 million people, has created a growing demand for forest products, including timber, fuelwood, and non-timber forest products (World Bank, 2020).

Communal land ownership is prevalent across many parts of Nigeria, making it difficult for private investors to access land for forestry activities. The land is held communally and is controlled by

traditional rulers or community leaders, who allocate land according to customary rules and practices that may not be conducive to private forestry development (Abalu, 2017). The allocation process may not be transparent, making it difficult for potential investors to acquire land for forestry activities. The lack of legal frameworks for land registration and tenure makes it difficult for private investors to secure long-term leases or purchase land for forestry activities. The absence of clear and enforceable land tenure laws has discouraged many investors from entering the sector (Aboyeji, 2019).

Farmers who rely on the land for agriculture may resist efforts by private investors to acquire land for forestry, leading to conflicts that have discouraged private investment in the sector (Ogundipe, 2019). In conclusion, the lack of access to land is a crucial factor hindering private forestry development in Nigeria. Addressing this challenge will require implementing clear, enforceable land tenure laws, improving access to credit, and resolving conflicts between farmers and private investors over land use.

Infrastructure: The lack of proper infrastructure hinders the growth of the private forestry sector, especially due to inadequate transportation networks. The absence of good road networks, bridges, and other transportation infrastructure makes it difficult for private forestry companies to transport their products to the market. This has further increased production costs, reduced profit margins, and discouraged private investors from investing in the sector (Jibowo & Adefisan, 2021).

Another infrastructure challenge is the lack of electricity supply in rural areas, where most private forestry activities occur. The absence of a reliable Power supply hinders the development of sawmills and other processing facilities essential for adding value to forest products. Inadequate electricity supply also limits the modernthe use of modern machinery and equipment, making it difficult for private investors to operate at maximum capacity (Ogunleye *et al*., 2020).

Eal. Environmental Policy and Regulatory Law: Several policy and regulatory barriers hinder private forestry growth in Nigeria. One of the significant policy challenges facing private forestry development in Nigeria is the lack of a clear regulatory framework for forest management. The forest sector is governed by multiple laws and regulations that often overlap or contradict each other, leading to confusion and a lack of clarity. For example, the National Forestry Law emphasizes sustainable forestry practices, biodiversity protection, and community participation in forest management at the federal level. At the same time, the State Forest Law prioritizes economic development over environmental conservation, potentially allowing more extensive logging and land conversion at the state level.

This has made it difficult for private investors to navigate the regulatory landscape, leading to a lack of investment in the sector (Adewumi *et al*., 2021). In addition, there is a constitutional mandate for forest management. The government agencies responsible for forestry management are often understaffed and under-resourced to fulfill their mandates effectively. This has resulted in poor enforcement of regulations and a lack of control over forest resources (Udom, 2021). Therefore, there is a need for a comprehensive policy and regulatory framework that provides clarity and consistency for private investors in the forestry sector. The government should invest in building the capacity of institutions responsible for forestry management and enforcing regulations. This would help to promote sustainable forest management practices, improve the availability of forest products, and provide economic opportunities for rural communities (Afolayan *et al*., 2021).

Conclusion

Private forestry in Nigeria holds significant promise for job Creation, economic diversification, and environmental sustainability. However, its growth is constrained by weak legal and regulatory systems, limited access to finance, inadequate infrastructure, and low levels of awareness and technical capacity among forest owners. Without targeted interventions, these barriers will continue to limit the sector's contribution to national development. Unlocking the full potential of private forestry requires a coordinated effort to create an enabling environment that supports investment, promotes sustainable practices, and empowers local communities.

Recommendations

To advance private forestry development in Nigeria, the following actions are essential:

- **Strengthen legal and regulatory frameworks:** Establish clear, consistent, and enforceable policies that encourage private sector participation and protect forest resources.
- **Improve access to finance:** Develop tailored financial products such as low-interest loans, credit facilities, and insurance schemes to support forest owners and investors.
- **Invest in infrastructure:** Expand roads, electricity, and market access in forested regions to reduce operational costs and attract investment.
- **Enhance capacity building and awareness:** Implement training programs and public awareness campaigns to educate stakeholders on sustainable forest management and the broader value of forests.
- **Promote community-driven initiatives:** Support community-based financing models and participatory forest management to reduce illegal logging and improve local livelihoods.
- **Encourage stakeholder collaboration:** Foster partnerships among government, private sector, civil society, and local communities to ensure inclusive and sustainable forestry development.
- **Provide investment incentives:** Introduce tax breaks, subsidies, and other measures to stimulate private-sector engagement in forestry.

By implementing these measures, Nigeria can build a resilient and sustainable private forestry sector that contributes meaningfully to economic growth, environmental conservation, and community development.

References

Abalu, G.O. (2017). Land tenure systems in Nigeria: A review of the literature. *International Journal of Social Sciences and Humanities Reviews*, 7.1: 1-14.

Aboyeji, O. (2019). Challenges of private sector forestry development in Nigeria. *Journal of Forestry Research and Management*, 16.1: 23-36.

Adegboyega, O., & Ajao, A. M. (2019). Financing small-scale private forestry projects in Nigeria: Prospects and challenges. *Journal of Research in Forestry, Wildlife, and Environment*, 11.1: 1–12.

Adekunle, A. A., Olufunke, E. O., & Olufemi, J. F. (2020). Financing Private Forestry Development in Nigeria: The Nexus between Interest Rates, Bank Credit and Forest Resources. *The Journal of Social Sciences Research*, 6.4: 1304–1314.

Adekunle, V. A. 2020. Private forest management and sustainable livelihoods in Nigeria. *Forests, Trees and Livelihoods*, 29.3-4: 216-226.

Adeniyi, O. R., Ayodele, J. T., & Agunbiade, E. O. (2021). Financial accessibility and sustainability of forest-based small and medium enterprises (SMEs) in Nigeria. *Journal of Research in Forestry, Wildlife, and Environment*, 13.1: 82–90.

Adetoro, F. A., Ayeni, A. O., & Ajibola, M. O. (2019). Private forestry development and social benefits in Nigeria. *Journal of Agriculture and Ecology Research International*, 18.2: 1–11.

Adewale, B.A. and Oni, O.A. 2020. Analysis of challenges affecting the development of private forestry in Nigeria. *Journal of Forestry Research and Management*, 17.1: 1-10.

Adewumi, F. O., Adediji, A. T., Oyinlola, M. A., & Adisa, R. S. (2021). Private forestry investment in Nigeria: An examination of the regulatory environment. *Forest Policy and Economics*, 134: 102511.

Adewumi, T. O., Oyebo, O., & Gbadegesin, A. (2020). Financing forestry projects in Nigeria: The role of banks and other financial institutions. In T. O. Adewumi (Ed.), *Forest and forestry financing in Nigeria*, 1–14. Springer.

Afolayan, A. T., Adefisan, E. A., Olawoye, J. E., & Adeyemo, T. A. (2021). Private sector participation in forestry development in Nigeria: A review of policies and prospects. *Journal of Agricultural Extension*, 25.2: 95–108.

Ajayi, O. C., Ogunjobi, K. O., & Oduwaye, L. A. (2018). Prospects and challenges of private forestry in Nigeria. *Journal of Forest and Environmental Science*, 34.2: 89–96.

Akinbowale, A. S., Adesuyi, F. E., Offiah, S. J. & Fasalejo, O. F. (2019). Contribution of private forestry to forest development in Nigeria: A Case Study of Evergreen Planter, Ogun State. *International Journal of Scientific and Education Research*, 3.3:19 – 31.

Akindele, S. O., Adegbite, A. A., & Adeofun, C. O. (2020). Private forestry development and the environment: A review of the literature. *Environmental Science and Pollution Research*, 27.23: 28823–28834.

Areo, O.S., Omole, A.O., Adejoba, A.L, Bolarinwa, O.L., Odebunmi, G.F. and Oyewumi, O.R. Private Forestry Establishments In Nigeria: A Review. *Ethiopian Journal of Environmental Studies & Management* 16.2: 254 – 265.

Ayodele, O. I. (2020). Financing sustainable forestry development in Nigeria: Opportunities and challenges. *Forests, Trees and Livelihoods*, 29.2: 83–95.

FAO. 2018. Private Forestry in Nigeria: Opportunities and Challenges. Food and Agriculture Organization of the United Nations. 72-25 https://doi.org/10.4060/cb1447en.

FAO. 2020. The State of Food and Agriculture 2020. *Overcoming water challenges in agriculture*. Rome. 72-25 https://doi.org/10.4060/cb1447en.

Fapohunda, O. R., Adegboyega, O. A., & Ajayi, A. E. (2020). The challenge of smallholder forestry in Nigeria: Prospects and strategies. *Forests, Trees and Livelihoods*, 29.1: 13–24.

Food and Agriculture Organization (FAO). 2015. State of the World's Forests 2014: Enhancing the Socioeconomic Benefits from Forests. Rome: FAO.

Iwuchukwu, F. U., Ewuzie, U., Ajala, O. J., Ojukwu, V. E., Nnorom, I. C., Egbueri, J. C., Pande, C. B., and Ighalo, J. O. 2023. A Consideration of the Climatic Drivers, Focal Points and Challenges of Soil Erosion, Land Degradation, Landslides and Landscapes in Nigeria. In J. C. Egbueri, J. O. Ighalo, and C. B. Pande (Eds*.), Climate Change Impacts on Nigeria:*

Environment and Sustainable Development, 449–477. Springer International Publishing. https://doi.org/10.1007/978-3-031-21007-5_23.

Jibowo, A.A. & Adefisan, E.A. (2021). Infrastructure provision and the development of the Nigerian forestry industry. *Journal of Environmental Management and Sustainable Development*, 10.2:36-47.

Mwaura, P. (2020). Forest certification in Nigeria: A case study of forest plantation management under government control. *Journal of Sustainable Forestry*, 39.5: 437-454.

National Bureau of Statistics. (2021). Nigerian Gross Domestic Product Report Q1 2021.

National Forestry Service. (2021). Private forestry.

Ogundipe, A.A. 2019. Private sector forestry investment in Nigeria: Opportunities and challenges. *International Journal of Agricultural Economics and Rural Development*, 2.1: 1-12.

Ogunjobi, J. O., Oshodi, O. S., & Ajala, S. O. (2021). Determinants of participation in the forestry value chain among rural farmers. *International Journal of Energy Economics and Policy*, 11.13: 149–154.

Ogunleye, O.O., Aderinto, A.A. & Akinbile, L.A. (2020). The role of infrastructure in the development of the forestry sector in Nigeria. *Journal of Environmental Science and Sustainable Development*, 3.1: 18–28.

Ogunwale, A. B., Ajayi, C. A., & Adewole, A. M. (2020). Private sector investment in forestry development: A panacea for economic growth in Nigeria. *Journal of Environmental Management and Tourism*, 11.10: 2143–2151.

Ogunwusi, A. A., Oyebanji, O. A., Adeniji, O. A., & Oladele, F. A. (2017). Analysis of income generation from forest products in rural Ogun State, Nigeria. *Journal of Agriculture and Environmental Sciences*, 6.2: 59–67.

Olaoye, J. O., Ojo, A. T., Adebayo, A. O., & Ojo, O. A. (2020). Financing challenges of private forestry development in Nigeria. *Journal of Agricultural Economics and Rural Development*, 6.1: 28–38.

Olawuyi, D. S., Adekunle, V. A., & Popoola, L. (2019). Agroforestry adoption and its effects on rural livelihoods: evidence from Nigeria. *International Journal of Agricultural Sustainability*, 17.5: 451–465.

Oluwole, F. A., Ololade, O. O., & Oduwaye, O. A. (2017). The importance of forest ecosystem services in rural livelihoods in Nigeria—*Journal of Environmental Management*, 196:80-91.

Onyekwelu, J. C., Okoye, C. U., Nnamani, C. V., & Agwu, J. A. (2018). Non-timber forest products and rural livelihoods in Nigeria: the case of honey production in Enugu State. *Journal of Agricultural and Environmental Ethics*, 31.1: 57–72.

Popoola, L., T.O. Amusa, T. O., & Jimoh, S.O. (2019). Prospects for public-private partnerships in the Nigerian forestry sector. *African Journal of Rural Development* 4 (1): 125–140.

Udom, I. S. (2021). Forestry resources management in Nigeria: Challenges and prospects. *Environmental Science and Pollution Research*, 28.5: 5131–5141.

World Bank. (2016). Nigeria: Forests and Climate Change program. *World Bank Group Forest Action Plan.* FY16–20: 56-58

EFFECT OF AGROFORESTRY PRACTICES ON YIELD AND SOIL PROPERTIES IN JERE AND KONDUGA LOCAL GOVERNMENT AREAS, BORNO STATE

Garba, M[1]., Gupa, M.A[1]., Umar, L.A[2]. and Adeogun, P. F. [1]

[1]Department of Forestry and Wildlife, Faculty of Agriculture, University of Maiduguri Borno State, Nigeria
[2]Federal College of Forest Resources Management, Maiduguri, Borno State.
**Corresponding email: musagarba101@unimaid.edu.ng, 07039079308*

Abstract

This study investigated the effects of agroforestry practices on crop yield and soil properties in Jere and Konduga Local Government Areas of Borno State, Nigeria. A mixed-methods approach involving field surveys, soil analysis and crop yield assessments was adopted. Data were collected from 120 farmers, comprising both agroforestry practitioners and non-practitioners. Results revealed that 83.3% of farmers practicing agroforestry experienced increased crop yields, with maize and millet yields significantly higher under agroforestry than under conventional farming. Soil analyses showed that agroforestry plots had superior physical and chemical properties, including higher bulk density, greater soil moisture content, and improved pH, organic matter, nitrogen, phosphorus, and potassium levels. Regression analysis further identified organic matter and soil moisture as the strongest predictors of crop yield. Farmers perceived agroforestry as highly beneficial for enhancing soil fertility, although constraints such as a lack of seedlings, land tenure insecurity, labour shortages, and limited technical knowledge hinder wider adoption. The study concludes that agroforestry is a sustainable practice capable of enhancing soil quality, improving crop productivity and promoting resilience in semi-arid agricultural systems. It is recommended that increased extension support, secure land tenure, access to high-quality seedlings, and enhanced farmer training be provided to promote effective adoption of agroforestry.

Keywords: Agroforestry, Crop yield, Soil properties

Introduction

Agriculture remains the backbone of rural livelihoods in Sub-Saharan Africa, where the majority of the population depends on smallholder farming for food, income, and employment. However, the sector faces critical challenges, including declining soil fertility, land degradation, erratic rainfall, and population pressure (FAO, 2021). These issues are particularly severe in Nigeria's northeastern region, including Borno State, where fragile ecosystems, poor soil management, and the effects of climate change have continued to undermine agricultural productivity (Audu *et al*., 2023). Consequently, smallholder farmers in areas such as Jere and Konduga Local Government Areas (LGAs) often experience low crop yields and deteriorating soil conditions, posing significant threats to food security and rural livelihoods (Olanrewaju & Abubakar, 2022).

Agroforestry has emerged as One of the most promising land-use systems for addressing these challenges. Defined as the deliberate integration of trees and shrubs with crops and/or livestock on the same land, agroforestry provides both productive and protective functions (Nair, 2020). Unlike

monocropping systems, agroforestry improves soil fertility through litter fall, nitrogen fixation by leguminous trees, and nutrient recycling from deeper soil horizons (Sileshi *et al.*, 2014). These processes enhance soil structure, organic matter content, and nutrient availability, while also reducing erosion and improving water retention (Bayala & Teklehaimanot, 2014). Such improvements in soil health often translate into higher and more sustainable crop yields.
In Nigeria, studies have shown that agroforestry systems such as alley cropping, boundary planting, parkland systems, and improved fallows contribute significantly to maintaining soil fertility and boosting crop performance (Adeyemi *et al*., 2021). For instance, research conducted in northern Nigeria found that soils under agroforestry practices had higher organic carbon and available nitrogen than those under conventional monocropping systems, leading to improved maize and sorghum yields (Ibrahim *et al*., 2022). Similarly, agroforestry has been recognized as a climate-smart agricultural practice that supports both adaptation and mitigation strategies in the Sudan–Sahel ecological zone (Oladele *et al*., 2025).

In Borno State, where desertification and land degradation are pressing challenges, agroforestry has been promoted as a sustainable solution to restore soil fertility and enhance crop productivity. Local studies in Jere LGA have indicated that farmers were aware of agroforestry practices and recognized their potential benefits. However, adoption remains influenced by socioeconomic factors such as household size, farming experience, and access to extension services (Ali & Buba, 2021). Similarly, experimental trials on leguminous species in the region demonstrated significant improvements in soil nitrogen and organic matter, showing potential for integration into smallholder cropping systems (Audu *et al*., 2023). Despite these findings, evidence on the localized impact of agroforestry on both crop yield and soil properties in Jere and Konduga LGAs remains limited.

Therefore, examining the effects of agroforestry practices on soil properties and crop yields in these areas is crucial. Such knowledge would not only fill existing research gaps but also provide evidence-based recommendations for farmers, policymakers, and extension workers. In particular, understanding the extent to which agroforestry enhances soil fertility and improves crop performance will contribute to sustainable land use, food security, and rural resilience in Borno State.

Materials and Methods

Study Area

The study was conducted in Jere and Konduga Local Government Areas (LGAs) of Borno State, Nigeria. Both LGAs are located in the semi-arid region of the country, characterized by fragile ecosystems, recurrent droughts, and advancing desertification (Olagunju, 2015). Jere LGA lies adjacent to Maiduguri, the state capital, and benefits from relatively better market access, infrastructural facilities, and extension services (Bwala *et al*., 2021). Konduga LGA, on the other hand, is located southeast of Maiduguri and is more rural in character, with most communities engaged primarily in subsistence farming (Aliyu & Mustapha, 2019). Climatically, the two LGAs fall within the Sudan–Sahel zone, characterized by long dry seasons and short, erratic rainy seasons. The mean annual rainfall ranges from 500 mm to 800 mm, usually concentrated between June and September, while average daily temperatures exceed 30°C, especially during the dry

season (Adebayo & Tukur, 1999; NIMET, 2021). Relative humidity remains low for most of the year, contributing to the vulnerability of soils to erosion and degradation (FAO, 2015). Soils in the area are predominantly sandy loams and loamy sands, which are inherently low in organic matter and nutrients, making them highly dependent on sustainable management practices for agricultural productivity (Lal, 2004). The area has sparse savanna vegetation with scattered trees such as *Faidherbia albida*, *Azadirachta indica* (neem), *Parkia biglobosa* (locust bean), and *Vitellaria paradoxa* (shea butter tree) (Gupa *et al*., 2024). Today, many of these species are preserved through agroforestry practices, particularly parkland systems and boundary planting. These trees play important ecological and socioeconomic roles by improving soil fertility, providing shade, and serving as sources of fodder, fruits, fuelwood, and income (Garrity *et al*., 2010).

The inhabitants of the study areas are predominantly farmers and agro-pastoralists. Major crops cultivated include millet, sorghum, maize, groundnut, and cowpea, often intercropped with vegetables during the rainy season (Adesiji *et al.*, 2013). Livestock rearing, particularly cattle, sheep, and goats, is also a major livelihood activity (Shettima *et al.,* 2017). In both LGAs, farmers practice a mix of conventional cropping and agroforestry-based systems. However, the extent of adoption and the degree to which agroforestry influences crop yield and soil fertility have not been systematically studied, thereby justifying the relevance of this research.

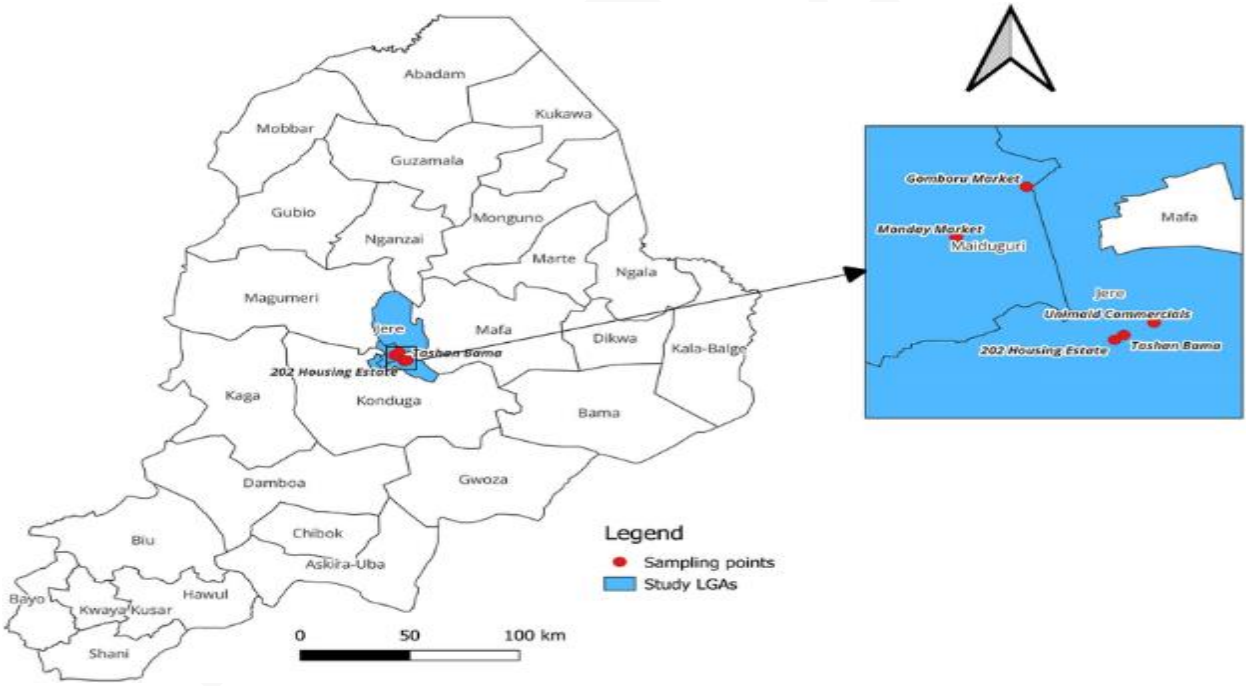


Fig. 1 Map of Borno State Showing the Study Area

Sample Size and Sampling Technique

A multi-stage sampling technique was employed. At the first stage, Jere and Konduga LGAs were purposively selected for their prominence in agricultural production and for the presence of farmers practicing agroforestry. At the second stage, four farming communities were randomly selected from each LGA. At the third stage, farmers were stratified into two groups: agroforestry practitioners and non-agroforestry practitioners. Respondents were then proportionately sampled

from each group. A total of **120 farmers** were selected for the study, comprising 60 farmers practicing agroforestry and 60 farmers practicing conventional farming.

Research Instruments

Two main instruments were used for data collection: a structured questionnaire and field sampling protocols.
The questionnaire was designed to obtain information on demographic characteristics, farm management practices, perceptions of agroforestry, and constraints to adoption. Both closed and open-ended questions were included to generate quantitative and qualitative data. Field instruments included augers for soil sampling, sample bags, weighing scales, and laboratory test kits. Soil samples were collected from agroforestry and non-agroforestry plots at two depths (0–15 cm and 15–30 cm). These were analyzed for physical and chemical properties, including pH, organic matter, nitrogen, phosphorus, potassium, and bulk density. Crop yield data for maize and millet were recorded from selected farms during the harvest season.

Data Collection

Data was collected in two phases. The first phase involved administering 120 questionnaires to selected farmers across the study areas. Research assistants fluent in the local languages (Kanuri and Hausa) assisted in administering the questionnaire to minimize language barriers and reduce the risk of misinformation in the data. The second phase involved field visits for soil sampling and crop yield measurement. Soil samples were collected using standard soil augers, carefully labelled, and transported to the laboratory for analysis.

Method of Data Analysis

Data obtained from the questionnaires were coded and analyzed using the Statistical Package for Social Sciences (SPSS, version 25). Descriptive statistics, including frequencies, means, percentages, and standard deviations, were used to summarize respondents' socioeconomic characteristics and perceptions of agroforestry. Inferential statistics such as independent t-tests were used to compare soil properties and crop yields between agroforestry and conventional farms. Regression analysis was also employed to examine the relationship between agroforestry practices and crop yield. Laboratory data on soil properties were subjected to Analysis of Variance (ANOVA) to determine significant differences between agroforestry and non-agroforestry plots. Results were presented in tables, figures, and charts for clarity and ease of interpretation.

Results and Discussion

Socioeconomic Characteristic of the Respondents

Table 1 shows the socioeconomic characteristics of the 120 respondents involved in the study. The results show that 79.2% of respondents were male and 20.8% were female**,** indicating that agricultural or related activities in the study area are predominantly male-dominated. This trend is consistent with several studies that report that men largely control farming activities in most parts of Nigeria due to cultural norms, land ownership systems, and gender-based division of labour, in

which women are often restricted to supportive or household-based roles (FAO, 2018; Adebayo & Yisa, 2020).

The age distribution shows that 26.7% of respondents were between 20 and 35 years old, 41.7% were between 36 and 50 years old, and 31.6% were 51 years old and above. This implies that most respondents fall within the economically active age bracket. This finding aligns with previous studies indicating that middle-aged farmers are more productive, risk-responsive, and more likely to adopt new agricultural technologies than very young or elderly farmers (Nwaiwu *et al*., 2013). The educational status of respondents shows that 16.7% had no formal Education, 30.0% had primary Education, 35.0% had secondary Education, and 18.3% had tertiary Education, indicating a moderate level of literacy among respondents. This is an important factor in the adoption of improved technologies and ICT-based agricultural services. Education improves farmers' ability to access, interpret, and use information for decision-making (Mignouna *et al*., 2020). The fact that 83.3% had some form of formal Education suggests a high potential for successful awareness, understanding, and adoption of ICT facilities among the respondents.

Regarding farming experience**,** 20.8% had less than 10 years, 45.0% had 10–20 years, and 34.2% had more than 20 years**.** This indicates that the majority of the respondents are highly experienced farmers. Farming experience has been shown to positively influence productivity, managerial ability, and technology adoption, as experienced farmers are better positioned to evaluate the benefits and risks associated with innovations (Bello, 2020). However, long-term experience may also sometimes lead to resistance to change, especially where traditional practices dominate. The farm size distribution shows that 12.5% operated on less than 1 hectare, 54.2% on 1–3 hectares, and 33.3% on more than 3 hectares**.** The dominance of small- to medium-scale farmers indicates that agriculture in the study area is largely subsistence or semi-commercial. This agrees with national agricultural statistics, which show that over 80% of Nigerian farmers operate on small landholdings of less than 5 hectares (National Bureau of Statistics [NBS], 2020; World Bank, 2021).

The household size distribution shows that 40.0% of respondents had household sizes of 1-5 members, 45.8% had 6-10 members, and 14.2% had more than 10 members**,** indicating generally large household sizes. This finding is consistent with rural demographic patterns in Northern Nigeria, where extended family systems are common (NPC & ICF, 2019). The finding is also consistent with Gupa *et al*. (2024), who reported that agroforestry farmers had household sizes ranging from 1 to 10, with an average of 7.0. Because they rely on family labour, rural people's household sizes are always bigger when compared to their city counterparts

Table 1: Socioeconomic Characteristics of Respondents (n = 120)

Variable	Category	Frequency	Percentage (%)
Gender	Male	95	79.2
	Female	25	20.8
	Total	**120**	**100**
Age (years)	20–35	32	26.7
	36–50	50	41.7
	51 and above	38	31.6

	Total	**120**	**100**
Education Level	None	20	16.7
	Primary	36	30.0
	Secondary	42	35.0
	Tertiary	22	18.3
	Total	**120**	**100**
Farming Experience (years)	<10	25	20.8
	10–20	54	45.0
	>20	41	34.2
	Total	**120**	**100**
Farm Size (ha)	<1	15	12.5
	1–3	65	54.2
	>3	40	33.3
	Total	**120**	**100**
Household Size	1–5	48	40.0
	6–10	55	45.8
	>10	17	14.2
	Total	**120**	**100**

Source: Field Survey, 2025

Influence of Agroforestry Practices on Crop Yield

Table 2 presents farmers' opinions on how agroforestry practices have influenced their crop yields in the study area. The results indicate that a substantial proportion of respondents (83.3%) reported an increase in crop yield since adopting agroforestry practices, while 8.3% reported a decrease and 8.3% observed no noticeable change. This finding strongly suggests that most farmers perceive agroforestry as a beneficial land-use system that enhances agricultural productivity. This aligns with several empirical studies that confirm that agroforestry enhances crop yields by improving soil fertility, conserving moisture, and regulating microclimate (Garrity *et al*., 2010; FAO, 2013; Jama *et al*., 2017). Studies across sub-Saharan Africa similarly reveal significant yield increases in maize, sorghum, and millet under agroforestry systems compared to sole cropping (Ajayi *et al*., 2019).

The rate of effect of agroforestry on crop yield further supports this observation, as 73.3% of respondents rated the effect as either high (43.3%) or very high (30.0%), indicating a widespread belief in the strong positive impact of trees integrated into cropping systems. High-yield responses have been attributed to improved soil organic matter, enhanced nutrient cycling, and increased soil moisture retention under agroforestry systems (Sileshi *et al.*, 2014). However, the perception of low yield effect by 10.0% of respondents may be linked to challenges such as tree–crop competition for Light, water, and nutrients, poor tree species selection, or improper spacing, which have been reported to influence yields in poorly managed agroforestry systems negatively (Ong *et al*., 2014).

These findings corroborate the works of Garrity *et al*. (2010) and Ezeaku (2012), who reported that agroforestry systems in semi-arid and tropical regions improve soil fertility through organic matter accumulation, biological nitrogen fixation, and improved water infiltration—factors that

collectively enhance crop growth and Yield. Similarly, Lal (2004) noted that the presence of trees in farmlands reduces wind erosion, moderates temperature, and lowers evapotranspiration, thereby creating a more favorable microenvironment for crop production. Additional studies by Sileshi *et al*. (2014) and Ajayi *et al.* (2006) further confirm that agroforestry significantly improves crop resilience to climate variability, thereby stabilizing and increasing long-term productivity.

Table 4.2: Farmers' Responses on the Effects of Agroforestry on Crop Yield (n = 120)

Variable	Category	Frequency	Percentage (%)
Observed yield change since practicing agroforestry	Increase	50	83.3
	Decrease	5	8.3
	No change	5	8.3
Rate of effect of agroforestry on Yield	Very High	18	30.0
	High	26	43.3
	Moderate	10	16.7
	Low	6	10.0
Mean years of agroforestry practice	—	8.4 years	—

Crop Yield under Agroforestry and Conventional Systems

Table 4.3 presents the comparative mean yields of maize and millet under agroforestry and conventional farming systems. The results reveal a consistent pattern of higher yields under the agroforestry system for both crops when compared to the conventional system. This general trend aligns with several empirical studies that have established that agroforestry systems significantly outperform conventional monocropping in terms of crop productivity due to improved soil health, water-use efficiency, and microclimatic moderation (Garrity *et al*., 2010; Sileshi *et al*., 2014).

For maize, the mean Yield under agroforestry was 2,450 kg/ha, while the conventional system recorded 1,980 kg/ha. The observed difference was statistically significant with a t-value of 3.87 and a p-value of 0.000, indicating that agroforestry significantly enhances maize productivity. This finding is consistent with studies by Sileshi *et al*. (2014) and Ajayi *et al*. (2017), who reported yield increases of 30–120% for maize grown under agroforestry systems in sub-Saharan Africa. The improved maize yield under agroforestry has been attributed to enhanced soil fertility from organic matter inputs, biological nitrogen fixation by leguminous trees, improved soil moisture retention, and reduced nutrient leaching (Bayala *et al*., 2014).

Similarly, for millet, farmers practicing agroforestry obtained a higher mean yield of 1,860 kg/ha, compared to 1,520 kg/ha under the conventional system. The t-value of 3.42 and p-value of 0.001 indicate a statistically significant yield advantage in favour of agroforestry. These results support the findings of Bayala *et al*. (2012), who reported that millet grown in parkland and agroforestry systems recorded significantly higher grain yields than under sole cropping, due to improved nutrient cycling, reduced soil erosion, and greater soil moisture availability.

The results collectively indicate that agroforestry systems outperform conventional farming systems in terms of crop productivity. The higher yields recorded under agroforestry reflect the

combined ecological and agronomic benefits of sustainable land-use practices, including organic matter enrichment from litter fall, nitrogen fixation by leguminous tree species, improved soil structure, enhanced nutrient recycling, and better water-use efficiency (Sileshi *et al*., 2015). Furthermore, the low p-values (< 0.05) obtained for both maize and millet confirm that the observed yield differences are statistically significant and not due to random variation, but rather due to the beneficial effects of agroforestry practices, as widely reported in tropical agroecological studies (Ong *et al*., 2014).

Table 3: Comparative Crop Yield under Agroforestry and Conventional Systems

Crop	Farming System	Mean Yield (kg/ha)	Standard Deviation	t-value	p-value
Maize	Agroforestry	2,450 ± 310		3.87	0.000**
	Conventional	1,980 ± 280			
Millet	Agroforestry	1,860 ± 220		3.42	0.001**
	Conventional	1,520 ± 240			

Soil Physical Properties

Table 4 presents the comparison of key soil physical properties between agroforestry and conventional farming systems. The parameters measured include soil pH, bulk density, soil moisture content, and soil texture at 0–15 cm depth. The findings clearly demonstrate that agroforestry systems exhibit more favourable soil physical conditions than conventional systems. This observation is consistent with long-established literature, which shows that agroforestry improves soil quality through continuous organic inputs, reduced erosion, and better microclimatic regulation (Tadesse *et al*., 2020).

The soil pH under agroforestry (6.74 ± 0.18) was slightly higher than that of the conventional system (6.21 ± 0.26), with a t-value of 2.89 and a p-value of 0.005, indicating a statistically significant difference. This implies that agroforestry practices help maintain near-neutral soil conditions, which are generally more suitable for nutrient availability, microbial activity, and overall soil fertility than acidic soils common under continuous conventional tillage. This outcome aligns with findings by Sileshi *et al*. (2015), who reported that tree litter decomposition and root exudates under agroforestry help buffer soil acidity and stabilize soil pH.

The bulk density was significantly lower in agroforestry soils (1.32 ± 0.05 g/cm³) compared to conventional soils (1.49 ± 0.08 g/cm³), with a t-value of 4.27 and a p-value of 0.000. Lower bulk density indicates better soil structure, higher porosity, improved root penetration, and enhanced water infiltration. This improvement is largely attributed to continuous organic matter inputs from leaf litter, fine root turnover, biological activity, and minimal soil disturbance under agroforestry systems. This finding agrees with studies by Haynes and Naidu (1998) and Beedy *et al*. (2010), which observed significantly lower bulk density under tree-based land-use systems compared with sole cropping.

Similarly, the soil moisture content was considerably higher under agroforestry (18.7 ± 2.3%) than under conventional farming (14.2 ± 2.7%), and the difference was statistically significant (t = 3.91; p = 0.000). This finding indicates that agroforestry systems conserve more soil moisture, mainly

due to canopy shading that reduces evaporation, improved soil structure, and enhanced water-holding capacity associated with higher organic matter content. This result corroborates the findings of Ong *et al*. (2014*)* and Nair *et al*. (2010), who demonstrated that agroforestry improves soil-water dynamics and enhances moisture availability for crops, especially in semi-arid environments.

In terms of soil texture, the agroforestry plots were classified as loamy sand, while the conventional plots were classified as sandy loam. This slight textural variation suggests that agroforestry soils retain more fine particles and organic residues, which promote soil aggregation, nutrient retention, and long-term fertility improvement. Although soil texture is generally inherent, agroforestry practices can enhance micro-aggregation and fine particle stabilization through organic binding agents and biological activity (Saha *et al*., 2018).

Table 4: Soil Physical Properties under Agroforestry and Conventional Systems

Soil Parameter	Agroforestry (Mean ± SD)	Conventional (Mean ± SD)	t-value	p-value
Soil pH (0–15 cm)	6.74 ± 0.18	6.21 ± 0.26	2.89	0.005**
Bulk Density (g/cm³)	1.32 ± 0.05	1.49 ± 0.08	4.27	0.000***
Soil Moisture (%)	18.7 ± 2.3	14.2 ± 2.7	3.91	0.000***
Soil Texture	Loamy Sand	Sandy Loam	—	—

Soil Chemical Properties

The chemical properties of soils from Jere and Konduga LGAs reveal notable variations with important implications for soil fertility, nutrient availability, and agricultural productivity. The soil pH values indicate that soils in Jere are slightly alkaline (pH 7.71), whereas soils in Konduga are slightly acidic (pH 6.66). These differences are agronomically significant because soil pH strongly influences nutrient solubility, microbial activity, and plant nutrient uptake (Brady & Weil, 2017; Havlin *et al*., 2019). Slightly acidic to neutral soils generally promote better nutrient availability for most crops, particularly phosphorus and micronutrients (Landon, 2014). Thus, the pH of Konduga falls within the optimal range for most food crops. At the same time, the slightly alkaline nature of Jere soils may reduce the availability of micronutrients such as iron (Fe), zinc (Zn), and manganese (Mn) through precipitation reactions (Brady & Weil, 2017). The electrical conductivity (EC) values were low in both locations (0.18 dS/m in Jere and 0.07 dS/m in Konduga), indicating non-saline soil conditions. This is favourable for crop growth, as high salinity reduces water uptake by plants due to osmotic stress and causes ion toxicity, leading to yield decline (FAO, 2015). The observed EC values are consistent with typical levels reported for Sudan–Sahel soils in northeastern Nigeria, which are generally low in soluble salts due to their low inherent salt content and seasonal leaching during rainfall periods (Lawal *et al*., 2018).

However, the concentrations of exchangeable bases varied notably between the locations. Exchangeable Ca^{2+} and Mg^{2+} were higher in Jere (2.20 and 14.80 cmol/kg, respectively) than in Konduga (4.20 and 9.60 cmol/kg). Variations in Ca^{2+} and Mg^{2+} are often linked to parent material composition, soil texture, and leaching intensity, as sandy soils subjected to higher rainfall tend to lose Mg more rapidly. In contrast, clay-rich soils retain more base cations (Brady & Weil, 2017).

Potassium (K^+) and sodium (Na^+) levels were relatively low in both areas, as is typical of highly weathered tropical soils that undergo continuous cropping and limited nutrient replenishment (Sanchez, 2019). However, the Na^+ values (4.00 and 3.48 cmol/kg) suggest a slight sodicity risk, particularly in Jere, as elevated Na^+ can reduce soil structural stability, limit infiltration, and impair root growth (FAO, 2015). The total exchangeable bases (TEB) and effective cation exchange capacity (ECEC) were higher in Jere (21.24 and 21.74 cmol/kg, respectively) than in Konduga (17.51 and 18.11 cmol/kg, respectively). Higher CEC values indicate a greater nutrient-holding capacity, which is largely controlled by soil organic matter and clay content (Brady & Weil, 2017). This trend is consistent with the organic carbon (0.82%) and organic matter (1.41%) values in Jere, which exceeded those of Konduga (0.53% and 0.91%). Although these values are low in absolute terms, they are typical of Sahelian soils, where high temperatures accelerate organic matter mineralization and sparse vegetation limits the accumulation of organic residues (Bationo *et al*., 2018).

The C: N ratios (3.42 for Jere and 3.12 for Konduga) indicate rapid organic matter decomposition and limited humus formation, which is characteristic of nutrient-poor tropical soils and implies the need for continuous organic amendments such as compost, manure, or agroforestry litter inputs to sustain fertility (Brady & Weil, 2017; Sanchez, 2019). The available phosphorus (P) levels were higher in Konduga (16.10 mg/kg) than in Jere (10.56 mg/kg). This is significant because phosphorus deficiency is One of the most widespread fertility constraints in tropical soils due to fixation by iron and aluminium oxides (Sanchez, 2019; Bationo *et al*., 2018). The relatively higher P content in Konduga may be attributed to differences in soil texture, as soils with higher clay and silt contents have greater P retention capacity through adsorption mechanisms (Havlin *et al*., 2019). This is supported by the textural results, which showed that Konduga contains higher clay (22.20%) and silt (20.70%) fractions, while Jere has lower clay (12.20%) and silt (8.20%), classifying Jere as loamy sand and Konduga as sandy clay loam. The coarser texture of Jere soils explains the lower nutrient and organic matter levels, as sandy soils are prone to rapid infiltration, intense leaching, and poor nutrient retention compared to finer-textured soils (Hazelton & Murphy, 2016; Brady & Weil, 2017). Overall, these chemical property variations explain the observed differences in soil fertility potential between the two locations and highlight the importance of soil-specific management strategies.

Table 6: Soil Chemical Properties

Parameters	**JERE**	**KONDUGA**
pH in H_2O (1:2.5)	7.71	6.66
EC (dsm^{-1})	0.18	0.07
cmol(H)/Kgsoil E. A	0.50	0.60
cmol(H)/Kgsoil Ca^{2+}	2.20	4.20

cmol(H)/Kgsoil Mg^{2+}	14.80	9.60
cmol(H)/Kgsoil K^{+}	0.24	0.23
cmol(H)/Kgsoil Na^{+}	4.00	3.48
TEB or CEC	21.24	17.51
ECEC	21.74	18.11
% Base of Sat.	97.70	96.69
% N	0.24	0.17
% O.C	0.82	0.53
% O.M	1.41	0.91
C: M	3.42	3.12
Mg/Kg soil P	10.56	16.10
% Clay	12.20	22.20
% Sand	79.60	57.10
% Silt	8.20	20.70
Textural Class	Loamy sand	Sandy clay loam

Farmers' Perceptions of Soil Fertility and Agroforestry

Table 7 presents farmers' views on the impact of agroforestry practices on soil fertility and the types of soil improvements they have observed. The results reveal a strong positive perception among farmers regarding the benefits of agroforestry to soil health and productivity. Farmers' perceptions are particularly important because they are based on long-term interactions with the land and often reflect real changes in soil conditions and crop performance (Sileshi *et al*., 2017). A significant majority of respondents (88.3%) agreed that agroforestry practices have improved soil fertility, while 11.7% disagreed. This high level of agreement demonstrates widespread recognition of agroforestry as a soil-enhancing land management system. Similar high levels of farmer agreement on the fertility benefits of agroforestry have been reported across sub-Saharan Africa (FAO, 2013). Farmers' perceptions are often guided by visible improvements in crop vigor,

darker soil color, improved tilth, and ease of tillage, which are widely accepted field indicators of improved soil fertility (Brady & Weil, 2017; Sanchez, 2019).

When asked about the type of soil improvement observed, 80.0% of the farmers reported increased organic matter as a major benefit. This finding suggests that the continuous addition of leaf litter, root biomass, and decomposed organic residues from trees enriches the soil with humus, thereby improving nutrient availability, cation exchange capacity, and microbial activity. This observation is strongly supported by scientific studies showing that agroforestry significantly increases soil organic carbon stocks and biological activity compared to sole cropping systems (Saha *et al*., 2018; Lal, 2017). Furthermore, 70.0% of respondents observed better soil moisture retention, indicating that agroforestry systems help conserve soil water through canopy shading that reduces evaporation, improved infiltration from enhanced soil structure, and higher water-holding capacity from increased organic matter. This is particularly important in semi-arid environments, where moisture stress is a major limitation to crop production. Similar findings have been reported by Dagar (2020), who confirmed that agroforestry improves soil-water dynamics and enhances drought resilience.

Additionally, 61.7% of farmers reported reduced soil erosion, reflecting the protective roles of tree roots, litter cover, and canopy interception in stabilizing the soil surface and minimizing topsoil loss during heavy rainfall and wind action. This aligns with earlier studies showing that agroforestry can reduce soil erosion by 30–80% compared to open-field cultivation (Bayala & Prieto, 2020). Reduced erosion is critical for maintaining long-term soil fertility, as topsoil contains the highest concentration of organic matter and essential nutrients. Another 46.7% of respondents acknowledged improved soil texture, suggesting that agroforestry contributes to better soil aggregation, porosity, and structural stability through organic matter buildup, root activity, and biological binding agents. Although soil texture itself is an inherent property, agroforestry improves soil structural condition and aggregation, making soils more favourable for root growth and water movement (Bronick & Lal, 2005; Nair, 2008).

Table 7: Farmers' Perceptions of Soil Fertility and Agroforestry

Variable	Category	Frequency (n=60)	Percentage (%)
Perception of soil fertility improvement due to agroforestry	Yes	53	88.3
	No	7	11.7
Type of soil improvement observed	Increased organic matter	48	80.0
	Better moisture retention	42	70.0
	Reduced erosion	37	61.7
	Improved soil texture	28	46.7

Constraints to Agroforestry Practice

Table 8 presents the major constraints to farmers' adoption and maintenance of agroforestry practices in the study area. The results reveal that while agroforestry offers multiple environmental, agronomic, and economic benefits, several institutional, socioeconomic, and technical barriers continue to limit its widespread implementation. These constraints are consistent with previous studies, which show that agroforestry adoption in developing economies is often hindered by a combination of input scarcity, land tenure issues, knowledge gaps, and labour limitations (2014; FAO, 2019). The most commonly reported constraint was the lack of seedlings, cited by 53.3% of respondents. This indicates that farmers have limited access to quality tree planting materials, which restricts their ability to establish new agroforestry plots or sustain existing ones. The shortage of seedlings is often associated with weak institutional support for community nurseries, insufficient government interventions, and inadequate distribution networks for improved tree species. Similar findings have been reported by Ajayi *et al*. (2011), who observed that poor access to planting materials significantly reduces farmers' participation in agroforestry initiatives across sub-Saharan Africa.

The second major constraint was land tenure insecurity, reported by 40.0% of respondents. This reflects the uncertainty many farmers face regarding ownership, inheritance rights, and long-term access to cultivated land. Land tenure insecurity discourages long-term investments, such as tree planting, because farmers fear losing their trees before they reach maturity. Since most agroforestry trees require several years before economic returns are realized, farmers operating under insecure tenure arrangements are often reluctant to commit to such systems (FAO, 2019). Secure land tenure has been consistently identified as a key determinant of sustained agroforestry adoption. Lack of technical knowledge was cited by 33.3% of farmers, highlighting significant gaps in awareness and skills regarding appropriate agroforestry practices, including species selection, spacing, pruning, tree–crop compatibility, and soil fertility management. Without adequate technical guidance, farmers may fail to achieve optimal benefits from agroforestry systems or may experience poor tree survival and reduced crop yields. This finding underscores the critical role of agricultural extension services and farmer training programmes in promoting effective adoption of agroforestry. Similar observations have been documented by Meijer *et al*. (2015), Sileshi *et al*. (2017), and Dagar (2016), who emphasized that knowledge and advisory support strongly influence farmers' willingness and capacity to adopt agroforestry technologies.

Labour shortage, reported by 30.0% of respondents, is another important constraint to agroforestry practice. Agroforestry systems are generally labour-intensive, particularly during the establishment phase, which involves land preparation, planting, watering, weeding, pruning, and protection of young trees. In rural farming communities where labour is shared between crop production, livestock management, and off-farm income activities, competition for labour often limits farmers' ability to sustain agroforestry practices (Franzel *et al*., 2014). This constraint may be more severe among smallholder farmers with limited household labour availability. Lastly, pest damage on young trees was identified by 20.0% of respondents as a limiting factor to agroforestry practice. Pest infestations, particularly during the seedling and early growth stages, significantly reduce tree survival rates and discourage further investment in tree planting. Insect attacks, livestock browsing, and disease outbreaks are known to be major causes of early tree mortality in agroforestry systems (Nair, 2008; Akinnifesi *et al*., 2010). Without adequate pest management

knowledge and protective measures, farmers may suffer repeated losses, leading to a decline in motivation to continue with agroforestry.

Table 8: Constraints to Agroforestry Practice

Constraint	Frequency (n=60)	Percentage (%)
Lack of seedlings	32	53.3
Land tenure insecurity	24	40.0
Labour shortage	18	30.0
Lack of technical knowledge	20	33.3
Pest damage on young trees	12	20.0

Regression Analysis of Factors Influencing Crop Yield under Agroforestry

Table 9 presents the results of a regression analysis examining the factors that significantly influence crop yield in agroforestry systems. The model yields an R^2 of 0.63, indicating that the predictor variables explain 63% of the variation in crop yield. The overall model is statistically significant ($F = 15.21$; $p < 0.001$), confirming that the selected factors collectively have a meaningful impact on crop productivity. Among the predictors, organic matter content had the strongest positive effect on crop yield ($\beta = 0.415$, $t = 3.87$, $p = 0.000$*). This indicates that soils with higher organic matter—common in agroforestry plots—substantially enhance crop performance by improving nutrient availability, water retention, and soil structure.

Soil moisture content was also a significant positive contributor ($\beta = 0.322$, $t = 2.74$, $p = 0.007$), reflecting the importance of adequate water availability for crop growth. Agroforestry systems, which improve shading and reduce evaporation, likely increase soil moisture levels, thereby promoting higher yields. Farm size showed a positive and significant influence on Yield (*$\beta = 0.278$, $t = 2.54$, $p = 0.013$), suggesting that larger farms may benefit from economies of scale and more efficient management practices, thereby enhancing overall Similarly, farming experience had a positive effect (*$\beta = 0.196$, $t = 1.98$, $p = 0.049$), indicating that experienced farmers are better able to implement agroforestry practices effectively, optimize inputs, and make decisions that increase yield. On the other hand, extension contact had a positive but non-significant effect ($\beta = 0.184$, $t = 1.67$, $p = 0.098$), suggesting that while interaction with extension agents may provide useful technical support, it was not a major determinant of Yield in the studied population.

Table 9: Regression Analysis of Factors Influencing Crop Yield under Agroforestry

Predictor Variable	β Coefficient	t-value	p-value
Farm Size	0.278	2.54	0.013*
Farming Experience	0.196	1.98	0.049*
Organic Matter Content	0.415	3.87	0.000***
Soil Moisture Content	0.322	2.74	0.007**
Extension Contact	0.184	1.67	0.098
$R^2 = 0.63$, $F = 15.21$, $p < 0.001$			

Conclusion

The study concludes that agroforestry is an effective and sustainable farming practice that enhances both crop yields and soil quality in semi-arid regions such as Jere and Konduga LGAs. The study apparently showed that a considerable proportion of agroforestry farmers were within the economically and productively active age range, mostly male, married, and literate. The income from agroforestry practices is used for food and additional investment, improving agroforestry farmers' livelihood resilience. The practices significantly enhance fertility, while also supporting ecological sustainability. Despite its benefits, adoption is constrained by socioeconomic and technical challenges that must be addressed to maximize agroforestry's potential.

Acknowledgement

The authors are indeed thankful to the authorities in the Ministry of Environment Department of Forestry and Wildlife in MMC and Jere LGA for their support in providing data on agroforestry farmers.

References

Adebayo, A. A., & Tukur, A. L. (1999). Adamawa State in maps. Department of Geography, Federal University of Technology, Yola.

Adebayo, A. A., & Yisa, E. S. (2020). Gender roles and agricultural productivity in rural Nigeria. Journal of Rural Studies, 78, 412–420. *https://doi.org/10.1016/j.jrurstud.2020.06.014*

Adesiji, G. B., Tyabo, I. S. & Bolarinwa, K. K. (2013). Effects of extension services on farmers' productivity in Nigeria. *Journal of Agricultural Extension,* 17(2), 68–82.

Adeyemi, O., Oyekale, A. S., and Ogunleye, A. S. (2021). Agroforestry systems and soil fertility management in Nigeria. *Agroforestry Systems*, 95(3), 567–579.

Ajayi, O. C., Akinnifesi, F. K., Sileshi, G. & Chakeredza, S. (2011). Adoption of agroforestry technologies in southern Africa. *Agroforestry Systems,* 81(3), 239–250.

Ajayi, O. C., Place, F., Akinnifesi, F. K. & Sileshi, G. W. (2017). Agricultural success from agroforestry. *World Development*, 98, 379–394.

Ajayi, O. C., Sileshi, G. W. & Akinnifesi, F. K. (2019). Agroforestry for food security and climate resilience in Africa. *Food Security,* 11(4), 857–870.

Ajayi, O.C., Akinnifesi, F.K., Mullila-Mitti, J., DeWolf, J.J. & Matakala, P.W. (2006). Adoption of agroforestry technologies in Zambia: synthesis of key findings and implications for policy. Paper presented at the Agricultural Consultative Forum (ACF) University and the Center for Natural Resources Policy Analysis at the University.

Akinnifesi, F. K., Ajayi, O. C., Sileshi, G., Chirwa, P. W. & Chianu, J. (2010). Fertiliser trees for sustainable food security. *International Journal of Agricultural Sustainability,* 8(1–2), 1–12.

Ali, A. & Buba, H. (2021). Farmers' awareness and adoption of agroforestry practices in Jere LGA, Borno State. *Journal of Environmental Management,* 29(2), 112–121.

Aliyu, A. & Mustapha, M. (2019). Rural livelihood systems in Konduga Local Government Area of Borno State. *Nigerian Journal of Rural Sociology,* 19(1), 33–45.

Audu, E. B., Audu, H. O., Azare, I. M., Shehu, A. U., & Ike, F. (2023). Examination of rainfall trend over the northeastern part of Nigeria. *Journal of Agriculture and Food Environment,* 10(2), 23–34.

Bayala, J. & Prieto, I. (2020). Water acquisition, sharing and redistribution by roots: Applications to agroforestry systems. *Plant and Soil, 453*(1–2), 17–28. https://doi.org/10.1007/s11104-019-04173-z

Bayala, J., Sanou, J. & Teklehaimanot, Z. (2014). Advances in Knowledge of Processes in Soil–tree–crop Interactions in Parkland Systems in the West African Sahel: A review. *Agriculture Ecosystem Environment* 205:25–35

Beedy, T. L., Snapp, S. S., Akinnifesi, F. K. & Sileshi, G. W. (2010). Impact of *Gliricidia sepium* intercropping on soil organic matter fractions in a maize-based cropping system. *Agriculture, Ecosystems & Environment, 138*(3–4), 139–146.

Bello, E. I. (2020). Effects of post-harvest conditions on oil quality from rubber seeds. *Journal of Oleo Science,* 69(11), 1289–1300.

Brady, N. C. & Weil, R. R. (2017). *The nature and properties of soils* (15th ed.). Pearson.

Bwala, M. (2021). Impact of Irrigational Runoff on Fish Biodiversity in River Ngadda, Maiduguri – Borno State. Nigerian *Journal of Pure and Applied Sciences*. 10.48198/NJPAS/20.B04.

Dagar, J.C. Sileshi, G. W. & Akinnifesi, F. K. (2020). Agroforestry to Enhance Livelihood Security in Africa: Research Trends and Emerging Challenges. In book: *Agroforestry for Degraded Landscapes: Recent Advances and Emerging Challenges* (pp.71–134). Publisher: Springer Nature. DOI:10.1007/978-981-15-4136-0_3

Determinants of Agricultural Sustainability in Southeast Nigeria -The Climate Change Debacle (2013). Global *Journal of Agricultural Research* 1(2):1- 13*, www.ea- journals.org*

FAO. (2013). Advancing agroforestry on the policy agenda. Food and Agriculture Organization of the United Nations.

FAO. (2015). Status of the world's soil resources. FAO. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/a-i5199e.pdf

FAO. (2018). Gender and land rights. FAO. Food and Agriculture Organization of the United Nations. https://www.fao.org/gender-landrights-database

FAO. (2019). Agroforestry for landscape restoration. FAO. Agroforestry for landscape restoration: Exploring the potential of agroforestry to enhance the sustainability and resilience of degraded landscapes.

Food and Agriculture Organization of the United Nations.

FAO. (2020). Land tenure and rural development. FAO. Land tenure and rural development.

Food and Agriculture Organization of the United Nations. https://www.fao.org/3/y4307e/y4307e00.htm

FAO. (2021). The state of food and agriculture. FAO. The state of food and agriculture 2021: Making agrifood systems more resilient to shocks and stresses.

Food and Agriculture Organization of the United Nations. https://www.fao.org/3/cb4476en/cb4476en.pdf

Food and Agriculture Organization (FAO) (2019). Guide for Designing, Monitoring and Evaluating Land Administration Programs. *Food and Agriculture Organization of the United Nations (FAO)*, Rome. http://www.fao.org/inaction/herramienta-administracion tierras/glossary/s/en/ .Accessed 11 April, 2026.

Garrity, D. P., Akinnifesi, F. K., Ajayi, O. C., Weldesemayat, S. G., Mowo, J. G., Kalinganire, A., Larwanou, M., & Bayala, J. (2010). Evergreen agriculture. Food Security, 2(3), 197–214.

Gupa, M.A., Bello, A.G., Nasiru, A.M., A.A. Barau & A.A. Senchi(2024). Role of Agroforestry as a Strategy for Improving Livelihood Income in Borno State, Nigeria. *Journal of Arid Agriculture*. 25 (2): 6 – 14. ISSN: 0189-7551 www.jaaunimaid.ng

Gupa, M.A., Bello, A.G. & Nasiru, A.M. (2017). Assessment of Agroforestry System for Restoring Ecosystem Services in Jere Local Government Area, Borno State, Nigeria. *Journal of Agriculture and Environment*. 13 (2): 149-157 ISSN 1595-465X

Havlin, J. L., Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (2019). *Soil fertility and fertilizers: An introduction to nutrient management* (9th ed.). Pearson.

Havlin, J. L., Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (2019). *Soil fertility and fertilizers: An introduction to nutrient management* (9th ed.). Pearson.

Haynes, R. J. & Naidu, R. (1998). Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: A review. *Nutrient Cycling in Agroecosystems, 51*(2), 123–137. https://doi.org/10.1023/A:1009738307837

Lal, R. (2004). Soil carbon sequestration impacts. Science, 304(5677), 1623–1627.

Landon, J. R. (2014). *Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics*. Routledge. https://doi.org/10.4324/978131584684.

Mignouna, D., Akinola, A., Abdoulaye, T., Alene, A., Manyong, V., Maroya, N., Aighewi, B., Kumar, L., Balogun, M., Lopez-Montes, A., Rees, D., & Asiedu, R. (2020). Potential returns to yam research investment in sub-Saharan Africa and beyond. Outlook on Agriculture. 49. 003072702091838. 10.1177/0030727020918388.

Mohammed Lawan Shettima, Gwana Adamu Mohammed, Hauwa Lawan Badawi, Mu'azu Abdullahi Kofan Na'isa, Bassey Effiong Edet (2017). Comparative Techniques of Raising Seedlings of Acacia seyal in the Arid Zone of Borno State, North – Eastern Nigeria. *International Journal of Environmental Protection and Policy*, *5*(6-1), 40–49. https://doi.org/10.11648/j.ijepp.s.2017050601.16

Nair, P. K. R. (2008). Agroecosystem management in the tropics. Springer Netherlands.

Nair, P. K. R. (2020). An introduction to agroforestry: Four decades of scientific developments **(2nd ed.). Springer.** https://doi.org/10.1007/978-3-030-75358-0

National Bureau of Statistics (NBS). (2020). National agricultural sample census report 2019/2020. *Abuja, Nigeria: National Bureau of Statistics.*

Nigerian Meteorological Agency (NiMet, 2021) Seasonal Climate Prediction. https://www.nimet.gov.ng/seasonal-climate-prediction/

Oladele, O., Bamigboye, R., Isa, M., Oloyede, F., Adenuga, A., & Adejunmo, M. (2025). Phytoextraction of cadmium by Pteris vittata L. and Pteris ensiformis burm. f. (ferns) grown on cadmium-contaminated soil in Obafemi Awolowo University, Ile-Ife. *Ife Journal of Science*, *27*(1), 251–263.https://doi.org/10.4314/ijs.v27i1.20

Olagunju, I.E. (2015). Drought, Desertification and the Nigerian Environment: A Review. Journal of Ecology and Natural Environment, 7, 196–209. http://www.academicjournals.org/JENE

Olanrewaju, A. A. & Abubakar, S. Z. (2022). Soil fertility management and crop productivity challenges in selected local government areas of Nigeria. *Journal of Agriculture and Environmental Sciences, 11*(2), 45–56.

Ong, H., Tabi, F. O., Moukam, A. & Yemefack, M. (2014). Geostatistical mapping of soil fertility constraints for yam-based cropping systems of North-central and Southeast Nigeria. *Geoderma Regional, 2–3*, 102–109. https://doi.org/10.1016/j.geodrs.2014.10.001

Sanchez, P. A. (2019). Properties and management of soils in the tropics (2nd ed.). Cambridge University Press.

Sileshi, G., Schroth, G., Rao, M.R., & Girma, H. (2017). Weeds, diseases, insect pests and tri-trophic interactions in tropical agroforestry. In: Ecological basis of agroforestry. CRC, Boca Raton, 73–94

Sileshi, G.W., Mafongoya, P.L., Akinnifesi, F.K. (2014). Agroforestry: fertilizer trees. *Encycl Agric Food Syst* 1:222–234. https://doi.org/10.1016/B978-0-444-52512- 3.00022-X

Sileshi, G.W., Mafongoya, P.L., Akinnifesi, F.K. (2014). Agroforestry: fertilizer trees. *Encycl Agric Food Syst* 1:222–234. https://doi.org/10.1016/B978-0-444-52512- 3.00022-X

Sileshi, Gudeta W., Job Kihara, Lulseged Tamene, Bernard Vanlauwe, Elijah Phiri, and Bashir Jama. "Unravelling causes of poor crop response to applied N and P fertilizers on African soils." *Experimental Agriculture* 58 (2022): e7.

Tadesse, M., Negese, A. & Elias, E.(2020). Land suitability evaluation for sorghum production using GIS-based multi-criteria analysis in Ethiopia. *Cogent Food & Agriculture, 6*(1), 1743624. https://doi.org/10.1080/23311932.2020.1743624

World Bank. (2021). World development indicators. World Bank.

ISTF-NIG 2026

PHYTOCHEMICAL COMPOSITION AND COMPARATIVE ANTIBACTERIAL ACTIVITY OF STEM AND LEAF EXTRACT OF *CISSUS QUADRANGULARIS* AND CONVENTIONAL ANTIBIOTICS AGAINST SELECTED BACTERIA.

[1*]OLATERU Tosin Comfort, [2]ADEJOH Olubunmi Pauline, [1]OLASUPO Oreoluwa [1]OLADAYO, Omoniyi Precious, [1] AMUZAT Temitope Fatimah, [1] ADEKUNLE Zainab [1]AYINDE Rachael Temidayo, and OLATERU John Ayomide.

[1]Department of Biology, The Polytechnic Ibadan, Ibadan, Oyo State
[2]Microbiology Research Section, Forestry Research Institute of Nigeria, Patent and Enterprise Incubation Centre, Ibadan, Oyo State.
[3]Department of Microbiology, Osun State University, Osogbo, Osun State.
Correspondence: tosinola21@gmail.com; +2348107048860

Abstract

The rising challenge of microbial resistance to conventional drugs has intensified interest in natural alternatives, particularly medicinal plants such as *Cissus quadrangularis*, which are widely used in Southwest Nigeria for fertility enhancement and the treatment of various ailments. This study evaluated the phytochemical composition and antimicrobial activity of the plant. Fresh leaves and stems were collected, air-dried, ground into powder, and extracted using ethanol and distilled water. Standard phytochemical Screening revealed the presence of diverse secondary metabolites, including saponins, alkaloids, tannins, flavonoids, phenols, steroids, diterpenes, terpenoids, glycosides, coumarins, and quinones. *Cissus quadrangularis* leaf extracts tested positive for all compounds, while stem extracts lacked phenols and steroids (aqueous) and alkaloids (ethanolic. Antimicrobial assays showed that aqueous extracts inhibited bacterial growth with zones of inhibition ranging from 10.0 mm to 25.0 mm, while ethanolic extracts exhibited activity (5.0–21.0 mm). Standard antibiotics, particularly ofloxacin and levofloxacin, exhibited inhibitory activity of 12-27 mm. These findings support the traditional medicinal use of *Cissus quadrangularis* and highlight the need for further pharmacological and clinical investigations.

Keywords: *Cissus quadrangularis*, Extracts, Antimicrobial susceptibility, Agar well diffusion

Introduction

Traditional medicine has become the mainstay of approximately 80% of people in developing countries for primary healthcare, and the use of herbal medicine has increased substantially across Africa **(**Eshete & Molla, 2021**).** The plant Kingdom represents a rich reservoir of pharmaceutical agents, and growing recognition of the importance of medicinal plants has driven renewed scientific interest. Plant-derived drugs are generally more accessible, less expensive, and associated with fewer adverse effects than their synthetic counterparts. Bioactive substances in medicinal plants, including tannins, alkaloids, carbohydrates, terpenoids, steroids, and flavonoids, are synthesized via primary and secondary metabolic pathways and exert a range of physiological effects on the human body (Krauss & Howard, 2020). Among the plants employed for reproductive health in Southwest Nigeria is *Cissus quadrangularis*, which is widely used by traditional physicians (Hamid & Patil, 2023).

Cissus quadrangularis L. (Vitaceae), known as the veldt grape, is a succulent vine traditionally used for bone fractures, dysmenorrhea, pelvic pain, postpartum hemorrhage, digestive disorders, infections, inflammation and infertility across Africa and Asia **(**Siddiqua & Mittapally, 2017**).** A perennial plant characterized by its thick, quadrangular stems, which give it its name. The plant extract has been proven to be antiviral, a free radical scavenger, antibacterial, anti-inflammatory, and antioxidant. The mixture of sesame oil and stem extract is used to treat wheezing and skin issues. CQ can reduce body weight, serum lipid levels, and serum glucose levels (Camil & Ravi, 2020). Despite the widespread traditional use of these plants, scientific investigations are still required to validate their antimicrobial potential and identify the active phytochemicals responsible for their biological activities. Therefore, this study aims to evaluate the phytochemical composition and antibacterial activity of these plants against selected pathogenic bacteria.

Materials and methods

Sample Collection and Preparation of Plant Extracts

Fresh leaves and stems of *Cissus quadrangularis* were collected from herbal farmers in Ibadan, Oyo State. Upon arrival, the samples were rinsed with distilled water and air-dried on a laboratory bench for 2 weeks. The collected plant materials were washed with clean water to remove dirt and contaminants. They were then air-dried at room temperature for several days until completely dried. Air-dried materials were ground into fine powder using an electric blender. For each sample, 40 g of powder was divided equally (20 g each) into two Erlenmeyer flasks, each containing 150 mL of ethanol and 150 mL of distilled water. Flasks were sealed with aluminum foil and left for 72 hours with intermittent shaking to prevent fermentation. Extracts were filtered through Whatman No. 1 filter paper and stored for analysis (Oloyede *et al*., 2010).

Phytochemical Screening of the stem and leaves of *the Cissus* plant.

Phytochemical Screening of the plant extracts was carried out to determine the presence of major bioactive compounds. Standard laboratory procedures were used to test for the presence of the following phytochemicals. Qualitative phytochemical Screening followed standard procedures described by Trease and Evans (2005). Tests were performed for tannins (ferric chloride reaction), alkaloids (ferric chloride after boiling), glycosides (Fehling's solution test), flavonoids (NaOH color reaction), and steroids (H_2SO_4 color reaction), among others.

Source of test bacteria and antibacterial activity

Pure cultures of *Escherichia coli* and *Pseudomonas aeruginosa* were obtained from the Department of Medical Microbiology. University College Hospital, Ibadan, while *Staphylococcus* species, *Bacillus* species, and *Enterococcus* species cultured from fresh fruits in a previous study were used as test organisms (Olateru & Ogunbanwo, 2019; Olateru *et al*., 2025). Agar well diffusion was used to assess antibacterial activity. Sterile Mueller-Hinton plates were inoculated, wells bored with a sterile cork borer, and filled with 0.1 mL of extract at concentrations ranging from 10–30 mg/mL. Plates were incubated at 37°C for 24 hours and zones of inhibition measured in millimeters (Ravea *et al*., 2019).

Antibiotic Susceptibility Testing

Antibiotic disc diffusion was performed on all isolates following standard protocols. Discs were placed aseptically on Mueller-Hinton agar inoculated with bacteria, and the plates were incubated at 37°C for 24 hours. Inhibition zone diameters were measured, and isolates were categorized as sensitive or resistant.

Results

Phytochemical Composition

Qualitative phytochemical Screening of aqueous and ethanolic extracts of *Cissus quadrangularis* (stem and leaf) demonstrated the presence of a wide range of secondary metabolites. The leaf extracts of *Cissus quadrangularis* showed positive results for all eleven tested phytochemicals in both solvents. In contrast, the stem extracts were deficient in tannins and phenols in the aqueous fraction, and alkaloids in the ethanolic fraction (Table 1)

Table 1: Phytochemical constituents of *Cissus quadrangularis* extracts

Phytochemicals	CQ Stem (A)	CQ Stem (E)	CQ Leaf (A)	CQ Leaf (E)
Saponin	+	+	+	+
Flavonoid	+	+	+	+
Alkaloid	+	–	+	+
Phenol	–	+	+	+
Tannin	–	+	+	+
Coumarin	+	+	+	+
Diterpenes	+	+	+	+
Terpenoid	+	+	+	+
Steroid	+	+	+	+
Glycoside	+	+	+	+
Quinones	+	+	+	+

CQ = *Cissus quadrangularis*; A = Aqueous; E = Ethanolic , + = Present; – = Absent

Antibiotic Susceptibility

The antibiotic susceptibility profile of the Gram-positive isolates is presented in Table 3. Pefloxacin (PEF) and Levofloxacin (LEV) consistently produced the largest zones of inhibition, ranging from 25 to 27 mm across *Staphylococcus* spp., *Bacillus* spp., and *Enterococcus* spp. Ciprofloxacin (CPX) and Ofloxacin (OFL) also demonstrated considerable antimicrobial activity. In contrast, Cotrimoxazole (COT), Amoxicillin (AMX), Ceftriaxone (CEF), and Tetracycline (TET) exhibited minimal or no inhibitory effects against the majority of the isolates (Table 3). The antibiotic susceptibility pattern of the Gram-negative isolates is summarized in Table 4. Levofloxacin (LEV) exhibited the largest and most consistent zones of inhibition against both *Escherichia coli* and *Pseudomonas* spp., reaching 23–24 mm. Ofloxacin (OFL) and Ciprofloxacin

(CPX) also showed reliable broad-spectrum activity. In contrast, Penicillin (PEN) demonstrated no inhibitory effect on any of the Gram-negative isolates, in line with the well-established intrinsic resistance of these organisms.

Table 2: Antibiotic susceptibility profile of Gram-positive bacteria

Serial No	Test Organism	Antibiotics/ Zone of Inhibition (mm)									
		COT	**CEF**	**AMX**	**ERY**	**CPX**	**OFL**	**AZY**	**PEF**	**LEV**	**TET**
1	*Staphylococcus spp*	0	0	0	0	0	0	0	23	25	0
2	*Staphylococcus* spp	0	0	0	0	20	20	0	0	25	0
3	*Staphylococcus* spp	0	0	0	0	0	12	0	12	20	0
4	*Staphylococcus* spp	10	0	0	0	23	20	17	22	24	19
5	*Staphylococcus* spp	0	0	0	0	0	0	0	0	0	0
6	*Staphylococcus* spp	0	0	0	0	0	0	0	0	0	0
7	*Staphylococcus* spp	0	0	0	0	18	20	15	20	0	0
8	*Staphylococcus* spp	0	0	0	0	23	23	15	20	24	0
9	*Staphylococcus* spp	0	0	0	0	0	0	0	0	0	0
10	*Bacillus* spp	0	0	0	0	0	0	12	22	19	0
11	*Bacillus* spp	0	0	0	0	19	18	0	17	24	0
12	*Bacillus* spp	0	0	0	17	19	20	0	22	22	0
13	*Bacillus* spp	0	0	0	0	22	27	0	22	22	0
14	*Bacillus* spp	27	22	0	19	17	22	22	22	22	19
15	*Bacillus* spp	0	0	0	19	23	22	20	20	19	18
16	*Bacillus* spp	0	0	0	0	25	23	0	23	23	0
17	*Bacillus* spp	0	0	0	0	0	0	25	20	21	0
18	*Enterococcus* spp	0	0	0	0	0	19	19	25	23	0
19	*Enterococcus* spp	0	0	0	0	24	24	0	22	25	0
20	*Enterococcus* spp	0	0	0	0	0	0	0	25	23	0
21	*Enterococcus* spp	0	0	0	0	25	25	22	23	23	0
22	*Enterococcus* spp	0	0	0	0	25	24	23	23	25	0
23	*Enterococcus* spp	0	0	0	0	23	22	0	22	23	0

COT: Cotrimoxazole; CEF: Ceftriaxone; AMX: Amoxicillin; ERY: Erythromycin; CPX: Ciprofloxacin; OFL: Ofloxacin; AZY: Azithromycin; PEF: Pefloxacin; LEV: Levofloxacin; TET: Tetracycline. Values are the zone of inhibition in mm; 0 = no inhibition.

Table 3: Antibiotic susceptibility profile of Gram-negative bacteria

Serial No	Test Organism	Antibiotics/ Zone of Inhibition (mm)									
		COT	**CEF**	**AMX**	**ERY**	**CPX**	**OFL**	**AZY**	**PEF**	**LEV**	**TET**
1	*Escherichia coli*	24	16	14	16	14	0	0	15	10	18
2	*Escherichia coli*	11	12	11	21	15	0	0	14	13	14
3	*Escherichia coli*	0	23	0	15	0	0	0	15	13	19
4	*Escherichia coli*	0	16	8	13	13	0	0	14	0	14
5	*Escherichia coli*	0	16	0	12	12	0	0	16	14	0
6	*Escherichia coli*	0	19	14	17	18	0	0	17	16	19
7	*Escherichia coli*	0	12	14	14	16	0	0	14	10	0
8	*Escherichia coli*	0	15	14	19	21	18	0	15	15	21
9	*Escherichia coli*	12	16	14	13	15	0	16	13	14	19

10	*Escherichia coli*	0	23	18	14	12	0	0	17	12	15
11	*Escherichia coli*	11	23	14	18	13	0	16	16	12	15
12	*Escherichia coli*	14	21	13	11	15	0	0	23	18	12
13	*Escherichia coli*	13	14	13	18	15	0	0	17	13	11
14	*Escherichia coli*	0	0	0	0	0	0	15	16	13	10
15	*Escherichia coli*	12	12	14	15	16	0	0	16	14	16
16	*Escherichia coli*	22	22	0	17	23	0	0	14	14	15
17	*Escherichia coli*	15	0	0	17	16	0	0	12	14	24
18	*Pseudomonas spp.*	0	23	0	15	0	0	0	0	0	0
19	*Pseudomonas spp.*	0	19	14	17	10	0	0	14	0	17
20	*Pseudomonas spp.*	16	23	14	0	0	0	0	0	0	16
21	*Pseudomonas spp.*	0	18	19	16	0	0	0	0	0	16
22	*Pseudomonas spp.*	17	23	21	23	0	0	0	0	0	17
23	*Pseudomonas spp.*	17	21	18	19	18	0	13	18	20	18
23	*Pseudomonas spp.*	17	17	17	17	17	0	9	17	17	17

APX: Ampicillin; LEV: Levofloxacin; CEF: Ceftriaxone; CPX: Ciprofloxacin; CHL: Chloramphenicol; PEN: Penicillin; TET: Tetracycline; GEN: Gentamicin; STR: Streptomycin; OFL: Ofloxacin. U = Urine; WS = Wound swab; WB = Wound biopsy; AT = Aspirate tracheal; SP = Sputum; TA = Tracheal aspirate; NS = Nasal swab. Values in mm; 0 = no inhibition.

Antibacterial Activity of *Cissus quadrangularis* Extracts

The antibacterial activities of stem and leaf extracts of *Cissus quadrangularis* are summarized in Table 6. The aqueous stem extracts exhibited the greatest inhibitory effect, with zones of inhibition reaching 28.0 mm against *E. coli*. Aqueous leaf extracts produced inhibition zones anging from 14.0 to 24.0 mm, while the ethanolic extracts showed comparatively lower activity in both stem and leaf fractions. *Pseudomonas aeruginosa* was inhibited mainly by the aqueous stem extract, with zones between 9.0 and 11.0 mm. In contrast, *Staphylococcus* spp. were susceptible to aqueous stem extracts (9.0–17.0 mm) and ethanolic leaf extracts (17.0 mm) (Table 4)

Table 4: Antibacterial activities of stem and leaf extracts of *Cissus quadrangularis*

Test Organism	Antibiotics/ Zone of Inhibition (mm)					
	Stem (A)	**Stem (E)**	**Stem (C)**	**Leaf (A)**	**Leaf (E)**	**Leaf (C)**
Escherichia coli	0	0	0	0	0	0
Escherichia coli	0	0	0	0	0	0
Escherichia coli	28	0	0	14	0	0
Escherichia coli	0	17	0	0	0	0
Escherichia coli	28	0	0	16	0	0
Escherichia coli	12	0	0	0	0	0
Escherichia coli	24	0	0	0	0	0
Escherichia coli	25	0	0	0	0	0
Escherichia coli	0	0	0	14	19	15
Escherichia coli	11	0	0	14	0	0
Escherichia coli	0	0	24	0	14	0
Escherichia coli	0	0	0	14	21	15
Escherichia coli	0	0	0	24	0	20
Escherichia coli	0	16	0	15	0	0

Escherichia coli	15	0	0	0	0	0
Escherichia coli	27	0	0	14	21	15
Pseudomonas aeruginosa	9	0	0	0	0	0
Pseudomonas aeruginosa	11	0	0	0	0	0
Staphylococcus spp.	17	0	0	0	0	0
Staphylococcus spp.	9	0	0	0	0	0
Staphylococcus spp.	0	0	0	0	17	0
Staphylococcus spp.	9	0	0	0	0	0

A = Aqueous; E = Ethanolic; C = Control. Values in mm; 0 = no inhibition.

Discussion

Phytochemical analysis of *Cissus quadrangularis* confirmed the presence of a wide range of secondary metabolites. These bioactive compounds are well known for their therapeutic and physiological relevance, providing scientific support for the traditional use of these plants in Southwest Nigeria (Ogunniyi *et al*., 2017; Kalita *et al*., 2026). Phenolic constituents, such as flavonoids and phenolic acids, are widely recognized for their antioxidant, anti-inflammatory, and antimicrobial activities. Their presence in both plant species may enhance the ability to mitigate oxidative stress, which is known to affect reproductive health adversely (Agarwal *et al*., 2012; Shapiro *et al*., 2018). Steroidal compounds identified in the extracts, due to their structural similarity to endogenous sex hormones, may partly account for the ethnomedicinal use of these plants to manage hormonal and reproductive conditions. Saponins, also detected in both species, exhibit anti-inflammatory properties and can interact with cell membranes, thereby improving the bioavailability of other phytochemicals. According to Patel (2021), the galactogenic and reproductive effects of medicinal plants may arise from synergistic interactions among saponins, tannins, alkaloids, and flavonoids.

Results from the antimicrobial assays showed that aqueous extracts generally produced larger zones of inhibition than ethanolic extracts, indicating that water-soluble constituents—particularly polar phenolics, saponins, and glycosides may be primarily responsible for the observed antimicrobial activity. This trend aligns with earlier reports (Oloyede *et al*., 2010; Adedayo & Abiola, 2017). Notably, the aqueous stem extract of *Cissus quadrangularis* exhibited the strongest activity, with inhibition zones of up to 28 mm against *E. coli*. The inhibition of bacteria by the extracts from the leaves and stems of the plant used in this study is consistent with reports by Khatri *et al*. (2025) and Amrinder *et al*. (2025), which established the antimicrobial properties of Cissus *quadrangularis leaves* against fungi and bacteria. Similarly, comparison with standard antibiotics revealed that fluoroquinolones—levofloxacin, ofloxacin, pefloxacin, and ciprofloxacin demonstrated the most consistent broad-spectrum efficacy, with inhibition zones reaching up to 27 mm. The lack of activity observed with penicillin against Gram-negative isolates is consistent with established intrinsic resistance mechanisms, particularly the outer membrane permeability barrier. The reduced effectiveness of amoxicillin and cotrimoxazole against several isolates may reflect prevailing patterns of antimicrobial resistance (Gauba *et al*., 2023)

Conclusion and Recommendation.

Phytochemical evaluation of the aqueous and ethanolic extracts of *Cissus quadrangularis* revealed the presence of several key secondary metabolites. These findings provide a scientific foundation for the traditional therapeutic use of these plants and suggest that they have antibacterial activity comparable to that of conventional antibiotics. The aqueous extracts generally exhibited stronger antimicrobial activity than the ethanolic extracts, although both were less effective compared to standard clinical antibiotics. The detection of bacterial contaminants in market-sourced plant materials further highlights the need for stringent quality control in the preparation of herbal remedies. Future research should prioritize bioassay-guided isolation and characterization of active compounds, as well as the determination of minimum inhibitory and bactericidal concentrations. In addition, in vivo studies assessing efficacy and safety are essential. Greater collaboration between scientific researchers and traditional medicine practitioners is recommended to standardize preparation techniques and validate the therapeutic potential of these important medicinal plants.

References

Adedayo, A. & Abiola, S. O. (2017). Phytochemical and antimicrobial properties of Moringa oleifera leaves. *Journal of Medicinal Plants Research*, 5(4), 45–52.

Agarwal, A., Virk, J. M., Ong, C. M., Sharma, S. A., Abu, R. K. & Sikka, B. S. (2012). Antioxidant therapy in male infertility: From molecular mechanisms to clinical applications. *Human Reproduction Update*, 32(50), 3049.

Amrinder Kaur, Sushma, & Seema Rani (2025). Phytochemical analysis and antimicrobial potential of *Cissus quadrangularis* extracts.*International Journal of Medical and Health Research* 11(3):62-65

Camil Rex, M., & Ravi, L. (2020). A review of Cissus quadrangularis L. as a herbal medicine. *Indian Journal of Natural Products and Resources*, *11*(3), 155–164.

Eshete, M. A., & Molla, E. L. (2021). Cultural significance of medicinal plants in healing human ailments among Guji semi-pastoralist people, Suro Barguda District, Ethiopia—*Journal of Ethnobiology and Ethnomedicine*, *17*(1), 61.

Gauba, A., and Rahman, K. M. (2023). Evaluation of antibiotic resistance mechanisms in gram-negative bacteria. *Antibiotics*, *12*(11), 1590.

Hamid, H. S., & Patil, S. (2023). A phytochemical and pharmacological review of an Indian plant: Cissus quadrangularis. In *Medical Sciences Forum* (Vol. 21, No. 1, p. 20). MDPI.Harborne, J. B. (2000). Phytochemical Methods. London: Chapman and Hall Ltd., pp. 49–188.

Kalita, P., Saikia, C., Jesudasan, R., & Pathak, K. (2026). Exploring the Phytochemical Composition and Pharmacological Potential of the Plant *Cissus quadrangularis* in Herbal Formulations. *Current Functional Foods*, *4*(1).

Khatri, R., Jain, R., & Purohit, S. (2025). Comparative Study of Antimicrobial Activity of Extract of Leaves of *Cissus quandrangularis* L. and *Cissus rotendifolia*: Comparative Antimicrobial Activity of Cissus sp. Extracts. *Arabian Journal of Medicinal and Aromatic Plants*, *11*(2), 188-208

Krauss, R. M. & Howard, B. V. (2020). A statement for health care professionals from the nutrition committee of the American Heart Association. Circulation, 102, 2284–2299.

Ogunniyi, D. M., Akinmoladun, O. B., Olorunfemi, O. B., Akinmoladun, M. A. & Akinmoladun, O. M. (2017). Phytochemistry and fertility-enhancing potential of traditional Nigerian herbs. *African Journal of Reproductive Health*, 143(3), 154–162.

Olateru T.C, Ajulor N. P., Nwaokolo V. M., Ugwu J. A. (2025). Characterization of Bacillus Species from fresh fruits and their Biodegradation potential in the reduction of heavy metal contents in Banana juices. *Journal of Science Technology and Innovation Research* (Special Issue) pp. 138-144.

Olateru**,** C. T, Ogunbanwo, S. T. (2019). Molecular Characterization and Antagonistic Activity of Fructophilic Lactic Acid Bacteria and Antagonistic Activity of Fructophilic Lactic Acid Bacteria Isolated from Selected Fruits. *Microbiology Research Journal International*, *26*(2), 1-17

Oloyede, G. K., Onocha, P. A., Soyinka, J., Oguntokun, O. & Thonda, E. (2010). Phytochemical screening, antimicrobial and antioxidant activities of four Nigerian medicinal plants. *Annals of Biological Research,* 1(1), 114–120.

Patel, S. R. (2021). Studies for developing shoot cultures of *Leptadenia reticulata (Retz.)* Wight and *Tylophora indica (Burm. F.) Merrill with phytochemical analysis* (Doctoral dissertation, Maharaja Sayajirao University of Baroda (India)). Ravea, A. F. G., Kuss, A. V., Peila, G. H. S., Ladeira, S. R., Villarreal, J. P. V. and Nasceafex, P. S. (2019). Biochemical identification techniques and antibiotic susceptibility profile of lipolytic bacteria from effluents. *Brazilian Journal of Biology*, 79(4), 555–365.

Shapiro, B., Miguel, A. J., Tchouanguep, F. F., Ngu, C. N. A., & Nyam, D. G. A. (2018). Herbal medicine and fertility: A review of medicinal plants with antioxidant properties. *Phytotherapy Research,* 132(1), 1–14.

Siddiqua, A., & Mittapally, S. (2017). A review of Cissus quadrangularis. *Pharma innov*, *6*(7 Part E), 329.

Trease, G. E. & Evans, W. C. (2005). Pharmacognosy (15th ed.). Philadelphia: Saunders.

ISTF-NIGERIA 2026

ENVIRONMENTAL AND HEALTH RISKS OF URBAN FLOODING IN JERE LOCAL GOVERNMENT AREA, BORNO STATE, NIGERIA

***[1]Umar, L.A., [2]Ali, B. [3]Modu M. [4]Owa, G.T, [5]Hamidu, S.T and [6]Iro, I.I,**

[1,3,5,6] Federal College of Forest Resources Management, Maiduguri, Borno State. Nigeria.
[2]Federal University Gashua, Gashua, Yobe State
[4]Federal College of Forestry Jos, Plateau State, Nigeria
Correspondimg email: bnkather78@gmail.com

Abstract

Urban flooding has become One of the most destructive environmental challenges in Nigeria, driven by climate change, rapid urbanization, and infrastructural decay. This study assesses the environmental and health risks of urban flooding in Jere Local Government Area (LGA), Borno State. The research employed a mixed-methods approach, combining structured questionnaires administered to 100 respondents across five purposively selected districts with secondary data from government agencies, scientific reports, and published literature. Findings revealed that 56% of respondents experienced severe flooding within the past five years, while 68% reported direct personal or household impacts, including displacement, property loss, and illness. Major environmental risks included soil erosion (66%), water pollution (28%), and biodiversity degradation. Health risks were dominated by waterborne diseases (80%), which intensify during flood episodes. The 2024 Alau Dam collapse significantly heightened the magnitude and spread of flooding, further exposing infrastructural deficiencies. The study concludes that environmental degradation, inadequate drainage systems, poor waste management, and weak institutional preparedness collectively amplify flood risks in Jere. It recommends integrated flood risk management strategies, improved drainage infrastructure, strengthened public health surveillance, and community-centered resilience programs.

Keywords: Urban Flooding, Environmental Impacts, Health Risks, Waterborne Diseases, Jere Climate Change, Nigeria

Introduction

Flooding is One of the most recurrent and devastating natural hazards affecting human settlements worldwide. In recent decades, flood frequency and intensity have increased significantly, largely due to anthropogenic climate change, unregulated urbanization, and increasing land-use pressure (IPCC, 2021). Developing nations, particularly those in sub-Saharan Africa, are disproportionately affected due to weak infrastructure, poor planning, and limited disaster management capacity (Alderman *et al.,* 2012; Aja & Olaore, 2014). Urban flooding occurs when runoff exceeds the capacity of drainage systems or when natural water channels overflow their banks (Butler *et al.,* 2018). Urban floods differ from riverine floods because impermeable surfaces—roads, pavements, rooftops—increase runoff intensity.

In Nigeria, urban flooding has emerged as a severe environmental and public health challenge. Cities such as Lagos, Ibadan, Port Harcourt, Kano, Makurdi, and Maiduguri regularly experience destructive flood events, resulting in loss of lives, displacement, and widespread infrastructural damage (National Emergency Management Agency, 2022; Danhassan *et al.,* 2023). In Borno State,

the situation is worsened by rapid urban expansion, environmental degradation, and the increasingly unpredictable rainfall patterns linked to climate variability.
Urban flooding results from multiple, interconnected factors, including extreme rainfall, land-use changes, poor drainage, population pressure, and climate-induced hydrological changes (Xu *et al.,* 2023). Urban flooding in northern Nigeria, especially in cities like Kano and Kaduna, is a growing issue, driven by heavy rainfall, inadequate drainage and rapid urbanization (Adebayo & Oladipo, 2015). In 2024, the Nigerian Meteorological Agency warned that climate change and urbanization are increasing flood risk in the region.

Jere Local Government Area, located adjacent to Maiduguri metropolis, has become a flood hotspot. The flat topography, insufficient drainage networks, and clogged waterways make the area highly vulnerable. Urban flooding reached unprecedented levels following the collapse of the Alau Dam in September 2024, which released heavy inflows from the Ngadda River and inundated several communities such as Gwange, Lagos Street, Bama Road, Budum, Muna IDP Camp, Shikari general area, State Lowcost and Maiduguri Zoo, as reported by UNICEF (2024).
This study provides a comprehensive assessment of the environmental and health risks associated with urban flooding in Jere LGA. By integrating, this study contributes to a deeper understanding of the drivers, consequences, and mitigation needs of urban flood risks in northeastern Nigeria.

Materials and Methods

Study Area

Jere LGA is located in Borno State, northeastern Nigeria. It covers an area of 868 km² and has a population of 209,107 (NPC, 2006). It consists of 12 districts, several of which are highly flood-prone due to flat terrain and proximity to the Ngadda River and Alau Dam. The climate is characterized by hot, dry conditions, with average temperatures of 36-43°C during the peak heat months. Annual rainfall ranges from 400 to 552 mm (NIMET, 2021).

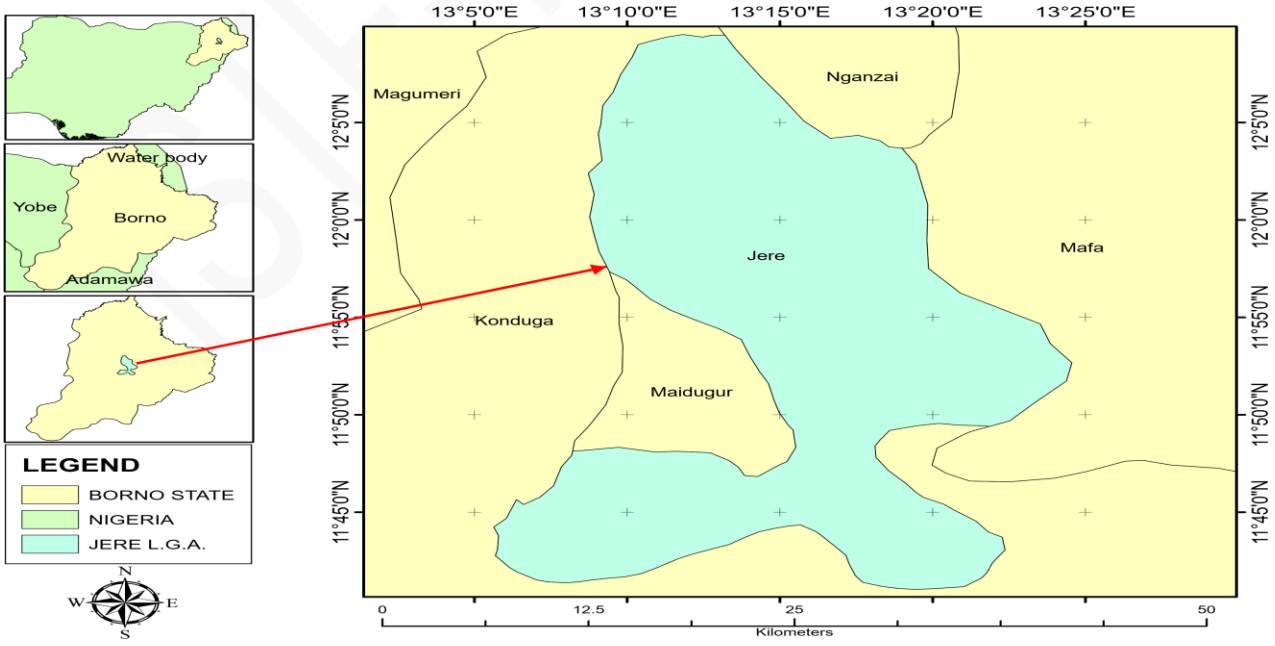


Figure 1: Map of Jere L.G.A of Borno State

Research Design

A descriptive cross-sectional survey design was employed. This design is appropriate when assessing perceptions, experiences, and risk factors within a population at a single point in time. The design was cost-effective and time-efficient, allowed for a large sample size, and could be used to study various topics and populations.

Sampling

Procedure and Sample Size

A purposive sampling method was employed to select five (5) districts from a total of twelve (12) affected areas. The selected districts include Mashamari, Mairi, Gongulon - Lawanti, and Galtimari. Twenty (20) respondents from each of the selected districts were randomly selected for data collection, totaling One hundred (100), as adapted from Gupa *et al.* (2024). This was likely done to ensure a representative and balanced sample, allowing comparisons across districts and minimizing bias.

Data Collection

Both primary data and secondary information were used. The primary data were collected through a structured questionnaire, while secondary sources included published journals, ministerial documents, and the Internet. The data were collected for the Assessment of Environmental and Health Risk of urban Flooding in Jere Local Government Area. The collected data were coded and analyzed using the Statistical Package for the Social Sciences (SPSS, version 20) to address the study's research questions. Descriptive statistical tools, such as frequency distributions, percentages, and tables, were used.

Frequency Distribution Fi = Count (Xi)…….. (1)

Where:

Fi = frequency of the specific Value or Class Xi.

Percentage P$i = \frac{Fi}{N} x100$ …… (2)

Where:

P_i is the percentage of the category.

F_i is the frequency of the category

N is the sum of all percentages in a distribution that must equal.

Results and Discussion

Demographic Information of the Respondent

Demographic information for respondents in the study area is presented in Table 1. The largest group of respondents (36%) are between 20 and 29 years old. A significant portion of the

respondents are between 30 and 39 years old (32%). 22% are between 40 and 49 years old. 8% are below 20 years old. Only a small number of respondents (2%) are above 50 years old. These results are lower when compared with the findings of Nura and Alison, (2023) who reported that, most of the people were working class (aged 25 – 45 years), who's income was at most NGN 600, 000 per annum; about 74.8% of the respondents have lived for at least 4 years before the flood event and 95% have experienced flooding events in the study area before the 2017 event. Residential houses with concrete frames and unreinforced masonry were less damaged (damage percentage 1.8%) than residential unreinforced masonry buildings (22.4%).

This is lower when we compared findings of Nmecha *et al.,* (2024) which revealed that, the number of the respondents are 57% of Men and 43 appeared to be Female in his work carried out in Oguta, Imo State Nigeria while age group of the respondents wtith highest is above 30 years with 59%, followed by 20-30 is recorded to 30%, least is 20years is 1% only. Our result is lower when compared with the work of Bwala *et al*. (2015), who revealed that the active age group that mostly participates in flood control in Maiduguri ranges between 20-32 years, forming 72.0% of the respondents, 22.4% are of 33-45 years and 5.6% fall into the 46-57 years age bracket. In another study conducted in Abeokuta by Adelekan (2011), it was reported that the total number of respondents interviewed comprised 131 (52.8%) men and 117 (47.2%) women, of whom 21% had no formal Education, while 19% had some education at the primary school level. 40% and 20% of respondents have secondary and post-secondary Education, respectively. A high proportion (61.3%) is engaged in the informal sector as artisans (22.2%), traders (37.1%), and farmers (2%), while 30.2% are civil servants. Only (4%) are professionals, and 4.5% are unemployed. Most respondents fall into the low-income group, with 63.3% earning less than ₦20,000 per month and 35.1% earning between ₦20,000 and ₦60,000 per month. Only 1.6% of respondents earn a monthly income of ₦60,000 or more.

There are two groups with the same percentage: 30% students and civil servants; 26% are business People; 12% are farmers; and only 2% are artisans. This result is higher than that reported by Bwala *et al*. (2015), who found that civil servants in the study areas accounted for only 17.6%, traders for 20.4%, and farmers and artisans each for 21.2%. This article shows that Jere Local Government has the largest number of civil servants and students among the local governments in Borno State. The largest group of respondents (40%) has lived in Jere LGA for over 15 years, 28% for 11-15 years, 22% for 6-10 years, and 10% for less than 5 years. This shows that the majority of respondents (68%) have lived in the area for over 10 years.
30% of the respondents have a Diploma/NCE. 24% have an HND/ Degree. 22% have a post-graduate qualification, 8% have non-formal Education, 8% have a primary school certificate, and 8% have an SSCE.

Table 1. Demographic information of the Respondent

Variables	Frequency	Percentage (%)
Age		
Below 20 Years	8	8
20 – 29	36	36
30 – 39	32	32
40 – 49	22	22
Above 50	2	2
Occupation		

Student	30	30
Civil servant	30	30
Farmers	12	12
Business	26	26
Artisan	2	2
How long have you lived in Jere Local Government Area		
< 5 Years	10	10
6 – 10years	22	22
11 – 15 years	28	28
above 15 years	40	40
Educational Status		
(a) Non-formal Education	8	8
(b) Primary school certificate	8	8
(c) SSCE	8	8
(d) Diploma/NCE	30	30
(e) HND/ Degree	24	24
(f) Post-graduate	22	22

Source: Field Survey 2025

Environmental and Health Risk

In Table 2, 68% of respondents have been personally affected by flooding in the past, experiencing displacement, injury, or property loss, while 32% have not been directly affected. This suggests that a significant majority of respondents have had a personal experience with flooding. Respondents identified the most significant environmental risks associated with urban flooding as: Waterborne diseases (80%), Vector-borne diseases (4%), Air pollution (12%), and Noise pollution (4%). Most of the respondents are more concerned about the risk of waterborne diseases associated with urban flooding. The results are similar to those of Bwala *et al*. (2015), who reported that 79% of the respondents agreed that waterborne diseases were the most significant environmental health risk. Based on its impact on health and well-being, 88% of respondents believed that urban flooding affects residents' health and well-being in their area, while 12% did not. This suggests that a clear majority of respondents are aware of the health implications of urban flooding. For changes in flooding frequency or severity, 66% of respondents have noticed changes in their area over the past 5 years, and 34% have not. This indicates that a significant proportion of respondents perceive a change in flooding patterns, which may be related to climate change or other factors.

In northeastern Nigeria's Borno, Adamawa, and Yobe states, there was a second cholera outbreak in 2022, with over 1,500 probable cases and 64 fatalities, according to a UN report dated September 20, 2022. Approximately 17 local government units in the three states are experiencing water contamination incidents due to flooding during the height of the rainy season in August 2022. 36 people died and over 900 instances of cholera were suspected in Yobe State, where over 60,000 people were impacted by flooding. In September 2022, the states of Adamawa, Borno, and Yobe officially declared a cholera outbreak linked to flooding. The 2022 flooding increased the number of people who contracted waterborne diseases such as diarrhea and cholera due to poor sanitation infrastructure (Aliyu *et al.,* 2023). Flood-induced soil erosion affects agricultural lands,

undermining food security. Polluted floodwaters carry plastics, feces, chemicals, and sediments into wells and rivers. These findings align with those of Ezemonye *et al*. (2015), who documented deteriorating water quality after floods in Uyo. Infrastructure damage, though respondents reported it as low, is severe during large-scale events, as demonstrated by the 2024 dam collapse. Health risks in Jere are largely predictable and preventable. The dominance of waterborne diseases is consistent with global patterns in flood-prone, low-infrastructure communities (Alderman *et al.,* 2012). Cholera remains One of the deadliest flood-related diseases in northeastern Nigeria. The perception of worsening flood severity confirms scientific reports of climate-induced hydrological changes in the Sahel region.

Table 2. Environmental and Health Risk Associated with Urban Flood

Variables	Frequency	Percentage (%)
Have you or a family member been affected by flooding in the past? (e.g. displacement, injury, loss of property)		
Yes	68	68
No	32	32
What are the most significant environmental risks associated with urban flooding in your area?		
Waterborne diseases	80	80
Vector-borne diseases	4	4
Air pollution	12	12
Noise pollution	4	4
Have you thought about how urban flooding affects the health and well-being of residents in your area?		
Yes	88	88
No	12	12
Have you noticed any changes in the frequency or severity of flooding in your area over the past 5 years?	66	66
Yes	34	34
No		

Source: Field Survey 2025.

Frequency distribution organizes data by showing how often each value or class interval occurs, calculated simply by counting occurrences (f) for each category. Percentage in statistics expresses the relative frequency of a category as a proportion of the total, scaled to 100, using the formula (F/N)*100, which standardizes the count for easy comparison. While tables in statistics present frequency competency in rows and columns.

Conclusion and Recommendations

Urban flooding in Jere LGA is a growing environmental and health crisis. Poor drainage, rapid urban expansion, waste mismanagement, and climatic changes have all contributed to rising flood vulnerability. The 2024 Alau Dam collapse worsened the situation, revealing major infrastructural weaknesses. Environmental consequences are severe, including erosion and pollution, while health risks, especially waterborne diseases, remain critical. Based on the study findings, flooding in Jere Local Government can be reduced through better drainage, environmental protection, strong policies, Public health preparedness, and active community involvement, all working together to build resilience and support sustainable development.

References

Adelekan, I.O. (2011). Vulnerability Assessment of an Urban Flood in Nigeria: Abeokuta Flood 2007. *National Hazard* 56:215-231

Adebayo, A.A & Oladipo, F.O (2025). Urban flooding in northern Nigeria: Causes, Impacts, and mitigation strategies. *Journal of Ecology and the Natural Environment.* 10(4):53-64.

Aja, G.N., & A.Y. Olaore (2014). The Impact of Flooding on the Social Determinants of Health in Nigeria: *A Case for North-South Institutional Collaboration to Address Climate Issues. Developing Country Studies* 4 (22): 6–12.

Alderman, K., Turner, L. R., & Tong, S. (2012). Floods and human health: A systematic review. *Environment International,* 47:37-47.

Aliyu, A., Liman-Hamza, K., & Lawal, A. (2023). Floods in Sub-Saharan Africa: causes, determinants and health consequences. *Nigeria Medical Journal,* 64(1):13–24.

Butler, D., Digman, C., Makropoulos, C. & Davies, J. (2018). Urban Drainage, 4th edition. Boca Raton, FL: CRC Press. https://doi.org/10.1201/ 9781351174305.

Bwala, H.B., Oladosu, R.O., & Nghalmi, S.M. (2015). Application of Physical Planning Strategies to Flood Control in Maiduguri, Borno State, Nigeria. *Research Journal of Environmental and Earth Sciences* 7(1): 1–8, 2015. ISSN: 2041-0484; e-ISSN: 2041-0492.

Danhassan, S.S., Abubakar, A., Zangina, A.S., Ahmad, M.H., Saddam A., H., S. A., I., M.Y., & Zhang, J. (2023). *Flood Policy and Governance: A Pathway for Policy Coherence in Nigeria, Sustainability*, 15:2392. 1 – 24.

Ezemonye, L. I., Oyibo, O. G., & Atuanya, E. I. (2015). Public health implications of microbial contamination of borehole water in Uyo, Nigeria. *International Journal of Environmental Health Research,* 25(1), 40–52.

Gupa, M.A., Lawal, S., Mathew, E.D., Sa'idu, M., & Isah, M. (2024). Assessment of Forest Extension Needs for Agroforestry Farmers in Jere L.G.A., Borno State, Nigeria—46th *Annual Conference of Forestry Association of Nigeria* (FAN).

IPCC (2021) Summary for Policymakers. In: Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R. and Zhou, B. (eds.) (2021). Climate Change: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3–32. doi:10.1017/9781009157896.001.

National Population Commission (NPC) (2006). https:\\nationalpopulation.gov.ng\

Nigerian Emergency Management Agency (2022). Report on flood disasters in Nigeria. Abuja: Government press. https:\\nema.gov.ng

Nigerian Meteorological Agency (NIMET) (2021). Seasonal climate prediction (SCP) for the year. https:\\nimet.gov.ng

Nigerian Meteorological Agency (NIMET) (2024). Annual Flood Outlook. https:\\www.nimet.gov.ng

Nmecha, M.I., Osumune, C.P., Adedokun, A.A., Asinobi, A.O., Esomonu. I. and Njionye, U. (2024). Assessment of the Environmental and Health Risk of Urban Flooding in Oguta, Imo State, Nigeria - Condensed Version with Sustainable Procurement Integration. *Alvan Journal of Social Sciences* 1(2):1 – 22. https://www.ajsspub.org.

Nura. U and Alison. G. (2023). Flooding in Nigeria: A Review of its Occurrence and Impacts and Approaches to Modelling Flood Data. *International Journal of Environmental Studies*. 80(3).

UNICEF. (2024). Nigeria Situation Report on Maiduguri Flood Response. 10 – 23 September, 2024

Xu, T., Xie, Z., Jiang, F., Yang, S., Deng, Z., Zhao, L., Wen, G. and Du, Q. (2023). Urban Flooding Resilience Evaluation with Coupled Rainfall and Flooding Models: A small area in Kunming City, China as an example, *Water Science and Technology,* 87 (9), 2289–2302.

ISTF-NIG 2026

SPATIOTEMPORAL DYNAMICS OF VEGETATION CARBON DENSITY IN SELECTED LOCAL GOVERNMENTS, OSUN STATE, NIGERIA (2006–2022)

[*1]Afolabi O. S., [2]Adedeji A.A, [3]Mephors J.O, and [4]Oloketuyi, AJ

[1,3]GIS&RS section, Department of Environmental Modeling and Biometrics, Forestry Research Institute of Nigeria, Jericho, Ibadan, Oyo State, Nigeria
[2]Department of Urban and Regional Planning, Federal University of Oye Ekiti, Nigeria
[4]Ecology section, Department of Forest Conservation Protection, Forestry Research Institute
Corresponding email: mosadioluwaolamidipupo@gmail.com; +2348060835178

Abstract

Terrestrial vegetation plays a critical role in regulating atmospheric carbon dioxide through photosynthesis, thereby influencing climate and carbon cycle dynamics. In Nigeria, increasing deforestation, urban expansion, and agricultural intensification have raised concerns about declining vegetation cover and reduced carbon sequestration capacity. This study assesses the spatiotemporal dynamics of vegetation cover and associated carbon density in Ife North, Ife South, and Ife Central Local Government Areas of Osun State between 2006 and 2022. Multi-temporal Landsat imagery for 2006, 2016, and 2022 was analyzed using the Normalized Difference Vegetation Index (NDVI) as a proxy for vegetation health, biomass, and carbon density. The results reveal a progressive decline in high-NDVI areas from approximately 40 percent in 2006 to 15 percent in 2022, alongside a corresponding increase in low-NDVI zones. Spatial analysis shows that vegetation loss is most pronounced in Ife Central, the urban core. At the same time, Ife North and Ife South experienced moderate but consistent degradation linked to peri-urban growth. These trends reflect sustained land-use conversion and fragmentation of vegetated landscapes, with significant implications for carbon storage and environmental sustainability. The study underscores the need for strengthened land-use planning, vegetation conservation, and the adoption of sustainable forest management and REDD-based strategies to enhance carbon sequestration and mitigate future emissions in the region.

Keywords: Vegetation dynamics; NDVI; carbon density; land-use change; remote sensing;

Introduction

Terrestrial vegetation plays a vital role in the global carbon cycle by regulating atmospheric carbon dioxide (CO_2) through photosynthesis (Afolabi, 2011). As One of the major natural carbon sinks, vegetation helps stabilize greenhouse gas concentrations and moderates climate change. Consequently, estimating carbon stock in terrestrial ecosystems is essential for understanding the global carbon cycle and for formulating effective climate change mitigation policies (Liu et al., 2021). Vegetation carbon density refers to the quantity of carbon stored within plant biomass over a given area. It is a critical parameter in carbon budgeting because accurate carbon stock estimation depends largely on reliable vegetation carbon density data. Furthermore, vegetation carbon density is increasingly important in setting emission reduction targets aimed at limiting global temperature rise to below 1.5°C (Erb et al., 2018). However, this ecological function is being threatened by

increasing anthropogenic activities, especially in developing countries where land-use changes are rapid and often uncontrolled.

Land-use change, such as deforestation, agricultural expansion, urban development, bush burning, and infrastructure development, contributes significantly to carbon emissions while simultaneously reducing ecosystems' capacity to absorb carbon. In Nigeria, land-use conversion from natural vegetation to built-up and agricultural uses has intensified environmental degradation and greenhouse gas emissions (Momodu et al., 2011). Houghton et al. (2009) also reported that land-use change is a major contributor to net carbon emissions in the country. However, the contribution of the forestry sector to the national carbon balance remains poorly documented due to inadequate and inconsistent data-collection systems (CBN, 2000; FMANR, 1996). Globally, several policy initiatives have emerged to reduce emissions associated with land-use change. One of the most prominent is Reducing Emissions from Deforestation and Forest Degradation (REDD+), which provides incentives for sustainable land management and forest conservation (Gibbs et al., 2007; Sohngen et al., 2014). In addition, voluntary carbon markets now offer mechanisms for offsetting carbon emissions through carbon credits, thereby increasing the need for accurate estimates of vegetation carbon storage capacity (Tallis et al., 2013).

Advancements in Remote Sensing (RS) and Geographic Information Systems (GIS) have significantly improved environmental monitoring and carbon assessment. Satellite imagery enables the measurement of vegetation indices such as the Normalized Difference Vegetation Index (NDVI), which is widely used as a proxy for vegetation health, biomass, and carbon density (Xu et al., 2021). These technologies provide cost-effective, time-efficient means for assessing vegetation dynamics across large spatial and temporal scales. The Ife region of Osun State, comprising Ife North, Ife South, and Ife Central, has experienced substantial landscape transformation over the last two decades. Rapid urbanization around Ile-Ife has led to the conversion of vegetated land into residential, commercial, institutional, and agricultural uses. These transformations have resulted in vegetation loss, habitat fragmentation, and declining carbon sequestration potential, thereby threatening environmental sustainability in the region (Afolabi, 2011).

Several studies have examined land-use and vegetation changes in Nigeria. For instance, Afolabi (2011) assessed land-use dynamics in Ile-Ife and reported rapid urban encroachment into surrounding vegetated areas. Momodu et al. (2011) investigated the environmental consequences of land conversion in southwestern Nigeria and found increasing pressure on natural ecosystems. Xu et al. (2021) demonstrated the usefulness of NDVI and remote sensing techniques in monitoring vegetation biomass and carbon dynamics across developing regions. Similarly, Liu et al. (2021) emphasized the importance of satellite-based carbon stock assessment for climate mitigation planning. Despite these contributions, most previous studies focused mainly on land-use/land-cover change, urban growth, or general vegetation decline, with limited attention to the spatiotemporal dynamics of vegetation carbon density at the local government scale. Specifically, there is inadequate empirical evidence linking vegetation change to carbon sequestration patterns in Ife North, Ife South, and Ife Central. This knowledge gap limits evidence-based planning for climate adaptation, urban management, and sustainable land administration in the area. Therefore, this study assesses the spatiotemporal dynamics of vegetation carbon density in the selected local

government areas between 2006 and 2022 using remote sensing techniques. The study seeks to answer the following research questions:

1. What is the current spatial distribution of vegetation and vegetation carbon density?
2. How does vegetation carbon density change over time?

Study Area

The study area comprises Ife North, Ife South, and Ife Central in Osun State, southwestern Nigeria (Figure 1). The area lies within the tropical wet-and-dry climatic zone, characterized by distinct wet and dry seasons that strongly influence vegetation growth and land surface conditions. The terrain is generally undulating, interspersed with isolated hills and gentle slopes, while the soils are largely fertile and supportive of intensive agricultural activities. Historically, the area's land cover consisted of forest patches, extensive farmland, and dispersed rural settlements. In recent decades, however, rapid population growth, urban expansion around Ile-Ife, and increased agricultural intensification have significantly transformed the natural landscape, leading to notable changes in land use and land cover patterns (Sedjo & Sohngen, 2007)

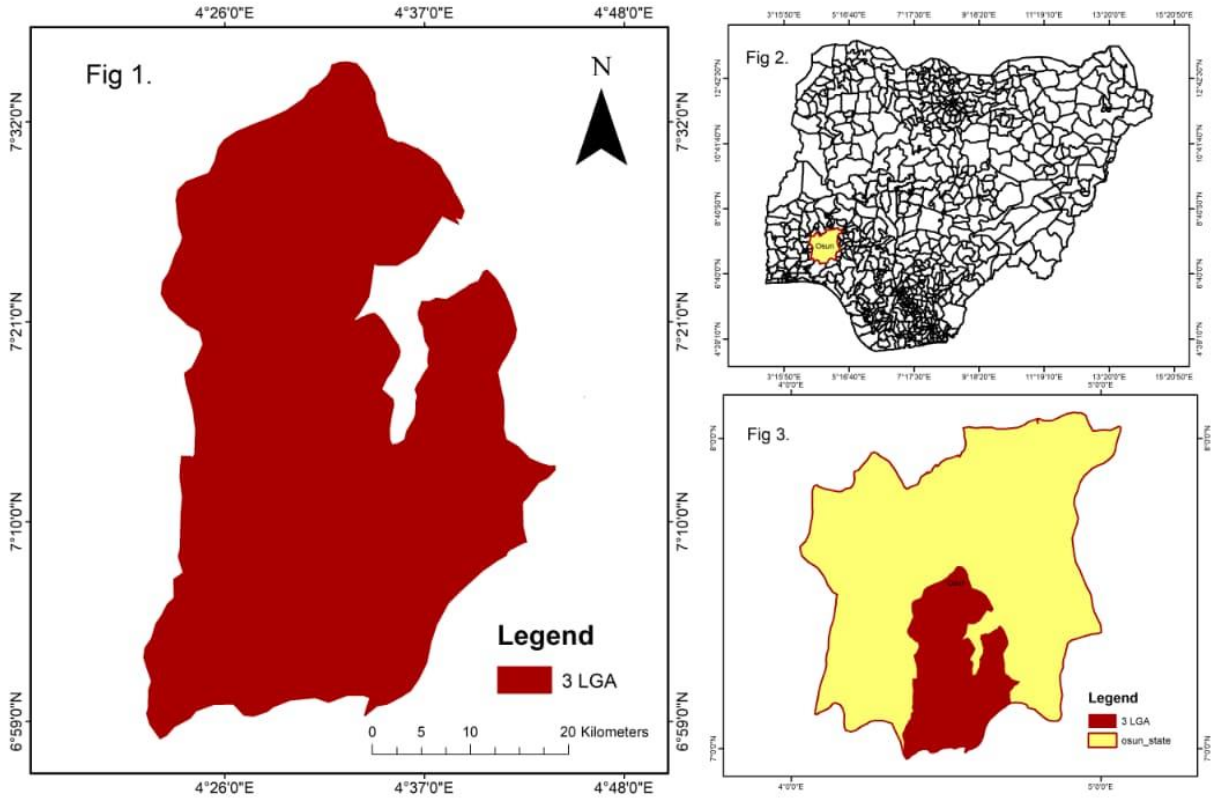


Figure 1: **Study area Map**
Source: FRIN GIS Studio

Land Use and Land Cover Dynamics

Historically, farmlands, secondary forests, and small settlements dominated the land use structure of the study area. Over the past two decades, accelerated urbanization and infrastructure development have led to the conversion of vegetated surfaces into built-up areas and other impervious land uses. These changes have contributed to the reduction and fragmentation of forested areas and ecological corridors (Sedjo & Sohngen, 2007). The resulting land cover dynamics have important environmental implications, particularly for vegetation health and carbon storage capacity, as the decline in dense vegetation reduces the landscape's ability to sequester atmospheric carbon.

Methodology

Data Acquisition and Pre-processing

Multitemporal satellite imagery was used to assess vegetation dynamics across the study period. Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI) images for the years 2006, 2016, and 2022 were obtained from the United States Geological Survey Earth Explorer platform. All images were selected based on a cloud cover threshold of less than 20 percent to minimize atmospheric interference. Radiometric correction was applied to ensure consistency across scenes, after which the images were clipped to the combined boundary shapefile of Ife North, Ife South, and Ife Central Local Government Areas.

NDVI Computation

Vegetation condition was assessed using the Normalized Difference Vegetation Index (NDVI), a widely applied indicator of vegetation vigor and greenness. NDVI was computed using the standard formula: NDVI = (NIR − RED) / (NIR + RED). For Landsat 5 and Landsat 7 imagery, the near-infrared (NIR) and red bands corresponded to Band 4 and Band 3, respectively, while for Landsat 8 imagery, NIR and red information were derived from Band 5 and Band 4. The resulting NDVI values ranged from −1 to +1, with higher values indicating healthier, denser vegetation cover. The observed NDVI ranges showed noticeable temporal variation, reflecting changes in vegetation density between 2006, 2016, and 2022.

NDVI Classification and Interpretation

For analytical clarity and visualization, NDVI outputs were classified into vegetation density categories. High NDVI values indicated areas of dense, healthy vegetation, typically associated with forests and productive farmlands. Low NDVI values corresponded to sparse vegetation, bare surfaces, or built-up areas. This classification facilitated spatial comparison of vegetation patterns and enabled clearer interpretation of land cover changes over time.

Data Limitations

Several data-related challenges were encountered during the analysis. Portions of the 2006 imagery were affected by cloud cover, while Landsat 7 scenes exhibited scan line corrector (SLC) errors that produced striping. In addition, sensor and calibration differences among Landsat 5, 7, and 8 introduced minor inconsistencies in spectral responses. These limitations were addressed through

scene compositing, careful visual inspection, and consistency checks during processing. Despite these mitigation measures, small pixel-level discrepancies in NDVI values may persist and should be taken into account when interpreting the results.

Results and Interpretation

The NDVI map of the study area for 2006 is presented in Figure 1. NDVI values range from −1 to 1, indicating a clear distinction between non-vegetated surfaces and areas of dense vegetation. High NDVI values were concentrated in forest patches and extensive rural farmland, suggesting relatively healthy, continuous vegetation cover during the period. Low NDVI values were mainly observed around emerging peri-urban zones and settlement clusters, indicating limited built-up expansion and relatively low vegetation disturbance in 2006. Overall, the spatial pattern suggests that the landscape was still largely dominated by natural and agricultural vegetation, while urban development remained localized.

This finding indicates that the study area retained substantial vegetation resources in 2006 before the acceleration of urban growth and intensified land conversion experienced in later years. The predominance of moderate-to-high NDVI zones suggests stronger biomass productivity and a higher carbon sequestration potential during the period. This outcome is consistent with Afolabi's (2011) findings, which reported that the Ile-Ife axis and surrounding settlements still maintained considerable vegetation cover before rapid urban encroachment. Similarly, Momodu *et al.* (2011) observed that many peri-urban areas in southwestern Nigeria initially exhibited relatively stable vegetation conditions before being affected by residential expansion and infrastructure development.

The concentration of low NDVI values around settlement clusters also aligns with the work of Xu *et al.* (2021), who noted that declining NDVI values are commonly associated with increasing anthropogenic activities such as land clearing, road construction, and built-up growth. In the same vein, Liu *et al.* (2021) emphasized that areas with high vegetation indices generally correspond to zones of greater biomass accumulation and carbon storage. Therefore, the 2006 NDVI distribution represents an important ecological baseline, indicating that the study area had greater vegetation integrity and carbon density before the more pronounced landscape transformations observed in subsequent years.

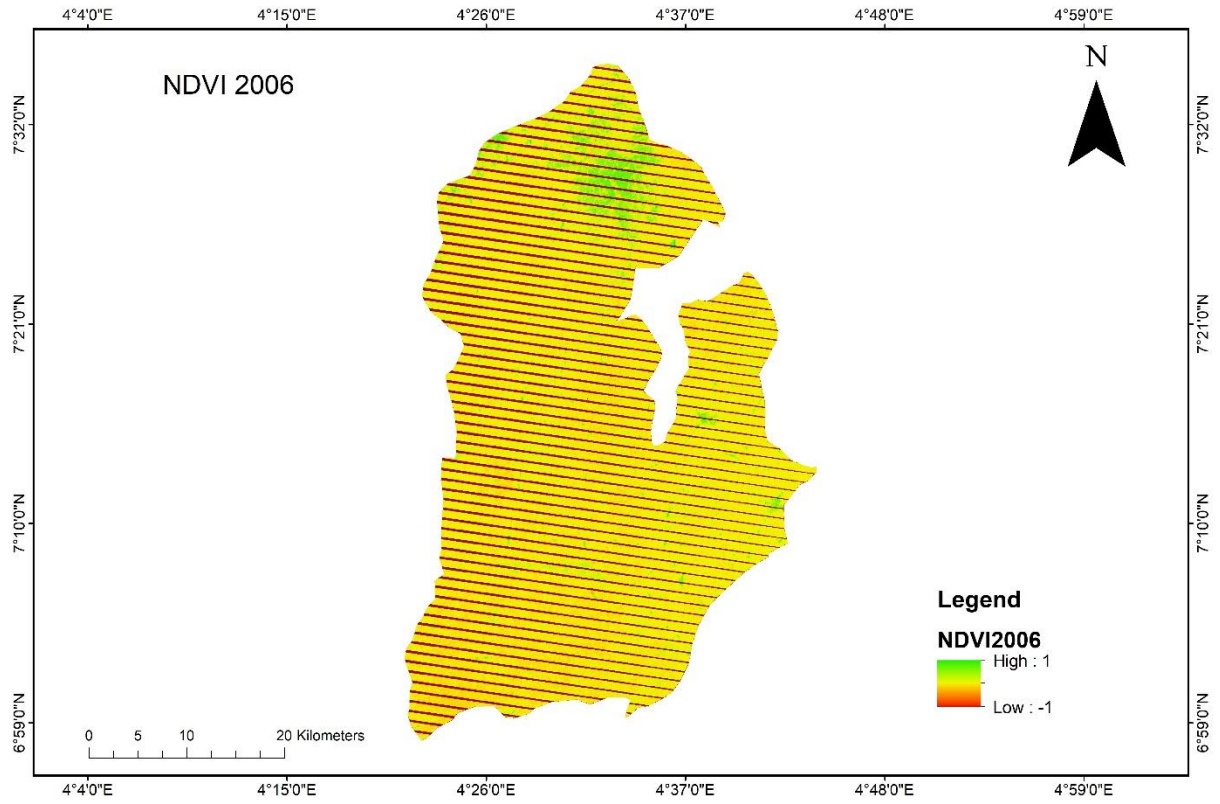


Figure 1: NDVI map of the study area for 2006

The NDVI distribution for 2016 is illustrated in Figure 2 and shows a noticeable shift in vegetation condition compared with 2006. NDVI values range from approximately 0.031 to 0.442, with a visible reduction in areas of high NDVI. Vegetation loss is evident, particularly around expanding settlement corridors and road networks. The spread of low NDVI values reflects increased urbanization, infrastructural development, and intensified agricultural activities. While pockets of moderate vegetation persist, they appear more fragmented, indicating increasing pressure on continuous vegetation cover across the study area.

This observed decline suggests that the study area experienced accelerated land transformation between 2006 and 2016. The reduction in high-NDVI zones indicates declining biomass productivity and a likely decline in vegetation carbon storage capacity. This finding supports Afolabi's (2011) position that continued urban expansion around Ile-Ife and adjoining communities was gradually replacing vegetated land with residential and commercial development. Similarly, Momodu *et al.* (2011) reported that land-use conversion in southwestern Nigeria increasingly contributed to vegetation depletion and ecosystem stress.
The fragmentation of moderate vegetation patches further suggests disruption of formerly continuous green spaces, which may reduce ecological resilience and biodiversity. This aligns with the findings of Xu *et al.* (2021), who observed that fragmented vegetation landscapes often emerge where human activities intensify, and natural land cover becomes subdivided. In addition, Liu *et al.* (2021) emphasized that declining NDVI values are commonly associated with lower biomass

accumulation and reduced carbon sequestration potential. Therefore, the 2016 NDVI pattern represents a transitional stage in which urban growth, transport expansion, and agricultural intensification significantly altered the ecological structure of the study area.

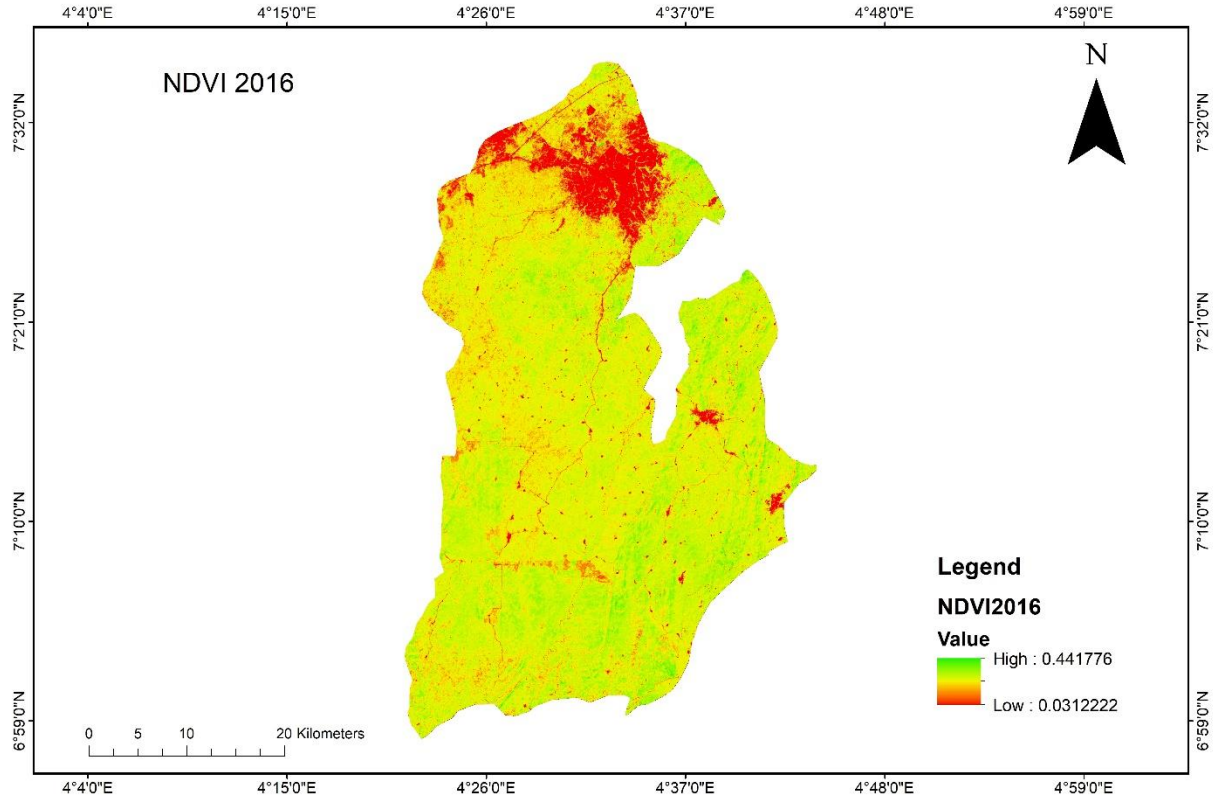


Figure 2: NDVI distribution for 2016

The NDVI map for 2022 is shown in Figure 3, with values ranging from −1 to 0. The dominance of low NDVI values across the landscape indicates a substantial decline in dense vegetation. Formerly continuous vegetated areas now appear fragmented, with sparse vegetation interspersed among built-up and altered land surfaces. This pattern reflects sustained urban expansion, land conversion, and cumulative land-use change over time. The near absence of high NDVI zones suggests reduced vegetation health and density, with potential implications for ecosystem services such as carbon sequestration and microclimate regulation. This finding indicates that vegetation degradation had become more severe by 2022 compared with earlier years. The widespread occurrence of low NDVI values suggests major reductions in biomass productivity and vegetation carbon density across the study area. This supports Afolabi's (2011) observation that continuous urban encroachment around Ile-Ife would place increasing pressure on surrounding vegetated lands if growth remained uncontrolled. Similarly, Momodu et al. (2011) found that persistent land conversion in southwestern Nigeria contributes significantly to ecosystem degradation and declining green cover. The fragmentation of formerly continuous vegetation also implies weakening ecological connectivity, which may reduce habitat quality, biodiversity stability, and landscape resilience. This agrees with Xu et al. (2021), who reported that sustained anthropogenic

disturbance often leads to patchy vegetation patterns and lower NDVI values in rapidly urbanizing environments. In addition, Liu et al. (2021) noted that areas characterized by persistent low vegetation indices generally possess lower carbon storage capacity and diminished ecological functioning.

The near disappearance of high-NDVI zones further suggests that the study area is transitioning from a vegetation-dominated landscape to a more built-up, disturbed environment. Such changes may intensify local heat conditions, increase surface runoff, and weaken natural climate regulation functions. Therefore, the 2022 NDVI pattern confirms the cumulative impact of long-term urbanization and land-use pressure on vegetation resources within the study area.

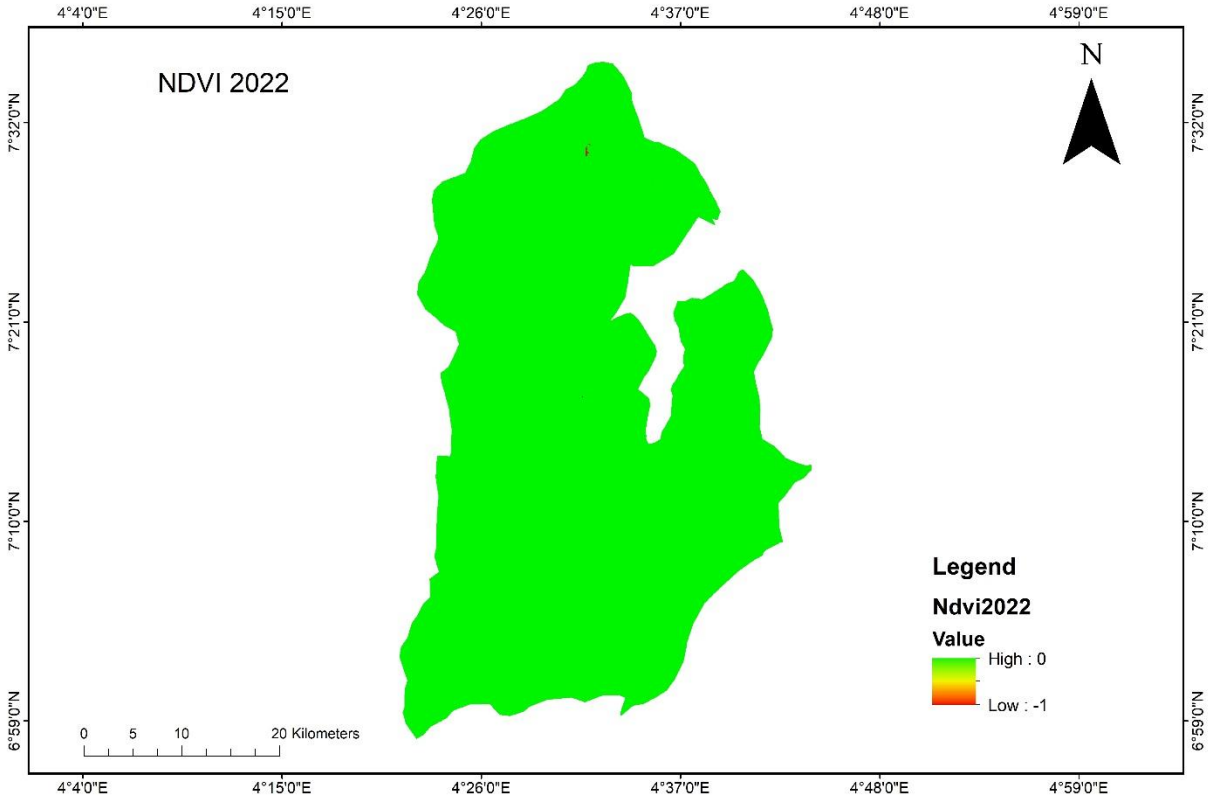


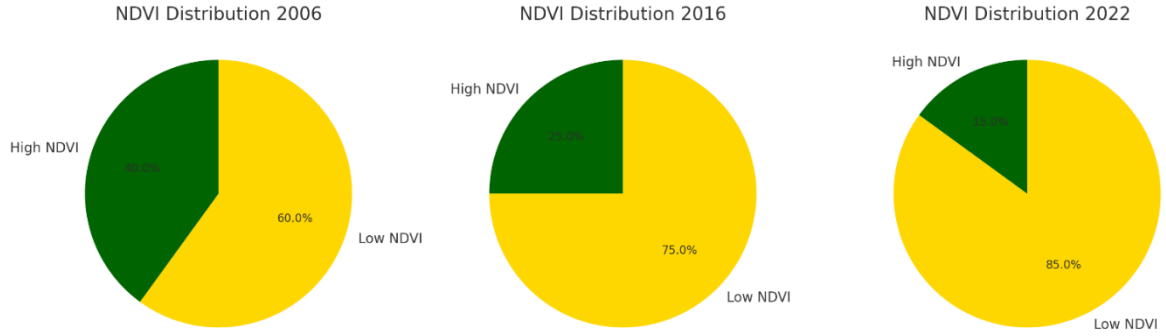
Figure 3: NDVI map for 2022

The pie charts summarizing the proportional distribution of high and low NDVI classes for 2006, 2016, and 2022 are presented in Figure 4. In 2006, high-NDVI areas accounted for approximately 40 percent of the total land area, while low-NDVI areas covered about 60 percent. By 2016, high NDVI coverage had declined to roughly 25 percent, with low NDVI areas increasing to 75 percent, as shown in Table 1. This trend became more pronounced in 2022, when high-NDVI areas further decreased to about 15 percent, while low-NDVI areas expanded to approximately 85 percent. The pie charts clearly illustrate the progressive decline in vegetation cover over the study period, reinforcing the spatial patterns observed in the NDVI maps. Based on the NDVI classes, the approximate proportions of land cover per category for each year can be presented in pie charts:

Table 1: Proportional distribution of high and low NDVI classes for 2006, 2016, and 2022

Year	High NDVI	Low NDVI
2006	40%	60%
2016	25%	75%
2022	15%	85%

Colors: Dark Green = High NDVI, Yellow/Brown = Low NDVI.



Across the three Local Government Areas, vegetation decline is not spatially uniform. Ife Central, as the traditional urban core, exhibits the highest concentration of low NDVI values and the greatest degree of vegetation fragmentation. Ife North and Ife South show moderate but consistent vegetation loss, largely associated with peri-urban expansion and the conversion of farmland and secondary vegetation to built-up uses. The combined spatial and temporal analysis confirms a steady transition from vegetated landscapes to more impervious and modified surfaces between 2006 and 2022. The NDVI results collectively demonstrate a clear downward trend in vegetation density and continuity within the study area over the 16 years. The decline in high-NDVI zones reflects the cumulative effects of urban and population growth, as well as land-use transformation. These changes have important environmental implications, particularly for carbon storage potential, ecological stability, and long-term landscape sustainability. The findings highlight the need for improved land-use planning and vegetation conservation strategies to mitigate further degradation of the region's vegetative resources.

Conclusion

This study examined vegetation dynamics and changes in carbon density in Ife North, Ife South, and Ife Central LGAs over 16 years using NDVI derived from multi-temporal Landsat imagery. The findings indicate a clear and consistent decline in vegetation cover across the study area, with high NDVI zones shrinking substantially between 2006 and 2022. Spatial patterns reveal that vegetation loss is most severe in Ife Central, reflecting its role as the urban core. At the same time, Ife North and Ife South show gradual degradation associated with peri-urban expansion and land conversion. The growing dominance of low-NDVI areas highlights the cumulative impact of urbanization, population growth, and intensified land use on vegetation health and continuity. These changes imply a reduction in the landscape's carbon storage and sequestration potential, thereby increasing vulnerability to climate-related risks. Overall, the study demonstrates that ongoing land-use transformation in the Ife region poses a significant challenge to environmental sustainability and carbon management objectives.

Recommendations

Based on the findings of this study, several measures are recommended to address vegetation loss and declining carbon sequestration capacity in the study area:

1. Local planning authorities should enforce land-use regulations that limit unplanned urban expansion into vegetated and agricultural lands, particularly in peri-urban zones of Ife North and Ife South.
2. The integration of agroforestry, forest landscape restoration, and conservation agriculture should be encouraged to enhance vegetation cover while supporting local livelihoods.
3. Targeted tree planting, green belts, and the preservation of urban open spaces should be prioritized in Ife Central to reduce vegetation fragmentation and improve ecosystem services.

References

Afolabi, A. T. (2011). Sustainable forest management. In O. Kola-Olusanya, A. Omotayo, & O. Fagbohun (Eds.), *Environment and sustainability: Issues, policies and contentions* (pp. 67–99). University Press Plc.

Central Bank of Nigeria. (2000). *Annual report and statement of accounts for the year ended 31st December 2000*. CBN.

Erb, K. H., Kastner, T., Plutzar, C., Bais, A. L. S., Carvalhais, N., Fetzel, T., Gingrich, S., Haberl, H., Lauk, C., Niedertscheider, M., Pongratz, J., Thurner, M., & Luyssaert, S. (2018). Unexpectedly large impact of forest management and grazing on global vegetation biomass. *Nature, 553*(7686), 73–76. https://doi.org/10.1038/nature25138

Federal Ministry of Agriculture and Natural Resources. (1996). *Memorandum to the Presidential Committee of Experts on the National Agricultural Land Development Authority (NALDA)*. FMANR.

Gibbs, H. K., Brown, S., Niles, J. O., & Foley, J. A. (2007). Monitoring and estimating tropical forest carbon stocks: Making REDD a reality. *Environmental Research Letters, 2*(4), 045023. https://doi.org/10.1088/1748-9326/2/4/045023

He, N. P., Wen, D., Zhu, J. X., Tang, X. L., Xu, L., Zhang, L., Hu, H. F., Huang, M., & Yu, G. R. (2017). Vegetation carbon sequestration in Chinese forests from 2010 to 2050. *Global Change Biology, 23*(4), 1575–1584. https://doi.org/10.1111/gcb.13479

He, N. P., Yan, P., Liu, C. C., Xu, L., Li, M. X., Van Meerbeek, K., Zhou, G. S., Zhou, G. Y., Liu, S. R., Zhou, X. H., Li, S. G., Niu, S. L., Han, X. G., Buckley, T. N., Sack, L., & Yu, G. R. (2023). Predicting ecosystem productivity based on plant community traits. *Trends in Plant Science, 28*(1), 43–53. https://doi.org/10.1016/j.tplants.2022.08.015

Houghton, R. A., Hall, F., & Goetz, S. J. (2009). Importance of biomass in the global carbon cycle. *Journal of Geophysical Research: Biogeosciences, 114*(G2), G00E03. https://doi.org/10.1029/2009JG000935

Momodu, A. S., Siyanbola, W. O., Pelemo, D. A., Obioh, I. B., & Adesina, F. A. (2011). Carbon flow patterns in Nigeria's forest zones are influenced by land-use change. *African Journal of Environmental Science and Technology, 5*(9), 700–709.

Obioh, I. B., Momodu, A. S., Siyanbola, W. O., Oketola, F. O., Ibitoye, F. I., Akinbami, J. F. K., & Adegbulugbe, A. O. (1996). Greenhouse gas emissions from major sectors in Nigeria. In B.

Jallow et al. (Eds.), *National greenhouse gas inventories: Interim results from the U.S. Country Studies Program*.

Sedjo, R. A., & Sohngen, B. (2007). *Carbon credits for avoided deforestation*. Resources for the Future.

Siyanbola, W. O., Oketola, F. O., Pelemo, D. A., Momodu, S. A., Adegbulugbe, A. O., Adesina, F. A., Ojo, L. O., & Ijalana, S. A. (1996). *Greenhouse gas emission reduction in Nigeria: Least-cost reduction strategies and macroeconomic impacts (Vol. 3b: Forestry sector report)*. U.S. Country Studies Program.

Sohngen, B., Beach, R. H., & Andrasko, K. (2014). Avoided deforestation as a greenhouse gas mitigation tool: Economic issues. *Journal of Environmental Quality, 37*, 1368–1375. https://doi.org/10.2134/jeq2007.0548

Tallis, H., Ricketts, T., Guerry, A. D., Wood, S. A., Sharp, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., … Chaplin-Kramer, R. (2013). *InVEST user's guide*: the Natural Capital Project, Stanford University.

Xu, L., Saatchi, S. S., Yang, Y., Yu, Y. F., Pongratz, J., Bloom, A. A., Bowman, K., Worden, J., Liu, J. J., Yin, Y., Domke, G., McRoberts, R. E., Woodall, C., Nabuurs, G. J., de Miguel, S., Keller, M., Harris, N., Maxwell, S., & Schimel, D. (2021). Changes in global terrestrial live biomass over the 21st century. *Science Advances, 7*(27), eabe9829. https://doi.org/10.1126/sciadv.abe9829

ISTF-NIG 2026

TREE SPECIES DIVERSITY AND COMPOSITION OF PUJE FOREST AND RAFINKADA SWAMP IN WUKARI LOCAL GOVERNMENT AREA, TARABA STATE, NIGERIA

Maza, V.H[1*], Allah-Sarki, Emmanuel Ibrahim[2]

[1]Department of Forestry and Wildlife Management, Federal University Dutsin-ma, Katsina State.
[2] Department of Biological Sciences, Taraba State University, Jalingo.
Corresponding email: mvhikon1@gmail.com; 08163902185

Abstract

This study assessed the tree species composition, diversity, and structural characteristics in the Puje Sacred Forest and the Rafin-Kada Crocodile Swamp Forest in the Wukari Local Government Area, Taraba State, Nigeria. Systematic sampling was conducted using 50 m × 50 m plots in Puje Forest and 25 m × 100 m plots in Rafin-Kada Forest. Trees with a diameter at breast height (DBH) ≥10 cm were measured, identified, and analyzed for basal area, frequency, Density, relative Dominance, and Importance Value Index (IVI). Diversity indices, including Shannon-Wiener, Simpson, Margalef richness, and Pielou evenness, were computed, and species similarity was evaluated using Jaccard's coefficient. A total of 46 tree species were recorded across the forests, comprising 37 native species, 5 economic species, and 4 species that are both native and economic. Puje Forest contained 884 individuals representing 33 species in 15 families, dominated by Fabaceae, while Rafin-Kada Forest had 603 individuals in 22 species across 12 families. The highest IVI values were observed for *Gmelina arborea* (141.4) in Puje and *Ficus thonningii* (33.18) in Rafin-Kada. Mean DBH and basal area were higher in Puje (8.2 m; 1.87 m²/ha) than in Rafin-Kada (4.38 m; 0.71 m²/ha). Both forests displayed inverse J-shaped DBH distributions, indicating strong regeneration potential. Shannon-Wiener and Simpson indices were 2.61 and 0.82 for Puje, and 2.78 and 0.92 for Rafin-Kada. Margalef richness was higher in Puje (4.72), while Pielou evenness was greater in Rafin-Kada (0.90). The Jaccard similarity coefficient was 0.33, reflecting moderate species overlap. This study highlights the ecological and cultural importance of sacred forests and provides baseline data to guide sustainable forest management and biodiversity conservation.

Introduction

The Earth's surface is home to a diverse array of plants and animals, currently estimated at 1.8 million, yet is greatly threatened by biodiversity loss, erosion, and the depletion of genetic diversity, as well as the extinction of global species, which constitutes an important concern to national and international authorities (Gusu *et al.,* 2021). The shrinking size and deteriorating quality of natural forests, driven by unsustainable harvesting for agriculture, construction, industrial logging, and urban expansion, have led to habitat destruction, biodiversity loss, soil degradation, climate change, and reduced food supply (Babu *et al.,* 2025). Trees are essential components of land resources, and their sustainable management ensures ecosystem functionality, resilience, and stability for future generations (Salami *et al.,* 2021; Geetha, 2025). The twenty-first century has seen a dramatic decline in global biodiversity, particularly in tropical regions, largely due to increasing anthropogenic pressures (Keck *et al.,* 2025). Forests support ecological processes, provide livelihoods, drive economic growth, and mitigate climate change. Their structure and composition depend on ecological conditions, species diversity, and regeneration

status (Babu *et al.,* 2025). Floristic inventories are crucial for accurate vegetation assessment and the restoration of degraded areas (Lee *et al.,* 2024). Sacred natural sites, including forests, rivers, lakes, and hills, serve as in-situ conservation areas with cultural and spiritual significance. In Nigeria, sacred groves are traditional biodiversity conservation systems that often protect unique patches of vegetation through religious practices (Aina-Oduntan *et al.,* 2022). Over time, these sites have also been recognized as Indigenous Peoples' and Community Conserved Areas (ICCAs), providing both ecological and cultural benefits (Stevens *et al.,* 2024). Notable examples in Wukari Local Government Area include the Puje Forest and Rafin Kada Crocodile Swamp Forest, which preserve biodiversity and cultural heritage.

Despite studies on forest diversity in Wukari and southern Taraba, the Puje Forest and Rafin-Kada Crocodile Swamp Forest remain poorly documented due to restricted access and traditional prohibitions. The Rafin-Kada forest, now reduced to a linear riparian strip, lacks data on species composition, abundance, and structural characteristics, including Diameter at Breast Height (DBH) and basal area. Comprehensive floristic inventories are needed to provide baseline information critical for sustainable management and conservation. Sacred forests play an essential role in maintaining ecological functions and protecting indigenous species, highlighting their value in biodiversity conservation (Sullivan *et al.,* 2024). This study, therefore, aims to document the tree species, evaluate diversity, and assess structural parameters in the Puje Forest and the Rafin Kada Crocodile Swamp Forest, thereby contributing to sustainable forest management in Taraba State.

Materials and Methods

Study Area

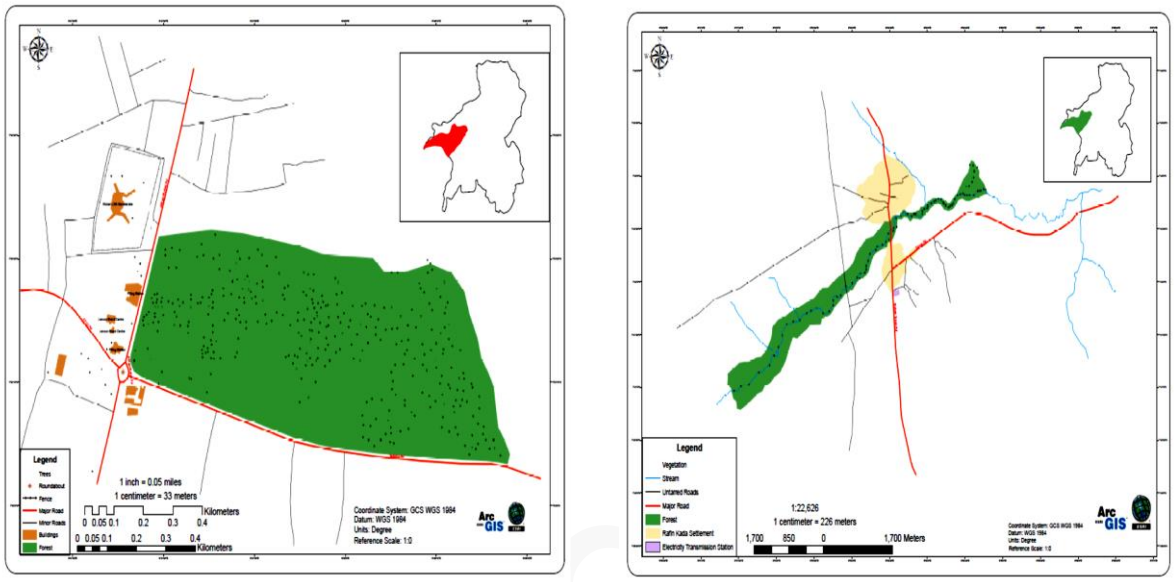
This study was conducted in Wukari Local Government Area, Taraba State, Nigeria, situated between longitudes 9°08′–10°23′ E and latitudes 7°35′–8°15′ N, at an elevation of approximately 200 m above sea level (Yakub *et al.*, 2022). Gassol LGA bounds Wukari to the north, Ukum LGA of Benue State to the south, Ibi LGA to the west, and Donga LGA of Taraba State and a portion of Abako town (Benue State) to the east. The area lies within a savannah vegetation zone, featuring riparian forests along watercourses and rocky outcrops as prominent landforms. Wukari experiences two distinct climatic seasons: a rainy season and a dry season (Otitoju *et al.,* 2018).

Sampling Sites, Sampling Technique and Sampling Plots

The study was conducted in Puje Sacred Forest and Rafin-Kada Crocodile Swamp Forest in Wukari LGA, Taraba State. Puje Forest (51.79 ha) lies along Wukari-Tsokundi and Wukari-Jalingo roads and serves as an important cultural and ecological site for the Jukun people. It features flat tropical savanna terrain with diverse tree species, minimal agricultural encroachment, and occasional cattle grazing. Rafin-Kada Crocodile Swamp Forest, located along the Wukari-Takum road, represents a wetland ecosystem with six crocodile-inhabited ponds. The forest has been heavily impacted by agriculture, particularly rice farming, leaving tree cover largely restricted to riparian zones along streams, resulting in a linear forest structure. Coordinates of both sites were recorded using GPS, as shown in Figure 1.

Systematic sampling was used to establish experimental plots in both forests. In Puje Forest, two parallel 1000 m line transects, 100 m apart, were laid at the forest centre, with 50 m × 50 m sample plots positioned alternately along the transects. In the Rafin-Kada Crocodile Swamp Forest,

transects followed the stream boundaries, and 25 m × 100 m plots were placed at regular 25 m intervals between transects to capture the linear tree distribution.



A: Puje Forest **B:** Rafin-Kada Crocodile Swamp Forest

Figure 1: Aerial Map of Puje Forest (A) and Rafin-Kada Crocodile Swamp Forest (B)
(Source: Arc GIS using Coordinates)

Data Collection

All trees with a diameter at breast height (DBH) ≥10 cm within the sample plots were tagged, measured, and identified to species level. The frequency, abundance, and scientific names of all trees were recorded, for specimens that could not be identified on site, bark, leaves, and fruits were collected and identified using the PlantNet App (Coskunserce, 2024) and reference books, including *Tropical Community Tree Crops* (Okpeke, 2005), *Trees of Nigeria* (Keay, 2023), and *Useful Plants of West Tropical Africa*. Local names were also employed to support species identification.

Tree Growth Measurement

The circumference of all trees with a diameter at breast height (DBH) equal to or greater than 10cm was measured at breast height using measuring tape, and the Diameter at Breast Height (DBH) of each Tree was determined using the formula:

Diameter at Breast Height (DBH) $= \frac{C}{\pi}$, where C is the circumference of the tree, π is 3.1416

Data Analysis

Basal area, frequency, Density, relative Density, relative Dominance, and Importance Value Index (IVI) were calculated to assess tree distribution and Dominance. Tree species diversity was

evaluated using Simpson's Diversity Index, Shannon-Wiener Index, Margalef's species richness, and Pielou's evenness. In contrast, species similarity between sites was determined using Jaccard's Similarity Coefficient and dissimilarity index.

The basal area of each tree was calculated using the formula adopted from Zakaria *et al.* (2016).

The basal area BA= $\frac{\pi D^2}{4}$

Where: B.A. = Basal area (m²), D = Diameter at breast height (m) and л=pie 3.1416.

$$\boldsymbol{Frequency} = \frac{\textbf{number of plots in which species occur}}{\textbf{/Total number of plots sampled}}$$

Relative frequency is the degree of dispersion of individual species in an area in relation to the number of all the species that occur.

$$\boldsymbol{Relative\ frequency\ R.F} = \frac{(\textbf{species frequency of individual species})}{\textbf{/Total frequency value of all species}}\ \boldsymbol{X\ 100}$$

$$\boldsymbol{Density\ (D)} = \frac{\textbf{number of individual species}}{\textbf{/Area Sampled}}$$

Relative Density (R.D.) is the study of the numerical strength of a species in relation to the total number of individuals of all the species, and will be calculated using

$$\boldsymbol{Relative\ Density} = \frac{\textbf{species density of individual species}}{\textbf{/Total Density for all Species}}\ \boldsymbol{X\ 100}$$

$$\boldsymbol{Relative\ Dominance} = \frac{\textbf{Total basal area of a species}}{\textbf{/Total basal area of all species}}\ \boldsymbol{X\ 100}$$

Importance value index (IVI) = Relative Frequency + Relative Density + Relative Dominance

Ecological Diversity Assessment

Simpson Diversity Index (1-D)

The Simpson Diversity Index (SDI) was used to analyze tree species diversity.

SDI = 1-D

Where D= The Simpson Index is computed using

D = $\frac{\sum n(n-1)}{N(N-1)}$

SDI= 1- $\frac{\sum n(n-1)}{N(N-1)}$

Where n is the number of individuals of each species, and N is the total number of individuals in the community.

A perfectly homogeneous population will have an Index Value of zero (0) while a perfectly heterogeneous population will have an Index Value of One (1).

Shannon-Wieners Diversity Index (H^1)

The Shannon-Wiener Diversity Index was computed using

$\mathbf{H^1 = -\sum Pí \ ln \ Pí}$ (Shannon, 1948)

Where Pí = $\frac{n}{N}$

Species Richness (Margalef's index d)

Margalef's index (d) was used to estimate species richness from the relationship between the total number of species (S) and the total number of individuals N).

This was done using the equation $\mathbf{d = \frac{S-1}{Ln(N)}}$

Pielou's Species Evenness Index (E)

Species Evenness was computed using Pielou's ratio of Observed Diversity H' to Maximum Diversity Hmax, which value is usually from zero (0) to One (1) (Motwani *et al*., 2014). Closeness of the value to One is an indication of species evenness.

The Equation is as follows: $\mathbf{E = \frac{H\prime}{Hmax} \frac{= H\prime}{LnS}}$

Where H' is the Shannon-Wiener value or Observed Diversity, and LnS is the natural Logarithm of the total number of species in the community.

Similarity Index and Dissimilarity Index

The Jaccard Similarity Coefficient (Sj) was used to compute the Similarity of species between the two sites.

$\mathbf{Sj = \frac{a}{a+b+c}}$; Where

a is the number of species common to the two sites,

b is the number of species found in only One of the sites

c is the number of species found only in the other site.

The Index of Dissimilarity = 1-Sj, where Sj is the Jaccard index Value of Similarity.

Results

A total of 46 tree species were recorded across the two study sites, comprising 37 native species, 5 economic species, and 4 species that were both native and economic (Table 1). In Puje Forest, 884 individual trees representing 33 species and 15 families were documented (Table 2; Figure 2),

while Rafin-Kada Crocodile Swamp Forest had 603 individuals belonging to 22 species and 12 families (Table 3; Figure 1). The most dominant family at both sites was Fabaceae, with 8 species in Puje Forest and 4 in Rafin-Kada. In contrast, the fewest species in Puje included Bignoniaceae, Cannabaceae, Combretaceae, Fagaceae, Loganiaceae, Sapotaceae, Rhamnaceae, and Rubiaceae, each with 1 species. In Rafin-Kada, Anacardiaceae, Annonaceae, Rhamnaceae, and Rosaceae each had One species.

The most abundant species in Puje Forest were *Gmelina arborea* (39.71%, IVI = 141.4) and *Azadirachta indica* (10.07%, IVI = 18.73), followed by *Prosopis africana* (6.06%, IVI = 15.69), *Trichilia emetica* (4.76%, IVI = 12.86), *Vitex doniana* (4.98%, IVI = 12.08), and *Vachellia seyal* (5.10%, IVI = 11.59). The least abundant species were *Ekebergia capensis*, *Quercus suber*, and *Tectona grandis* (0.12%, IVI = 0.52 each), followed by *Ziziphus mauritiana* (0.23%, IVI = 1.04) (Table 4.2). In Rafin-Kada Forest, the most abundant species were *Ficus thonningii* (20.23%, IVI = 33.18), *Bridelia micrantha* (9.95%, IVI = 22.7), and *Antidesma venosum* (9.45%, IVI = 20.97). In comparison, the least abundant were *Psidium guajava* (0.66%, IVI = 4.7) and *Azadirachta indica* (1.66%, IVI = 7.83) (Table 4.3).

In Puje Sacred Forest, the total mean DBH and basal area were 8.2 m and 1.87 m²/ha, respectively, with *Daniellia oliveri* exhibiting the highest mean DBH (0.54 m) and basal area (0.23 m²), followed by *Mangifera indica* (0.45 m; 0.16 m²) and *Gmelina arborea* (0.42 m; 0.14 m²). The lowest values were recorded in *Tectona grandis* (0.11 m; 0.01 m²), *Annona senegalensis* (0.13 m; 0.02 m²), and *Quercus suber* (0.15 m; 0.02 m²) (Table 2).

In Rafin-Kada Crocodile Swamp Forest, the total mean DBH and basal area were 4.38 m and 0.71 m²/ha, with *Daniellia oliveri* again showing the highest values (0.25 m; 0.06 m²), while *Annona squamosa*, *Elaeis guineensis*, *Psidium guajava*, *Raphia sudanica*, and *Vitex doniana* had the lowest (0.15 m; 0.02 m²) (Table 3). DBH class distribution in Puje Forest showed that 62.23% of trees were 10–30 cm, 26.58% were 31–60 cm, 9.39% were 61–90 cm, and 1.81% exceeded 90 cm. In Rafin-Kada Forest, 79.60% were 10–30 cm, 16.17% were 31–60 cm, 3.32% were 61–90 cm, and 0.33% exceeded 90 cm. Both forests exhibited an inverse J-shaped DBH distribution, indicating good regeneration potential (Figure 3; Tables 4.4a and 4.4b).

In Puje Sacred Forest, the total mean DBH and Basal Area were recorded as 8.2m and 1.87 m²/ha, respectively. The species with the highest mean DBH and Mean Basal Area was *Daniellia oliveri,* with 0.54m and 0.23 m², respectively. This was followed by *Mangifera indica* (0.45 and 0.16m^2) and *Gmelina arborea* (0.42m and 0.14m^2). Meanwhile, the species with the least mean DBH and Basal Area was *Tectonic grandis,* with 0.11m and 0.01 m2, respectively. This was followed by *Annona senegalensis* (0.13m and 0.02m^2) and *Quercus suber* (0.15m and 0.02m^2) as shown in Table 4.2. However, in Rafin-Kada Crocodile Swamp Forest, the total mean DBH and Basal Area were recorded as 4.38m and 0.71 m²/ha, respectively. The highest mean DBH and Basal Area were recorded in *Daniellia oliveri* with 0.25m and 0.06 m², respectively. Least values were recorded in *Annona squamosa, Elaeis guineensis, Psidium guajava, Raphia sudanica and Vitex doniana,* with 0.15m and 0.02 m^2 each, as shown in Table 3.

The Diameter at breast height (DBH) distribution in Puje Sacred Forest, as presented in Table 5, showed that 62.23% of trees were in the 10-30cm class, 26.58% in the 31-60cm class, 9.39% in the 61-90cm class, and only 1.81% in the >90cm class. The DBH distribution in Rafin Kada Forest (Table 6) showed that 79.60% of trees were in the 10-30cm class, 16.17% in the 31-

60cm class, 3.32% in the 61-90cm class, and only 0.33% in the >90 cm class. The percentage class distribution is presented in Figure 3, which shows an inverse J-shaped DBH distribution curve for both forests. Table 5 presents the diversity indices for the two study sites. The Shannon–Wiener index (H′) was 2.61 in Puje Sacred Forest and 2.78 in Rafin-Kada Crocodile Swamp Forest, while the Simpson index was 0.82 and 0.92, respectively. Margalef's richness index was higher in Puje (4.72) than in Rafin-Kada (3.28), whereas Pielou's evenness was greater in Rafin-Kada (0.90) than in Puje (0.75). Overall, all diversity and evenness indices were higher in Rafin-Kada except for species richness. The Jaccard similarity and dissimilarity coefficients between the forests were 0.33 and 0.67, respectively, indicating moderate species overlap.

Table 1: Species Encountered in the Study Area

S/N	Species	Common name	Family	Status
1	*Albizia lebbeck*	Siris tree	Fabaceae	N
2	*Anacardium occidatale*	Cashew	Anacardiaceae	E
3	*Andira inermis*	Cabbage tree	Fabaceae	N
4	*Annona senegalensis*	Wild custard apple	Annonaceae	N
5	*Annona squamosa*	Sugar apple	Annonaceae	N
6	*Antidessima venosum*	Tassel-berry	Phyllanthaceae	N
7	*Asmina triloba*	Durnal Pawpaw	Annonaceae	N
8	*Azadirachta indica*	Neem	Meliaceae	E
9	*Bombax ceiba*	Senegal coal tree	Malvaceae	N
10	*Bridelia micrantha*	Bridelia	Phyllanthaceae	N
11	*Cassia fistula*	Golden shower tree	Fabaceae	N
12	*Ceiba pentandra*	White Silk cotton tree	Malvaceae	N/E
13	*Combretum collinum*	Boza	Combretaceae	N
14	*Ekebergia capensis*	Cape ash	Meliaceae	N
15	*Elaeis guineensis*	Palm tree	Arecaceae	N/E
16	*Erythrina crista-galli*	Cockspur coral tree	Fabaceae	N
17	*Ficus altissima*	Council tree	Moraceae	N
18	*Ficus racemosa*	Indian fig tree	Moraceae	N
19	*Ficus sycamorus*	Sycamore fig	Moraceae	N
20	*Ficus thorningii*	Small fig tree	Moraceae	N
21	*Gmelina arborea*	Gmelina	Lamiaceae	E
22	*Hymenaea courbail*	Brazilian Copel	Fabaceae	N
23	*Daniellia oliveri*	African balsam	Fabaceae	N
24	*Mangifera indica*	Mango	Anacardiaceae	E
25	*Nauclea latifolia*	Pincushion tree	Rubiaceae	N
26	*Parkia biglobossa*	African Locust beans	Fabaceae	N
27	*Pouteria campechiana*	Canistel	Sapotaceae	N
28	*Prosopis africana*	Iron tree/musquite	Fabaceae	N
29	*Prunus serotina*	Black cherry	Rosaceae	N
30	*Psidium guajava*	Guava	Myrtaceae	E
31	*Quercus suber*	Cork oak	Fagaceae	N
32	*Raphia sudanica*	Ivory Coast wind palm	Arecaceae	N
33	*Samanea saman*	Rain tree	Fabaceae	N
34	*Spathodea campanulata*	African Tulip tree	Bignoniaceae	N
35	*Sterculia setigera*	Kukuki (Hausa)	Malvaceae	N
36	*Strychros spinosa*	Kaffri orange	Loganiaceae	N
37	*Syzygium cumin*	Java plum	Mytrtaceae	N
38	*Tectona grandis*	Teak tree	Lamiaceae	N/E
39	*Toona ciliata*	Red cedar	Meliaceae	N
40	*Trema orientale*	Indian Charcoal tree	Cannabaceae	N
41	*Trichilia emetica*	Natal mahogany	Meliaceae	N
42	*Vachelia seyal*	shittin Wood tree	Fabaceae	N
43	*Vitellaria paradoxa*	Sheabutter	Sapotaceae	N/E
44	*Vitex doniana*	Black plum	Lamiaceae	N
45	*Vitex polygona*	Taruma	Lamiaceae	N

46	***Ziziphus mauritiana***	**Indian plum**	**Rhmanaceae**	**N**

Where N is the native species, and E is the economic species

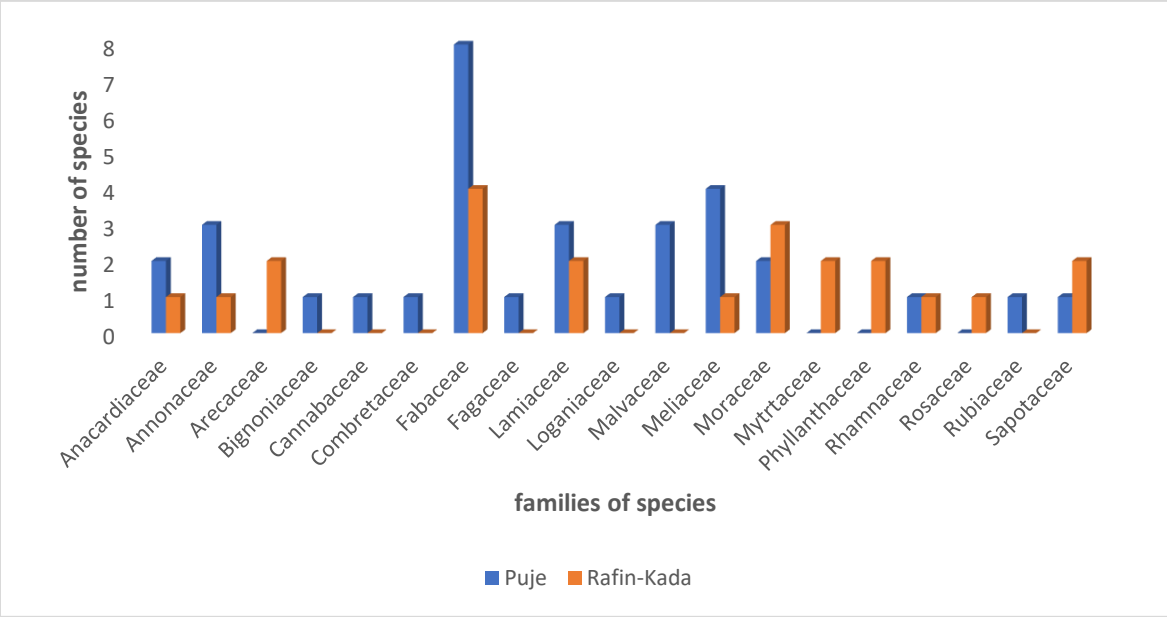


Figure 2: Family Composition of Tree Species in the Puje Forest and Rafin-Kada Crocodile Swamp Forest

Table 2: **Composition and Distribution of Tree Species in Puje Forest**

S/N	*Species*	NoI (n)	%D	MDBH (m)	B.A.	F	R.F	D	R.D	R.Do	IVI
1	*Albizia lebbeck*	6	0.68	0.22	0.04	0.25	2.03	1.2	0.68	0.01	2.72
2	*Anacardium occidatale*	14	1.59	0.25	0.05	0.35	2.84	2.8	1.59	0.05	4.47
3	*Andira inermis*	7	0.8	0.23	0.05	0.25	2.03	1.4	0.8	0.02	2.83
4	*Annona senegalensis*	6	0.68	0.13	0.02	0.25	2.03	1.2	0.68	0.01	2.71
5	*Annona squamosa*	8	0.91	0.17	0.03	0.25	2.03	1.6	0.91	0.01	2.94
6	*Asmina triloba*	4	0.46	0.22	0.04	0.1	0.81	0.8	0.46	0.01	1.27
7	*Azadirachta indica*	89	10.07	0.23	0.05	0.85	6.89	17.8	10.07	1.78	18.73
8	*Bombax ceiba*	9	1.02	0.26	0.06	0.35	2.84	1.8	1.02	0.03	3.88
9	*Cassia fistula*	13	1.48	0.23	0.05	0.5	4.05	2.6	1.48	0.04	5.56
10	*Ceiba pentandra*	4	0.46	0.22	0.04	0.2	1.62	0.8	0.46	0.01	2.08
11	*Combretum collinum*	4	0.46	0.24	0.05	0.1	0.81	0.8	0.46	0.01	1.27
12	*Ekebergia capensis*	1	0.12	0.24	0.05	0.05	0.41	0.2	0.12	0.01	0.52
13	*Erythrina crista-galli*	5	0.57	0.16	0.03	0.15	1.22	1	0.57	0.01	1.79
14	*Ficus racemosa*	5	0.57	0.23	0.05	0.2	1.62	1	0.57	0.01	2.2
15	*Ficus sycamorus*	22	2.49	0.27	0.06	0.55	4.46	4.4	2.49	0.15	7.09
16	*Gmelina arborea*	351	39.71	0.42	0.14	1	8.1	70.2	39.71	93.55	141.4

17	*Daniellia oliveri*	20	2.27	0.54	0.23	0.2	1.62	4	2.27	0.49	4.37
18	*Mangifera indica*	24	2.72	0.45	0.16	0.45	3.65	4.8	2.72	0.49	6.85
19	*Nauclea latifolia*	11	1.25	0.22	0.04	0.25	2.03	2.2	1.25	0.03	3.3
20	*Parkia biglobossa*	17	1.93	0.3	0.08	0.5	4.05	3.4	1.93	0.11	6.09
21	*Prosopis africana*	59	6.68	0.34	0.1	0.9	7.29	11.8	6.68	1.73	15.69
22	*Quercus suber*	1	0.12	0.15	0.02	0.05	0.41	0.2	0.12	0.01	0.52
23	*Spathodea campanulata*	3	0.34	0.33	0.09	0.05	0.41	0.6	0.34	0.01	0.75
24	*Sterculia setigera*	10	1.14	0.3	0.08	0.4	3.24	2	1.14	0.04	4.41
25	*Strychros spinosa*	11	1.25	0.17	0.03	0.4	3.24	2.2	1.25	0.02	4.5
26	*Tectona grandis*	18	2.04	0.11	0.01	0.25	2.03	3.6	2.04	0.02	4.08
27	*Toona ciliata*	1	0.12	0.36	0.11	0.05	0.41	0.2	0.12	0.01	0.52
28	*Trema orientale*	11	1.25	0.21	0.04	0.15	1.22	2.2	1.25	0.03	2.49
29	*Trichilia emetica*	42	4.76	0.24	0.05	0.95	7.7	8.4	4.76	0.42	12.86
30	*Vachelia seyal*	45	5.1	0.22	0.04	0.75	6.08	9	5.1	0.43	11.59
31	*Vitellaria paradoxa*	17	1.93	0.24	0.05	0.65	5.27	3.4	1.93	0.42	7.6
32	*Vitex doniana*	44	4.98	0.16	0.03	0.85	6.89	8.8	4.98	0.22	12.08
33	*Ziziphus mauritiana*	2	0.23	0.28	0.07	0.1	0.81	0.4	0.23	0.01	1.04
	Total	884	100	8.2	1.87	12.4	100	176.8	100	100	300

Where NoI= Number of Individuals, %D=Percentage of Distribution, MDBH= Mean Diameter at Breast Height, B.A=Basal Area, F=Frequency, R.F=Relative Frequency, D=Density, R.D=Relative Density, Do=Dominance and IVI=Important Value Index

Table 3: **Composition and Distribution of Tree Species in Rafin Kada Crocodile Swamp Forest**

S/N	***Species***	**NoI**	**%D**	**MDHB**	**B.A**	**F**	**R.F**	**D**	**R.D**	**R.Do**	**IVI**
1	*Annona Squamosa*	13	2.16	0.15	0.02	0.5	3.58	2.6	2.16	2.47	8.2
2	*Antidessima venosum*	57	9.45	0.21	0.04	0.95	6.79	11.4	9.46	4.72	20.97
3	*Azadirachta indica*	10	1.66	0.17	0.03	0.4	2.86	2	1.66	3.31	7.83
4	*Bridelia micrantha*	60	9.95	0.22	0.04	1	7.15	12	9.96	5.61	22.7
5	*Elaeis guineensis*	11	1.82	0.16	0.02	0.4	2.86	2.2	1.83	2.8	7.49
6	*Ficus altissima*	41	6.8	0.2	0.04	0.75	5.36	8.2	6.8	4.52	16.68
7	*Ficus sycamorus*	19	3.15	0.22	0.04	0.75	5.36	3.8	3.16	5.49	14.01
8	*Ficus thorningii*	122	20.23	0.23	0.05	1	7.15	24.4	20.2	5.8	33.18
9	*Hymenaea courbail*	27	4.48	0.22	0.04	0.75	5.36	5.4	4.48	5.23	15.07
10	*Daniellia oliveri*	14	2.32	0.25	0.06	0.5	3.58	2.8	2.33	7.15	13.05
11	*Mangifera indica*	9	1.49	0.21	0.04	0.35	2.5	1.8	1.5	4.99	8.98
12	*Parkia biglobossa*	11	1.82	0.26	0.06	0.4	2.86	2.2	1.83	7.3	11.99
13	*Pouteria campechiana*	35	5.8	0.18	0.03	0.9	6.43	7	5.81	3.65	15.89
14	*Prunus serotina*	19	3.15	0.23	0.05	0.4	2.86	3.8	3.16	5.7	11.72
15	*Psidium guajava*	4	0.66	0.15	0.02	0.2	1.43	0.8	0.67	2.6	4.7
16	*Raphia sudanica*	12	1.99	0.15	0.02	0.5	3.58	2.4	2	2.65	8.23
17	*Samanea saman*	25	4.15	0.2	0.04	0.75	5.36	5	4.15	4.51	14.02
18	*Syzygium cumni*	25	4.15	0.19	0.04	0.85	6.08	5	4.15	4.32	14.54

19	*Vitellaria paradoxa*	16	2.65	0.19	0.03	0.5	3.58	3.2	2.66	4.15	10.38
20	*Vitex doniana*	13	2.16	0.16	0.02	0.55	3.93	2.6	2.16	2.76	8.84
21	*Vitex polygona*	27	4.48	0.21	0.04	0.7	5	5.4	4.48	5.11	14.59
22	*Ziziphus mauritiana*	33	5.48	0.22	0.04	0.9	6.43	6.6	5.48	5.16	17.07
	Total	603	100	4.38	0.71	14	100	121	100	100	300

Where NoI= Number of Individuals, %D=Percentage of Distribution, MDBH= Mean Diameter at Breast Height, B.A=Basal Area, F=Frequency, R.F=Relative Frequency, D=Density, R.D=Relative Density, Do=Dominance and IVI=Important Value Index

Table 4: Diameter at Breast Height (DBH) of Puje Forest

	Diameter at Breast Height Distribution Classes				
Plots	10-30 (cm)	31-60 (cm)	60-90 (cm)	>90 (cm)	Total
A	18	8	6	4	36
B	25	14	5	0	44
C	26	9	4	0	39
D	21	6	1	0	28
E	23	28	3	0	54
F	23	28	2	0	53
G	26	12	3	1	42
H	32	5	4	2	43
I	36	17	3	0	56
J	40	16	4	0	60
K	19	11	7	2	39
L	23	11	6	5	45
M	27	2	4	0	33
N	35	8	4	0	47
O	21	12	8	1	42
P	31	6	3	1	41
Q	27	10	2	0	39
R	35	6	6	0	47
S	27	16	2	0	45
T	35	10	6	0	51
Total	550	235	83	16	884
Percentage	62.23%	26.58%	9.39%	1.81%	

Table 5: Diameter at Breast Height (DBH) of Rafin-Kada Crocodile Swamp Forest

	Diameter at Breast Height Distribution Class				
Plots	**10-30 (cm)**	**31-60 (cm)**	**61-90 (cm)**	**>90 (cm)**	**Total**
A	23	5	0	0	28
B	22	3	0	0	25
C	16	6	3	0	25
D	21	8	2	0	31
E	19	4	2	0	25
F	19	5	0	0	24
G	22	3	2	0	27
H	25	8	0	0	33
I	23	6	0	0	29

ISTF-NIG 2026

J	24	6	1	0	31
K	19	7	1	0	27
L	23	5	0	0	28
M	24	3	0	0	27
N	29	4	2	0	35
O	26	4	1	0	31
P	21	5	1	1	28
Q	23	8	0	0	31
R	31	4	1	0	36
S	34	3	1	1	39
T	36	4	3	0	43
Total	480	101	20	2	**603**
percentage	**79.60%**	**16.17%**	**3.32%**	**0.33%**	

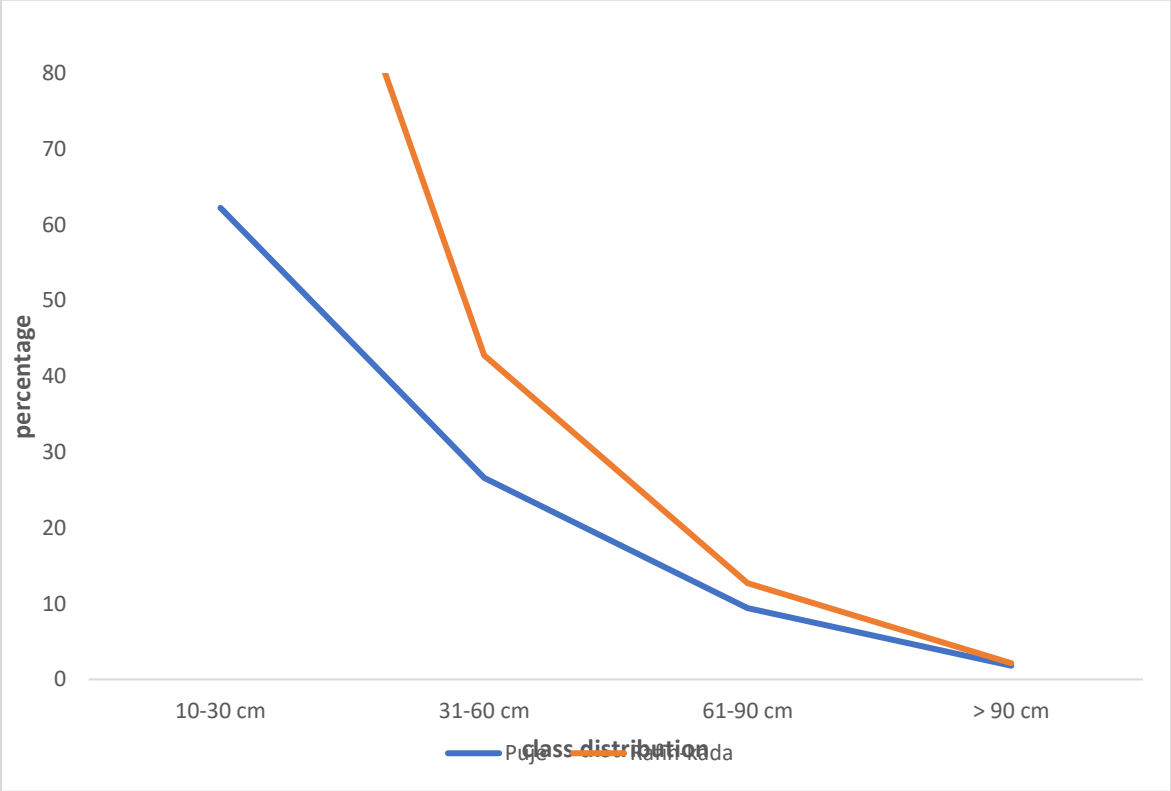


Figure 3: Diameter at Breast Height Distribution Curve of Puje Forest and Rafin-kada Crocodile Swamp Forest

Table 6: Diversity Indices

Indices	Puje Forest	Rafin-Kada Forest
Shannon-Weiner Index H[1]	2.61	2.78
Simpson Diversity Index SDI	0.82	0.92

Margalef's Richness Index d	4.72	3.28	
Pielou's Evenness Index E	0.75	0.90	
Jaccard Similarity Coefficient			0.33
Jaccard Dissimilarity Coefficient			0.67

Discussion

The study revealed that both Puje Sacred Forest and Rafin-Kada Crocodile Swamp Forest maintain high species composition across diverse families, characteristic of tropical forest ecosystems (Ikyaagba *et al.,* 2019). Higher species richness in Puje Forest is likely due to its status as a sacred forest with traditional conservation practices, while restrictive swamp conditions and farming activities in Rafin-Kada limit species richness (Ijomah *et al.,* 2022). The Fabaceae family was most frequent at both sites due to its abundance in savanna ecosystems, its hard-seeded dispersal traits, and its socio-economic importance (Mato *et al.,* 2024; Aigbe *et al.,* 2025). Important Value Index (IVI) analysis showed *Gmelina arborea*, *Azadirachta indica*, and *Prosopis africana* dominated Puje Forest, while *Ficus thonningii*, *Bridelia micrantha*, and *Antidesma venosum* dominated Rafin-Kada Forest, reflecting regeneration potential and ecological success (Abdullahi & Bada, 2024; Salami *et al.,* 2021; Mato *et al*., 2024). Least abundant species included *Ekebergia capensis*, *Quercus suber*, and *Tectona grandis* in Puje and *Psidium guajava* in Rafin-Kada, consistent with previous reports (Mato *et al.,* 2024).

DBH distribution indicated both forests are dominated by younger to medium-aged trees, particularly Rafin-Kada, with an inverse J-shaped distribution typical of regenerating tropical forests (Ikyaagba *et al.,* 2019; Onyekwelu *et al.,* 2022). Basal area values were higher in Puje Forest (1.87 m^2/ha) than in Rafin-Kada (0.71 m^2/ha), suggesting greater biomass and carbon storage potential (Maiguru *et al.,* 2023; Salami *et al.,* 2021; Abdullahi & Bada, 2024). Biodiversity indices indicated moderate to high diversity and fairly even species distribution. Shannon-Wiener indices were 2.61 (Puje) and 2.78 (Rafin-Kada), Simpson indices 0.82 and 0.92, Margalef richness 4.72 and 3.28, and Pielou's evenness 0.75 and 0.90, reflecting healthy forest ecosystems (Mato *et al.,* 2024; Soba *et al.,* 2023; Aigbe *et al*., 2025; Ikyaagba *et al.,* 2019). The Jaccard similarity index (0.33) indicated low species overlap between the forests, highlighting distinct species compositions likely driven by ecological, genetic, and anthropogenic differences (Onyekwelu *et al.,* 2022). Overall, Puje Forest serves as a biodiversity hotspot, while Rafin-Kada supports unique swamp-adapted species, emphasizing the need for targeted conservation strategies.

Conclusion

Forest loss in tropical Africa is increasing due to ineffective management and human activities. Sacred forests, protected by traditional laws, maintain higher biodiversity than degraded forests. Puje Forest is a biodiversity hotspot with greater species richness and basal area, while Rafin-Kada Forest supports unique swamp-adapted species but requires targeted conservation. Both forests show good regeneration potential, and this study provides baseline data for ongoing monitoring in Wukari LGA, Taraba State.

Based on the findings, long-term monitoring plots should be established to track changes in forest diversity and structure. Reforestation efforts in Wukari Local Government Area should prioritize native and dominant species, including *Prosopis africana*, *Trichilia emetica*, *Vitex doniana*, *Vachellia seyal*, *Ficus thonningii*, *Bridelia micrantha*, and *Antidesma venosum*. Further research should investigate the ecological roles of dominant species to inform conservation strategies better. In addition, deliberate efforts should be made to restore and protect the hydrological and ecological integrity of Rafin-Kada Crocodile Swamp Forest through targeted reforestation, establishment of buffer zones, and strict prohibition of farming activities to preserve its biodiversity and cultural significance.

References

Abdullahi, I.N. & Bada, M.O. (2024). The Potential of Agroforestry Species Diversity and Abundance in a Disturbed Forest Reserve of Ogun State, Nigeria. *Open Journal of Ecology*, 14, 831–844. https://doi.org/10.4236/oje.2024.1411047

Aigbe, H.I, Edet D. I., Ekwugha, U.E., Echereobia, C., Okeke, A.N., Nnanyere, A.O., Duru, C.I., and Uluocha, O.B. (2025). Assessing biodiversity and floristic composition of tree species in Okomu forest reserve, Edo State, Nigeria, *Journal of Wildlife and Biodiversity*, 9(2), 62–76. DOI: https://doi.org/10.5281/zenodo

Babu, S., Niveditha, E. A., Sooraj Dev, K., & Shamil Haque, K. M. (2025). Forest Degradation: Loss of Biodiversity and Ecosystem Services. In *Forest Degradation and Management: An Indian Perspective* (pp. 125–137). Cham: Springer Nature Switzerland.

Coskunserce, O. (2024). Use of a Mobile Plant Identification Application and Out-of-School Learning Method in Biodiversity Education. *Ecology and Evolution*, 14(4), e10957. https://doi.org/10.1002/ece3.10957

Gasu, M. B., Gasu, G. N., & Ntemuse, U. E. (2021). A review of biodiversity loss and climate change: Policy measures and adaptation strategies in Nigeria. *Malaysian Journal of Tropical Geography (MJTG)*, *47*(1 and 2), 100–122.

Geetha, K. (2025). Integrating Forest Ecology and Climate Resilience: Pathways toward Sustainable Ecosystem Management. *National Journal of Forest Sustainability and Climate Change*, 25–33.

Ijomah, J.U, Igiri, M.R., & Okey, I.B. (2022). Evaluation of Tree Species Diversity, Abundance and Soil Physicochemical Properties of Ukpon River Forest Reserves, Cross River, Nigeria. *Asian Journal of Research in Agriculture and Forestry* 8(4): 109-122

Ikyaagba, E. T., Amonum, J. I and Okwoche, S. (2019): Tree Species Composition and Diversity of IpinuIgede Sacred Forest in Oju Local Government Area of Benue State, Nigeria. *Journal of Agriculture and Ecology Research International*, 18(3): 1–10.

Keay, R. W. J. (2023). *Trees of Nigeria*. Oxford University Press, (Rev. ed.) New York. 476p

Keck, F., Peller, T., Alther, R., Barouillet, C., Blackman, R., Capo, E., Chonova, T., Couton, M., Fehlinger, L., Kirschner, D., Knüsel, M., Muneret, L., Oester, R., Tapolczai, K., Zhang, H., & Altermatt, F. (2025). The global human impact on biodiversity. *Nature*, *641*(8062), 395–400.

Lee, J. W., Kim, T. W., Park, J. H., Han, Y. S., Hwang, J., Lee, S. H., and Lim, C. Y. (2024). The floristic inventory and distribution characteristics of vascular plants in the forest restoration post-monitoring site. *Korean Journal of Plant Resources*, *37*(5), 475-526.

Maiguru, A. A. & Joseph J. A. (2023). Evaluation of Tree Species Composition and Density in Bisaula Forest Reserve, Taraba State, Nigeria. *Journal of Research in Engineering and Computer Science,*1(5): 47-53

Mato, I.B., Ajibade, G.A., Madu, A.H., Suleiman, M.Z., & Imam, I.U. (2024). Diversity and Conservation Status of Tree Species in the Nigerian Defence Academy Biological Garden. *World Scientific News,* 190(2): 200-215

Okpeke, L. K. [2nd Ed] (2005). Tropical Community Tree Crops. Spectrum Books Limited, Ibadan, Onitsha, Zaria, Nigeria. XXII; 503p; iII., 22cm ISBN: 9780294651

Onyekwelu, J.C., Agbelade, A.D., Tolorunju, M.S., Lawal, A., Stimm, B. & Mosandl, R. (2022). Conservation Potentials, Tree Species Diversity, Distribution and Structure of Sacred Grooves in South-Western Nigeria. *Journal of Tropical Forest Science*, 34(3): 334–346.

Otitoju O, Otitoju GTO and Boyi R (2018). Risk assessment of agricultural farmland: A case study of Wukari, Taraba state, Nigeria. *Journal of Pharmacognosy and Phytochemistry,* 7(1): 2110-2113

Salami, K. D., Shuaibu, R. B., Adekunle, V.A. J, & Ogunsola, J. D (2021). Comparative Analysis of Density, Diversity and Similarity of Forest Tree Species in Three Selected States of Northern Nigeria. *Journal of Research in Forestry, Wildlife & Environment,* 13(3).

Soba, T.M., Abdulazeez, B.S., Clement, S.A., Ndagi, H.I., & Ibrahim, I.O (2023). An Ecological Assessment of Tree Species Diversity, richness and status in the Faculty of Agriculture, Shabu-Lafia, Nasarawa State University, Keffi, Nasarawa State, Nigeria. *East African Scholars J Agri Life Sci*, 6 (7): 141-149

Stevens, S., Hay-Edie, T., Larrea, C. M., Ramos, A., Broome, N. P., Eghenter, C., & Mellis, C. (2024). Recognizing territories and areas conserved by Indigenous peoples and local communities (ICCAs) that overlap with protected areas. *IUCN WCPA Good Practice Guidelines Series*, (34).

Sullivan, M. K., Browne, L., Penagos Zuluaga, J. C., Liu, J., Surendra, A., & Estrada-Villegas, S. (2024). Sacred forest biodiversity conservation: A meta-analysis: *Conservation Science and Practice*, *6*(1), e13055.

Yakub, W., Muhammad Saddiq, A., Ibrahim Solomon, R., Babale Bawa, D., & Abdullahi, M. (2022). Spatial variability of soil organic carbon, total nitrogen, and soil pH in soils of Wukari Local Government Area, Taraba State, *Nigeria. Asian. Journal of Agriculture and Allied Sciences, 5(1),* 1–11.

EVALUATING ECOSYSTEM RESTORATION APPROACHES FOR DEGRADED LAND HOTSPOTS: A CASE STUDY OF JIGAWA STATE, NIGERIA

[1]Iroko, O. A., [2]Salami, K. D., [3]Obadiah, C. and [2]Umar, M. Y.

[1]Forestry Research Institute of Nigeria, P.M.B. 5054 Jericho, Ibadan, Oyo State
[2]Department of Forestry and Wildlife Management, Federal University Dutse, Jigawa State, Nigeria
[3]Department of Forestry, Wildlife and Ecotourism, Nasarawa State University, Lafia Nasarawa State
**Corresponding Email: foristsalam@yahoo.com; 07034294371*

Abstract

Land degradation has become a major environmental challenge in Jigawa State, Nigeria, where increasing pressure from agriculture, overgrazing, fuelwood harvesting, and climate-related stress has led to the emergence of numerous ecological hotspots. This study therefore assessed the effectiveness of existing restoration strategies implemented across selected degraded hotspots in Jigawa State. Multistage sampling applied using field observations, community interviews, and a review of government and NGO intervention records, the research evaluated the performance of measures such as afforestation, controlled grazing, sand-dune stabilization, water-harvesting structures, and soil conservation techniques. The study revealed that respondents were predominantly middle-aged males, with 35% within the 31–40 age bracket and 70% male, mainly local farmers (50%) with tertiary (35%) or secondary (30%) education. Awareness of environmental degradation was high at 90%, with deforestation (80%) and desertification (70%) identified as the most critical forms, primarily caused by unsustainable farming (65%) and overgrazing (55%). Major impacts included reduced agricultural productivity (75%) and loss of grazing land (60%), leading to increased poverty (55%) and farmer-herder conflicts (40%), with local farmers (45%) being most affected. While 60% were aware of restoration projects led mainly by local NGOs (25%), only 15% rated them very effective. Afforestation/reforestation (75%) and agroforestry (55%) were the most preferred strategies. Socio-economically, 30% reported increased income but 40% saw no change, while 40% cited poor funding and lack of follow-up as challenges. In all, 40% agreed on long-term sustainability, indicating mixed perceptions of restoration outcomes. The study concludes by recommending improved restoration frameworks that integrate local participation, adaptive management, and sustainable land-use practices. The assessment provides insights that can guide future interventions aimed at restoring ecological integrity and enhancing resilience in degraded landscapes across Jigawa State

Keywords: Restoration Strategies, Degrade, Hotspots and Jigawa State

Introduction

In the ecosystem services framework, "land" is known as a terrestrial ecosystem that comprises not just soil resources, but also vegetation, water, other biota, climatic factors, landscape setting and ecological processes that operate within one system ensuring its functions and services (Salami *et al.,* 2026; Khatiri *et al.,* 2026). Land is a major resource for many people in Africa (Adewuyi, 2016). As a result, it contributes significantly to their income. More than half of the population depends on the exploitation of land directly for their long-term livelihood (Zahid *et al.,* 2026). They extract/exploit the land in the forms of crop farming, animal husbandry and mining

(Kavanagh, 2026). Many also depend on the land to build their houses while construction companies equally excavate the top soil for various infrastructural development. All of these socio-economic activities are known to impact, often negatively, on the condition of the soil, vegetation and water resources (Salami *et al*., 2025; Adewuyi *et al.,* 2017).

When the impact is negative and continuous over a long period of time, it results in land degradation in different forms. Adewuyi (2011); Koala, (2026) reported that land degradation can take the forms of loss of biodiversity, decrease in vegetation density, tree cover, revegetation/deforestation, soil erosion (sheet, rill and gully) and reduction in Soil Organic Carbon (SOC). Other causes of land degradation are climate variation/change, bush burning, fuelwood harvesting drought, compaction (physical), salinization, acidification and nutrient imbalance. Jigawa State, located in Nigeria's semi-arid northwest, faces significant environmental challenges, notably desertification, deforestation, and land degradation (Salami, 2022). These issues have intensified due to climate change and unsustainable land-use practices. The Hadejia-Nguru Wetlands, a vital ecosystem supporting over a million people, have experienced substantial degradation, leading to diminished agricultural productivity and biodiversity loss.

In response, initiatives like the Agro-Climatic Resilience in Semi-Arid Landscapes (ACReSAL) and the Great Green Wall (GGW) have been implemented to restore degraded lands and promote sustainable practices. Jigawa State, located in the Sudan and Sahel savannah ecological zones of northern Nigeria, has over the years become increasingly vulnerable to environmental degradation. The state experiences recurring issues of desertification, drought, gully erosion, deforestation, and overgrazing, which threaten both ecological stability and the livelihoods of rural populations. These environmental issues are particularly evident in areas like Guri, Birniwa, and parts of the Hadejia-Nguru Wetlands, where land degradation has severely impacted agricultural productivity, water availability, and biodiversity (ACReSAL, 2024). With over 80% of the population relying on agriculture, the degradation of land poses a direct threat to food security and economic sustainability. This situation is compounded by population pressure, climate variability, poor land-use practices, and the limited enforcement of environmental protection laws Salami *et al.,* 2014). Various interventions, including the Great Green Wall Initiative and the ACReSAL project, are currently being implemented in Jigawa State to combat land degradation and promote ecological restoration. However, there is still a knowledge gap in understanding the actual impact and effectiveness of these restoration techniques, particularly in rural communities that are most affected by degradation. This study thereby assessed degraded hotspots across the Jigawa state and evaluate the current restoration strategies in place, with the goal of informing better policy and intervention approaches for sustainable land management.

Methodology

Description of the study site

The study was carried out at Forestry Nursery of the Department of Forestry and Wildlife Management, Federal University Dutse, Jigawa State. It lies between latitude 11.00°N to 13.00°N and longitudes 8.00°E to 10.15°E (Gidado *et al.,* 2023). The study area Dutse covered by Sudan area and also characterized by hot wet summer and cool dry winter with average raining season of 3-5 (644 m) (Jibo *et al.,* 2022). Sunshine hours indicates that the town enjoys 10-11 hours of sunshine depending on the season. The topography is characterized by high land area which is

almost 750m. Soil tends to be fertile ranging from sandy-loam (Salami and Lawal, 2018). The mean annual temperature in the area supports the growth of variety of plants. The area's relatively uniform climate and soil conditions ensured that the results obtained from the study were reliable and applicable to similar agro-ecological zones. The topography of the area is generally flat, with a high land area of approximately 750 meters. The soil type in this region is predominantly sandy-loam, as reported in previous studies (Garba *et al*., 2021). This soil type is characterized by a mix of sand, silt, and clay, providing a suitable medium for plant growth

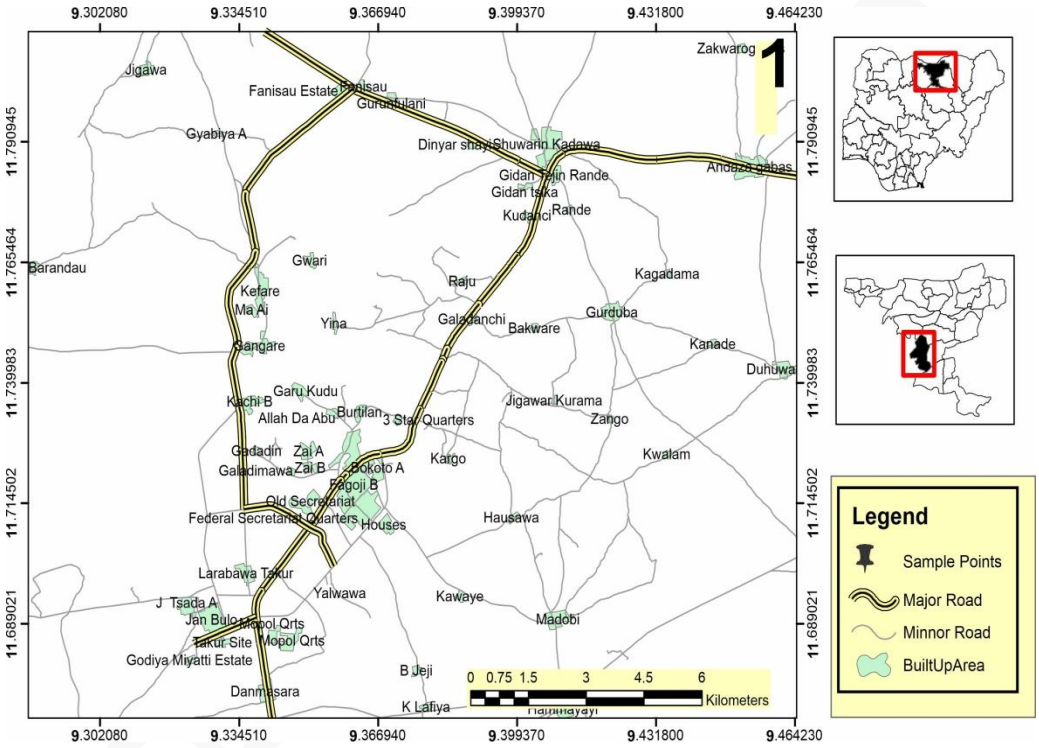


Figure 1: Showing the map of the Study Area

Source: Salami *et al*., 2023



Figure 2: Gully Erosion in Malam Maduri, Hadejia L.G.A, Jigawa State



Figure 3: Gully Erosion in Kaugama, Jigawa State

Data collection

A structured questionnaire was designed to assess the causes, impact and strategies of restoring the degraded hotspot. The questionnaire was including demographic information and Likert scale questions to evaluate the questions. The study was carried out in four different local government bases on the impact of ecological changes which are: Birnin kudu, Hadejia, Kaugama, and Dutse all located within the Sudan and Sahel savannah zones.

Sampling Design

Multistage stage sampling was adopted for the study. Stratified random sampling method were employed to select the targeted group such as Environmental Non-governmental Organization, farmer and rural people. Head of affected community and Non-governmental Organization will be consulted for discussion. Determine the appropriate sample size using a statistical formula (for example Cochran's formula). Consider the desired level of precision and confidence level (for instant 95% confidence level). A sample size of 100-150 targeted would likely be adequate. Therefore, 180 copies of questionnaires were administered among the targeted groups in the study area. Twenty questionnaires were administered for each of the group which make sixty for the three targeted groups in each local government. Therefore, 240 copies of questionnaires were administered for the study.

Data Analysis

The study pursued four objectives to assess restoration strategies in degraded hotspots of Jigawa State, Nigeria. First, degraded hotspots in the study area were identified using descriptive statistics including frequency, mean, and percentage. Second, the causes and impacts of land degradation in these areas were determined through Likert scale responses, frequency, mean, and percentage analysis. Third, restoration strategies currently employed were assessed using mean and percentage. Finally, community involvement and the socio-economic effects of restoration projects were evaluated using frequency, mean, and percentage. Together, these methods provided a comprehensive evidence base on degradation patterns, drivers, interventions, and local outcomes.

Results

The demographic profile of respondents reveals a diverse range of age groups, with the majority (84) falling within the 31-40 age bracket, indicating a predominantly middle-aged population. Males comprise 70% of respondents, while females make up 30%, highlighting a gender imbalance. The respondents are largely local farmers (50%), followed by community leaders (20%), and government/policy officers (15%). Notably, 35% of respondents have tertiary education, while 30% have secondary education, indicating a relatively educated population. The age and education distribution suggests that respondents are likely to be economically active, with a good understanding of environmental issues and restoration efforts. The dominance of local farmers and community leaders highlights the importance of engaging these stakeholders in restoration initiatives

Table 1: Demographic Characteristics of Respondents

Variable	Category	Frequency (n=240)	Percentage (%)
Age Distribution	Below 20	12	5
	21–30	72	30
	31–40	84	35
	41–50	48	20
	Above 50	24	10
	Total	**240**	**100**

Gender	Male	168	70
	Female	72	30
	Total	**240**	**100**
Category of Respondents	Local Farmers	120	50
	Community Leaders	48	20
	NGO Representatives	24	10
	Government/Policy	36	15
	Officers	12	5
	Others		
	Total	**240**	**100**
Educational Level	No formal education	36	15
	Primary	48	20
	Secondary	72	30
	Tertiary	84	35
	Total	**240**	**100**

The survey reveals a high level of awareness (90%) about environmental degradation, with deforestation (80%) and desertification (70%) identified as the most critical forms of degradation. Unsustainable farming (65%) and overgrazing (55%) are the leading causes, followed by charcoal/firewood collection (45%) and climate change/drought (40%). Government neglect/poor policies (30%) also contribute significantly. To address these issues, implementing sustainable farming practices, promoting alternative livelihoods, and strengthening environmental policies are recommended.

Table 2: Showing the Awareness of Environmental Degradation

Variable	Category	Frequency (n=240)	Percentage (%)
General Awareness	Yes	216	90
	No	24	10
Critical Forms of Degradation	Deforestation	192	80
	Desertification	168	70
	Overgrazing	144	70
	Soil Erosion	132	55
	Water Scarcity	96	40
	Others: e.g., mining, urban expansion	18	7.5
Major Causes	Unsustainable	156	65
	Farming	132	55
	Overgrazing	108	45
	Charcoal/firewood	96	40
	collection	72	30

	Climate change/drought		
	Government neglect/poor policies	24	10
	Others – e.g., lack of education		

The impacts of environmental degradation are far-reaching, with reduced agricultural productivity (75%) and loss of grazing land (60%) being the most significant community impacts. This has led to increased poverty/ung employment (55%) and conflicts between farmers and herders (40%). The most affected groups are local farmers (45%), pastoralists/herders (25%), and women and children (10%). The degradation also affects future generations (5%), emphasizing the need for urgent action to mitigate these impacts and ensure sustainable development.

Table 3 Showing the Impacts on Stakeholders

Variable	Category	Frequency (n=240)	Percentage (%)
Community Impacts	Reduced agricultural productivity	180	75
	Loss of grazing land	144	60
	Increased poverty/unemployment	132	55
	Conflicts between farmers and herders	96	40
	Migration	72	30
	Others e.g., food insecurity	12	5
Most Affected Groups	Local farmers	108	45
	Pastoralists/herders	60	25
	Women and children	24	10
	Entire community	36	15
	Future generations	12	5

The data suggests that a significant portion of respondents (60%) are aware of restoration projects in their area, with local NGOs (25%) and international NGOs (15%) taking the lead. However, the effectiveness of these projects is a concern, with only 15% rating them as very effective. The preferred restoration strategies are afforestation/reforestation (75%) and agroforestry (55%), indicating a strong interest in sustainable land management practices. Community-based management (40%) and stronger policies (25%) are also seen as important, highlighting the need for a multi-stakeholder approach to address environmental challenges.

Table 4: Showing Restoration Efforts and Strategies

Variable	Category	Frequency (n=240)	Percentage (%)
Awareness of Restoration Projects	Yes	144	60
	No	96	40
Project Leadership	Local NGOs	60	25
	International NGOs	36	15
	Government agencies	24	10
	Community-based initiatives	18	7.5
	Others	6	2.5
Effectiveness Rating	Very effective	36	15
	Moderately effective	84	35
	Not effective	24	10
Preferred Restoration Strategies	Afforestation/Reforestation	180	75
	Agroforestry	132	55
	Soil & water conservation	108	45
	Alternative livelihoods	96	40
	Community-based management	72	30
	Stronger policies	60	25

The data highlights the perceived impact of a project or initiative on households and the community. About 30% of respondents reported an increase in income, while 40% saw no change, and 10% experienced a negative impact. In terms of community benefits, improved infrastructure (35%) and increased tourism/business (45%) were the most commonly cited advantages. However, challenges such as poor funding and lack of follow-up were also reported by 40% of respondents. The perception of long-term sustainability is mixed, with 40% agreeing and 25% neutral, indicating a need for more effective implementation and communication strategies to build trust and confidence in the initiative.

Table 5 Socio-Economic Effects of Restoration

Variable	Category	Frequency (n=240)	Percentage (%)
Household Impact	Increased income	72	30
	New job opportunities	48	20
	No change	96	40
	Negative impact	24	10

Community Benefits (multiple responses allowed	Improved infrastructure	60	25
	Better access to resources	84	35
	Increased tourism/business	36	15
	Enhanced environmental quality	108	45
	Strengthened cohesion	72	30
Challenges Faced	Yes - e.g., poor funding, lack of follow-up	96	40
	No	144	60
Perception of Long – Term	Strongly agree	48	20
	Agree	96	40
	Neutral	60	25
	Disagree	24	10
	Strongly disagree	12	5

Discussion

Demographic Characteristics of Respondents

The demographic profile of respondents reveals a diverse range of age groups, with the majority (84) falling within the 31-40 age bracket, indicating a predominantly middle-aged population. This aligns with findings by Ogunjinmi *et al.* (2018), who noted that middle-aged individuals are more likely to be involved in environmental conservation efforts in Nigeria. Males comprise 70% of respondents, while females make up 30%, highlighting a gender imbalance. According to Adekunle et al. (2013), gender disparities in environmental conservation are common in Nigeria, often due to cultural and societal factors. This is consistent with the findings of Enaruvbe and Iwasaki (2016), who emphasized the crucial role of local farmers and community leaders in environmental restoration efforts. Notably, 35% of respondents have tertiary education, while 30% have secondary education, indicating a relatively educated population. As noted by Ogunjinmi *et al*. (2018), education level is a significant predictor of environmental awareness and participation in conservation efforts.

Awareness of Environmental Degradation

The survey indicates high public awareness of environmental degradation at 90%, with deforestation and desertification identified as the most critical forms at 80% and 70% respectively, alongside overgrazing at 70%, soil erosion at 55%, and water scarcity at 40%. These perceptions align with documented trends in Nigeria, where deforestation proceeds at 3.5% annually, losing 1.5 million trees daily largely due to logging and fuelwood demand. Unsustainable farming, cited by 65% of respondents, contributes directly to land degradation through exposure of bare soil and deep plowing, which degrade land 5–10 times faster than no-till practices. Overgrazing, noted by 55%, increases soil erosion and reduces vegetation cover, with studies showing it weakens ecosystem functions and drives desertification when combined with aridity (Pankaj *et al.,* 2026).

Grassland degradation: ecological aspects for sustainable management. Charcoal and firewood collection, identified by 45%, remains a major driver as over 70% of Nigerians depend on biomass for cooking, leading to indiscriminate felling and ecosystem collapse. Nigeria loses over 350,000 hectares of forest each year, with charcoal production linked to erosion, reduced tree availability, and biodiversity loss. Climate change and drought, at 40%, exacerbate these issues by causing irregular rainfall, crop failures, and enhanced desertification, particularly in Northern states where 50–75% are affected. Government neglect and poor policies, flagged by 30%, hinder enforcement, though initiatives like the Great Green Wall and NEWMAP aim to restore degraded landscapes.

Impacts on Stakeholders

The impacts of environmental degradation are far-reaching and devastating, affecting not only the environment but also the livelihoods of communities. According to the survey, reduced agricultural productivity (75%) and loss of grazing land (60%) are the most significant community impacts. This is consistent with findings by Enaruvbe and Iwasaki (2016), who noted that environmental degradation can lead to decreased agricultural productivity, food insecurity, and increased poverty. The loss of grazing land has also led to conflicts between farmers and herders (40%), as they compete for scarce resources. This is a major concern in Nigeria, where conflicts between farmers and herders have been escalating in recent years (Adebayo, 2018). These groups are often the most vulnerable and have limited access to resources, making them more susceptible to the impacts of environmental degradation. The degradation also affects future generations (5%), emphasizing the need for urgent action to mitigate these impacts and ensure sustainable development. As noted by Ogunjinmi *et al.* (2018), environmental degradation has long-term consequences that can affect the well-being and livelihoods of future generations.

Restoration Efforts and Strategies

The survey's findings on restoration efforts and strategies highlight the importance of collaborative approaches to environmental conservation. According to the data, 60% of respondents are aware of restoration projects, with local NGOs (25%) and international NGOs (15%) leading the efforts. This is consistent with research by Enaruvbe and Iwasaki (2016), who noted that NGOs play a crucial role in forest restoration efforts in Nigeria. The preferred restoration strategies, such as afforestation/reforestation (75%) and agroforestry (55%), focus on addressing the root causes of environmental degradation and promoting sustainable development. These approaches are supported by research, which shows that they can help to improve biodiversity, reduce soil erosion, and increase carbon sequestration (Adebayo, 2018; Ogunjinmi *et al.,* 2018). However, the survey also reveals that 40% of respondents are unaware of restoration projects, indicating a need for increased awareness and outreach. This highlights the importance of community-based management and policy frameworks that support environmental conservation (Ogunjinmi *et al.,* 2018). To achieve effective restoration, it is essential to strengthen community-based management and policy frameworks, support alternative livelihoods and sustainable development initiatives, and increase awareness and outreach about restoration projects. By working together, we can promote sustainable development and mitigate the impacts of environmental degradation.

Socio-Economic Effects of Restoration

The survey's findings on the socio-economic effects of restoration efforts highlight the complexities of environmental conservation. This is consistent with research by Adebayo (2018), who noted that environmental restoration can lead to improved livelihoods and income opportunities for local communities. However, the survey also reveals that 40% of households report no change, and 10% have experienced a negative impact. This underscores the need for more effective restoration strategies that prioritize community engagement and benefit-sharing (Ogunjinmi *et al.,* 2018). At the community level, the benefits of restoration are more pronounced, with improved environmental quality (45%) and better access to resources (35%) being the most significant advantages. These findings are consistent with research by Enaruvbe and Iwasaki (2016), who highlighted the importance of community-based approaches to environmental restoration Despite these benefits, challenges persist, including poor funding and lack of follow-up (40%). Addressing these challenges will be crucial to ensuring the long-term success of restoration efforts (Adebayo, 2018).

Conclusion

Environmental degradation in Jigawa State poses a serious threat to livelihoods, biodiversity, and long-term development. The study reveals that while awareness is high and restoration efforts are underway, their effectiveness is limited by weak institutional support and insufficient community engagement. Sustainable restoration requires a multi-stakeholder approach that integrates ecological, economic, and social dimensions. The findings underscore the urgency of scaling up restoration strategies such as afforestation, agroforestry, and soil conservation, while empowering local communities to take ownership of these initiatives. Without coordinated action, the degradation was continued to undermine food security, increase poverty, and exacerbate conflicts.

Recommendations

Based on the analysis, the following recommendations are proposed to enhance restoration efforts in Jigawa State: it is recommended that the government strengthens policy enforcement on land use and resource management, increases funding and technical support for restoration projects, and establishes monitoring and evaluation frameworks to track progress. NGOs and communities can contribute by promoting community-based natural resource management, conducting awareness campaigns and training on sustainable practices, and supporting alternative livelihoods to reduce pressure on forests and land. Collaborative strategies should involve fostering partnerships between government, NGOs, and local leaders, integrating traditional knowledge with scientific approaches, and expanding restoration to include water conservation and biodiversity protection. Additionally, future research should focus on conducting longitudinal studies to assess long-term impacts of restoration and exploring innovative techniques such as climate-smart agriculture and green infrastructure.

References

Abubakar, S.M. (2000). Assessment of land Degradation under Different Agricultural Land Use Types in a Part of Kastina State, Nigeria. In Falola, J. Afolabi; Ahmed, K; Liman, M.A.

and Maiwada, A.(eds), Proceedings of the National Workshop on land Administration and Development in Northern Nigeria, Kano. Dept of Geog. BUK, pp 91-106

ACReSAL Jigawa State. (2024). Agro-Climatic Resilience in Semi-Arid Landscapes: Project Activities and Reports. Retrieved from https://jigawaacresal.org

Adebayo, A. A. (2018). Environmental degradation and sustainable development in Nigeria. *Journal of Environmental Science and Technology*, 11(2), 55-65.

Adekunle, V. A. J., Olagoke, A. O., and Ogundare, L. F. (2013). Biodiversity and sustainable management of a tropical forest ecosystem: A case study of Ogbomoso forest, Nigeria. *Journal of Environmental Science and Technology*, 6(2), 65-76.

Adewuyi, T. O. Olofin, E. A. and Olutunmogun, A. K. (2017). Examination of the Relationship between Vegetation Cover Indices and Land Degradation in the Peri- Urban Area of Kaduna Metropolis, Nigeria.Journal of Research in Forestry, Wildlife & Environment, Federal University of Agriculture, Makurdi, Benue State, Nigeria. ISBN: 2141 – 1778, Vol. 9(3) 50-60

Adewuyi, T.O. (2011). Land Degradation in the Peri-urban Area: The Case of Kaduna Metropolis, Nigeria. Lambert Academy Publishing, Germany. ISSN: 13 – 978-3847302490 158pp

Adewuyi, T.O. (2016). Globalisation, Ecology and Land Degradation in Africa.In U.A. Tar, B.E. Mijah and M.E.U. Tedheke (eds)'Globalisation in Africa: Perspective on Development, Security and the Environment', Lexington Press, Lanham, Maryland, U.S.A. pp 345 – 362

Adewuyi, T.O. and Mustapha, I.A. (2017). Geo-spatial Analysis of Forest Reserves in Northern Nigeriaand its Implications to the Environment and National Security.In: Shuaibu, S, Tangban OE, Ahmed OA, Osakwe CCC. (eds); Defence, Security

Enaruvbe, G. O., & Iwasaki, K. (2016). Assessment of forest restoration efforts in Nigeria: A review. Journal of Environmental Management, 172, 1-11.

Garba, A., Salami, K. D. and Akanbi W. B. (2021). Assessment of Endangered economic tree species and conservation Techniques in Jigawa state *FUDMA Journal of Agriculture and Agricultural Technology* V 7(2)116-123

Gidado, H. A. Salami, K. D., Kareem, A. A., Jibo, A. U., Adam Fatima, Oginni, D. O. (2023) Effect of frequencies of watering and water volumes on the growth performance of *Adansonia digitata* (Linn) Seedlings. *Australian Journal of Science and Technology* ISSN Number (2208-6404) Volume 7; Issue 1; March 2023 Australian

Jibo, A.U, Salami, K. D. and Mahmoud, I. (2023). Comparative Study of Parkia biglobosa (Jacq) R. Br. ex G. Don and Azardirachta indica A. Juss Root System Of The Planting Stocks Through Potting and Seedbed. *Ethiopian Journal of Environmental Studies & Management*, *16*(2), 142-150.

Kavanagh, A. M. (2026). How to Confront Climate Crisis: Pointed Interventions in the Social Studies Classroom.

Khatiri, K. N., Eslamian, S., & Sharifi, R. (2026). The Nexus of Ecohydrology: Interdisciplinary Approaches to Sustainable Water Resource Management. *Global Nexus Handbook*, *2*, 655-673.

Koala, V. (2026). Modeling land degradation sensitivity with the MEDALUS framework in the Massili River Basin, Burkina Faso: A 30-Year Case study. *Total Environment Advances*, 200142

Ogunjinmi, A. A., Onwumere, O. C., & Ogunjinmi, K. O. (2018). Factors influencing participation in forest conservation in Nigeria. Journal of Sustainable Forestry, 37(3), 245-259.

Pankaj, D. A., Jhariya, M. K., Banerjee, A., and Bargali, S. S. (2026). Grassland degradation: ecological aspects for sustainable management. *Proceedings of the Indian National Science Academy*, 1-21.

Salami K. D., Sulaiman, I. M. Adeniyi, K. andTukur, N. Y (2026) Restoration and Sustainability of Ecological Resource for Biodiversity Conservation in Nigeria. March 2026 In book: Climate Smart Actions (Csa) Aquaculture, Agroforestry And Resources

Salami, K. D and Lawal, A. A (2018). Tree species Diversity and Composition in the Orchard of Federal University Dutse, Jigawa State. *Journal of Forestry Research and Managemen*t. ISSN 0189-8418, *www.jfrm.org.ng*,Vol 15(2):112-122

Salami, K. D. (2022). Ecological Restoration in The Savannah Landscape: A Concern Of 20th Century. *Organization*, *3*, 3.

Salami, K. D. Bellu, Z., Jibo A. U. and Nazil, A. (2026) Influence of Different Mulching Materials on Growth of *Adansonia Digitata* Linneous Seedlings NL Journal of Agriculture and Biotechnology Volume 3 Issue 2 April 2026

Salami, K. D., Akinyele, A. O., and Odewale, N. (2014). Mitigation of Deforested area, Means of Sustaining Non–Timber Forest Products. In *Proceedings of the 3rd Annual Conference paper of the Association of Women in Forestry and Environment of Nigeria, held at Federal University of Technology, Akure* (pp. 261-266)

Salami, K.D., Akinyele, A.O. Lawal, A. A. Abubakar, A. W. Jibo, A. U. and Adeniyi, K. A. (2025) Resilience and Restoration: Tropical Ecosystems in the Face of Human Impact. Theme: The Concept of Value Chains in Agriculture, Climate Action and Environmental Resources

Zahid, I., Danyal, M., Sahir, E. F., Azhar, R., Kashif, A., & Shan, H. (2026). Mixed-method study on the perception of residents of rural flood-prone community towards the impacts of climate change and variability on health and wellbeing: Chiniot, Pakistan. *BMJ Public Health*, *4*(1).

ISTF-NIG 2026

REGENERATION DYNAMICS AND POPULATION STRUCTURE OF WOODY SPECIES IN AFAKA FOREST RESERVE, NIGERIA.

Sodimu, A. I[1*], Bayo, D[2]., Rasheed, F.M[3] and Achimi, J. O[1]

[1]*Savanna Forestry Research Station, Forestry Research Institute of Nigeria, PMB 1039, Samaru – Zaria, Kaduna, Nigeria*
[2]*Northern Guinea Research Station, Forestry Research Institute of Nigeria, Nasarawa, Nigeria.*
[3]*Federal College of Forestry Mechanization, Forestry Research Institute of Nigeria, P.M.B 2273, Afaka – Kaduna, Nigeria*
**Corresponding author: tunsod88@gmail.com.*

Abstract

Forest Reserve Areas can sustain their valuable species through an effective regeneration system. At present, most of the preserved and permanently protected forest areas are being industrialized, and valuable species are being legally removed. Given the ecological and anthropogenic problems that have led to the extinction of valuable flora and fauna species, it became imperative to study the regeneration dynamics and population structure of woody species in the natural setting of the Afaka Forest Reserve. Four (4) plots (A–D) of 100m x 100m were laid. The point-centered quadrant sampling method was used. Transects were selected on a pure random basis, and data were collected on species diversity and families, density of woody stems, diameter class distribution, regeneration potential, and relative frequency. Natural regeneration was evaluated by counting wildlings (≤30 cm height) within 2 m of each mature tree. A total of 21 families and 181 species were recorded for species diversity in the natural protected areas of the Afaka Forest Reserve. The densities of woody plants varied between 625.01 and 961.51 per hectare in plots I, II, III and IV. At the same time, the highest number of trees in diameter-class distribution was apportioned to the 10 – 19cm class interval in plots I, II, III and IV, respectively. Diameter class 50cm and above had the lowest number of trees allocated to it. The regeneration potential of the diverse species was very poor, with significant implications for their regeneration and conservation. However, *Isoberlinia doka* Craib & Stapf had the highest regeneration potential in each of the examined plots, followed closely by *Acacia senegal*, *Parkia biglobosa*, and *Terminalia avicennoides* Gull & Peer—important woody plants of economic importance, like *Triplochiton scleroxylon* k. Schum, *Macaranga hurifolia* had zero regeneration potential in the reserve.

Keywords: Vandalized, Natural Forest, Regeneration Dynamics, Conservation, Woody Species,

Introduction

Biological diversity conservation strategies that include a variety of individual management strategies for specific species are neither feasible nor effective (Attiwill, 1994; Borowski, 2015; Magaji *et al.,* 2018). As an alternative, 'coarse-filter' management strategies focus on maintenance of broad patterns of forest age and composition under the assumption that this will provide the necessary habitat to support a wider variety of native species (Franklin, 1993; Larsen *et. al.,* 1997). Native species are assumed to be adapted to the natural disturbance regime of their environment; thus, management that mimics this regime has become a popular approach to maintaining species

diversity and ecological integrity (Hunter, 1993; Bergeron *et al.,* 2002). With this approach, natural processes are to be protected, including forest regeneration after disturbances such as fire or logging (Sobamowo *et al.,* 2019). A central component of biodiversity conservation in managed forest landscapes is the landscapes the successful regeneration of natural tree species mixes after logging (Bergeron & Harvey, 1997*; Sodimu et al*., 2020). This often proves to be a substantial challenge. Site preparation and planning of tree seedlings have been widely adopted as strategies to ensure rapid and successful postharvest regeneration. These require a substantial silvicultural and financial investment, however, and are not always successful in meeting legal regeneration standards, let alone achieving a natural species mix. Although natural regeneration can be much less expensive and lead to more natural species mixes, its success depends on the availability of seed sources, microsites,n and environmental and microenvironmental and biotic factors that favor the establishment and early survival of tree seedlings (Nguyen-Xuan e*t al*., 2000; Ogunkalu *et al.,* 2017).

We need to conserve forest resources due to their economic importance. Several direct and indirect benefits are available in the forest, such as timber and non-timber products. Apart from timber products in the forest, plant foods such as leaves, seeds, nuts, fruits, tubers and roots serve as sources of food income (Oduwaiye *et al.,* 2002; Sodimu *et al.,* 2020). Also, species of economic importance, such as those with medicinal and aesthetic value, can be preserved in perpetuity in a well-preserved forest. The forests of Nigeria comprise swamp forest, tropical rainforests and secondary forest regrowth. The lowland tropical rainforest was described as a complex mosaic of communities with varying status and floristic composition (Sodimu et *al.,* 2019). Structurally, the forests consist of three layers: the tree layer, the shrub layer, and the undergrowth. Many of the emergent species in the forest grow slowly and require substantial overhead shade in their early life to survive and thrive (Dinendra e*t al.,* 2015; Sodimu et *al.,* 2019). However, it is now recognized that many of them grow very rapidly in full Light conditions (Areola, 1991).

The emergent species persist for a long time in a state of suppressed regrowth under the canopy's shade until a gap occurs, allowing them to grow. The forestry growth cycle consists of a mosaic of gap-phase, build-up, and mature-phase build-up forests, as explained by Van der Maarel (1996). At present, most preserved forest areas are being vandalized, and valuable species are being illegally removed. The only way Forest Reserves can sustain these valuable species is through effective regeneration programmes. NEST (1991) indicated that 350,000 ha of forest and natural vegetation were lost in Nigeria. It led to problems such as desertification, soil erosion, declining soil fertility, flooding, and the extinction of important flora and fauna species (IUCN, 1980; Gabriel & Adedapo, 2017). Forests are dynamic; seedlings germinate, grow, and compete with each other and with large trees. Some survive for hundreds of years. Changes that will be predominant in the future forest depend not only on climate and soils but also on management decisions made today. Changes in forest composition will affect the quality and variety of forest resources available to future generations and wildlife (Sodimu *et al.*, 2019). Sustainable management of forest ecosystems is a goal set by most nations (Norton, 1996; Dinendra *et al*., 2015), and maintaining biological diversity is One important component of this (Hansen *et al.,* 1991).

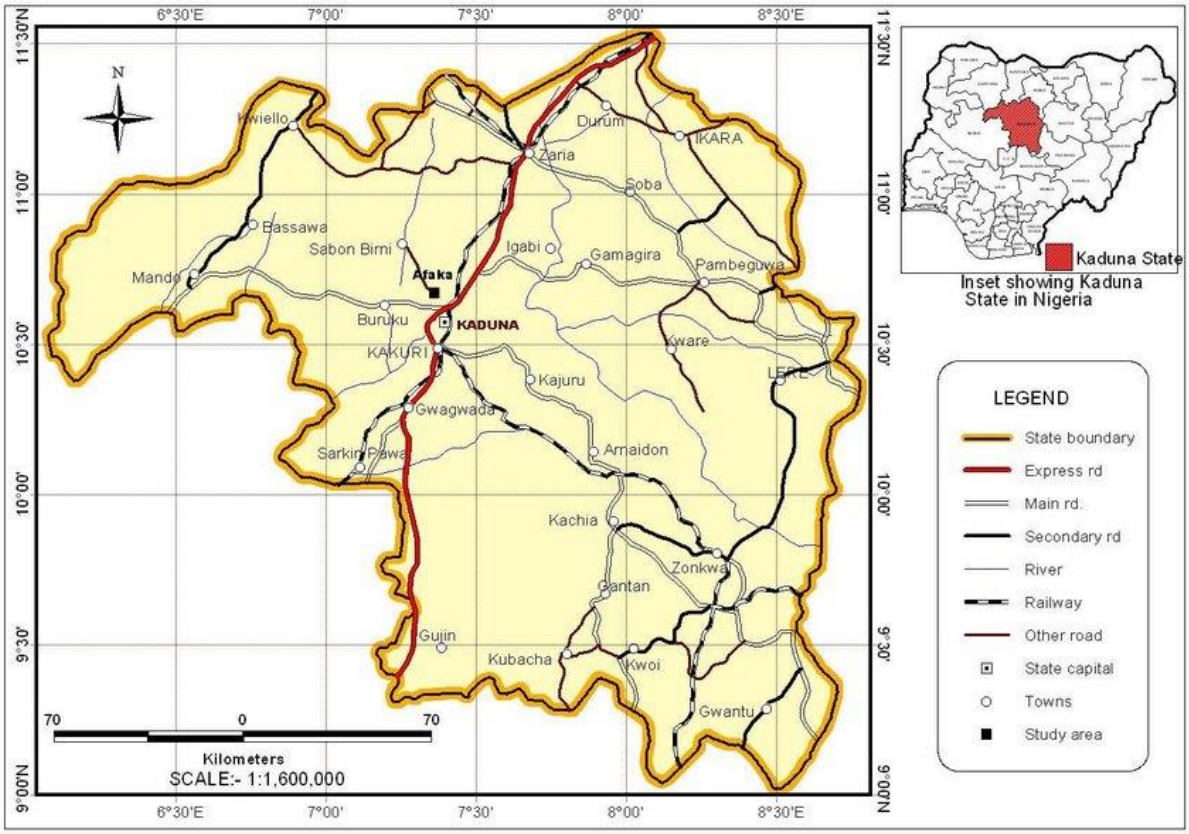
High demand for timber and increased accessibility are driving greater exploitation of these high-elevation forests. They are characterized by slow post-disturbance regeneration and slow growth

rates in established trees. Thus, meeting objections to the regeneration of natural species mixes and the sustainability of fiber and other ecosystem components can prove challenging (Selmants & Knight, 2003; Sodimu *et al.,* 2017). The only way Forest Reserves can sustain these valuable species is through effective regeneration programmes. Forest and natural vegetation loss in Nigeria each year due to anthropogenic activities is of great concern. It led to problems such as desertification, soil erosion, declining soil fertility, flooding and extinction of important flora and fauna species (IUCN, 1980). Therefore, we need to assess the natural regeneration potential of forest reserves to maintain species of economic significance, including non-timber forest products (NTFPs), and to sustain aesthetic values in perpetuity. The objective of the study is to assess species diversity and potential for forest regeneration in the natural forest of Afaka Forest Reserve.

Materials and Method

Study Area

The study was conducted in the natural forest of the Afaka Forest Reserve. Afaka is in the Igabi Local Government Area. Igabi Local Government Area is located in the Northern Guinea Savanna region of Nigeria on latitude 10^0E 37^1N /10^0 41^1N, and longitude $7^0$$47^1$E/$7^0$$51^1$E (Figure 1) (Otegbeye *et. al.,*2001). Igabi Local Government Area shares boundaries with Kaduna South, Kaduna North, Giwa Local Government, and Zaria Local Government areas of Kaduna State. It has an annual rainfall of about 1000mm -1500mm per annum. Major crops grown in the area include maize, cassava, millet, sorghum, guinea-corn and watermelon. The area is home to various tribes and ethnic groups, including Yoruba, Hausa, Igbo, Ijaw, Fulani, and Gbagyi. Hausaa has an estimated population of about 570,00 people and covers about 4556.95 square kilometers. (NPC,2006)



Source: Saka, 2021

Figure 1: Showing the Study location of Afaka Forest Reserve

Sampling Techniques

Four (4) sampling plots of 100m x 100m were laid in Old Afaka Forest Reserve. The technique used was adopted from Cuttam and Curts (1956), Oduwaiye *et al.* (2002 Sodimu *et* al. (2017. The point-centred quadrant method of sampling was used in each of the selected plots. Transects were selected using a systematic sampling method. The first One was selected at random. Along the direction of each transect, sampling points were taken at 5m intervals, which helped ensure sufficient sampling and avoided possible overlapping and duplication of units of measurement (Sodimu *et al.,* 2020). At each sampling point, the following parameters were assessed. Distance to four nearest woody plants, One in such quadrant; Height of the tree, which was measured through the use of a Haga altimeter and Diameter of each tree, which was measured through the use of a diameter tape.

(i) Density:

Densities of woody stems were determined in all study plots. The distance between sample points for each woody plant was used to estimate stem density. The estimation was based on the formula;

$$\boldsymbol{D = \frac{10^4\ stem\ ha^{-1}}{d^2}}$$ ..... Equation 1

Where d^2 = is the average distance in m^2 (Cuttam and Curtis 1956; Sodimu, *et. al*.,2020)

Diameter class distribution was determined through the measurement of the Diameter of the woody stand in all the plots at DBH (1.37m height)

(ii) Regeneration potentials:
Natural regeneration was evaluated by counting wildlings (≤30 cm height) within 2 m of each mature tree.

$$\boldsymbol{Regeneration\ Potential = \frac{Number\ of\ Wildlings\ of\ Individual}{Density\ of\ the\ Woody\ Stem}}$$ ..... Equation 2

(iii) Relative frequency:

$$\boldsymbol{Relative\ Frequency = \frac{Number\ of\ individual\ of\ the\ species}{Number\ of\ individual\ of\ all\ species} \times 100}$$ ..... Equation 3

(iv) Species abundance:

Species abundance, indicating the number of species contained in the number of individual plants.

Results and Discussion

In ascending order, families in the permanent protected area include Fab*aceae > Combretaceae, Sterculiaceae> Verbenaceae,* and, to a lesser extent, some other families, including *Sapotaceae> Euphorbiaceae> Ochnaceae*, and Ochnaceae, and so on. The species that are most common in acceding order are *Isobanilia doka>Parkia biglobosa>Prosopis africana>Vitex doniana> Acacia senegal > Lawsonia inermis* (Table 1). These results agree with the work of Sodimu (2016) and Sodimu *et al. (*2020), which found that the first four (4) families dominated Old Afaka and Buruku forest Reserves, with high levels of spread.

Table 1: Species Diversity and Families in the Natural Forest of Afaka Forest Reserve

S/No	Families	Number of Species	Percentage (%) Spread
1	Fabaceae	28	15.4

2	Ebenaceae	6	3.32
3	Annonaceae	8	4.42
4	Anaccardiaceae	7	3.87
5	Combretaceae	15	8.28
6	Longaniaceae	5	2.76
7	Meliaceae	7	3.87
8	Rhamnaceae	7	3.70
9	Rubiaceae	6	3.87
10	Sapotaceae	8	4.42
11	Sterculiaceae	10	5.53
12	Verbanaceae	7	3.87
13	Papilioceae	8	4.42
14	Casalpiniaceae	6	3.32
15	Myristicaceae	7	3.87
16	Ochnaceae	8	4.42
17	Irvingiaceae	10	5.53
18	Chysobaniaceae	6	3.32
19	Euphorbiaceae	8	4.42
20	Lythraceae	8	4.42
21	Myrtaceae	6	3.32
	TOTAL	**181**	**100**

The density of the woody stem, as indicated in Table 2, revealed that plot III in the permanent protected area had 961.51 stems/ha, which was the highest when compared to plot I, plot II, and plot IV with 857.64 stems/ha, 760.72 stems/ha, and 625.01 stems/ha, respectively.

Table 2: Density of Woody Plants at Various Plots in the Natural Forest of Afaka Forest Reserve.

S/N	Site	Stem (ha^{-1})
1	Plot I	857.64

2	Plot II	760.72
3	Plot III	961.50
4	Plot IV	625.01

Diameter class distribution of woody stems assessed in plots I, II, III and IV; however, the number of trees assessed for Diameter was 80, 125, 85 and 80, respectively. The highest number of trees was apportioned to diameter class 10 – 19cm for each of the plots A, B, C and D, that was 40 trees, 60 trees, 75 trees, and 40 trees, respectively, followed by diameter class 20 – 29cm (Fig. 2). Diameter class 50cm and above had the lowest number of trees allocated to it. Perhaps this is due to overexploitation and the activities of illegal loggers in the reserve, hunting for trees with larger girths for conversion into sizable wood. The above observation was in agreement with the work of Sodimu *et al.* (2020), who also noted that the diameter classes of 10 cm-19 cm and 19 cm are commonly found in most forest reserves around Kaduna, Northern Guinea Savanna eco-zones.

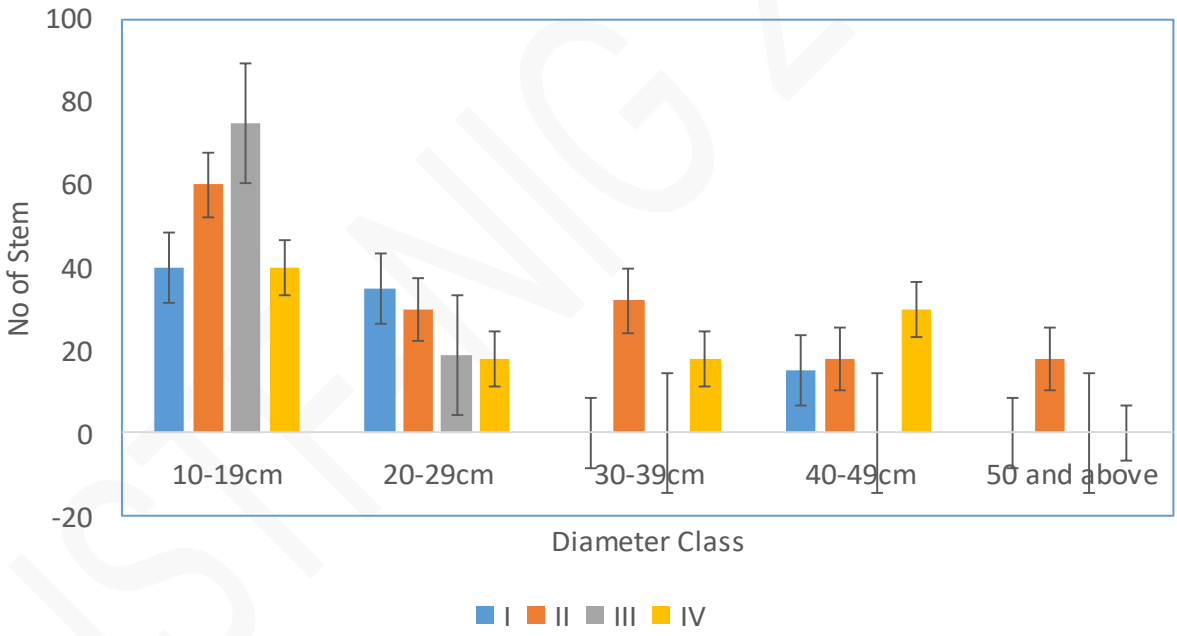


Figure 2: Diameter Class distribution of woody stems in plots I, II, III and IV of the Natural Forest of Afaka Forest Reserve

The regeneration potential of the diversified species, as indicated in Table 3, is very poor. It therefore has great implications for the regeneration and conservation of the various species encountered. *Isoberlinia doka* had the highest regeneration potential among the examined plots in the Natural Forest of Afaka Forest Reserve, followed by *Acacia senegal*, *Parkia biglobosa*, and *Terminalia avicennoides*. However, most of the important woody plants, such as *Triplochiton*

scleroxylon, had no regeneration potential. Regeneration potential of most species is zero, owing to the complete absence of mother trees, which would have produced the wildlings within the assessed area. The results align with the works and observations of Oduwaiye *et. al. (*2002); Sodimu *et. al*. (2017); Sodimu *et. al.* (2020)

Table 3: Regeneration Potential of Species Assessed in the Natural Forest of Afaka Forest Reserve

S/N	Species	Plot I	Plot II	Plot III	Plot IV
1	*Prosopis africana*	0.00	*0.00*	*0.00*	*0.03*
2	*Entada Africana* Gull &Perr.	*0.01*	*0.00*	*0.00*	*0.00*
3	*Vitex doniana* Linn.	*0.00*	*0.00*	*0.00*	*0.01*
4	*Terminalia avicennoides* Guill. &Perr.	*0.05*	*0.02*	*0.01*	*0.02*
5	*Macaranga hurifolia*	*0.00*	*0.00*	*0.00*	*0.00*
6	*Triplochiton scleroxylon* K.Schum	*0.00*	*0.00*	*0.00*	*0.00*
7	*Isoberlinia doka* Craib&Stapf.	*0.44*	*0.75*	*0.76*	*0.68*
8	*Annona senegalensis* Pers.	*0.00*	*0.05*	*0.00*	*0.00*
9	*Carissa adolia* Linn.	*0.01*	*0.00*	*0.00*	*0.00*
10	*Pilostigma thornningii* (Schum)	*0.00*	*0.00*	*0.03*	*0.00*
11	*Acacia senegal* (Houtt)	*0.03*	*0.02*	*0.04*	*0.01*
12	*Lophira lanceolata* Banks ex Gaertn.	*0.01*	*0.00*	*0.00*	*0.00*
13	*Combretum ghasalense* Engl.& Diels	*0.01*	*0.00*	*0.01*	*0.00*
14	*Parkia biglobosa* (Jacq) Benth	*0.02*	*0.04*	*0.01*	*0.02*
15	*Parinari curatellifolia* Planch.	*0.00*	*0.02*	*0.00*	*0.00*

In Table 4, plots A, B, C and D, 21, 19, 16 and 18 species were observed. In plot A, *Acacia senegal* showed the highest relative frequency (67.2%); the species also showed some spread in plots B, C, and D, with relative frequencies of 56%, 46.6%, and 45.4%, respectively. This was followed by *Isoberlinia doka* in plots B and D, with relative frequencies of 20.5% and 15.9%, respectively. However, in plot C, *Acacia senegal* was closely followed by *Annona senegalensis*, with a relative frequency of 7.56%. This is in agreement with the work of Sodimu *et al.* (2020), who observed that *I. doka* and *A. senegal* have a wider distribution in the Northern Guinea Savannah ecozone.

Table 4: Relative Frequency of Species in Natural Forest of Afaka Forest Reserve

S/N	Species	Plot I	Plot II	Plot III	Plot IV
1	*Terminalia avecinnoides* Guill. &Perr.	5.850	8.492	6.462	8.739
2	*Khaya senegalensis* Ders.	0.278	0.450	0.303	0.000
3	*Vitellaria paradoxa* C.F. Gaertn	0.543	1.046	1.256	1.817
4	*Pilostigma thonningii*(schum*)*	4.403	2.063	5.229	2.008
5	*Annona senegalensis* Pers.	8.951	3.487	7.757	0.000
6	*Acacia Senegal*(Houtt*)*	67.208	56.010	46.644	45.372
7	*Lannea barteri* (Oliv)	1.733	0.699	0.000	1.205
8	*Gardenia imperialis*(K .Schum)	1.338	5.846	0.000	1.012
9	*Carissa adolia* Linn.	4.703	1.848	5.687	2.460
10	*Sterculia setigera* Del.	1.538	7.946	0.000	6.422
11	*Isoberlinia doka* Craib&Stapf.	8.188	20.541	7.653	14.879
12	*Entada Africana* Gull & Perr.	0.349	0.320	0.000	0.904
13	*Diospyros mespiloformis* Hochst.	0.368	0.000	0.000	0.304
14	*Prosopis Africana* (Gull & Perr) Taub	0.412	0.000	0.000	0.000
15	*Combretum ghasalens* Engl.& Diels	0.288	1.139	0.000	0.000
16	*Anogeisus liocarpus(DC*) Gull &Perr	6.850	0.000	0.000	0.501
17	*Parkia biglobosa*(Jacq) Benth	5.465	0.000	0.00	0.000
18	*Triplochiton scleroxylon* K.Schum.	0.890	0.000	1.711	0.000
19	*Vitex doniana* Linn	0.890	0.000	1.811	1.306
20	*Strychnos spinosa* Lam.	0.418	0.000	2.005	0.000
21	*Tectona grandis* L.f.	2.256	0.000	0.000	1.605
22	*Macaranga hurifolia* Beille.	0.000	9.692	1.247	6.745
23	*Parinari curitellifolia* Planch.	0.000	0.460	0.000	0.604
24	*Lophira lanceolata* Banks ex Gaertn	0.000	0.560	2.467	0.000
25	*Lawsonia inermis* L.	0.000	0.256	7.242	0.000
26	*Psidium guajava* L.	0.000	0.350	0.303	1.705
27	*Irvingia gabonensis*(Bail*)*	0.000	1.089	1.543	1.309

Conclusion and Recommendation

None of the tree species in the protected natural forest of Afaka Forest Reserve was observed to be flowering during the assessment period. However, it was not possible to determine whether most of the diverse species had entered the generative phase or were still in the vegetative phase. The analysis found that most woody species were not regenerating. There were cases in which the mother trees of the observed wildlings were absent from the plots, or the wildlings of woody species were absent. This situation poses a great threat to the conservation of the diverse species in the Forest Reserve. Based on the findings, we recommend conducting research to determine whether the seeds or fruits produced are under adequate physiological conditions to germinate and grow into wildlings for regeneration purposes. purposes, enrichment planting with native species will be necessary for the sustainability of the forest reserve.

References

Areola, O. E (1991). Ecology of Natural Resources in Nigeria. CAB. pp. 278

Attiwill, P.M. (1991). The Disturbance of Forest Ecosystems: The Ecological Basis for Conservative Management. *For. Ecol. Manag*. 63:247–300.

Bergeron Y, A. Leduc, B. Harvey, & S. Gauthier. (2002). A Guide for Sustainable Management of the Canadian Boreal Forest. *Silva. Fenn*. 36:81–95

Bergeron, Y., & B. Harvey. (1997). Basing Silviculture on Natural Ecosystem Dynamics: An Approach Applied to the Southern Boreal Mixed Wood Forest of Quebec. *For. Ecol. Manag.* 92: 235–242.

Borowski, T (2015). Modifications of Natural Rubber (*Hevea brasiliensis*): Production, Application and Comparison. *International Journal of World Scientific News, 20-5*

Cuttam, G. & Curtis, J.T. (1956). Use of Distance Measure in Phytosociological Sampling. Ecology, 37, 451- 460

Dinendra Raychaudhuri, Sumana Saha, Souvik Sen, Dhruba Chandra Dhali (2015). Spiders (Araneae: Arachnida) of Reserve Forests of Dooars: Gorumara National Park, Chapramari Wildlife Sanctuary and Mahananda Wildlife Sanctuary. *International Journal of World Scientific News.* 20:1-339

Franklin, J. (1993). Preserving Biodiversity: Species, Ecosystems, or Landscapes? *Ecol. Appl*. 34: 202–205

Gabriel, A.A and Adedapo, A.A(2017). Exotic Versus Indigenous and Implications for Environmental Forestry Management in the Niger Delta, Nigeria. *International Journal of World Scientific News.* 74:36 -5

Hansen, A.J., T.A. Spies, & F.J. Swanson. (1991). Conserving Biodiversity in Managed Forests: Lessons from Natural Forests. *Bioscience.* 41:382–392

Hunter, M. L. (1993). Natural fire regimes as spatial models for managing boreal forests. *Biol. Conserv*. 65:115–120.

IUCN World Conservation Strategy (1980). Living Resources conservation for Sustainable Development -IUCN-UNEP-WWF 1980

Larsen, D.L., R. Shiftly, F.R. Thomson, B.L. Bokkshire, D.C. Dey, E.W. Kurzejeski, & K. England. (1997). Ten Guidelines for Ecosystem Researchers: Lessons from Missouri. *J. For.* 95: 4-8

Magaji, Y., Ajibade, G.A., Yilwa, V.M., Appah, J., Haroun, A.A., Alhaji, I., Umadi, M.M. & Sodimu, A.I. (2019). Concentration of Heavy Metals in the Soil and Translocation with

Phytoremediation Potential by Plant Species in a Military Shooting Range. *International Journal of World Scientific News*. Vol. 92(3):260–271. EISSN: 2392 – 2192

National Population Commission (2006). National Population Commission (NPC) News Bulletin, Kaduna State. 13-15

Nguyen-Xuan, T., Y. Bergeron, D. Simard, J.W. Fyles, and D. Pare. (2000). The importance of Forest Floor Disturbance in the Early Regeneration Patterns of the Boreal Forest of Western and Central Quebec: A Wildfire Versus Logging Comparison. *Can. J. For. Res.* 30:1353–1364.

Nigerian Environmental Study Team Nigeria's Threatened Environment (1991) A National Research Profile. Nigerian Environmental Study/Action Team (NEST), Ibadan, Nigeria. 287 – 290

Norton, T. (1996). Conservation of biological diversity in temperate and boreal forest ecosystems. *For. Ecol. Manag.* 85:1–7.

Oduwaiye, E.A., Oyeleye, B., & Oguntala, A.B (2002). Species diversity and potential for forest regeneration in the Okomu permanent sample plot. *Proceedings of the 28th Annual Conference of the Forestry Association of Nigeria.* 264-269

Ogunkalu, O.A., Sodimu, A.I., Suleiman, R.A. & Adedire, O.O. (2017). Survey of Benefits and Constraints of Urban Trees in Kaduna Metropolis. *International Journal of World News of Natural Sciences*, Vol. II Pp 19–27. EISSN: 2543–5426.

Otegbeye, G.O., Owonubi, J.J. & Oviasuyi, P. K. (2001). Interspecific Variation Growth of Eucalyptus growing in Northern Nigeria. *Proceedings of Paper Presented at the 27th Annual Conference of the Forestry Association of Nigeria*. Pp 12-16

Saka, M.G. (2021). Determination of mean annual increment and optimal rotation age for sustainable management of eucalyptus species in Afaka Forest Reserve, Nigeria. *International Journal of Forestry, Ecology and Environment*, 5 (1),187 – 195.DOI: 10.18801/ijfee. 040221.21 https://www.journalbinet.com/ijfee-journal.htm.

Selmants, P.C., and Knight, D.H. (2003). Understory Plant Species Composition 30–50 years After Clear Cutting in Southeastern Wyoming Coniferous Forests. *Forest Ecology Management* 185:275–289.

Sobamowo, G., Kamiyo, O.M., & Adeoye, O.A.(2019). Temporal Variation in Species Composition, Diversity and Regeneration Status Along Altitudinal Gradient Slope. *International Journal of World Scientific News.* 138:2:167-191

Sodimu, A.I., Onwumere, G.B. & Yilwa, V.M. (2019). Assessment of Soil-Based Heavy Metals from Anthropogenic Activities in Kaduna Guinea Savanna of Nigeria. *International Journal of World Scientific News*. Vol. 125: 83-93 EISSN: 2392 – 2192

Sodimu, A.I., Yilwa, V.M. and Onwumere. G.B. (2017). The Impact of Gas Flaring from Kaduna Refining and Petrochemical Company (KRPC) on Plant Diversity in Kaduna Northern Guinea Savanna Eco-Region of Nigeria. International Journal of *World Scientific News*. Vol. 69:168–178. EISSN: 2392 – 2192.

Sodimu, A.I., Ogunkalu, O.A., Komolafe, A.S., & Sadiq, Z.K. (2017). Economic Analysis of Wonderful Kola *(Hydrocotyle asiata*) Marketing in Kaduna North Local Government Area of Kaduna State, Nigeria. International Journal of *World News of Natural Sciences*. Vol. 9, PP 1 – 6. EISSN: 2543 – 5426.

Sodimu, A.I., Onwumere, G.B. & Yilwa, V.M. (2019). Soil-Based Heavy Metals Originating from Anthropogenic Activities on Floristic Composition of Some Selected Sites in Kaduna

Northern Guinea Savanna of Nigeria. *Asian Journal of Environment and Ecology.* Vol. 10 (4); 1–10. ISSN: 2456 – 690X. DOI: 10.9734/AJEE/2019/V10: 430122.

Sodimu, A., Sulaiman, R., Maikano, S. & Lapkat, G. (2020). Assessment of Species Diversity and Potentiality in Buruku Forest Reserve, Kaduna State, Nigeria. *Asian Journal of Research in Agriculture and Forestry.* 5(1): 39–46. ISSN: 2581–7418. DOI:9734/AJRAF/2020/v5i130077.

Van der Maarel, E (1996).. Pattern and Process in Plant Community: Fifty Years After A. S. Watt. *Journal of Vegetation Science* 7: 19–28.

ISTF-NIG 2026

SPATIAL VARIATION OF LEAD IN ROADSIDE TREE LEAVES ALONG A TRAFFIC DENSITY GRADIENT IN KADUNA CITY, NIGERIA.

***Sodimu, A. I[1], Bayo, D[2]., Achimi, J. O[1], Yakubu, M.H[1] and Baraya, H. D[1]**

[1]Savanna Forestry Research Station, Forestry Research Institute of Nigeria, PMB 1039, Samaru – Zaria, Kaduna, Nigeria
[2]Northern Guinea Research Station, Forestry Research Institute of Nigeria, Nasarawa, Nigeria.

ABSTRACT

Pollution of the city/urban atmosphere by contaminants from automobiles and other sources is considered a serious problem. Lead (Pb) has long been known as a potential health hazard, especially in cities where petrol is burnt in motor vehicles; various anthropogenic activities release large quantities of lead into the environment. Consequently, this study assessed the spatial variation of lead (Pb) in roadside trees along a traffic density gradient in Kaduna city. Leaves of six (6 dominant tree species were selected (*Mangifera indica. L; Eucalyptus camaldulensis Dehnh; Albizia lebbeck Linn; Anarcadium occidentale. L; Azadirachta indica. Linn and Psidium guajava. L)* for screening from ST_1 (Roadside – Ali Akilu Road, with high vehicular traffic route); ST_2 (Roadside –Waff Road, with medium vehicular traffic route) and ST_3 (Roadside – Kanta Road, with low vehicular traffic route). Ten (10) matured sample leaves were detached from the side of each selected tree facing the road from different locations during and at the end of the rainy season (dry season) using a subjective sampling method. The leaves were ashed to remove dust particles, oven-dried for 24 hours, crushed into a fine powder, and stored. They were stored in a plastic container with a lid, labelled, and then moved to the laboratory for analysis of lead (Pb) content using a spectrophotometer (AA220fs). The results show that the mean lead (Pb) content of tree leaves at the three (3) vehicular routes ranged from 0.14mg/kg at ST3 to 0.99mg/kg at ST1. However, there was no significant difference in lead content between the three (3) vehicular routes. Mean lead content ranged from 0.27mg/kg in *Mangifera indica.* and *Psidium guaj va* to 0.88mg/kg in *Anarcadium occidentale.* Moreover, no significant differences were found in lead content among the six tree species. Bio-remediation methods can be adopted by planting tree species capable of absorbing lead (Pb) from the atmosphere to reduce urban heat, mitigate air pollution, and support biomonitoring. Also, the law should set standards for emissions levels from all generating plants. It is essential to inform people living near high-traffic routes about the roads and vegetation.

Keywords: Roadside, Pollution, Vehicle Traffic route; Lead (Pb); Danger

INTRODUCTION

The city atmosphere is subject to significant contamination, the composition of which reflects contributions from various sources. (Colombo *et al.,*1999). These sources are mainly anthropogenic and include asphalt, weathered street materials, biomass combustion, industries and automobiles. (Takada *et al.,* 1990). Roads are an important infrastructure that plays a major role in stimulating social and economic activities. However, road construction has also led to significant environmental pollution (Bai *et al.,* 2008). Several research studies have indicated the need for a better understanding of trace metal pollution of roadside soils (De Kimple & Morel, 2000; Manta *et al.,* 2002). Trace metals in roadside soils may originate from various human activities, including industrial and energy production, construction, vehicular movement, waste disposal, and coal and fuel combustion. However, a larger proportion comes from vehicular movement. (Li *et al.,* 2001). Air pollution is a major problem in the city and may occur in gaseous or particulate form. The contribution of city atmospheric contaminants by automobiles appears to be more significant, particularly in developing countries. (Gunn, 2003; Hor ginamani and Ravichandran,2010). According to Ade Olalu (1980) and Mabogunje (1980), in developing countries like Nigeria, improved road accessibility increases the number of vehicles. It creates a variety of ancillary employment, ranging from vehicle repairs, vulcanizers, and welders to auto-electricians, battery chargers and dealers, and other facilitators of motor transportation. These activities send trace metals, especially Lead (Pb), into the air, and the metals are subsequently deposited into nearby trees and soils, which are also absorbed by plants growing on those soils.

Heavy metals such as iron, copper, zinc and manganese are essential components of many alloys, pipes, wires and tyres in motor vehicles. They are released into the roadside environment due to mechanical abrasion and normal wear and tear. The metallic pollutants in the air gradually precipitate onto the ground surface, depending on wind patterns, and their concentrations are therefore elevated in adjacent areas (Hutchison *et al.,* 2007). Given the increasing human activities, heavy metal pollution of soil, water, and the atmosphere represents a growing environmental problem in the city and concerns food quality and human health. Excessive accumulation could lead to heavy metal contamination of roadside vegetation, wildlife, domestic animals, and human settlements. Due to the disturbance and acceleration of nature's slowly occurring geochemical cycle of metals by human activity, most soils in rural and urban environments may have One or more of the heavy metals above defined background values, high enough to pose risks to human health, plants, animals, and ecosystems (Alloway, 1995). Among heavy metals, lead (Pb) has long been recognized as a potential health hazard (Rowchowdhury & Gautum, 1995; Shen *et al.,* 1996; Nariagu *et al.,* 1996; Kim *et al.,* 1996; Shannon & Graef, 1996). However, in humans, lead (Pb) is known to cause various diseases, including retardation of mental development, damage to the central nervous system, and inhibition of hemoglobin synthesis (Rohn *et al*., 1982; Ogwuegbu & Muhanga, 2005). Duruibe *et al.* (2007) noted that the effects may be acute, chronic, neurotoxic, carcinogenic, mutagenic, or teratogenic.

In automobiles, lead is mainly a component of engine oil, other lubricants and fuel (Dong-Sheng & Peart, 2006; Sodimu *et al.,* 2017). Leaded fuel is still widely used in many developing countries

because it is less expensive. Fossil fuel combustion and exhaust emissions have been identified as the primary sources of atmospheric metallic nuisance (Aribike, 1996; Onianwa & Adoghe, 1997; Moller *et al.,* 2005). Aerosol and deposited dust in urban areas contain higher levels of many potentially toxic trace metals than those found in non-urban areas. Variation in isotopic ratios is used as an indicator of Pb contamination in the environment (a fingerprint of Pb sources). The deduction of isotope ratios is based on the different half-lives of the 206Pb, 207Pb, and 208Pb parent isotopes. The Pb source can have diverse or overlapping isotopic-ratio ranges, which can be used to verify the origin of the pollution. In environmental sciences 206Pb/207Pb, 208Pb/206Pb, and 207Pb/208Pb ratios are commonly used. According to Sun *et al*. (2018), the anthropogenic sources of Pb have relatively low 206Pb/207Pb ratios in the range from 0.96 to 1.20, while naturally occurring Pb has generally higher 206Pb/207Pb ratios (>1.20). Zaborska (2014) reported a 206Pb/207Pb ratio of 1.22 as representative of old, uncontaminated Polish rocks. The ratio of 206Pb/207Pb in leaded gasoline used in Central and Eastern Europe was 1.16–1.17, while in unleaded gasoline and diesel used in Africa and other undeveloped countries fell within the ranges 1.14–1.15 and 1.14–1.16, respectively (Yao *et al.,* 2015). Flora in cities is more prone to heavy metal pollution due to the pervasive pressure from automotive emissions (Li *et al*., 2001). Leaves are the most sensitive parts of trees to air pollutants, as major physiological processes are concentrated in the leaf (Rejini & Janardhanan, 1989).

Vehicular movement is an important source of lead (Pb) and other heavy metals in the environment. Plants play crucial environmental roles, including serving as sinks for contaminants and indicators of air pollution. Many studies have shown that heavy metals are responsible for certain diseases that are lethal to humans, flora, and fauna (Jarup, 2003; Michalke, 2003; Silva *et al.,* 2005). For these reasons, various Government Departments and several Non-Governmental Organizations (NGOs) are very concerned about the effects of vehicular lead (Pb) emissions on the environment. The objective of the study is to evaluate the lead content of leaves from some roadside trees in Kaduna City, Nigeria. However, information on roadside contamination with heavy metals, especially lead (Pb), in Kaduna city is limited, and this study seeks to bridge this gap.

Materials and Method

Study Area

The study was carried out in Kaduna State. The State lies within the Guinea Savanna eco-region. It is located between Longitudes $06^{o}15^{1}$E and $08^{o}50^{1}$E and latitudes $09^{o}2^{1}$N and $11^{o}32^{1}$N (Figure 1). It covers an area of about 48,473 square kilometers and has an estimated population of 6,113,503, of which 3,090,438 are males, and 3,023,065 are females. (NPC, 006).

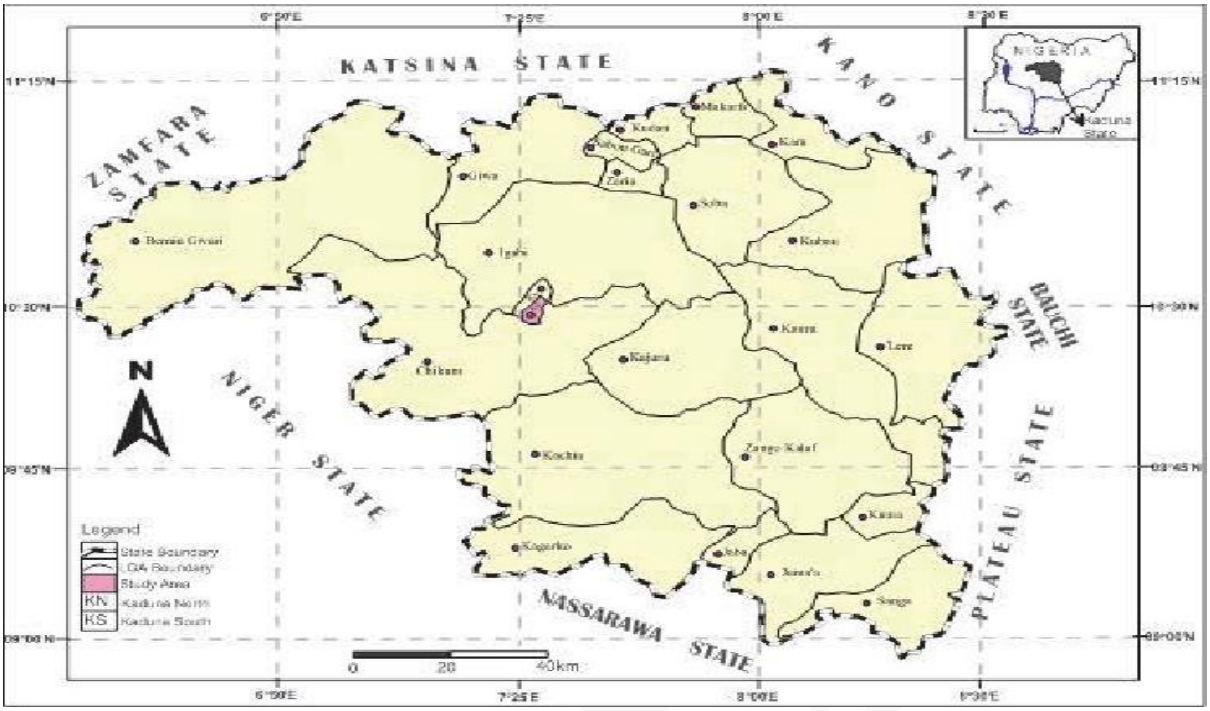


Figure 1: Map of Kaduna State Showing the Study Areas.

Source: Sodimu (2016)

Sampling Procedure and Treatment

In line with the criteria adopted from Witting (1993) and Market (1993), six (6) dominant tree species were selected (*Mangifera indica*. L*; Eucalyptus camaldulensis Dehnh: Albizia lebbeck Linn; Anarcadium occidentale. L; Azadirachta indica. Linn and Psidium guajava. L)* for screening from ST_1 (Roadside - Ali Akilu Road, with high vehicular traffic route); ST_2 (Roadside –Waff Road, with medium vehicular traffic route) and ST_3 (Roadside – Kanta Road, with low vehicular traffic route). Ten (1) mature sample leaves were detached from the side of each selected tree facing the road at different locations at the end of the rainy season (dry season) to avoid rain washing out the metal, using a subjective sampling method. The heavy metal load in plant leaves is known to correlate more with surface levels than with soil levels. (Kabata-Pendias and Penias,2000). The experimental design adopted was a Completely Randomized Design (CRD).

Laboratory Analysis

Leaf samples from different vehicular traffic routes were washed to remove dust particles and oven-dried for 24 hours. Leaf samples were crushed into fine powder, stored in a black plastic container with lids, then carefully labelled and kept on a bench away from sunlight until used.

Analytical Procedure

The AOAC (2005) method was adopted. 1g of each sample was digested using aqua regia (1:2, v/v of HNO3 and HCl) and extracted with deionized water. The extract was then aspirated into the AA220fs spectrophotometer after inserting a hollow-cathode lamp containing lead (Pb). The analysis was carried out at the Federal Ministry of Agriculture and Rural Development Annex, Gonigo, Kaduna State. Data collected were subjected to descriptive analysis and ANOVA at $P<0.05$

Results and Discussion

The results of the analysis of the heavy metal (Pb) content of the various plants in the sample location ST_I, ST_2 and ST_3 are presented on Table 1

Table 1: Lead (Pb) Content of Selected Trees in Mg/kg.

S/N	Species	ST_1 Lead(Pb) (Mg/Kg)	ST_2 Lead(Pb) (Mg/Kg)	ST_3 Lead(Pb) (Mg/Kg)	x Mean
1	*Mangifera indica*	0.80	0.01	0.01	0.27
2	*Anarcardium occidentale*	2.60	0.01	0.01	0.88
3	*Albizia lebbeck*	1.00	2.00	0.01	1.00
4	*Eucalyptus cammadulensis*	1.50	0.01	0.01	0.51
5	*Azadirachta indica*	0.02	2.10	0.01	0.71
6	*Psidium guajava*	0.01	0.01	0.80	0.27
		R=0.01-2.60	R = 0.01-2.00	R=0.001-0.80	
		Mean= 0.99	**Mean = 0.69**	**Mean= 0.14**	

Table 1 indicates that the lead content of tree leaves at ST_1 ranged from 0.01mg/kg in *Psidium guajava* to 2.60mg/kg in *Anacardium occidentale*, with a mean of 0.99mg/kg. At ST_2, it ranged from 0.01 mg/kg in other trees to 2.00mg/kg in *Albizia lebbeck* with a mean of 0.69mg/kg, while at ST3, it ranged from 0.01mg/kg in other trees to 0.80mg/kg in *Psidium quajava* with a mean of 0.14mg/kg. No significant differences were found in lead (Pb) content of plant leaves with respect to vehicular traffic routes (P-value = 0.80 > 0.05). Mean lead (Pb) content was the highest in *Anarcardium occidentale* (0.88mg/kg) and least in *Mangifera indica* and *Psidium guajava* (0.27mg/kg). No significant differences were found in lead (Pb) content with respect to tree species (P-value 0.88 => 0.05). The above results agree with Don-Sheng and Peart (2006), Atayese *et al.*

(2009), Bako *et al.* (2014), Magaji *et al.* (2019), and Sodimu *et al.* (2020), who observed that heavy metal levels in vegetation correspond with traffic intensity.

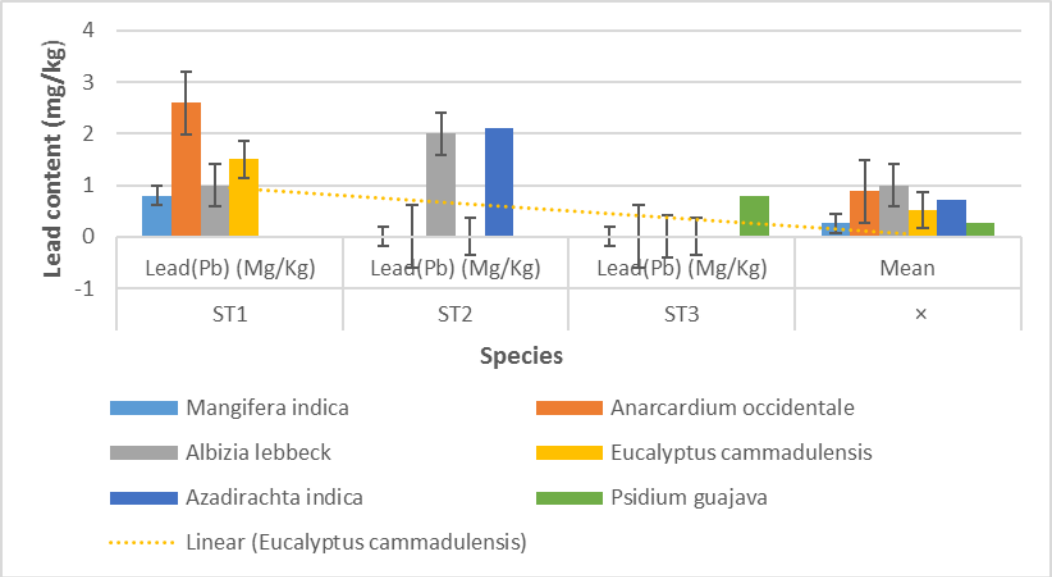


Figure 2: Variation in lead (Pb) content of different vehicular routes in Kaduna city.

We observed that the lead (Pb) content of the leves was highest at the heavy-traffic route (ST_1). Four (4) of the six (6) tree leaves analyzed, namely *Mangifera indica. L. Anacardium occidentale. L: A bizia lebbeck. Linn* and *Eucalyptus cammadulensis. Dehnh* shows this trend (Figure 2). However, an exception was observed in *Azadirachta indica. L at* ST_2 and *Psidium guajava. L at* ST_3. The higher concentration of lead (Pb) in plant leaves at ST1 is most likely attributable to the higher volume of traffic on this route. A similar observation was made by Aksoy and Ozturk (1996), Al-Shayeb (2005), and Sodimu (2016). Another possible reason for this observation is that the ST_2 route is a single-carriage road, whereas the ST_1 route is a dual-carriage road. (Niijar, 2002; Grace, 2004), who emphasized that carriage roads can influence contaminant levels, the higher concentration of lead (Pb) in *Azadirachta indica. L at* ST_2 and *Psidium guajava at* ST_3 may be attributed to other factors and sources of lead (Pb), such as vehicle type and condition, vehicle speed, generators, plant resistance and arrangement of leaf structure, and types of soil uptake. Similar observations were also made by Kabata-Pendias and Pendias (2000), Zaidi *et al.* (200), and Sodimu *et al.* (2017).

Atmospheric deposition of heavy metals contributes to plant contamination. Lead (Pb) occurs naturally in plants but is considered non-essential to their growth and development (Kabata-Pendias & Pendias, 2000). Plant-related factors can also introduce variation in the lead (Pb) leaf concentration across plants. Such factors may include low exposure to and low uptake of metals (Dong-Sheng & Peart, 2006), plant resistance (Lin *et al.,* 1988), and differences in leaf cuticle (Cape & Unsworth, 1988; Kabata-Pendias & Pendias, 2000)—*anacardium occidentale. L,* which

accumulated the highest amount of Lead (Pb) in ST1, has been reported to have good potential for bio-monitoring of urban/city air pollution. (Enete *et al.,* 2012; Sodimu *et al.,* 2020).

Conclusion and Recommendation

Lead (Pb) concentration is generally higher along the high-traffic route than along the medium- and low-traffic routes in Kaduna city. The study indicates that traffic volume may influence lead concentrations in the leaves of roadside plants, potentially posing adverse health risks to urban residents, road users, and vegetation. Promulgation of favorable tree planting able to absorb lead (Pb) (bio-remediation) in the city to reduce urban/city heat, mitigate air pollution, and support biomonitoring. Also, the law should set standards for emissionsfor emissions from the air and from energy-generating plants. Moreover, private automobile use and vehicle traffic volume need to be reduced by encouraging the use of sustainable transport systems, especially mass transit and other sustainable modes. Finally, essential to educate people living near high-traffic routes about the dangthe dangers of high traffic and the potential dangers of planting seeds and other vegetation on roads and other areas

References

Adefolalu, A. (1980). Transport and rural integrated development in: proceedings of the National Conference on: Integrated Rural and Women Development., 1: 294–299.

Aksoy, A., a d Ozturk, M (1996). "*Phoenix dactylifera L* as a Bio-indicator of Heavy Metal Pollution in Turkey" *Journal of Race Microprobe Technology*, 14: 605.

Alloway, B. J. (1995). "Heavy Metals in Soils". 2nd Edition. Blackie Academic and Professional, London, UK. pp. 258 – 272.

Al-Shayeb, S., Al-Rakhi, M.A., & Seaward, M.R.D (1995). "The Date Palm (*Phoenix dactylifera L)* as a Bio-indicator of lead and other elements in an arid environment.*" Science Total Environment,* 168:1-10

AOAC (2005 Official Method of Analysis. Association of Official Analytical Chemists (11th edit.) Washington. D.C. Pp 31

Aribike, D.S(1996). Environmental Impacts of Industrialization in Nigeria. A Treatise Paper Presented at the *Conference of the Nigerian Society of Chemical Engineers.* Nov. 14-16

Atayese, M.O, Eigbadon, A.I, Oluwa, K.A., and Adesokan, J.K. (2009). Heavy Metal Contamination of Amarantus Grown Along Major Highways in Lagos, Nigeria. *African Crop Science Journal*. 16: 225 – 235

Bai J, Cui B, Wang Q, Gao H, Q (2008). Assessment of heavy metal contamination of roadside soils in Southwest China. Stoch. Environment. Research Risk Assessment DOI 10.1007/s00477-008-0219-5

Bako, S.P., Ezealor, A.U., & Yahuza, T (2014). Heavy Metal Deposition in Soils and Plants Impacted by Anthropogenic Modification of Two Sites in the Sudan Savanna of North Western Nigeria. *INT CH* 697 -721.

Cape, J.N. & Unsworth, M.H. (1988). Deposition, Uptake and Residence of Pollutant. In: Air Pollution and Metabolism (Eds.) S. Shuttte–Hostede, W.M. Darrall, L.W. Bank, and A.R. Welbur. *Elsevier Applied Science, London.* 1 – 8.

Colombo, J.C, Landani, P., and Bilos, C. (1999). Source Distribution and Variability of Airborne Particles and Hydrocarbons in La Lata area, Argentina. *Environmental Pollution*, 104: 303-31

De Kimple, C.R., & Morel, J.F (2000). Urban soil management: a growing concern. Soil Science. 165: 31–40.

Don-Sheng, G., & Peart, M. R. (2006). Heavy Metal Concentration in Plants and Soil at Roadside Locations and Parks of Urban Guangzhou. *Journal of Environmental Sciences.* 18 (3): 495–502.

Duruibe, J O, Ogwuegbu, M.O.C., & Egwurugwu, J. N (2007). "Heavy Metal Pollution and Human Biotoxic Effect*". International Journal of Physical Sciences,* 2 (5): 112–118.

Enete, I.C., Ogbonna, C.E., & Officha, M.C. (2012). Using Trees as an Urban Heat Island Reduction Tool in Enugu City, Nigeria, Based on Their Air Pollution Tolerance Index. The *Ethiopian Journal of Environmental Studies and Management.* 5 (4) 1: 484 – 488.

Gunn, E. O. (2003). Towards a Green Transport Policy in Nigeria. In: Adin, A., E.N., and Ekop, O B and Attah, V. I (Eds), Environmental Pollution and Management in the Tropics. *Energy snap press.* Pp 42

Grace, N (2004). Assessment of Heavy Metal Contamination of Food Crops and Vegetation from Motor Vehicle Emissions in Kampala City, Uganda. Dept of Botany, Makerere University, Kampala. *A technical report submitted to IDRC-AGKOPOLIS* Pp12

Horaginamani, S.M. & Ravichandran, M (2010). Ambient Air Quality n an Urban Area and its Effect on Plants and Human Beings: A Case Study of Tiruchirappalli, India. Khatamandu University Journal of Science, Engineering and Technology, 6(2): 13-19

Hutchison, Y., Fang, J., Leonard, S. S., & Rao, K. M. (2007). Cadmium Inhibits th Electron Transfer Chain and Induces Reactive Oxygen Species. Free Radical Biology and Medicine. 36: 1434–1443.

Jarup, L (2003). "Hazards of Heavy Metal Contamination" *Brazilian Medical Bulletin,* 68: 425 426

Kabata-Pendias, A., and Pend as, H (2000). Trace Elements in The Soil and Plants 1st Edition. Boca Raton, Florida. CRC Press. Pp 37

Kim, R; Rotinitzky, A and sp rrow, D. (1996). A Longitudinal Study of Low-Level Lead Exposure and Impairment of Renal Function. A Normative Aging Study. *Journal of. American. Medical Association.* 275 (15): 1177

Li, FR, Ling, F Gao, XQ (2001). Traffic –Related Heavy Metal Accumulation in Soils and Plants in Northwest China. *Soil and Sediment Contaminant,* 16: 473-484.

Lin, Z. F., Li, S.S. and Sun, G.C. (1988). Mineral Elements of Plant Leaves in Southern Sub-Tropical Areas of Dinghushan. *Acta Ecologica Sinica*, 9 (4): 320 – 324

Magaji, Y., Aj Bade, G.A., Yilwa, V.M., Appah, J., Haroun, AAA.A., Alhaji, I., Umadi, M.M. and Sodimu, A.I. (2019). Concentration of Heavy Metals in the Soil and Translocation with Phytoremediation Potential by Plant Species in Military Shooting Range. *International* Journal of *World Scientific News*. Vol. 92( ):260–271. EISSN: 2392 – 2192

Mabogunje, A. (1980). "Development process-a spatial perspective". Hutchinson and Co. Publishers Ltd., Pp. 234-24

Market, B. (1993). Plant and Biomonitors/Indicators for Heavy Metals in Terrestrial Environment: *VCH Press, Weinheim*. Pp 15

Manta DS, Angelone M, Bellanca A, Neri R, Spr vier M (2002). Heavy metal in urban soils: A case study from the city of Palermo (Sicily), Italy. Sci. Total Environ., 300: 229-243.

Michalke, B (2003 Element Specification Definitions, Analytical Methodology and Some Examples "Ecotoxical. *Environ. Saf.,* 56: 122-139

Moller, A; Muller, H.W and Abdullah, A. (2005): Urban soil pollution in Damascus, Syria: Concentration and Patterns of Heavy Metals in the S ils of the Damascus Ghouta" *Geoderma* 124:63-71

Nariagu, J., Blenkson, M.L., & Ocran, K (1996). Childhood Lead Poisoning in Africa: A Growing Public *Health Problem. Science Total Environment.* 181 (2) 35 -43

Niijar, R.S., Jain, S.S. & Parida, M. (2002). Development of Transport-Related Air Pollutant Modelling for an Urban Area. *Journal of the Indian Road Congress*, No. 487.

NPC (2006). Nigerian Population Commission Bulletin. Pp 25

Ogwuegbu, M.O. and Muhanga, (2005). Investigation of Lead Concentration in the Bodies of People in the Copper Belt in Zambia. *Journal of Environ.,* 1: 66-75

Onianwa, P. C. & Adoghe, J. O. (1997). Heavy Metal Contact of Roadside Dust Gutter Sediment in Ibadan, Nigeria. *Environment. Int.* 23: 873–877.

Rejini, M. B. J., & Janardhanan, K (1989). Effect of Heavy Metals on Seed Germination and Pearly Seedling Growth of Groundnut, Sunflower and Ginger" *Geosios,*16: 164-170

Rohn, R.O., Shelton, J.E., and Hill, .R (1982). Soma-Tomdine Activity Before and After Chelation Therapy in Lead Intoxicated Children. *Archives of Environmental Health,* 37: 369-373

Rowchowdhury, A., and Auturn, A. K (1995). Alteration of Human Sperm and Other Seminal constitution After Lead Exposure. *Indian Journal of Physiology and Allied Sciences.* 49 (2): 68

Shannon, M & Greaf, J. (1996). Lead Intoxication in a Child with Pervasive Development Disorders. *Journal of Toxicology Clin. Toxicology,* 34 (2): 177

Shen, X., Rosen, J., Guo, D., & Wu, S. (1996). Childhood Lead Poisoning in China. *Science. Total Environment,* 181 (2):101

Silva, A. L. O; Barrocas, P.R.; Jacobs, S. C., and Mreira, J C (2005) Dietary Intake and Health Effects of Selected Toxic Element*s. Brazilian J. Plant Physiol.* 17:79-93

Sodimu, A.I (2016). Soil Heavy Metal Content from Some Human Activities and the Effect on Biodiversity in Kaduna Northern Guinea Savanna of Nigeria. Unpublished Ph. D Thesis

Submitted to the *Department of Biological Sciences, Nigeria Defence Academy, Kaduna*, pp. 305

Sodimu, A.I., Yilwa, V.M. and Onwumere. G.B. (2017). The Impact of Gas Flaring from Kaduna Refining and Petrochemical Company (KRPC) on Plant Diversity in Kaduna Northern Guine Savanna Eco-Region of Nigeria. *International Journal of World Scientific News*. Vol. 69:168–178. EISSN: 2392 – 2192.

Sodimu, A.I., Olorukooba, M.M, Lapkat, G.L., Osunsina, O., Awobona, T.A. and Likita, M. S (2020). Assessment of Selected Eaves of Roadside Trees as Bio-Indicators of Traffic-Related Lead Pollution in Kaduna City, Nigeria. *Journal of Sustainable Environmental Management.* Vol.12, 130 – 138. ISSN:2141 – 0267.

Sun, J., Yu, R., Hu, G., Su, G., Zhang, Y., (2018). Catena tracing of heavy metal sources and mobility in a soil depth profile via isotopic variation of Pb and Sr. Catena 171 (Februar), 440–449. https://doi.org/10.1016/j.catena.2018.07.04

Takada, H., Onda, T., & Ogura, N. (1990). Determination of Polycyclic aromatic hydrocarbons in Urban Street Dusts and Their Source Materials by Capillary Gas Chromatography. Environmental Science and Technology. 24:1179 – 11

Witting, R. (1993). General Aspects of Biomonitoring Heavy Metals by Plants, Plants as biomonitors/indicators for Heavy Metals in the Terrestrial Environment. *Market B, VCH publisher,* Weinheim, pp. 3-28

Yao, Z, Wu, B., Shen, X., Cao, X., Jiang, X., Ye, Y & He, K (2015). Road Emissions on Characteristic of VOC from Rural Vehicles and their Zone Formation Potential in Beijing, China. Atmospheric Environment. 105: 91 – 96.

Zaborska, A. (2014). Anthrogenic lead concentrations and sources in Baltic Sea sediments based on lead isotopic composition. Mar. Pollut. Bull. 85 (1), 99–113. https:// doi.org/10.1016/j.marpolbul.2014.06.013

Zaidi, M.I., Asrar, A, & Farooqi, M.A (2005). The Heavy Metal Concentration Along Roadsides Trees of Quetta and its Effects on Public Health." *Journal of Applied Sci*ences. 5 (4) 708–711.

SUB-THEME 3:
FOREST POLICY AND GOVERNANCE FOR SUSTAINABLE FOREST MANAGEMENT

ISTF-NIG2026

TROPICAL FOREST GOVERNANCE AND FOREST COVER DYNAMICS (2000–2020): IMPLICATIONS FOR RESILIENT ECONOMIES AND ENVIRONMENTAL SUSTAINABILITY

Owese, T[1], Olowoyo, F.B[2], Udoh, E.D[3], Obadimu O.O[1], Olla B.A[1] and Tella, M. O[1]

Forestry Research Institute of Nigeria, Ibadan, Nigeria[1]
Federal College of Forest Resources Management Ishiagu, Nigeria[2]
**Corresponding author email: theophiluso2020@gmail.com, 08062295420*

Abstract

Broadly defined, tropical forests are home to at least two-thirds of the world's organisms, a number that amounts to no fewer than 3 million species. Tropical forests are vital to biodiversity conservation, climate regulation, and the livelihoods of millions of people, yet many tropical countries continue to experience significant forest loss despite the existence of governance frameworks intended to promote sustainable forest management (SFM). Forest policy is challenged with the limited empirical evidence on the extent to which governance quality influences long-term forest cover dynamics across tropical regions. This study therefore, investigated the relationship between forest governance and forest cover change, cutting across fifteen tropical countries in Africa; South America, and Asia–Oceania between 2000 and 2020. Four indicators from the Worldwide Governance Indicators; Control of Corruption, Rule of Law, Government Effectiveness, and Voice and Accountability were assessed for governance quality while forest cover data were obtained from Food and Agriculture Organization. Relationship between governance and forest cover change ($r = 0.1793$), indicating that improvements in governance are associated with modest gains or reduced losses in forest cover. Regionally correlations were negligible in Africa ($r = -0.0114$), moderately negative in Asia–Oceania ($r = -0.4954$), and slightly positive and strongest in South America ($r = 0.0629$). Regression indicating that governance explains only 3.2% of the variance ($Y = 4.1624X - 5.0561$, $R^2 = 0.0321$). While governance remains an important institutional foundation for SFM, forest cover outcomes in tropical regions are shaped by broader socioeconomic and land-use pressures. Ensuring the strengthening of governance systems with integrated land-use policies is therefore essential for advancing forest conservation, resilient economies, and environmental sustainability.

Keywords: Tropical forests, Forest governance, Forest cover change, Sustainable forest management and Environmental sustainability.

Introduction

Tropical forests cover approximately 7% of the Earth's surface (FAO, 2020), yet they directly influence the well-being of approximately 1.5 billion people worldwide through their provision of livelihoods, food, and and indirectly benefit much of the rest of humanity through ecosystem services (United Nations, 2021). Tropical forests provide critical ecological and socio-economic services but are increasingly threatened by agricultural expansion, logging, infrastructure development, and population pressures, resulting in significant deforestation and forest degradation (FAO, 2020; FAO and UNEP, 2020; Curtis *et al*., 2018). Tropical forests play a critical role in carbon sequestration, climate regulation, water cycling, and biodiversity conservation (FAO, 2020; Sloan and Sayer, 2020). They are particularly vulnerable to deforestation due to high demand for agricultural land, timber, and urban development (Geist and Lambin, 2002; Hosonuma

et al., 2012). The loss of tropical forests not only undermines ecological integrity but also threatens socio-economic stability, especially in countries heavily dependent on forest resources (Curtis *et al*., 2018). Recent satellite-based assessments indicate that tropical forest loss remains concentrated in South America, Africa, and Southeast Asia, despite global commitments to forest conservation (Potapov 2022; Rosenbarger, 2022).

Forest governance encompasses institutional arrangements, policy frameworks, and regulatory enforcement mechanisms that determine how forests are accessed, used, and protected (Larson 2016; Arts, 2022). Control of Corruption, Rule of Law, Government Effectiveness, and Voice and Accountability being the key are key parameters in the assessment (World Bank, 2021). Effective governance is associated with reduced illegal logging, improved compliance with sustainable forest management practices, and equitable resource access (Anderson and Kaimowitz, 2018; Agrawal and Gupta, 2016). Nevertheless, research shows that governance alone cannot fully prevent deforestation; socioeconomic pressures, market incentives, and land-use policies also significantly influence outcomes (Meyfroidt and Lambin, 2020; Sloan and Sayer, 2020). Therefore, integrating governance measures with economic, environmental, and social policies is essential for achieving sustainable forest management in tropical regions. Previous studies focus on single countries or case studies, limiting the ability to draw cross-national inferences about governance impacts on tropical forest cover (Curtis *et al*., 2018; Rosenbarger, 2022). This study provides a comparative, multi-country analysis, seeking to understand forest governance and forest cover dynamics across the world tropical belt.

This study therefore investigated tropical forest governance and forest cover dynamics from 2000 to 2020 and assess their implications for resilient economies and environmental sustainability. Specifically, it seeks to: assess forest governance quality in tropical countries using four indicators: control of corruption, rule of law, government effectiveness, and voice and accountability, to analyze trends and regional patterns in tropical forest cover between 2000 and 2020, and to examine how governance indicators influence tropical forest resilience, as measured by changes in forest cover. The research questions are as follows: (i) how do governance indicators affect tropical forest cover regionally and globally (ii) what are the trends and regional patterns in tropical forest cover between 2000 and 2020, and (iii) how do governance indicators influence tropical forest resilience, as measured by changes in forest cover across tropical countries?

Methodology

The study was conducted across 15 tropical countries distributed within Africa, South America, and Asia and Oceania, representing major global tropical forest regions. Tropical forests occur within the tropical climatic zone situated between 23°30′ North latitude (Tropic of Cancer) and 23°30′ South latitude (Tropic of Capricorn). Longitudinally, the tropical region extends across all longitudes (0°–180° East and West), forming a continuous circum-equatorial belt characterized by high solar radiation, relatively stable temperatures, and substantial annual rainfall that supports dense forest ecosystems (Feeley and Stroud, 2018; FAO, 2020). The countries included in this study fall within this tropical belt and collectively represent the world's most significant tropical forest ecosystems. The African countries are largely located within the Congo Basin, the second-largest tropical rainforest system globally and an important carbon sink contributing to climate regulation and biodiversity conservation. The South American countries represent portions of the Amazon Basin, the largest continuous tropical forest ecosystem in the world, where forest cover change has been strongly influenced by agricultural expansion, infrastructure development, and

land-use dynamics. Countries from Asia and Oceania cover tropical forest regions of Southeast Asia and the Pacific, widely recognized as biodiversity hotspots but also areas experiencing rapid forest conversion driven by plantation agriculture, logging, mining activities, and population pressures (FAO, 2020).

The sampling design of the study area was purposive and guided by three main criteria. Possessing substantial tropical forest resources and playing significant roles in global forest conservation was the first criteria. Second, consistent forest cover change data covering the period 2000–2020 were available from global forest monitoring databases, allowing standardized cross-country comparison. Third, governance performance data were accessible through the Worldwide Governance Indicators framework, enabling assessment of institutional quality using indicators such as Control of Corruption, Rule of Law, Government Effectiveness, and Voice and Accountability.

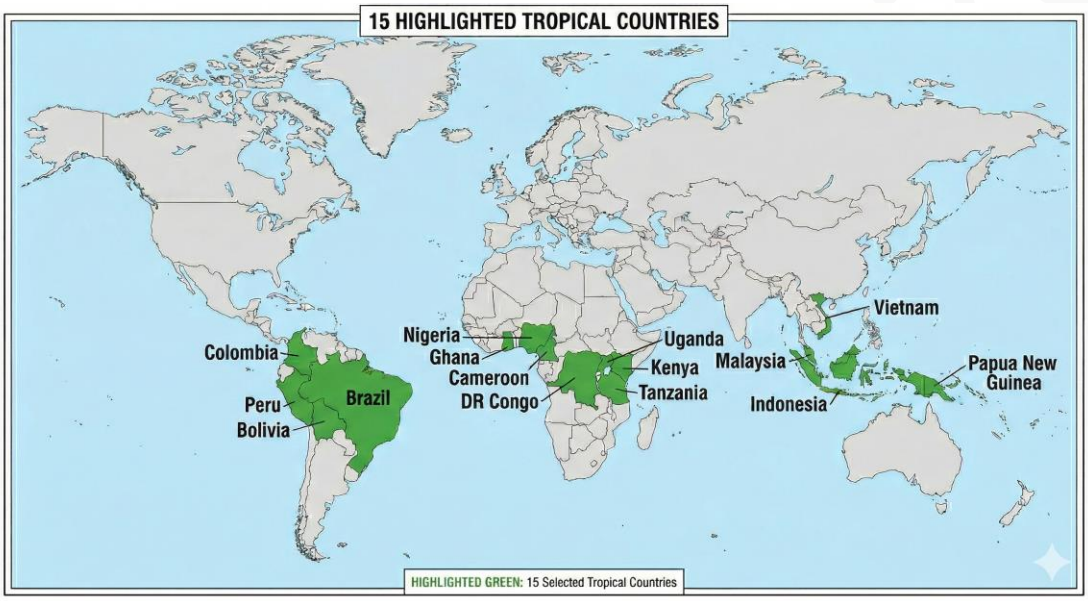


Figure 2: 15 Selected Tropical Countries in the Study Area

Data Sources

Forest Cover Data: Forest area data (Hectares) for 1990, 2000, 2010 and 2020 were sourced from the Global Forest Resources Assessment (FRA) of the Food and Agriculture Organization (FAO, 2020). The year 1990 serves as the global baseline for forest monitoring adopted by FAO, while the years 1990, 2000, 2010 and 2020 were selected to provide standardized decadal observation points consistent with recognized global forest assessment timelines. These datasets provides authoritative country-level forest statistics necessary to compute forest cover changes and annual deforestation rates. Governance Indicators: Governance data were extracted from the World Bank's Worldwide Governance Indicators (WGI, 2022). Four governance dimensions were used: *Control of Corruption, Rule of Law, Government Effectiveness,* and *Voice and Accountability.* These indicators reflect the institutional quality of countries and are widely used in environmental governance research (Kaufmann *et al*, 2010).

Governance data were obtained from the Worldwide Governance Indicators (WGI) published by the World Bank (2022). The indicators used include *Control of Corruption, Rule of Law, Government Effectiveness,* and *Voice and Accountability,* which collectively capture, enforcement capacity, adherence to rules, institutional quality and accountability relevant to forest governance. Forest outcome data were sourced from the Global Forest Resources Assessment (FRA) of the Food and Agriculture Organization, which provides standardized and internationally comparable data on forest area change and deforestation rates.

Analytical Technique

Descriptive statistics were used to summarize governance and forest outcome variables. Pearson correlation analysis examined the direction and strength of relationships. Ordinary Least Squares (OLS) regression analysis was then employed to estimate the effect of governance indicators on forest loss rates. All analysis used averaged country-level data to reduce short-term volatility. Statistical analyses were conducted using Microsoft Excel at the 5% significance level ($\alpha = 0.05$).

Results and Discussion

Table 1 is the descriptive statistics of the governance indicators across the 15 tropical countries, reveal noticeable variation in governance performance. The measuring scale on governance according to the indicator ranges from approximately −2.5 (very weak governance) to +2.5 (very strong governance). Results indicates that most of the countries in the study fall within the moderately weak to weak governance range. For Control of Corruption, a mean value of −0.68, with score range from −1.43 to 0.19 and a standard deviation of 0.43 were recorded, indicating generally weak control of corruption across the countries, though with moderate variation. For Rule of Law, a mean of −0.51, with score range from −1.69 to 0.47 and a standard deviation of 0.55, implying differences in the strength of legal institutions and enforcement mechanisms among the countries in the study area. In the case of Government Effectiveness, a mean score of −0.44, a minimum of −1.64 and a maximum of 0.96, and a standard deviation of 0.59, reflecting varying levels of governance quality and policy implementation across the sample. For the last indicator of the study; Voice and Accountability, a mean value of −0.27, with score range from −1.41 to 0.50 and a standard deviation of 0.61, suggesting relatively variation in citizen participation, political freedoms, and accountability mechanisms among the countries. Hence, this result reveals substantial variation in institutional quality, with overall negative mean scores reflecting generally weak governance performance. This heterogeneity pattern in governance dimensions is consistent with broader global observations from cross-country governance datasets. The Worldwide Governance Indicators (WGI) framework, which comprises dimensions such as Control of Corruption, Rule of Law, Government Effectiveness, and Voice and Accountability, is widely used to assess and compare governance quality across countries, precisely because these indicators capture meaningful differences in institutional capacities and public sector performance (World Bank, 2025). Moreover, large-scale cross-country analyses of WGI data demonstrate that governance indicators vary significantly across regions and over time, with countries exhibiting divergent performance levels in areas such as rule of law and voice and accountability (Handoyo, 2023). These findings support the interpretation that weak average scores and notable dispersion in governance measures reflect real differences in institutional quality and government effectiveness among the sampled tropical countries.

Table 1: Descriptive Statistics of Governance Indicators

Governance Indicator	Mean	Minimum	Maximum	Standard Deviation
Control of Corruption	-0.68	-1.43	0.19	0.43
Rule of Law	-0.51	-1.69	0.47	0.55
Government Effectiveness	-0.44	-1.64	0.96	0.59
Voice and Accountability	-0.27	-1.41	0.50	0.61

Table 2 is the Governance Indicators, Governance Index and Country Ranking of the 15 tropical countries. The negative mean values across all governance indicators imply that institutional quality remains below global governance benchmarks within the sampled countries. Such governance weaknesses are likely to influence forest cover outcomes through inadequate policy enforcement, weak institutional coordination, and limited stakeholder participation. However, the wide ranges and noticeable standard deviations demonstrate that governance performance varies substantially across countries, reinforcing the importance of institutional quality as a differentiating factor in forest governance effectiveness and forest cover change dynamics. Governance performance across the sample remained predominantly negative, reflecting structural governance challenges common within many tropical forest nations, including weak institutional enforcement, corruption pressures, and limited public participation mechanisms.

The governance ranking shows that Malaysia ranking first with Governance Index of 0.34 emerged as the strongest governance performer in the study area. Positive scores across control of corruption, rule of law, and particularly government effectiveness (0.96) indicate comparatively strong institutional capacity and administrative efficiency. Such governance conditions are often associated with stronger policy implementation and regulatory oversight in forest management. These countries exhibit mixed governance outcomes, characterized by moderate institutional functionality combined with persistent governance weaknesses. For instance, Brazil and Colombia display relatively stronger voice and accountability scores, suggesting participatory governance structures, yet negative corruption and institutional effectiveness indicators constrain overall governance performance.

Nigeria's governance profile reflects institutional challenges despite moderate citizen participation indicators. Such mixed governance conditions imply that forest outcomes in these countries may depend heavily on economic pressures, land-use policies, and enforcement capacity rather than governance quality alone. Vietnam recorded the lowest Voice and Accountability score (−1.41), implying limited participation despite moderate administrative effectiveness. Similarly, Papua New Guinea and Bolivia show governance constraints related to corruption control and legal enforcement, factors frequently linked to forest exploitation pressures. The DRC exhibited consistently low scores across all governance indicators, including the lowest rule of law (−1.69) and government effectiveness (−1.64). These results highlight institutional fragility, extremely weak regulatory enforcement, and limited governance capacity. Such conditions more often than not, are widely associated with illegal logging, uncontrolled agricultural expansion, and persistent forest degradation risks and other vices institutionalized by corruption.

Asia–Oceania shows the widest governance variation, ranging from strong performance (Malaysia) to weaker institutional accountability (Vietnam and Papua New Guinea). South America generally occupies the middle governance spectrum, suggesting relatively functional but

imperfect governance institutions. Africa records the lowest overall governance scores, reflecting persistent institutional constraints influencing forest policy implementation. These regional disparities reinforce the idea that tropical forest governance is shaped not only by environmental policy but also by broader political and institutional development trajectories.

The findings support the broader conclusion of this study that strengthening governance systems must occur alongside coordinated socioeconomic and land-use strategies to effectively reduce tropical forest loss and promote environmentally sustainable and resilient economies.

Table 2: Governance Indicators, Governance Index and Country Ranking

Country	CC	RL	GE	VA	GI	Rank
Nigeria	1.11	-0.94	-1.1	-0.43	-0.34	7
Ghana	-0.17	0.04	-0.27	0.50	0.03	2
Cameroon	-1.17	-1.07	-0.86	-1.07	-1.04	14
DR Congo	-1.43	-1.69	-1.64	-1.37	-1.53	15
Indonesia	-0.46	-0.03	0	0.16	-0.08	3
Malaysia	0.19	0.47	0.96	-0.27	0.34	1
Peru	-0.54	-0.5	-0.26	0.24	-0.26	6
Colombia	-0.36	-0.36	-0.06	0.10	-0.17	5
Brazil	-0.46	-0.21	-0.31	0.41	-0.14	4
Bolivia	-0.73	-1.19	-0.59	-0.01	-0.63	12
Vietnam	-0.49	-0.14	0.04	-1.41	-0.50	9
PNG	-0.89	-0.80	-0.70	0.09	-0.58	11
Uganda	-1.11	-0.33	-0.60	-0.63	-0.67	13
Tanzania	-0.54	-0.5	-0.73	-0.36	-0.53	10
Kenya	-0.91	-0.47	-0.41	0	-0.45	8

Across 15 Tropical Countries loss between 2000 and 2020, with no country recording a net gain in forest cover, reflecting a consistent pattern of declining forests across the tropics. This widespread reduction is consistent with global forest assessments showing that although the overall rate of forest loss has slowed compared to prior decades, net forest area continued to decline throughout the first two decades of the 21st century, with tropical forests accounting for a large share of these losses (FAO, 2020). Research also indicates that the tropics have experienced persistent tree cover loss due to agricultural expansion, logging, and other land-use changes, with tropical regions contributing disproportionately to global deforestation since 2000 (Hansen *et al*., 2025). These broader patterns suggest that despite international commitments and conservation efforts, structural pressures and insufficient governance and policy enforcement have been unable to fully halt deforestation across tropical countries, supporting the consistent negative trends observed in this study.

Table 3: Forest Cover Change (2000 – 2020)

Country	Forest Area 2000 (ha)	Forest Area 2020 (ha)	Net Change (ha)	% Change	Gain/Loss
Nigeria	24,893.04	21,626.95	-3,266.09	-13.12	Loss
Ghana	8,848.61	7,985.71	-862.9	-9.75	Loss
Cameroon	21,597.49	20,340.48	-1,257.01	-5.82	Loss
DR Congo	143,899.00	126,155.24	-17,743.76	-12.33	Loss
Indonesia	101,280.00	92,133.20	-9,146.80	-9.03	Loss
Malaysia	19,691.35	19,114.04	-577.31	-2.93	Loss
Peru	75,297.83	72,330.37	-2,967.46	-3.94	Loss
Colombia	62,735.50	59,141.91	-3,593.59	-5.73	Loss
Brazil	551,088.60	496,619.60	-54,469.00	-9.88	Loss
Bolivia	55,101.39	50,833.76	-4,267.63	-7.75	Loss
Vietnam	11,784.10	14,643.09	2,858.99	24.26	Gain
Papua New Guinea	36,277.97	35,855.76	-422.21	-1.16	Loss
Uganda	3,162.95	2,337.90	-825.05	-26.08	Loss
Tanzania	53,670.01	45,745.00	-7,925.01	-14.77	Loss
Kenya	3,961.19	3,611.09	-350.1	-8.84	Loss

Table 4 shows Worldwide Governance Indicator (WGI) scores (-2.5 to 2.5) are interpreted as; Low (-2.5 to -0.5), Medium (-0.5 to 0.5) and High (0.5 to 2.5). Medium sub-grades (Medium-Low, Medium-Mid and Medium-High) were introduced in this study for a finer differentiation of governance performance.

Table 4: Governance Index and Forest Cover Change Relationship

Country	Rank	Gov. Index	Net change (Ha)	Outcome Pattern	Interpretation
Nigeria	7	-0.34	-3,266.09	Medium-Low governance performance: forest degradation	Population pressure, fuelwood dependence, and land conversion drive loss.World Bank. (2021), Arowosoge, O. G. E., and Faleyimu, O. I. (2017), FAO(2020). Akinyemi, F. O., and Mashame, G. (2018)

Ghana	2	0.03	-862.90	Medium-Midgovernance performance: persistent forest decline	Agricultural expansion and mining pressures weaken conservation outcomes despite institutional improvements.UNEP (2019),Acheampong et al. (2019). Hansen, C. P., & Lund, J. F. (2011)
Cameroon	14	-1.04	-1,257.01	Low governance performance: institutional ineffectiveness linked to weak forest protection outcomes	weak forest protection Cerutti, P. O. et al (2013).Global Forest Watch. (2022)
DR Congo	15	-1.53	-17,743.76	low governance performance: conditions align with major forest decline	Deforestation Tyukavina, A., Hansen, M. C., Potapov, P. V., et al. (2018).World Bank. (2021)
Indonesia	3	-0.08	-9,146.80	Medium-Mid governance performance: large-scale forest conversion	Palm oil expansion and infrastructure development dominate forest dynamics.Austin (2019).Busch, J., & Ferretti-Gallon, K. (2017).
Malaysia	1	0.34	-577.31	Medium-High governance performance: forest decline	Economic expansion, plantation agriculture, and export-oriented land use outweighed governance capacity World Bank. (2022)Vijay et al. (2016), FAO (2020).
Peru	6	-0.26	-2,967.46	Medium-Low governance performance: weak enforcement	Illegal logging and agricultural encroachment remain dominant. Kowler, L. F., Ravikumar, A., & Larson, A. M. (2016), Perz, S. G. (2013) and FAO (2020)
Colombia	5	-0.17	-3,593.59	Medium-Mid governance performance: deforestation	Post-conflict land-use changes influence forest dynamics. Clericil. (2020). Armenteras., et al. (2017).
Brazil	4	-0.14	-54,469.00	Medium_Mid governance performance: reforms exist but insufficient against agricultural frontier expansion	Forest outcomes strongly linked to economic land-use drivers. Nepstad, D., McGrath, D., and Stickler, C. (2014) Curtis, P. G., et al. (2018)
Bolivia	12	-0.63	-4,267.63	Low governance performance: associated with agricultural expansion impacts.	Agricultural expansion Redo et al (2012), FAO (2020) and Müller (2012)
Vietnam	9	-0.50	2,858.99	Low governance performance: forest expansion	Strong reforestation programmes and state-led forest restoration policies. Meyfroidt, P., and Lambin, E. F. (2009), Phuc, T. X. (2013)
Papua New Guinea	11	-0.58	-422.21	Low governance performance: Institutional weakness linked with extraction-driven deforestation	Commercial logging pressures exceed governance capacity. Shearman, P. L., Bryan, J. E., Ash, J. (2009), Filer, C., & Sekhran, N. (2017)
Uganda	13	-0.67	-825.05	Low governance performance: continued deforestation	Deforestation Banana, A. Y., & Gombya-Ssembajjwe, W. (2000), FAO (2020) and Namaalwa, J., et al. (2009)
Tanzania	10	-0.53	-7,925.01	Low governance performance: limitations correlate with declining forest cover	Agricultural expansion and rural energy dependence dominate. Hosonuma, et al. (2012), Blomley, T. (2008) Treue, T., et al. (2014)
Kenya	8	-0.45	-350.10	Medium-Low governance performance: Institutional reforms reduce but do not reverse forest loss	Institutional reforms reduce but do not reverse forest loss. Kenya Forest Service. (2020), FAO (2020) and Ongugo, P. O. (2011)

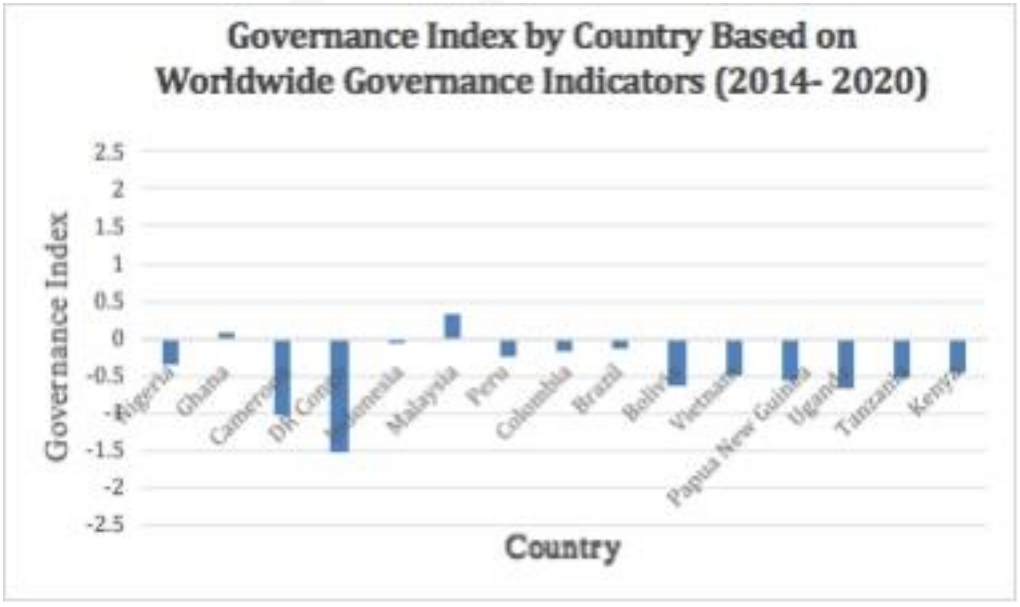


Figure 2. Governance Index by Country based on Worldwide Governance Indicators (2000 - 2020), interpreted as Low, medium and High Governance

Correlation between Governance Indicators and Forest Cover Change

Table 5 is the correlation analysis between governance scores and percentage forest cover change across the 15 tropical countries indicates a weak positive relationship (r = 0.1793), suggesting that countries with slightly higher governance scores experienced marginally lower forest loss between 2000 and 2020. While the effect is modest, this pattern aligns with broader empirical evidence showing that governance quality plays a role in mitigating deforestation. For instance, Fischer *et al.,* (2020) reviewed tropical countries and concluded that stronger governance is generally associated with reduced forest loss, highlighting the importance of institutional quality for forest conservation outcomes. Similarly, Sohag *et al.,* (2023) demonstrated that weaker institutional quality significantly increases deforestation, underscoring that even moderate improvements in governance can influence forest dynamics. These findings suggest that although governance alone may not fully prevent forest loss, it contributes to forest conservation alongside other socioeconomic and environmental factors.

Table 5: Pearson Correlation between Governance Indicators and Forest Cover Change Across 15 Tropical Countries

Country	Governance Indicator	% Forest Cover Change
Nigeria	-0.92	-13.12
Ghana	0.03	-9.75
Cameroon	-1.06	-5.82
DR Congo	-1.53	-12.33
Indonesia	-0.13	-9.03
Malaysia	0.30	-2.93
Peru	-0.30	-3.94
Colombia	-0.20	-5.73
Brazil	-0.20	-9.88
Bolivia	-0.58	-7.75
Vietnam	-0.51	24.76
Papua N :ew Guinea	-0.58	-1.16
Uganda	-0.71	-26.08
Tanzania	-0.53	-14.77
Kenya	-0.51	-8.84
Correlation	0.18	

Table 6: Pearson Correlation between Governance Indicators and Forest Cover Change in Africa, South America and Asia-Oceania (2014 - 2020)

Regions	Governance Score	% Forest Cover Change
Africa		
Nigeria	-0.92	-13.10
Ghana	0.03	-9.80
Cameroon	-1.06	-5.80

DR Congo	-1.53	-12.30
Uganda	-0.71	-26.10
Tanzania	-0.53	-14.80
Kenya	-0.51	-8.80
Correlation (r)	-0.01	
South America		
Brazil	-0.20	-9.90
Bolivia	-0.58	-7.80
Peru	-0.30	-3.90
Colombia	-0.20	-5.70
Correlation (r)	0.06	
Asia & Oceania		
Indonesia	-0.13	-9.00
Malaysia	0.30	-2.90
Vietnam	-0.51	24.30
Papua New Guinea	-0.58	-1.20
Correlation (r)	-0.50	

Conclusion and Recommendation

The relationship between forest governance quality and changes in forest cover over time in tropical regions has been investigated in this paper. The authors found that there is a very weak positive relationship globally, indicating that better governance is associated with some increase or less decrease in forest cover but also that the relationship is largely non-existent at the regional level (except for a very weak positive relationship in South America). The regression model showed that only a very small proportion of variation in forest cover could be explained by governance. Overall these findings indicate that good governance is still needed to support sustainable forest management however the actual amount of forest cover will be influenced by a variety of other social economic and land use factors. Therefore, strengthening governance and developing holistic approaches to land use planning is required to achieve long term sustainable forest conservation and development of resilient local economies.

References

Acheampong, E., Macgregor, C. J., Sloan, S., & Sayer, J. (2019). Deforestation is driven by cocoa expansion in Ghana. Nature Sustainability, 2, 994–1001.

Agrawal, A., and Gupta, K. (2016). Decentralization and forest governance: A review of the literature. Forest Policy and Economics, 61, 1–13. https://doi.org/10.1016/j.forpol.2015.08.006

Akinyemi, F. O., and Mashame, G. (2018). Analysis of drivers of deforestation in Nigeria. Environmental Monitoring and Assessment, 190(3), 1–15. https://doi.org/10.1007/s10661-018-6508-8

Anderson, L., and Kaimowitz, D. (2018). Governance and deforestation: A meta-analysis in economics. Ecological Economics, 144, 214–227. https://doi.org/10.1016/j.ecolecon.2017.07.030

Armenteras, D. (2017). Forest loss in Colombia linked to armed conflict dynamics. Biological Conservation, 206, 1–10.

Arowosoge, O. G. E. and Faleyimu, O. I. (2017). Forest depletion in Nigeria. Journal of Sustainable Forestry.

Arts, B. (2022). Forest governance and sustainability in tropical regions: A review. Land Use Policy, 114, 105968. https://doi.org/10.1016/j.landusepol.2022.105968

Austin, K. G. (2019). Oil palm expansion and deforestation in Indonesia. Environmental Research Letters, 14(2), 024038.

Blomley, T. (2008). Participatory forest management impacts in Tanzania. Oryx, 42(3), 380–391.

Busch, J., and Ferretti-Gallon, K. (2017). What drives deforestation reduction in Indonesia? World Development, 96, 406–417.

Cerutti, P. O., Tacconi, L., Lescuyer, G., and Nasi, R. (2013). Cameroon's hidden harvest: Commercial chainsaw logging, corruption, and livelihoods. Society & Natural Resources, 26(5), 539–553.

Clerici, N. (2020). Deforestation after peace agreement in Colombia. Nature Sustainability, 3, 974–982.

Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., and Hansen, M. C. (2018). Classifying drivers of global forest loss. Science, 361(6407), 1108–1111. https://doi.org/10.1126/science.aau3445

Feeley, K. J., and Stroud, J. T. (2018). Where on Earth are the tropics? Frontiers of Biogeography, 10(1–2), e38649. https://doi.org/10.21425/F5FBG38649

Food and Agriculture Organization. (2020). Bolivia Forest Resources Assessment.

Food and Agriculture Organization. (2020). Global Forest Resources Assessment 2020: Peru country report.

Food and Agriculture Organization. (2020). Global Forest Resources Assessment 2020: Terms and definitions. Food and Agriculture Organization of the United Nations.

Filer, C., and Sekhran, N. (2017). Forest governance challenges in PNG. Asia Pacific Viewpoint, 58(1), 89–101.

Finer, M., Jenkins, C. N., Pimm, S. L., Keane, B., and Ross, C. (2008). Oil and gas projects in the western Amazon: Threats to wilderness, biodiversity, and indigenous peoples. PLoS ONE, 3(8), e2932. https://doi.org/10.1371/journal.pone.0002932

Fischer, R., Giessen, L., & Günter, S. (2020). Governance effects on deforestation in the tropics: A review of the evidence. Environmental Science & Policy, 105, 84–101. https://doi.org/10.1016/j.envsci.2019.12.007

Food and Agriculture Organization of the United Nations & United Nations Environment Programme. (2020). The state of the world's forests 2020: Forests, biodiversity and people. Rome, Italy: FAO. https://doi.org/10.4060/ca8642en

Food and Agriculture Organization. (2020). Global Forest Resources Assessment 2020: Main report. FAO. https://doi.org/10.4060/ca9825en

Food and Agriculture Organization. (2020). Global Forest Resources Assessment 2020: Nigeria country report. Rome: FAO.

Food and Agriculture Organization. (2020). Kenya Forest Resources Assessment.

Food and Agriculture Organization. (2020). Malaysia Forest Resources Assessment. FAO.

Food and Agriculture Organization.(2020). Uganda Forest Resources Assessment.

Geist, H., and Lambin, E. (2002). Proximate causes and underlying driving forces of tropical deforestation. BioScience, 52(2), 143–150. https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2

Handoyo, S. (2023). Worldwide governance indicators: Cross country data set 2012–2022. Elsevier. https://doi.org/10.1016/j.dib.2023.109814

Hansen, C. P., and Lund, J. F. (2011). The political economy of timber taxation in Ghana. Forest Policy and Economics, 13(8), 630–641.

Hosonuma, N., Herold, M., and De Sy, V. (2012). An assessment of deforestation and forest degradation drivers in developing countries. Environmental Research Letters, 7(4), 044009. https://doi.org/10.1088/1748-9326/7/4/044009

Larson, A. M. (2016). Tenure challenges in the tropics: Lessons for forest governance. World Development, 87, 102–112. https://doi.org/10.1016/j.worlddev.2016.07.004

Meyfroidt, P., & Lambin, E. F. (2009). Forest transition in Vietnam. Global Environmental Change, 19(2), 199–209.

Meyfroidt, P. (2020). Landscapeing deforestation: Forest transitions. Annual Review of Environment and Resources, 45, 339–364. https://doi.org/10.1146/annurev-environ-012320-083846

Müller, R. (2012). Land-use policy and deforestation in Bolivia. Land Use Policy, 29(2), 386–396.

Nepstad, D McGrath, D., and Stickler, C. (2014). Slowing Amazon deforestation through public policy. Science, 344(6188), 1118–1123.

Ongugo, P. O. (2011). Forest management reforms in Kenya. International Forestry Review, 13(2), 208–218.

Perz, S. G. (2013). Road development and deforestation in the Peruvian Amazon. Environmental Management, 52(2), 373–385.

Phuc, T. X. (2013). Payments for forest environmental services in Vietnam. Forest Policy and Economics, 31, 1–11.

Potapov, P. (2022). Mapping tree cover loss and gain. Remote Sensing of Environment, 267, 112698. https://doi.org/10.1016/j.rse.2021.112698

Rosenbarger, A. (2022). Drivers of forest loss and the role of governance. Environmental Research Letters, 17(11), 114008. https://doi.org/10.1088/1748-9326/ac8b3a

Shearman, P. L and Bryan, J. E., Ash, J. (2009). Forest conversion in Papua New Guinea. Biological Conservation, 142(11), 2802–2812.

Sloan, S., and Sayer, J. (2020). Forest governance and sustainability. Journal of Forestry, 118(1), 8–13. https://doi.org/10.1093/jofore/fvz068

Sloan, S., and Sayer, J. A. (2015). Forest resources assessment of the humid tropics. Global Environmental Change, 34, 299–310.

Sohag, K., Gainetdinova, A., and Mariev, O. (2023). Economic growth, institutional quality and deforestation: Evidence from Russia. Forest Policy and Economics,150, 84 -101.

United Nations Department of Economic and Social Affairs (UNDESA). (2021). The Global Forest Goals Report 2021, United Nations. https://digitallibrary.in.org/record/3924461

Vijay, V. (2016). Expansion of oil palm plantations in Malaysia. Environmental Research Letters, 11(11), 114001.

World Bank. (2021). Democratic Republic of Congo Forest Sector Review. Washington, DC.

World Bank. (2022). Worldwide Governance Indicators (WGI). World Bank. https://info.worldbank.org/governance/wgi/

ENVIRONMENTAL ECONOMICS PERSPECTIVE OF GOOD FOREST GOVERNANCE AND POLICY FOR TRANSFORMING FORESTRY RESEARCH INTO MARKETABLE EXHIBITION PRODUCTS

***Ajayi, C.A., Arabomen, O.J., and Mansi, E.M**

Forest Economics and Extension Services, Forestry Research Institute of Nigeria, Ibadan, Jericho Hill, Ibadan, Nigeria
**Corresponding Email: chris07ng@yahoo.com*

Abstract

This review emphasized that environmental progress in Nigeria depends not only on policy but also on the economic resilience of its forest institutions. This fact has been further supported by the recent focus of the African Forest Forum's assessment on the participation of African negotiators in international multilateral processes on forests and related issues. The same philosophical methodology behind the response that a majority expressed the desire to have experiences in negotiations, especially in the acquisition of negotiation skills, and to overcome the kind of challenges that are seen as hindering the right acquisition of skills in negotiations, and the paucity of successful negotiators from Africa could be transferred to advance support for forests and related issues. This is usually a benefit-transfer approach used to value the forest as a "biological factory" for oxygen and social cohesion; there is a transition from a source of raw timber to a managed economic asset. In essence, by monetizing the social and ecological values of indigenous trees, Nigeria can move from a "scenic liability" to a global leader in sustainable bio-economies. The study emphasizes their role as social amenities, their ecological importance, and their potential to be incorporated into revenue-generating infrastructure, such as gazebos and recreational facilities, within public institutions like the Forestry Research Institute of Nigeria (FRIN),which has been scarcely studied. Forest resources are claimed to be central to economic development, environmental sustainability, and social well-being in Africa, as they provide functional, innovative social amenities within public forest institutions. While also offering opportunities for Indigenous forest tree species to provide timber, ecological services, and medicinal benefits, amongst others. This paper examines the social and environmental values of selected forest trees like *Terminalia superba*, *Entandrophragma angolense*, *Mansonia altissima*, *Afzelia africana*, *Blighia sapidia*, *Khaya senegalensis*, and *Nauclea diderrichii*. This paper, therefore, focuses on the FRIN Exhibition Showroom and reference communities in Oyo State as a critical nexus within the context of the Environmental Economics Perspective for Sub-Saharan Africa, specifically Nigeria, to address the "Resource Curse Paradox".

Keywords: Benefit-transfer approach; compensatory mechanisms; environmental economics; resource curse paradox; social amenities

Introduction

An environmental economics perspective is critical for Sub-Saharan Africa, specifically Nigeria, owing to population pressure and the need to address the "Resource Paradox": where Nigeria holds vast forest potential (1,160 reserves), yet suffers from extreme degradation and market margins

that currently signal economic inefficiency rather than growth. Below are the primary locations and the wards/communities acting as reference points for sustainable management (See Table 1).

Table 1: Key Forest Reserves and Reference Communities in Oyo State

Forest Reserve	Local Government Area (LGA)	Primary Communities/ Wards	Management Status / Reference Points
Opara	Atisbo, Saki West, Iwajowa	Ayegun, Waasimi, Border communities	The largest reserve (72.6% of state forest land). Target for community-led anti-poaching and border monitoring.
Igangan	Ibarapa North	Igangan, Ayete, Tapa	High-risk area for insecurity; current focus is on reclaiming land from illegal settlers and restoring biodiversity.
Gambari	Oluyole	Busogboro, Onipe, Ibusogboro	Historically used for Taungya farming, where farmers grow crops alongside young trees (a "win-win" Pareto model).
Ijaiye	Akinyele	Ijaiye, Alabata, Moniya	Significant for timber but highly degraded; focus is on reforestation and stricter logging regulations.
Osho	Ido	Ido, Bakatari	Under pressure from urban expansion, there is a need for a site for community-based mapping and school-led tree-planting initiatives.
Olokemeji	Ibarapa East	Olokemeji, Eruwa, Lanlate	Currently, a restoration model is being implemented through a partnership between the IITA Forest Center and the State.

Source: Geo-Information Society of Nigeria (GEOSON) Oyo State manages 9 gazetted forest reserves covering approximately 342,461 hectares. Retrieved from https://web.facebook.com/GazetteNGR/posts/the-oyo-state-government-has-reaffirmed-its-commitment-to-environmental-sustaina/1644590257669033/?_rdc=1&_rdr

Key Forest Reserves and Reference Communities in Oyo State highlight the sustainable forest management pathway to institutional sustainability and long-term environmental conservation through the benefit-transfer approach. In this context, this study has identified market failures and associated underutilized research results to transform a local ward into a global "Exhibition Product as the issues of raised concern of focus. As part of the Food and Agriculture Organization of the United Nations dynamic global series on sustainable forest-based bioeconomy approaches, held on June 26, 2025, the third webinar focused on the need to explore sustainable forest product supply chains that balance economic, environmental, and social needs. The fear has also been raised that global demand for forest products will grow significantly by 2050. According to the source, this will put increasing pressure on forest product value chains and resource availability (FAO, 2025). This study is "apt" because the current State of marketable exhibition products is sub-optimal. While 10% of Nigeria is gazetted as forest, the lack of marketable exhibition products means the standing forest is undervalued compared to immediate extractive gains - illegal logging or subsistence farming. Nigeria is currently in a "lose-lose" state where the negative externalities of deforestation, i.e., flooding in the South-South and erosion in the Southwest, are not priced into the market.

Compensatory Mechanisms Benefit Transfer Approach

An Environmental Economics approach uses Compensatory Mechanisms, e.g., providing woodlots for energy, to ensure the transition is "Pareto-Improving," where making the environment better does not impoverish the community. In Nigeria, the failure of forest policy to meet the Pareto optima test, i.e. where no One is made worse off, is fundamentally linked to the Total Economic Value (TEV) gap. Current GDP calculations often capture only formal timber exports, which have plummeted from 6.1% in 1958 to less than 1% today (2026). However, when including non-timber forest products (NTFPs) and ecosystem services such as carbon sequestration, the aggregate contribution to Nigeria's economy is estimated at nearly $8 billion annually**,** a value that is largely "invisible" in official accounts. Reference Forest Reserves in Southern Nigeria, highlighted below (see Table 2), have further attested to the foregoing claims, with major reserves in the Southwest, South-South, and Southeast claimed to serve as critical hubs for forest products whose value added is frequently omitted from national economic modeling (Artificial Intelligence Analysis Projections, 2001-2026).

Table 2: Reference Forest Reserves in Southern Nigeria

Forest Reserve	Region	Approx. GPS Coordinates	Primary Missed Economic Value
Omo	Southwest (Ogun)	6°45'N, 4°20'E	Carbon sinks; high biodiversity "value-in-use" for research.
Oluwa	Southwest (Ondo)	6°49'N, 4°40'E	NTFPs (snail, mushroom, teak leaves) are used by local gatherers.
Akure Ofosu	Southwest (Ondo)	7°10'N, 5°05'E	Timber value-added exhibition potential vs. illegal felling losses.
Cross River South	South-South (Cross River)	5°15'N, 8°20'E	REDD+ carbon credits and biodiversity storehouses.
Okomu	South-South (Edo)	6°25'N, 5°12'E	Ecosystem services related to wildlife conservation and ecotourism.
Afi River	South-South (Cross River)	6°15'N, 8°55'E	Watershed protection and direct use values of non-wood products.
Akpaka	Southeast (Anambra)	6°10'N, 6°47'E	Fuelwood and fodder account for 80% of the local rural household income.
Awa Hill	Southeast (Enugu)	6°26'N, 7°29'E	Medicinal herbs and wrapping leaves are omitted from the formal GDP.

The data above indicates an analysis of the "missed value" and *Pareto* failure. This is because governance fails the Pareto test: Total Economic Value (TEV) is not captured, leading to policies that favor a small group of illegal loggers/elites while impoverishing millions of rural dependents. This could be explained in the following exigency:

(i) Informal Economy Exclusion*:* Over 70% of households depend on fuel wood, and 80% of rural economies depend on forests for livelihoods. These transactions occur outside formal markets and are not valued in "Naira/Dollar worth" in policy decisions.

(ii)Externalized Costs*:* The $3.75 billion in commercial biodiversity value is ignored, while the $0.37 billion cost of conservation is treated as a "loss" by the State. This makes the public "worse off" by prioritizing short-term extraction over multi-billion-dollar ecosystem services.

(iii)Governance Blind Spots*:* Lack of land-use planning and poor coordination between ministries results in a "substantial but poorly monitored informal sector," where the true worth of forest product exhibitions (showing processing and value addition) is never realized.

A recent assessment by the African Forest Forum on the participation of African negotiators in international multilateral processes on forests and related issues has further supported the foregoing statistical facts. The consortium was concerned about a great majority of African forest experts wwhoave not participated in any international negotiations, have never experienced agenda item writing and discussion, nor hahavexperience in seseekingunds for travel and participation in negotiations,, whichwhich were athe issuesissues ras concerns The same philosophical methodology behind the response that a majority expressed the desire to have experiences in negotiations, especially in the acquisition of negotiation skills, and to overcome the kind of challenges that are seen as hindering the right acquisition of skills in negotiations. The paucity of successful negotiators from Africa could be transferred to advance support for forests and related issues (African Forest Forum, 2017). The foregoing core problem could be a major reason why Nigeria is not at the Pareto Optimum in economic terms.

National forest policy development should be country-led, rooted in broader national sustainable development goals and aligned with political, economic, social, and environmental priorities. In the same vein, submissions made at this discourse suggested that forest policy development processes often benefit from technical support from donor agencies and international processes such as REDD+ and FLEGT, and that effective national policies will place domestic issues and priorities in their regional and global contexts (FAO, 2026). The Pareto Optimum is reached when no One can be made better off without making someone else worse off. Available data indicate that Nigeria has about 1,160 constituted forest reserves covering roughly 10 per cent of the country's land area; however, studies suggest that many of these reserves have been severely degraded over the decades (Geo-Information Society of Nigeria, GEOSON).

Valuing the Forest as a Biological Factory for Oxygen and Social Cohesion

Turning from already identified market failures and associated underutilized research results to the main focus of this paper discourse is to transform a local ward into a global Exhibition Product. In recent efforts, the Nigerian government has shown evidence of leading such initiatives, shifting from price taker to market maker in global carbon (REDD+) and biodiversity markets, and in the analysis of discussant views and local context. The recommendation drawn from the analysis of the discussant's views and the local context is vital. They submitted support to use sites like Gambari (Oyo), Ikang (Cross River), and Okomu (Edo) as home turf for international negotiations (AFF, 2019; Oteng-Yeboah, 2016). Going beyond talk and paperwork, the success of this global carbon (REDD+) project was measured by training delegates in the specific wards they were drawn from, as good forest governance acts as the policy lever that bridges the gap between scientific discovery and commercial viability by aligning institutional frameworks with market incentives. The use of the Benefit-Transfer Method to value their local standing assets and propose at least One Revenue-Generating Social Amenity (such as a Shelterbelt Garden in Kano or a Mangrove Boardwalk in Abak) to attract local investors and tourists has received little or no attention from public federal agencies like FRIN. From an environmental economics perspective, some authors have argued that transforming forestry research into marketable products in Western Nigeria

optimizes state-owned natural capital through structured Governance. This approach justifies investment by creating a professional Commission to handle capital expenditure, internalizing environmental costs, and aligning exploitation with sustainable regeneration (Laws & Marquette, 2018; Levy, 2014; Mojeed, 2023, Google's Finance Data, 2026).

This conceptualization integrates environmental economics with forest governance to transform research into tangible market assets. The study advocates a utilitarian conservation model in which indigenous African tree species, such as *Khaya senegalensis* and *Afzelia africana*, are used to build revenue-generating, eco-friendly infrastructure within institutions like FRIN. By leveraging the economic, social, and environmental values of these species for social amenities and recreational facilities, this approach transforms public forest spaces into self-sustaining hubs, ensuring both institutional sustainability and long-term ecological conservation (Global Forest Resources Assessment, 2020). FAO sources are used to explore the report in more detail in this respect. Within the framework of environmental economics and sustainable governance, the literature provides sufficient evidence validating the social, environmental, and market values of these species.

In the context of social discourse, Arowosoge (2010) identifies *Terminalia superba* (White Afara) as a cornerstone of the Nigerian timber trade, specifically highlighting its role in small-scale furniture manufacturing and local employment. This submission validates social/economic support. Ofori *et al.* (2017) confirm its rapid growth and high carbon sequestration potential, noting its effectiveness in reclaiming degraded lands through agroforestry. This validates the environmental value, while International trade data from ITTO (2020) supports its high demand in the plywood and veneer industries. Gourlet-Fleury *et al.* (2013) discuss the high economic value of mahogany species, i.e., *Entandrophragma angolense* (Tiama Mahogany), noting that sustainable exports significantly bolster national GDPs in the Congo Basin through their social/economic support. Vuohelainen *et al.* (2012), in advancing their environmental support, emphasize that as an emergent canopy species, it is critical for maintaining the forest microclimate and providing nesting sites for large avian species. The World Bank (2020) reports that premium hardwoods like *E. angolense* command top-tier prices due to their aesthetic and structural durability. In the case of *Mansonia altissima* (African Black Walnut), Betti *et al.* (2016) document its use in high-end joinery and local craftsmanship, serving as a primary source of income for rural artisans.

This social/economic support has also been complemented by their additional role as environmental supporters, as noted by Aweto (2013). The source highlights the role of deciduous trees like *Mansonia* in nutrient cycling, where leaf litter improves topsoil organic matter. Its specific gravity and durability make it a stable commodity in West African timber markets (ITTO, 2020). *Afzelia,* on the other hand, has demonstrated its socio-economic importance due to its note-worthiness as a source of high-value timber and fodder (leaves) for livestock during the dry season, according to Ouédraogo et al. (2013). N'Golo et al. (2015) highlight the environmental supports they provide, which improve soil fertility for surrounding vegetation, by enhancing their nitrogen-fixing capabilities. They remain One of the most expensive and sought-after construction timbers on the market due to their resistance to termites and rot (FAO, 2021). Ekué *et al.* (2010), in examining *Blighia sapida* (Ackee/Apon) from the viewpoint perspective of social/economic support, claimed that extensive evidence has been documented on the multipurpose nature of this

tree, including how fruit sales provide a safety net for rural women's incomes. From an environmental support angle, Jimoh *et al.* (2012) discuss its role in traditional home gardens, where it provides essential shade and reduces soil moisture evaporation. Market studies show that while timber value is moderate, the combined value of Non-Timber Forest Products (NTFPs) and wood makes it highly profitable.

Khaya senegalensis has advanced social/economic support according to the study by Gaoue and Ticktin (2007). They associated this with their known impact of bark harvesting and timber sales on local livelihoods, noting its central role in both medicinal and construction sectors. Essentially, Fandohan *et al.* (2011) emphasize its resilience in gallery forests and its importance in protecting watersheds from drying out in the context of environmental support. Therefore, as a flagship mahogany species, it consistently appears in global market reports as a high-value export commodity. Adebisi (2008) identified *Nauclea diderrichii* (Opepe) as providing functional social/economic support in maritime construction and railway sleepers, providing specialized industrial jobs. Orwa *et al.* (2009), on the other hand, identify its preference for moist environments, making it ideal for stabilizing riverbanks and preventing flood-related erosion. Its natural durability reduces the need for chemical preservatives, giving it a "green" market advantage in sustainable construction exhibitions.

In view of the foregoing, while most land is under state control, which has very different forestry policy drivers, federal government institutions directly control numerous landholdings that could be better managed from an environmental perspective. This is why environmental economic valuation of national forests and the services they provide may help change policy-makers' perceptions of forest resources as a one-off revenue stream, helping them see them instead as longer-term resources meriting reinvestment if they are to continue being a productive part of transforming Forestry Research into marketable Exhibition Products. The key considerations for transforming forestry research into marketable exhibition products requires a shift from viewing forests solely as biological resources to treating them as social-ecological-technical systems**.**

1. Forest Governance as a Catalyst for Marketability

Good governance provides the essential "enabling environment" that reduces investment risks for the private sector. Key governance pillars that facilitate research-to-market transformation include:

- ***Clear Property and Harvesting Rights****:* Secure tenure is the primary determinant of sustainable management and gives researchers and entrepreneurs the legal certainty to invest in product development.
- ***Regulatory Transparency****:* Standardized rules on resource access and benefit-sharing, e.g., permits for collecting non-wood products, ensure that innovative products can be legally traded and certified.
- ***Innovation Governance****:* Specifically targeting the governance of innovation processes helps align forest management goals with the Creation of new bioeconomy products, such as high-value non-wood forest products (NWFPs).

2. Economic Policy for Research Transformation

Environmental economics uses various fiscal and market instruments to turn research outputs into commercial successes:

- ***Fiscal Incentives****:* Public funds can be used to subsidize the initial high transaction costs of "deal flow identification" and project preparation for sustainable forestry startups.
- ***Market-Based Instruments***: Certification and labeling (e.g., FSC or PEFC) transform abstract sustainability research into a "premium price" attribute that consumers can recognize at exhibitions.
- ***Direct Payments and Grants***: These can serve as "ignition points" for restoration value chains, providing short-term capital until a research-driven product (such as intercropped native timber) becomes financially self-sustaining.

3. Marketable Exhibition Products from Forestry Research

Exhibitions highlight the economic value of forests by showcasing tangible applications of research. Common categories include:

- ***Value-Added Timber***: New construction materials like cross-laminated timber (CLT), specialty wood panels, and "acid-resisting" timbers for chemical storage.
- ***High-Value NWFPs***: Innovative applications of resins, gums, medicinal plant extracts, and "biodiversity-based" products like specialized honey or essential oils.
- ***Agroforestry Innovations***: Intercropped systems that produce "exhibition-ready" goods like high-quality agroforestry coffee or sustainably sourced spices.
- ***Forestry Equipment & Tools***: Locally manufactured tools derived from specific tree species research, such as specialized hoe handles or traditional fishing traps.

4. Overcoming Market Transformation Constraints

Research often fails to reach the market due to socio-economic barriers rather than biophysical ones:

Methodology

This model demonstrates how forest-based social amenities can generate substantial revenue for public institutions through rental agreements and service charges.

Mahogany-Based Agroforestry (The Rainforest Asset)

African Mahogany (*Khaya grandifoliola*) acts as a long-term savings account, with high-value timber and substantial biomass.

Timber Value: Sawn mahogany timber can fetch between $700 and $1,400 per m^3. In a managed agroforestry system, the value of mature mahogany trees far exceeds any short-term crop revenue.

Land Equivalent Ratio (LER): Mahogany-based systems (e.g., mahogany-rice or mahogany-okra) typically have an LER of **1**.37 to 1.63, meaning they are 37-63% more productive than planting the same area with trees or crops alone.

Carbon Stocks: Mahogany stands can store massive amounts of carbon, with some Nigerian rainforest ecosystems reaching over 400 Mg C per ha.

A dimension of 37 feet by 39 feet is approximately 11.28 meters by 11.89 meters.
The standard conversion factor for Length is 1 foot = 0.3048 meters.

Step-by-Step Conversion Work
To convert these dimensions into the metric system, multiply each value in feet by the conversion factor.

(a) Convert Width (37 feet):
37 ft×0.3048 m/ft=11.2776 meters37 ft × 0.3048 m/ft = 11.2776 meters
37 ft×0.3048 m/ft=**11.2776** meters
Convert Length (39 feet):
39 ft×0.3048 m/ft=11.8872 meters39 ft × 0.3048 m/ft = 11.8872 meters
39 ft×0.3048 m/ft=**11.8872** meters

Area Calculation Work:
If you need the total surface area for these dimensions, use the formula
Area = Length × Cross × Width.
In Feet:
37 ft×39 ft=1,443 square feet37 ft × 39 ft equals 1,443 square feet
37 ft×39 ft=1, square feet

In Meters:
To finalize your project for the 37ft x 39ft (11.28m x 11.89m) site, here are the detailed technical specifications. Whether you are keeping the land or planting a climax mahogany community, these plans provide the practical work to accompany your project.

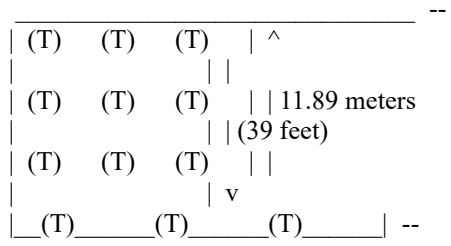
1. Bill of Quantities (BOQ): Perimeter Fencing
This BOQ is for a standard 6ft high chain-link fence on a total perimeter of 46.34 meters.

Item Description	Specification	Estimated Quantity	Average Unit Price (₦)	Total (₦)
Chain-link Mesh	2.1mm x 6ft (18m rolls)	3 Rolls	47,300	141,900
Galvanized Steel Posts	2.5m length (48mm diam.)	18 Pieces	12,500	225,000
Binding/Tie Wire	2.0mm Galvanized	1 Roll (25kg)	25,000	25,000
Cement	Dangote/Bua (50kg)	6 Bags	9,500	57,000
Sand & Gravel	Sharp sand / 1/2-inch granite	1 Tonne each	35,000	35,000
Labor (Installation)	Post digging & tensioning	Lump Sum	60,000	60,000
TOTAL				**543,900**

Note: Prices are estimates based on early 2026 market trends in Nigeria and should be verified with local suppliers.

2. Layout Diagram: High-Density Mahogany Spacing
For a plot of this size (134.06 m²), a 3m x 3m spacing is recommended for the first 10 years of "forest succession."

11.28 meters (37 feet)
|<------------------------->|



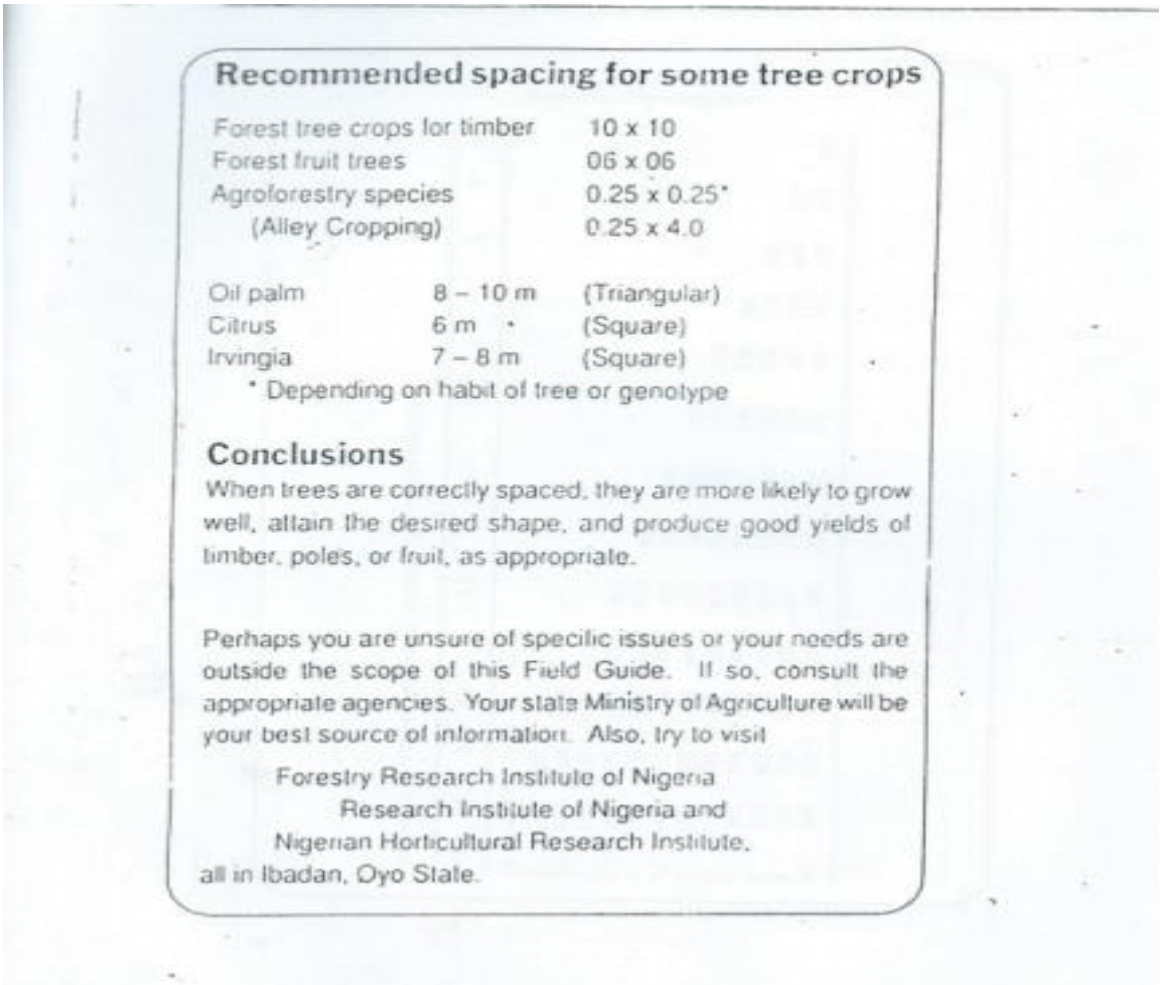
(T) = Tree Placement (e.g., *Khaya grandifoliola*)
Spacing: 3m between trees | 2.5m buffer from fence line

Key Layout Specs:
Total Trees: 12 to 16 trees.
Buffer Zone: Plant no closer than 2m (6ft) from the fence to prevent root damage to the foundation.
Intercropping: The 3m alleys between rows can be used for Nurse Crops like Okra or Rice during the first 3 years to maximize land-use efficiency.
Strategic "Succession" Advice
Post Spacing: Set your fence posts at 2.5m intervals. This provides the structural "permanence" required to protect the trees from livestock and leakage (theft).
Corner Reinforcement: Use "Stay-Posts" (diagonal supports) at the 4 corners to ensure the chain-link remains taut for the 10+ year project duration.
To determine the capacity of your 37ft x 39ft (11.28m x 11.89m) site, the study first establishes that the total area is 134.06 m², which is equivalent **to** 0.0134 hectares.

In the Nigerian Forestry and Forest Governance and Policy (Environmental Economics) discourse, different species require specific spacing to thrive, depending on their canopy spread and growth rate. Below is the accommodation capacity for your specific list of indigenous species:

Tree Capacity for 134.06 m² (0.0134 Ha)

Species	**Common Name**	**Recommended Espacement**	**Total Capacity on Site**
Terminalia superba	Afara	4m x 4m	4 - 6 Trees
Entandrophragma angolense	Gedu Nohor	5m x 5m	4 Trees
Mansonia altissima	Ofun	3m x 3m	9 - 12 Trees
Afzelia africana	Apa / Mahogany Bean	6m x 6m	2 - 4 Trees
Khaya senegalensis	Dry Zone Mahogany	4m x 4m	4 - 6 Trees
Nauclea diderrichii	Opepe	3m x 3m	9 - 12 Trees



Recommended spacing for some tree crops

Forest tree crops for timber	10 x 10
Forest fruit trees	06 x 06
Agroforestry species	0.25 x 0.25*
(Alley Cropping)	0.25 x 4.0

Oil palm	8 – 10 m	(Triangular)
Citrus	6 m	(Square)
Irvingia	7 – 8 m	(Square)

* Depending on habit of tree or genotype

Conclusions

When trees are correctly spaced, they are more likely to grow well, attain the desired shape, and produce good yields of timber, poles, or fruit, as appropriate.

Perhaps you are unsure of specific issues or your needs are outside the scope of this Field Guide. If so, consult the appropriate agencies. Your state Ministry of Agriculture will be your best source of information. Also, try to visit

Forestry Research Institute of Nigeria
Research Institute of Nigeria and
Nigerian Horticultural Research Institute,
all in Ibadan, Oyo State.

Detailed Analysis by Species Group

1. The Fast-Growers: ***Terminalia superba*** (Afara)
As a "Pioneer Species," Afara grows tall and straight. While it can be planted at 3.5m, a 4m spacing is safer for a small 37x39ft plot to prevent the canopy from completely blocking the sun for under-crops.
Calculation: 2 rows of 3 trees = 6 trees max**.**

2. The Massive Hardwoods: *Entandrophragma* and *Afzelia*
These are "Climax Community" species. They have massive root systems and wide crowns. *Afzelia africana* (Apa) is particularly slow-growing but very wide.
Capacity: Because your site is only 11.89m long, you can fit at most 2 rows of these trees.

3. The Timber Dense: ***Mansonia*** and ***Nauclea***
Nauclea diderrichii (Opepe) is often used in plantation forestry in Southern Nigeria. It handles closer spacing (3m**)** better than the others, making it the best choice if you want to maximize the number of trees on this specific small plot.
Calculation: 3 rows of 4 trees = 12 trees.

The "Missed Value" & Pareto Failure

Governance fails the Pareto test because the Total Economic Value (TEV) is not captured, leading to policies that favor a small group (illegal loggers/elites) while impoverishing millions of rural dependents:

Informal Economy Exclusion: Over 70% of households depend on fuelwood, and 80% of rural economies depend on forests for livelihoods. These transactions occur outside formal markets and are not valued in "Naira/Dollar worth" in policy decisions.

Externalized Costs: The $3.75 billion in commercial biodiversity value is ignored, while the $0.37 billion in conservation costs is treated as a "loss" by the State. This makes the public "worse off" by prioritizing short-term extraction over multi-billion-dollar ecosystem services.

Governance Blind Spots: Lack of land-use planning and poor coordination between ministries result in a "substantial but poorly monitored informal sector," where the true value of forest product exhibitions (which showcase processing and value addition) is never realized.

Capturing True Worth: Reforming the Model

To transition toward a Pareto improvement, the UN-REDD Program has proposed integrated environmental economic accounts for Nigeria. This would:

1. **Value Direct Use**: Properly pricing NTFPs, such as snails and mushrooms, which contribute up to 69% of total household income in some communities.
2. **Internalize Externalities**: Accounting for carbon sequestration valued in global dollars as a state asset.
3. **Support Value Addition**: Investing in local processing machinery for Enugu and Oyo communities to move from raw material gathering to high-value product exhibitions.

Although the commercial value of biological diversity in Nigeria exceeds the cost of conservation measures by more than $3 billion at 1993 values ($3.75 billion versus $0.37b), biodiversity conservation has not been recognized as a feasible investment in Nigeria's economic development and consequently, natural resources valuation has not been fully incorporated into the national economic planning. It has been estimated that the conservation cost ratio for Nigeria was about 3.8% of GDP, while the aggregate contribution of biodiversity to GDP was about 46% in 2001. In 1990, it was estimated that the monetary value of other benefits from conservation exceeded $6 billion (Nigeria, 2007).

To resolve the failure of the Pareto optima in Nigerian forestry, the Intergenerational Equity (The Stewardship Principle) must be introduced**.** In traditional economics, studies of this sort only measure current utility (Person A vs. Person B). In Environmental Economics, the third party represents the Future Generation. By including those who are not yet born in our "Total Economic Value" (TEV) calculations, we shift from a "zero-sum" conflict (Farmer vs. Government) to a "positive-sum" sustainability model.

1. **The UN-REDD Policy Modeling Tool: Bridging the Gap**
The UN-REDD (Reducing Emissions from Deforestation and Forest Degradation) framework acts as the financial bridge. It transforms "standing trees" into "tradable assets," allowing states like Cross River and Oyo to capture the "invisible" dollar value of their forests.

The Calculation:

- **The Calculation**: $Value = (Biomass \times Carbon Density) \times Global Carbon Market Price.$

Instead of a "failed Pareto test" where the government bans logging (making the logger worse off), the government receives Carbon Credits. These funds are then used to provide

The Principle of Cultivation and Preservation
Sustainable Forest Management (SFM). It establishes that "Value Added" is not just through extraction (working it) but through preservation (taking care of it). A policy that only "works" the land without "caring" for it violates the land use mandate and fails the economic Pareto test.

The Principle of Inheritance and Equity
This resolves the Intergenerational Equity conflict. If we deplete the Omo or Oluwa reserves today for quick Naira, we are "robbing" our grandchildren. Economic policies that do not account for "children's children" are inherently fraudulent under this scriptural lens.

The Principle of Communal Justice
Forestry governance fails when elites seize forest land. Land economics demands that the vulnerable forest-dependent community be protected. Granting land rights back to the wards in Ibarapa or Akpaka satisfies both the Pareto test and the moral law of Justice.
To move forward, Oyo and other Southern states must adopt Natural Capital Accounting (NCA). This allows the Ministry of Finance to see that a standing forest in Gambari is worth more in "Carbon Dollars" and "Watershed Security" than its one-time sale as timber.

The Temporal Gap: There is often a mismatch between short-term research funding and the long rotation cycles required for forest products.

Lack of Extension Services: Without technical assistance to bridge the "lab-to-field" gap, high-potential research remains academic.

Market Misalignment: Research must be "consumer-pull"- based on what the market demands, such as sustainable packaging, rather than "producer-push".
Traditional forestry is viewed as a "slow-growth" sector, heavily dependent on government funding and characterized by long gestation periods (15-25 years). By converting small parcels of institutional land (0.0134 Ha per unit) into Forestry Business Hubs, we unlock immediate market value from research.

1. The "Exhibition-to-Market" Engine

Asset Monetization: Instead of selling raw timber, FRIN outstations now market Shade-as-a-Service. Indigenous species (*Teak, Iroko*) are used to build premium gazebos that host private food and trade vendors.
Revenue Performance: A single 100sqm gazebo generates ₦7.8 million monthly in vendor sales. By capturing 15% of the Economic Rent, FRIN outstations earn ₦14.6 million per unit annually.

2. Strategic National Impact

Fiscal Self-Reliance: A cluster of 10 units per outstation creates a net annual profit of ₦126 Million. Across FRIN's national network, this creates a multi-billion-naira internal revenue stream, reducing the burden on the national budget.
Geopolitical Stability: From Onne (Coastal Windbreaks) to Kano (Desertification Barriers), FRIN is creating regional "Innovation Hubs" that drive local entrepreneurship and provide "green jobs" for youth in Adopted Villages.
Climate-Smart Infrastructure: We are moving the 2026 portfolio, specifically species like *Khaya senegalensis* and *Royal Palms*, from the nursery to the center of Sustainable City planning, capturing luxury real estate demand.

3. The Exhibition Premium (2026 Projection)

Our research has successfully revalued forest assets:
Ornamentals: *Royal Palms* at ₦25,000+ per unit as luxury staples.
NTFPs: *Ogbono* at ₦12,000/kg for industrial export.
Timber: *Teak* at ₦6,500/unit as a global Green Construction standard.

FRIN is no longer just a research institute; it is a National Land-Asset Manager. We are proving that 100 square meters of forest-managed land can out-earn traditional hectares of arable farming by over 40,000%. From an environmental economics perspective, good forest governance acts as an enabling mechanism that corrects market failures, such as the undervaluation of ecosystem services. It provides incentives to turn sustainable forestry research into marketable, value-added products. Good GovernanceGovernance (transparency, accountability, and participation) ensures that the economic benefits of forest products are balanced with environmental sustainability, preventing the tragedy of the commons.

Key Forest Reserves and Reference Communities in Oyo State
In Oyo State, reaching a Pareto optimum, where forest conservation benefits everyone without harming local livelihoods, requires shifting from top-down enforcement to Joint Forest Management (JFM) and Community-Based Models. As of April 2026, the Oyo State Government has reaffirmed its commitment to these inclusive practices, particularly focusing on gender-based inclusion and afforestation partnerships. The environmental economics perspective focuses on an enabling mechanism that corrects market failures (e.g., the undervaluation of ecosystem services). It provides incentives to turn sustainable forestry research into marketable, value-added products. In this respect, the focus on the Forestry Research Institute of Nigeria (FRIN) Exhibition Showroom and reference communities in Oyo State is necessary in the context of this paper's discourse.

3. Cost-Benefit Projection (2001–2026) & Nursery Economics

The negative market margins reported for FRIN and NIHORT reflect a High Initial Capital/Low Market Access trap.
(a) FRIN Baseline (1.5 ha): 53,333 seedlings with a margin of -₦982,841.28.
(b)NIHORT Baseline (12 ha): 83,333 seedlings with a margin of -₦132,278.83.

4. Problem-Solving Framework (Addressing your 5 points)

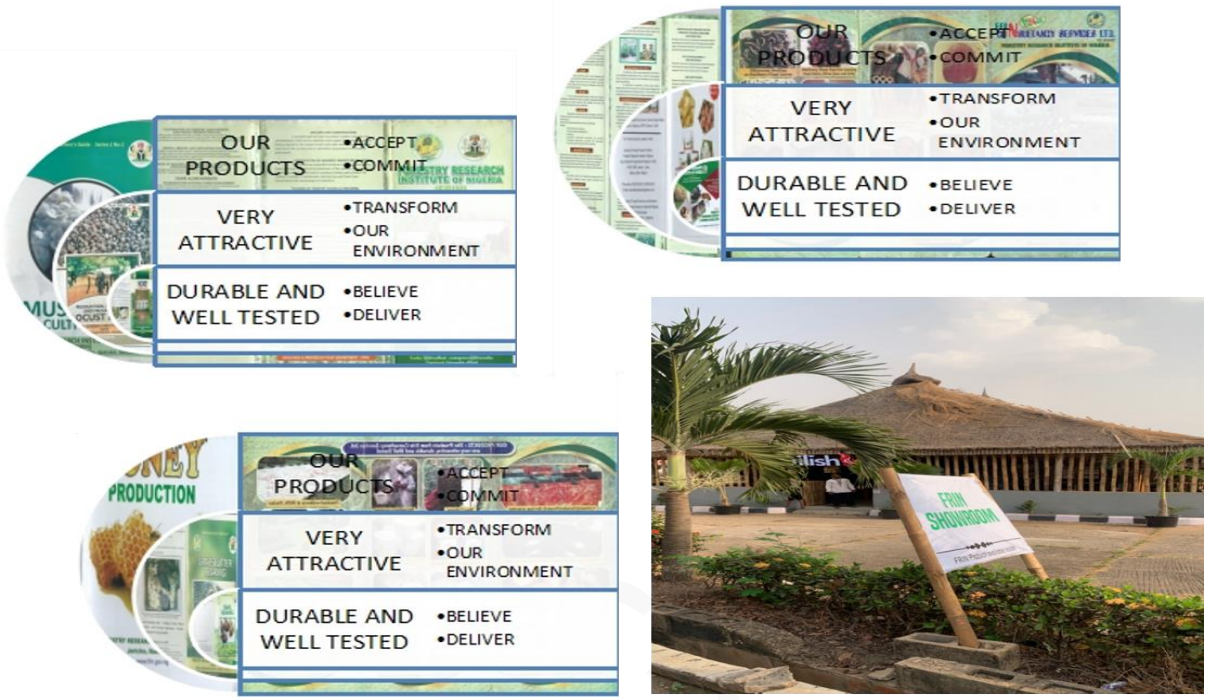
i. Inefficient Resource Allocation & Market Failures
Current policies ignore the Non-Market Value of forests. We need a transition where a woodlot is seen as a "Bio-factory" for marketable products (essential oils, certified timber) rather than just "scenery" (Akinyemi *et al*., 2024).
ii. Governance and Institutional Weaknesses
Fragmented management between the federal and State levels leads to "Open Access" problems where reserves are raided. Good GovernanceGovernance requires Tenure Security to encourage long-term investment in nurseries.
iii. Socio-Economic Trade-offs (Non-Pareto Improvements)
Moving from degradation to conservation often hurts people with low incomes who rely on the forest for fuel.

iv. Proposed Pareto-Improving Management Models

(a) The "Nursery-to-Market" Pipeline: Linking NIHORT/FRIN directly to private-sector reforestation contracts.
(b) Youth-Led "Tree-Preneurship": Moving from "scenery" to "survival" by teaching the next generation to treat 1 hectare of seedlings as a high-yield financial portfolio.
v. **Relevant Policy Reforms (2025–2026)**
(c) National Forest Policy (Revised): Integration of Forest Bonds to fund the negative margins of nurseries.
(d) Nigeria Carbon Market Framework (2025): Aligning Ikang and Okomu wards with Article 6 of the Paris Agreement to turn research into Exhibition Carbon Credits.

Capturing True Worth: Reforming the Model

To transition toward a Pareto improvement, the UN-REDD Program has proposed integrated environmental economic accounts for Nigeria. This would:
1. **Value Direct Use**: Properly pricing NTFPs, such as snails and mushrooms, which contribute up to 68.7% of total household income in some communities.
2. **Internalize Externalities**: Accounting for carbon sequestration (valued in global dollars) as a state asset.
3. **Support Value Addition**: Investing in local processing machinery for Enugu and Oyo communities to move from raw material gathering to high-value product exhibitions.



References

Adebisi, A. A. (2008). *Nauclea diderrichii* (De Wild.) Merr. In: Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa), Wageningen, Netherlands.

African Forest Forum (2019). International dialogues, processes and mechanisms to climate change: A compendium for professional and technical training in African forestry. *Technical Working Paper*. 32pp.

African Forest Forum (AFF), 2019. *Professional Forestry Education in Nigeria.*

Ajayi, C.A., & Babalola, F.D. (2006). Assessment of Two Public Nurseries Producing Tree Seedlings for Commercial Purposes in Ibadan, Oyo State, Nigeria. In: *The Nigeria Journal of Forestry* (July & December 2006) (eds. Udoh, E.S., Adekunle V.A.J. and Popoola, L.) The Forestry Association of Nigeria. 36 (1 & 2), 71–78.

Ajayi, C.A. (2002). Cost-Benefit analysis of seedling production in public enterprises: a case study of NIHORT and FRIN nurseries, Ibadan, Oyo State, Nigeria. A *BSc. dissertation* submitted to the Department of Forest Resources Management, University of Ibadan, Ibadan, Nigeria. 112pp.

Arowosoge, O. G. E. (2010). Contribution of timber trade to the economy of Nigeria: A case study of some selected sawmills in Ekiti State, Nigeria. *Food, Agriculture and Environment*, 8(2), 915–918.

Aweto, A. O. (2013). *Shifting Cultivation and Secondary Succession in the Tropics*. CABI Publishing. (Discussing the nutrient cycling of *Mansonia altissima* and deciduous forest species).

Betti, J. L., Njokunmbe, B. N., & Nzooh, D. Z. (2016). Non-Timber Forest Products and Livelihoods in the Periphery of the Dja Biosphere Reserve, Cameroon. *Journal of Ecology and the Natural Environment*.

Carsten Mann, Lasse Loft, Mónica Hernández-Morcillo, Eeva Primmer, Francesca Bussola, Enzo Falco, Davide Geneletti, Ewelina Dobrowolska, Carol M. Grossmann, Giorgia Bottaro, *et al.* (2022).Governance Innovations for forest ecosystem service provision – Insights from an EU-wide survey. *Environmental Science & Policy,* 132, 282-295

Ekué, M. R., Sinsin, B., Eyog-Matig, O., & Finkeldey, R. (2010). Uses, traditional management, socio-economic importance and conservation of *Blighia sapida* Konig (Sapindaceae) in Benin. *International Journal of Biodiversity and Conservation*, 2(4), 93–101.

FAO (2026**).** Sustainable Forest Management (SFM) Toolbox. Retrieved from https://www.fao.org/sustainable-forest-management-toolbox/modules/forest-policy/en

FAO (2025). Webinar #3: *From Forest to Market, Advancing forest-based bioeconomy solutions to ensure resource supply meets growing demand.* Retrieved from https://www.fao.org/forestry/our-focus/forest-products/sustainable-forest-based-bioeconomy-approaches/webinar-3/en, Thursday 26 June 2025

FAO, (2024). *State of the World's Forests: Forest-sector innovations.*

FAO (2021). *Global Forest Resources Assessment 2020: Main Report*. Rome, Italy.

Fandohan, A., et al. (2011). Conservation genetics of *Khaya senegalensis* in Benin. *African Biotechnology*, 10(63).

FRIN/NIHORT *Internal Audit Estimates (Projected 2001-2026).*

Gaoue, O. G., & Ticktin, T. (2007). Patterns of harvest of non-timber forest products by different ethnolinguistic groups in Benin. *Economic Botany*, 61(2), 150-161.

Google's Finance Data (2026). Google Finance provides a simple way to search for financial security data (stocks, mutual funds, indexes, etc.) and currency data. Retrieved from https://www.google.com/finance/beta/quote/USD-NGN30/04/26.

Gourlet-Fleury, S., Mortier, F., Fayolle, A., Baya, F., Ouedrogo, D., Benedet, F., & Picard, N. (2013). Tropical forest management: Looking for sustainability. *Nature & Faune*, 28(1), 11-15.

Higgins, S.I., Bond, W.J., & Trollope, W.S. (2020). Ecological roles of African tree species. *Tropical Ecology*, 36(3), 245–258.

Ibukun Emiola, News Agency of Nigeria. Retrieved from Tuesday, April 28 April 28 April 28 April 28, 2026. Enviro News Nigeria @**https://www.environewsnigeria.com/in-oyo-battle-for-forests-shifts- from-reserves-to-classrooms-communities/**

International Tropical Timber Organization (ITTO). (2020). Annual review and assessment of the world timber situation. Yokohama, Japan.

Jimoh, S.O., Adesoye, P.O., Adeyemi, A.A., & Ikyaagba, E.T. (2012). The role of home gardens in household food security in Nigeria. *Human Ecology*, 12(2), 141-154

Mando, A., Ouattara, B., Somado, A.E., Wopereis, M.C., & Breman, H. (2019). Soil conservation benefits of indigenous tree species in West Africa. *Agriculture, Ecosystems & Environment,* 273, 1-12. https://doi.org/10.1016/j.agee.2018.12.004

N'Golo, A.K., Becker, M., & Mussgnug, F. (2015). Nitrogen fixation and soil fertility improvement by *Afzelia africana* in West African Savannas. *Soil Science and Environmental Management*.

Nigeria (2007). National Biodiversity Strategy and Action Plan, 104 pp.

Nimmo, D.G., Campbell, B., & Angelsen, A. (2021). Biodiversity benefits of indigenous trees in African forests. *Biodiversity and Conservation,* 30(12), 3451–3469. https://doi.org/10.1007/s10531- 021-02234-7

Ofori, D.A., Swaine, M.D., Cobbinah, J.R., & Price, A.H. (2017). Genetic diversity and conservation of *Terminalia superba* Engl. & Diels. *Resources*.

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., & Anthony, S. (2009). Agroforestree Database: A tree reference and selection guide version 4.0. (worldagroforestry.org)

Osei, J., Ansong, M., & Zerbe, S. (2021). The role of forest trees in local economies and biodiversity. *African Journal of Ecology, 59*(2), 123–135. https://doi.org/10.1111/aje.12834

Ouédraogo, A., Thiombiano, A., & Guinko, S. (2013). Regeneration of the threatened species *Afzelia africana* Sm. in West Africa. *International Journal of Biological and Chemical Sciences*.

Oteng-Yeboah A. A. (2016). Training module on effective engagement of delegates in international multilateral processes, African Forest Forum, Nairobi.

Pokkadath, A., Chembrammal, R., & Thoppil, J. E. (2024). Phytopharmacological aspects of the genus *Terminalia*. Springer. https://doi.org/10.1007/978-3-031-28780-0

Vuohelainen, A. J., Vancutsem, C., & Achardm F. (2012). Forest structure and canopy dynamics of the African Mahogany (*Entandrophragma* spp.). *Biotropica*.

World Bank. (2020). Market Trends for High-Value Tropical Hardwoods: Africa Region Report. Washington, DC.

World Bank. (2020). The timber market in West Africa: Trends and opportunities. WorldBank Publications.

ISTF-NIG 2026

Proceedings of the 4th ISTF-NIGERIA International Conference. Held at the Faculty of Renewable Natural Resources Management, College of Agriculture and Renewable Natural Resources, Osun State University, Nigeria, from 19th – 21st of May, 2026.
Theme: Forest Ecosystem Conservation: A Roadmap For Resilient Economies And Environmental Sustainability

PARTICIPATION WITHOUT POWER: COMMUNITY PARTICIPATION AND STAKEHOLDER ENGAGEMENT IN FOREST GOVERNANCE IN SOUTHWESTERN NIGERIA

Akinyemi G. O[1]*, Akinyemi I. G[1], Ayanniyi O A[1], Ibitoye O.S[1]

[1]*Forestry Research Institute of Nigeria, Ibadan, Nigeria*

**Corresponding author: princetosyne@gmail.com*

Abstract

Community participation is widely recognized as a cornerstone of effective and sustainable forest governance, yet in many developing countries, local stakeholders remain marginally involved in decision-making processes. This study examines the levels, forms, and determinants of community participation and stakeholder engagement in forest governance in two forest reserves, Eporo and Little Ose, in southwestern Nigeria. Data were collected from 120 forest-dependent households using structured questionnaires and analyzed using descriptive and inferential statistics. The results indicate that participation in forest management is moderate, with activities largely limited to reporting illegal activities (25%) and tree planting (21.7%), while 21.7% of respondents reported no participation. Although awareness of forest laws was relatively high (65%), stakeholders reported low levels of consultation (mean = 2.38) and perceived fairness in enforcement (mean = 2.50), reflecting weak institutional inclusiveness. Key barriers to participation include poverty and forest dependence (31.7%), lack of awareness (24.2%), and perceived corruption or selective enforcement (18.3%). The findings suggest that while communities are willing to engage in forest governance, participation remains largely passive and constrained by institutional and socio-economic challenges. The study concludes that strengthening participatory forest governance requires improved transparency, enhanced community consultation, and the integration of livelihood support into forest management policies to build institutional trust and promote sustainable conservation outcomes in Nigeria.

Keywords: *Community participation; Forest governance; Stakeholder engagement; Institutional trust; Sustainable forest management*

Introduction

Tropical forests provide essential ecosystem services, including biodiversity conservation, carbon sequestration, watershed protection, and livelihood support for rural communities (FAO, 2020). Despite their ecological and socio-economic importance, forest ecosystems in many developing countries continue to be degraded by illegal logging, agricultural expansion, weak enforcement of regulations, and unsustainable resource extraction practices (Kaimowitz, 2003). In Nigeria, forest reserves serve as both ecological assets and livelihood sources for surrounding communities engaged in farming, timber extraction, fuelwood collection, and the harvesting of non-timber forest products (Adegboyega & Bolanle, 2021; Elujulo et al., 2023). This dual role creates complex governance challenges, particularly in balancing conservation objectives with local livelihood needs.

Participatory forest governance has emerged as a key strategy for improving natural resource management outcomes. It emphasizes the inclusion of local stakeholders in decision-making processes to enhance legitimacy, promote shared responsibility, and improve compliance with

environmental regulations (Dietz et al., 2003). When communities are actively involved, they are more likely to perceive governance systems as fair and legitimate, thereby strengthening voluntary compliance. Conversely, exclusion from governance processes often leads to resistance, low compliance, and weakened institutional trust (Tyler, 2006). Despite policy emphasis on participatory approaches, evidence suggests that community involvement in forest governance remains limited in many developing countries (Siddique et al., 2026). Participation is often restricted to implementation roles, with little influence on policy formulation or decision-making processes (Ramcilovic-Suominen & Hansen, 2012). In Nigeria, forest governance remains largely centralized, with communities playing minimal roles in formal governance structures. This has been associated with perceptions of unfair enforcement and limited consultation, which may reduce stakeholder willingness to engage in forest management activities (Elujulo et al., 2023). This study examines community participation and stakeholder engagement in forest governance in Eporo and Little Ose Forest Reserves in southwestern Nigeria. Specifically, it assesses participation levels, identifies barriers to engagement, and evaluates institutional factors influencing stakeholder involvement.

Material and Methods

Study Area

The study was conducted in Eporo and Little Ose Forest Reserves in Ekiti State, southwestern Nigeria. The region experiences a humid tropical climate, with annual rainfall of 1,500-2,000 mm and temperatures ranging from 22 to 32°C. The vegetation includes lowland rainforests and secondary forests that support biodiversity and rural livelihoods.

Study Design and Sampling

A cross-sectional survey design was adopted. A multi-stage sampling approach was used to select 120 respondents (60 per forest reserve: Eporo and Little Ose). In the first stage, purposive sampling was employed to select two forest reserves based on their high forest dependence and a history of forest governance interventions. Within each reserve, households were stratified into three purposively defined groups based on their primary forest-related occupation: farming, timber logging, and hunting. In the second stage, stratified random sampling was applied: from each occupational stratum, respondents were selected using simple random sampling (balloting) from household lists obtained through community gatekeepers and village heads. This approach ensured adequate representation of key livelihood groups while maintaining random selection within each group. A total of 120 household heads were interviewed (approximately 20 per stratum per reserve, proportional to estimated population size).

Data Collection

Structured questionnaires were administered through face-to-face interviews, capturing socio-economic characteristics, awareness of forest laws, patterns of participation, and perceptions of institutional governance.

Data Analysis

Data were analyzed using descriptive statistics and inferential methods, including correlation and t-tests. Statistical significance was set at $p < 0.05$.

Results

Socio-Demographic Characteristics of Respondents

The results indicate that the study population is predominantly engaged in forest-dependent livelihoods (Table 1). Farming was the primary occupation (40.0%), followed by timber logging (16.7%) and hunting (15.0%), reflecting a high reliance on forest resources for subsistence and income generation. Only a small proportion of respondents were forest officials (8.3%), indicating that most respondents were community members rather than institutional actors. Educational attainment was generally moderate, with secondary Education being the most common level (35.0%), followed by primary Education (30.0%). However, a notable proportion of respondents (18.3%) had no formal Education, which may influence both awareness and the capacity for meaningful participation in governance processes. Regarding residency, 61.7% of respondents had lived in the communities for more than 10 years, suggesting long-term familiarity with forest resource use and governance systems. This prolonged exposure implies that perceptions and participation patterns are shaped by sustained interaction with institutional structures.

Table 1: Socio-Demographic Characteristics of Respondents (n = 120)

Variable	Category	Frequency	Percentage (%)
Occupation	Farming	48	40.0
	Hunting	18	15.0
	Timber/logging	20	16.7
	Forest officials	10	8.3
	Others	24	20.0
Education	No formal Education	22	18.3
	Primary	36	30.0
	Secondary	42	35.0
	Tertiary	20	16.7
Years of residence	<10 years	46	38.3
	≥10 years	74	61.7

Awareness of Forest Laws and Information Channels

Awareness of forest laws among respondents was moderate: 65.0% reported awareness of at least One forest regulation, while 35.0% reported no awareness (Table 2). This suggests that a significant proportion of stakeholders still lack basic knowledge of forest governance frameworks, which may limit their ability to engage meaningfully in governance processes.The distribution of information sources reveals that both formal and informal communication channels shape awareness. Forestry officers (26.7%) and community meetings (23.3%) were the most prominent sources, indicating the continued relevance of institutional and community-based outreach mechanisms. Informal social networks, including friends and relatives (20.0%), also played a substantial role in disseminating information, highlighting the importance of social capital in

knowledge diffusion. Media channels such as radio (16.7%) and social media (13.3%) contributed to awareness, although to a lesser extent. The reliance on interpersonal and institutional channels suggests that awareness campaigns embedded within local governance structures may be more effective than purely media-based approaches. However, the relatively lower role of digital platforms indicates potential gaps in access to or utilization of modern communication tools in rural communities.

Table 2: Awareness of Forest Laws and Information Sources

Variable	Category	Frequency	Percentage (%)
Awareness	Aware	78	65.0
	Not aware	42	35.0
Information source	Forestry officers	32	26.7
	Community meetings	28	23.3
	Radio/media	20	16.7
	Friends/relatives	24	20.0
	Social media	16	13.3

Forms and Intensity of Community Participation

The results indicate that community participation in forest governance is present but limited in both scope and depth (Table 3). Participation is largely concentrated in a few activities, with reporting illegal activities being the most common form (25.0%). This is followed by tree planting (21.7%) and participation in awareness campaigns (16.7%). Patrol support accounts for 15.0% of responses, while 21.7% of respondents reported no participation at all. These findings suggest that participation is predominantly reactive and enforcement-oriented rather than proactive or decision-making-based. Activities such as reporting illegal practices indicate indirect engagement that supports institutional enforcement but does not necessarily reflect inclusion in governance processes. Similarly, involvement in tree planting and awareness campaigns reflects participation in implementation rather than planning or policy formulation. The relatively high non-participation rate (21.7%) further indicates that a significant segment of the population remains disengaged from forest governance activities. This may reflect barriers related to awareness, institutional trust, or livelihood constraints, which are explored in subsequent sections.

Table 3: Forms of Community Participation in Forest Governance

Participation Type	Frequency	Percentage (%)
Reporting illegal activities	30	25.0
Tree planting	26	21.7
Awareness campaigns	20	16.7
Patrol support	18	15.0
No participation	26	21.7

Institutional Perceptions and Governance Inclusiveness

Stakeholder perceptions of institutional arrangements reveal significant gaps in inclusiveness and fairness (Table 4). While respondents strongly agreed that forest laws are necessary for conservation (mean = 3.95) and for protecting future resources (mean = 3.80), their perceptions of governance processes were considerably less favorable. Perceived fairness of enforcement was relatively low (mean = 2.50), suggesting widespread concerns about equity and consistency in the application of forest regulations. Similarly, perceptions of community consultation in decision-making were even lower (mean = 2.38), indicating limited opportunities for stakeholders to influence governance processes meaningfully. Perceptions of fair treatment by forest officers (mean = 2.66) also reflected moderate dissatisfaction with institutional interactions. Notably, while respondents acknowledged that forest laws restrict livelihoods (mean = 3.73), they still recognized the deterrent value of penalties (mean = 3.50), indicating a pragmatic understanding of enforcement mechanisms. These results point to a disconnect between recognition of conservation goals and trust in governance systems. While stakeholders acknowledge the importance of forest laws, they perceive governance processes as insufficiently inclusive and potentially biased, which may undermine motivation to participate actively.

Table 4: Institutional Perceptions of Forest Governance (5-point Likert scale)

Statement	Mean	SD
Forest laws are necessary for conservation	3.95	0.92
Forest laws protect future resources	3.80	0.98
Forest laws restrict livelihoods	3.73	1.10
Penalties deter illegal activities	3.50	1.02
Forest officers treat communities fairly	2.66	1.15
Forest laws are fairly enforced	2.50	1.18
Communities are consulted in decision-making	2.38	1.20

Barriers to Effective Participation

The analysis of barriers reveals that both socio-economic and institutional factors constrain stakeholder participation in forest governance (Table 5). Poverty and dependence on forest resources emerged as the most significant constraint (31.7%), indicating that livelihood pressures limit stakeholders' capacity to engage in governance activities that may restrict resource use. When economic survival is contingent on forest exploitation, participation in conservation-oriented governance may be perceived as conflicting with immediate livelihood needs. Lack of awareness (24.2%) further limits participation by reducing understanding of governance processes and the opportunities available for engagement. Institutional challenges, including corruption and selective enforcement (18.3%), undermine trust in governance systems and discourage participation. When stakeholders perceive enforcement as inconsistent or corrupt, their motivation to engage diminishes substantially. Weak monitoring and logistical constraints (15.8%) also reduce the effectiveness of governance structures, limiting the practical channels through which stakeholders might contribute. The interaction between these factors suggests that participation is simultaneously constrained by structural economic conditions and institutional governance weaknesses, underscoring the need for integrated interventions that address both dimensions.

Table 5: Barriers to Community Participation in Forest Governance

Barrier	Frequency	Percentage (%)
Poverty and forest resource dependence	38	31.7
Lack of awareness	29	24.2
Corruption/selective enforcement	22	18.3
Weak monitoring and logistics	19	15.8
Other factors	12	10.0

Comparative Analysis Between Forest Reserves

A comparative analysis of the two study sites indicates that participation patterns are broadly similar in both the Eporo and Little Ose Forest Reserves. Although slight variations in mean participation levels and institutional perceptions were observed between the reserves, these differences were not statistically significant ($p > 0.05$). The independent-samples t-test results confirm that neither participation levels nor institutional trust scores differed meaningfully between the two sites. This finding suggests that the drivers and constraints of participation are not location-specific but are instead shaped by broader institutional and socio-economic conditions that transcend individual forest reserves. The systemic nature of these challenges implies that localized interventions targeting a single reserve are unlikely to produce transformative outcomes; rather, broad institutional reforms applicable across the forest governance system in southwestern Nigeria are required.

Table 6: Comparative Analysis of Participation Between Forest Reserves

Variable	Eporo Reserve	Little Ose Reserve	p-value
Mean participation score	2.61	2.49	> 0.05
Mean consultation score	2.42	2.34	> 0.05
Mean fairness score	2.54	2.46	> 0.05
% reporting no participation	20.0%	23.3%	> 0.05

Discussion

The findings reveal that participation in forest governance remains largely passive, despite moderate awareness levels. This suggests that awareness alone is insufficient to drive meaningful engagement, supporting previous findings that participation requires both knowledge and institutional inclusiveness (Oduro Appiah et al., 2021). The dominance of enforcement-support roles—such as reporting illegal activities—reflects a governance structure where communities are involved primarily as assistants rather than decision-makers, consistent with observations in other West African contexts (Ramcilovic-Suominen & Hansen, 2012). Low levels of perceived fairness and consultation highlight critical institutional weaknesses that undermine stakeholder engagement. According to procedural Justice theory, perceptions of fairness are central to legitimacy and compliance (Tyler, 2006). When communities perceive governance processes as exclusionary or arbitrarily enforced, their willingness to participate diminishes correspondingly.

The consistently low mean scores for consultation (2.38) and enforcement fairness (2.50) indicate that governance structures in both reserves fail to meet basic procedural inclusiveness standards, despite stakeholders recognizing that forest laws are necessary and important.

Socio-economic constraints, particularly poverty and dependence on forest resources, further limit participation. These findings align with studies showing that livelihood pressures often conflict with conservation objectives, creating a structural tension between participation in governance and the immediate economic needs of forest-dependent communities (Kaimowitz, 2003). This tension is particularly acute in contexts where no alternative livelihood options are available, rendering participation in potentially restrictive governance systems economically irrational for poor households. Corruption and selective enforcement also erode trust, reducing engagement and compliance (Sobeng et al., 2023). When stakeholders perceive that enforcement is applied inconsistently or that governance actors exploit their positions for personal gain, it fundamentally undermines the legitimacy of the governance system and the motivation to engage voluntarily. Addressing these trust deficits requires transparent and accountable institutional arrangements.

The absence of significant differences between the two forest reserves reinforces the interpretation that participation challenges are systemic rather than location-specific. This has important policy implications: interventions must target the broader governance framework rather than individual sites.

Conclusion

This study concludes that community participation in forest governance in southwestern Nigeria remains limited and largely passive, constrained by weak institutional inclusiveness, socio-economic pressures, and low levels of trust in governance structures. Although stakeholders recognize the importance of forest conservation, their involvement in decision-making processes is minimal, highlighting a gap between participatory governance principles and practical implementation. Strengthening participation requires a multi-pronged approach: improving transparency and accountability in enforcement, enhancing meaningful community consultation at the planning stage, and integrating livelihood support into forest management policies to reduce economic conflicts that deter engagement. Building institutional trust is foundational—communities that trust governance actors are more likely to participate, comply, and contribute to sustainable conservation outcomes. Future research should explore the longitudinal effects of participatory interventions and examine the role of customary institutions in bridging the gap between formal governance structures and community-level engagement in forest management in Nigeria.

References

Adegboyega, E. R., and Bolanle, A. O. (2021). Using forest resources for economic development and poverty reduction in Ekiti State. *International Journal of Applied Agricultural Sciences*, 7(4), 183–189. https://doi.org/10.11648/j.ijaas.20210704.17

Dietz, T., Ostrom, E., & Stern, P. C. (2003). The struggle to govern the commons. *Science,* 302(5652), 1907–1912. https://doi.org/10.1126/science.1091015

Elujulo, O., Adetula, O. I., Akinbowale, S. A., & Adelola, T. R. (2023). Dependence on forest resources and community perception of existing management strategies of Akure-Ofosu,

Oluwa, and Akure forest reserves in southwest Nigeria. *Journal of Applied Sciences and Environmental Management,* 27(1), 17–23. https://doi.org/10.4314/jasem.v27i1.4

Food and Agriculture Organization of the United Nations. (2020). Global Forest Resources Assessment 2020: Main report. FAO. https://doi.org/10.4060/ca9825en

Kaimowitz, D. (2003). Not by bread alone: Forests and rural livelihoods in sub-Saharan Africa. In T. Oksanen, B. Pajari, and T. Tuomasjukka (Eds.), Forests in poverty reduction strategies: Capturing the potential (pp. 45–76). European Forest Institute.

Oduro Appiah, J., Agyemang-Duah, W., Sobeng, A. K., & Kpienbaareh, D. (2021). Analyzing patterns of forest cover change and related land uses in the Tano-Offin forest reserve in Ghana: Implications for forest policy and land management. *Trees, Forests and People*, 5, 100105. https://doi.org/10.1016/j.tfp.2021.100105

Ramcilovic-Suominen, S., & Hansen, C. P. (2012). Why some forest rules are obeyed and others violated by farmers in Ghana: Instrumental and normative perspectives of forest law compliance. *Forest Policy and Economics,* 23, 46–54. https://doi.org/10.1016/j.forpol.2012.06.009

Siddique, M. R. H., Hossain, M., Rashid, A. Z. M. M., Shuvo, S. N., & Hasan, M. Z. (2026). Collaboration or capture? Unpacking the notion of forest governance in Madhupur and Lawachara forests of Bangladesh. *Environmental Policy and Governance*. Advance online publication. https://doi.org/10.1002/eet.2166

Sobeng, A. K., Oduro Appiah, J., Adei, D., Adomako, J., Agyemang-Duah, W., & Peprah, P. (2023). Community perception of forest reserve regulations enforcement in the Tano-Offin forest reserve, Ghana. *Cogent Social Sciences*, 9(1), 2154542. https://doi.org/10.1080/23311886.2022.2154542

Tyler, T. R. (2006). Why people obey the law (2nd ed.). Princeton University Press.

ISTF-NIGERIA 2026

ECOLOGICAL IMPACTS OF UNSUSTAINABLE WOOD HARVESTING IN ONIGAMBARI FOREST RESERVE, OYO STATE, NIGERIA

Akinyemi G.O.[1], Akinyemi I.G.[2], Owoeye Yewande[1] and Oyediran O.O.[3]

[1]Onigambari Research Station, Forestry Research Institute of Nigeria (FRIN), Ibadan, Nigeria
[2]Department of Crop Protection, Forestry Research Institute of Nigeria (FRIN), Ibadan, Nigeria
[3]Department of Basic Science and General Studies, Federal College of Forestry, Ibadan, Nigeria
Corresponding email: princetosyne@gmail.com

Abstract

Unsustainable wood harvesting remains a critical driver of forest degradation in tropical ecosystems, particularly where forest resources support rural livelihoods. This study assessed the ecological impacts of wood harvesting in the Onigambari Forest Reserve, Nigeria, focusing on forest structure, species composition, regeneration, soil properties, and community perceptions. A stratified random sampling design was employed across three disturbance gradients (core, moderately disturbed, and heavily disturbed zones), with data collected from fifteen 20 m × 20 m plots alongside a socio-economic survey. Results showed consistent declines in forest structural attributes with increasing disturbance. Mean tree height decreased from 24.6 m to 11.7 m, while basal area and tree density declined from 19.8 to 9.3 $m^2 ha^{-1}$ and 148 to 73 stems ha^{-1}, respectively. Canopy cover was reduced from 82% to 41%. Regeneration potential was significantly affected, with seedling and sapling densities decreasing markedly in disturbed zones. Key species, including *Triplochiton scleroxylon* and *Irvingia gabonensis*, showed reduced occurrence along the disturbance gradient. Soil analysis revealed progressive nutrient depletion, with organic matter declining from 3.9% to 2.0% and soil acidity increasing. Anthropogenic disturbance indicators increased substantially in heavily disturbed areas. Socio-economic findings indicated that 44.3% of respondents were involved in wood harvesting despite high awareness of its environmental consequences. The study concludes that unsustainable wood harvesting is driving structural simplification, reduced regeneration capacity, and soil degradation within the forest reserve, with significant implications for biodiversity conservation and ecosystem sustainability. Integrated management approaches combining regulated harvesting, community-based forest management, and alternative livelihood development are recommended to mitigate further degradation.

Keywords: Unsustainable wood harvesting; forest degradation; regeneration dynamics; soil fertility; community perception; tropical forest

Introduction

Tropical forests play a critical role in maintaining global biodiversity, regulating climate, and supporting the livelihoods of millions of people. In Nigeria, forest reserves remain important ecological assets, providing essential ecosystem services such as carbon sequestration, soil protection, and habitat provision, while also serving as key sources of income and subsistence for surrounding communities. However, these ecosystems are increasingly threatened by unsustainable wood harvesting practices, which contribute to the degradation of forest structure, loss of species diversity, and decline in soil fertility (Okon, 2018; Fuwape, 2001).

The Onigambari Forest Reserve, part of the larger Gambari forest complex in Southwestern Nigeria, exemplifies this challenge. The reserve comprises a mosaic of primary and secondary forest stands and supports a diversity of economically and ecologically important species, including *Triplochiton scleroxylon*, *Irvingia gabonensis*, and *Treculia africana* (Haastrup *et al*., 2020; Onyekwelu and Fuwape, 2013). Botanical assessments have further documented the presence of species such as *Cola gigantea* and *Pterygota macrocarpa*, underscoring the ecological significance of the reserve (Onyekwelu and Fuwape, 2013; FAO, 1999/2000). Despite its ecological value, the reserve is subjected to increasing anthropogenic pressure, largely driven by the dependence of nearby communities—Onipe, Onigambari, and Busogbooro—on forest resources for their livelihoods. Fuelwood extraction and marketing constitute major sources of household income (Okon, 2018), while non-timber forest products (NTFPs), including edible nuts and medicinal plants, contribute significantly to food security and rural well-being (Fadairo *et al*., 2021). This heavy reliance places considerable pressure on forest resources, often resulting in overexploitation.

Institutional limitations further exacerbate the situation. Forest governance in Nigeria is often constrained by weak enforcement capacity and inadequate implementation of regulatory frameworks. Existing policies, including provisions under the Land Use Act, have proven insufficient to curb illegal logging and the unregulated exploitation of forest resources (Oyediji and Adenika, 2022). Historical and empirical studies have shown that once tropical forests are degraded, particularly through repeated logging, natural regeneration becomes severely constrained without deliberate management interventions (FAO, 1999/2000). In Southwestern Nigeria, silvicultural studies have similarly demonstrated that intensive wood harvesting leads to soil nutrient depletion, reduced biodiversity, and impaired regeneration capacity (Onyekwelu and Fuwape, 2013).

Given the ecological importance of the Onigambari Forest Reserve and the increasing pressures it faces, there is a need for a comprehensive assessment of the impacts of unsustainable wood harvesting. This study therefore evaluated the effects of wood extraction on forest structure, species composition, regeneration dynamics, and soil fertility across a disturbance gradient within the reserve. In addition, it examined community perceptions of forest degradation to provide insights that can inform sustainable forest management strategies that balance conservation objectives with local livelihood needs.

Materials and Methods

Study Area

The study was conducted in the Onigambari Forest Reserve, located in southwestern Nigeria (Figure 1). The reserve is characterized by a tropical rainforest ecosystem comprising a mosaic of primary and secondary forest patches. Based on observable gradients in human activities and proximity to the forest interior, the study area was stratified into three disturbance categories. The core forest zone, situated in the interior, is relatively undisturbed and characterized by dense canopy cover, minimal anthropogenic interference, and high species diversity. The moderately disturbed zone, located between the core and buffer areas, exhibits evidence of selective logging

and partial canopy openings. In contrast, the heavily disturbed zone, primarily within the buffer areas, is subjected to intense anthropogenic pressures, including frequent wood harvesting, fuelwood collection, and localized agricultural encroachment.

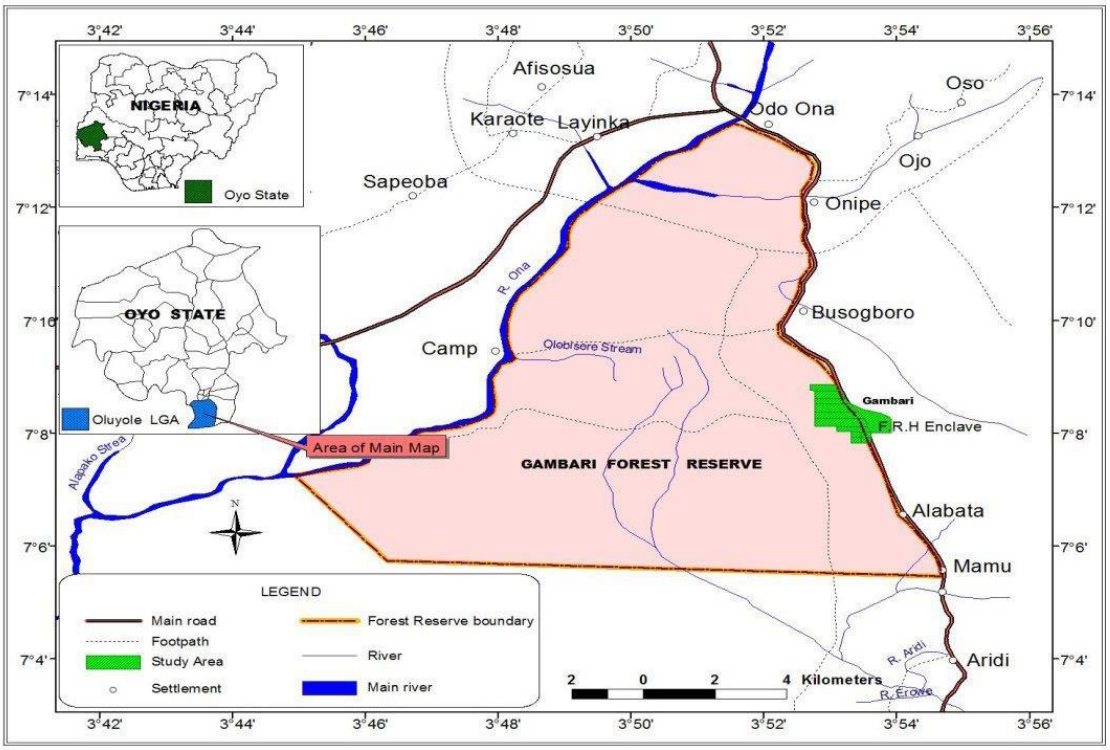


Figure 1: The Map of Onigambari Forest Reserve, Oyo State, Nigeria



Plate 1: Logs from Illegally Felled Teak (*Tectona grandis*) in Onigambari Forest Reserve



Plate 2: Logs from Illegally Felled *Cordia alliodora* in Onigambari Forest Reserve



Plate 3: Logs from Illegally Felled *Gmelina arborea* in Onigambari Forest Reserve

Sampling Design

A stratified random sampling approach was employed to capture ecological variability across the defined disturbance gradients. Each disturbance category constituted a stratum. Within each stratum, five sample plots measuring 20 m × 20 m (400 m²) were randomly established, resulting

in a total of fifteen plots across the study area. Plot locations were selected to adequately represent the vegetation structure and disturbance characteristics within each stratum.

Tree Inventory

Within each 20 m × 20 m plot, all trees with a diameter at breast height (DBH) ≥ 10 cm were identified, enumerated, and measured for total height. Species identification was carried out using standard botanical references, and where necessary, voucher specimens were collected for verification. Commonly encountered species included *Triplochiton scleroxylon*, *Irvingia gabonensis*, *Treculia africana*, *Cola gigantea*, and *Pterygota macrocarpa*. In addition to structural measurements, qualitative observations, such as tree health status and visible signs of harvesting (stumps, cut stems, and logging scars), were recorded. These data were used to assess forest composition, structure, and the extent of anthropogenic impact.

Assessment of Forest Disturbance

Forest disturbance within each plot was evaluated using direct field indicators of human activity. These included tree stumps, logging trails, charcoal production sites, evidence of bush burning, and timber residues such as off-cuts. The frequency and intensity of these indicators were used to validate and characterize the classification of plots into low, moderate, and high disturbance categories, thereby providing a spatial representation of anthropogenic pressure within the reserve.

Regeneration Assessment

Forest regeneration was assessed using nested subplots of 5 m × 5 m established within each main plot. Within these subplots, all seedlings (height < 1 m) and saplings (height ≥ 1 m and DBH < 10 cm) were counted and recorded. This approach enabled the evaluation of regeneration dynamics and recruitment potential across different disturbance levels.

Soil Sampling and Analysis

Soil samples were collected from a depth of 0–15 cm within each plot. Subsamples were taken from the four corners and the center of each plot and composited to obtain a representative sample. Laboratory analyses were conducted to determine key soil properties, including pH, organic matter content, total nitrogen, available phosphorus, and exchangeable potassium. These parameters were assessed to examine the influence of disturbance on soil fertility and its relationship with vegetation structure and regeneration.

Socio-Economic Survey

A socio-economic survey was conducted in communities surrounding the forest reserve, including Onipe, Onigambari, and Busogbooro. Structured questionnaires were administered to randomly selected adult respondents. Information collected included demographic characteristics, involvement in wood harvesting activities, awareness of forest regulations, and perceptions of the ecological impacts of resource exploitation. This component provided insights into the socio-economic drivers of forest disturbance and community–forest interactions.

Data Analysis

Collected data were analyzed using descriptive statistics, including means, frequencies, and percentages. Ecological variables such as tree density, species composition, and regeneration were compared across disturbance categories to evaluate the effects of unsustainable wood harvesting. Socio-economic data were analyzed to complement ecological findings, enabling an integrated assessment of the interactions between human activities and forest ecosystem dynamics.

Results

Forest Structure, Species Composition, and Regeneration

Marked differences in vegetation structure and composition were observed along the disturbance gradient in the Onigambari Forest Reserve. All structural attributes measured—mean tree height, basal area, tree density, and canopy cover—declined consistently from the core forest to the heavily disturbed zones, indicating progressive degradation associated with intensified wood harvesting. Mean tree height decreased from 24.6 m in the core forest to 11.7 m in heavily disturbed areas, reflecting the removal of mature, tall individuals and a shift toward shorter, secondary growth forms. A similar pattern was observed for basal area, which declined from 19.8 m^2 ha^{-1} in the core forest to 9.3 m^2 ha^{-1} in the buffer zones. This substantial reduction suggests a loss of large-diameter trees, a typical consequence of selective logging targeting commercially valuable species.

Tree density also showed a pronounced decline, dropping from 148 trees ha^{-1} in the core forest to 73 trees ha^{-1} in heavily disturbed areas. This reduction indicates both direct removal of trees and limited recruitment to replace harvested individuals. Canopy cover exhibited One of the most striking changes, decreasing from 82% in the undisturbed core to 41% in heavily disturbed zones. The resulting canopy openings likely alter microclimatic conditions—such as increased Light penetration and temperature—which can further influence species composition and regeneration dynamics. Regeneration indicators followed a similar declining trend. Seedling density decreased from 270 individuals ha^{-1} in the core forest to 97 individuals ha^{-1} in heavily disturbed areas, while sapling density declined from 95 to 34 individuals ha^{-1}. These reductions suggest that unsustainable harvesting not only affects existing forest structure but also compromises future forest recovery by limiting recruitment and establishment of young plants (Table 1).

The distribution of dominant species further highlights the ecological impact of disturbance. Key species such as *Triplochiton scleroxylon*, *Irvingia gabonensis*, *Treculia africana*, *Cola gigantea*, and *Pterygota macrocarpa* were most abundant in the core forest. They showed a steady decline in frequency toward the disturbed zones. For instance, *Triplochiton scleroxylon*, a highly valued timber species, decreased markedly in disturbed areas, reflecting targeted extraction (Table 2). Similarly, *Irvingia gabonensis*, an important non-timber forest product species, exhibited reduced occurrence, suggesting that both timber and livelihood-supporting species are being depleted. The observed patterns indicate that unsustainable wood harvesting is driving structural simplification, species depletion, and reduced regenerative capacity within the forest reserve. The combined decline in canopy cover, tree density, and regeneration potential underscores a trajectory toward ecological instability, with implications for biodiversity conservation and long-term forest productivity.

Table 1: Forest structural characteristics across disturbance levels

Parameter	Core Forest	Moderately Disturbed	Heavily Disturbed
Mean tree height (m)	24.6	18.3	11.7
Basal area (m^2 ha^{-1})	19.8	14.5	9.3
Tree density (stems ha^{-1})	148	112	73
Canopy cover (%)	82	64	41
Seedlings (ha^{-1})	270	180	97
Saplings (ha^{-1})	95	61	34

Table 2: Distribution of dominant tree species across disturbance levels

Species	Core Forest	Moderately Disturbed	Heavily Disturbed
Triplochiton scleroxylon	14	10	5
Irvingia gabonensis	9	6	2
Treculia Africana	11	7	4
Cola gigantean	12	8	3
Pterygota macrocarpa	8	5	2

Soil Properties and Disturbance Indicators

Soil physicochemical properties exhibited a clear declining trend along the disturbance gradient in the Onigambari Forest Reserve, reflecting the influence of unsustainable wood harvesting on soil quality. Soil pH decreased from 6.5 in the core forest to 5.8 in heavily disturbed areas, indicating a shift toward increased acidity. This pattern is commonly associated with nutrient depletion and reduced buffering capacity following continuous biomass removal and exposure of soil surfaces. Organic matter content showed a substantial decline from 3.9% in the core forest to 2.0% in heavily disturbed zones. This reduction suggests diminished litter input and accelerated decomposition rates due to canopy opening and increased soil temperature. Given the central role of organic matter in maintaining soil structure, water retention, and nutrient cycling, its depletion is a strong indicator of declining soil fertility (Table 3).

Similarly, key macronutrients—including nitrogen, phosphorus, and potassium—declined progressively with increasing disturbance intensity. Total nitrogen decreased from 0.23% to 0.12%, while available phosphorus and exchangeable potassium showed comparable reductions. These trends indicate that repeated harvesting and associated disturbances are disrupting nutrient cycling processes, leading to reduced soil productivity and potentially constraining vegetation recovery. Anthropogenic disturbance indicators further corroborated the extent of ecological degradation across the forest zones. The number of tree stumps increased markedly from 8 in the core forest to 42 in heavily disturbed areas, reflecting intensified logging pressure. Likewise, the frequency of logging tracks and timber off-cuts increased substantially, suggesting not only higher extraction rates but also inefficient harvesting practices that contribute to additional biomass loss and site disturbance.

The prevalence of charcoal kilns rose sharply from 1 in the core forest to 25 in heavily disturbed zones, highlighting the growing importance of charcoal production as a driver of forest exploitation. In addition, the occurrence of bush-burning scars increased with disturbance intensity, indicating recurrent fire events that can further degrade soil quality, reduce seed viability, and hinder forest regeneration. Overall, the combined decline in soil fertility parameters and the increase in disturbance indicators demonstrate a strong linkage between unsustainable wood harvesting and ecosystem degradation. The deterioration of soil quality, coupled with intensified human activity, suggests a feedback mechanism in which degraded soils limit vegetation recovery, thereby increasing the forest's vulnerability to further exploitation and long-term ecological decline (Table 4).

Table 3: Soil physicochemical properties across disturbance levels in the Onigambari forest reserve

Parameter	Core Forest	Moderately Disturbed	Heavily Disturbed
pH	6.5	6.2	5.8
Organic matter (%)	3.9	2.8	2.0
Total nitrogen (%)	0.23	0.18	0.12
Available phosphorus (mg kg^{-1})	11.5	8.4	6.3
Exchangeable potassium (cmol kg^{-1})	0.41	0.31	0.24

Table 4: Indicators of Anthropogenic Disturbance Across Forest Zones

Indicator (No. per transect)	Core Forest	Moderately Disturbed	Heavily Disturbed
Tree stumps	8	21	42
Logging tracks	3	11	17
Charcoal kilns	1	12	25
Bush-burning scars	2	9	13
Timber off-cuts	4	12	19

Socio-economic Characteristics and Perceptions of Harvesting Impacts

Communities surrounding the Onigambari Forest Reserve—including Onipe, Onigambari, and Busogbooro—demonstrated a high level of dependence on forest resources, particularly wood harvesting as a livelihood activity. Approximately 44.3% of respondents reported active involvement in wood extraction, underscoring the socio-economic importance of forest resources to local households. Farming was identified as the primary occupation (49%), indicating a strong linkage between agricultural livelihoods and forest resource use. The demographic structure revealed a predominance of male respondents (70%) and a relatively mature population, with over 60% aged 40 or older. This suggests that economically active adults largely undertake forest exploitation activities with long-standing familiarity with the forest environment (Table 5).

Awareness of forest regulations was moderate (59.3%), indicating some level of institutional knowledge; however, this has not translated into reduced exploitation pressure. This gap between awareness and compliance highlights potential weaknesses in enforcement mechanisms and the influence of livelihood needs on resource use decisions. Perceptions of ecological change were notably high across all communities. A substantial proportion of respondents (86.7%) reported a decline in tree cover, making it the most widely recognized impact of wood harvesting. Similarly, 81.7% observed a reduction in wildlife populations, suggesting that habitat degradation is already affecting faunal diversity. Perceived declines in soil fertility (73.7%) and increases in soil erosion (68.0%) further indicate that local communities are experiencing the consequences of land degradation associated with forest disturbance.

In addition, over 60% of respondents reported losses in non-timber forest products and deterioration in water quality. These findings point to broader declines in ecosystem services beyond timber resources, affecting food security, household income, and environmental health.
Overall, the socio-economic data align closely with the ecological findings, reinforcing the conclusion that unsustainable wood harvesting is driving both environmental degradation and livelihood vulnerability. The high level of local awareness of these impacts suggests an opportunity to adopt participatory forest management approaches that integrate community knowledge with sustainable resource-use strategies.

Table 5: Socio-economic characteristics and perceptions of wood harvesting impacts in communities surrounding the Onigambari forest reserve

Variable	Onipe (%)	Onigambari (%)	Busogbooro (%)	Overall (%)
Male respondents	72	70	68	70.0
Age > 40 years	61	64	59	61.3
Primary occupation: Farming	49	46	52	49.0
Involvement in wood harvesting	38	44	51	44.3
Awareness of forest regulations	65	59	54	59.3
Reduction in tree cover	82	87	91	86.7
Decline in wildlife populations	78	82	85	81.7
Reduced soil fertility	70	74	77	73.7
Increased soil erosion	62	69	73	68.0
Loss of non-timber forest products	58	63	70	63.7
Decline in water quality	55	61	65	60.3

Note: Values represent the percentage of respondents within each community who agreed with each statement. Responses are independent across variables; therefore, percentages are not expected to sum to 100%

Discussion

The findings of this study demonstrate a clear and consistent pattern of ecological degradation driven by unsustainable wood harvesting in the Onigambari Forest Reserve. The marked

reductions in tree density, basal area, and canopy cover across the disturbance gradient indicate substantial biomass loss and progressive structural simplification of the forest. For instance, the near halving of canopy cover and significant decline in basal area in heavily disturbed zones highlight the intensity of extraction pressure. These observations are consistent with reports from other forest ecosystems in Nigeria, where similar structural degradation has been linked to intensive logging and anthropogenic disturbances (Okon, 2018; Onyekwelu and Fuwape, 2013). The selective removal of economically valuable species—particularly *Triplochiton scleroxylon*—suggests a strong market-driven exploitation pattern, reinforcing findings from tropical forest systems where high-value species are disproportionately targeted (Okon, 2018).

Regeneration patterns observed in this study further indicate declining forest resilience. The substantial reduction in both seedling and sapling densities in disturbed areas suggests that recruitment processes are severely constrained. This limitation is likely a combined effect of canopy opening, soil degradation, and repeated disturbance. Similar findings have been reported in degraded forests in southwestern Nigeria, where high harvesting intensity suppresses regeneration and disrupts species replacement (Onyekwelu and Fuwape, 2013). The implication is that continued disturbance may result in long-term shifts in species composition, reduced biodiversity, and eventual ecosystem instability.

Soil analysis provides additional evidence of ecosystem decline. The progressive reductions in organic matter and essential nutrients (nitrogen, phosphorus, and potassium) across disturbance levels indicate declining soil fertility. These changes are likely associated with reduced litter input, increased soil exposure, compaction from logging activities, and erosion. Importantly, the observed soil degradation is not only a consequence of forest disturbance but also a reinforcing factor limiting regeneration. This soil–vegetation feedback mechanism has been highlighted in previous studies and global assessments by the Food and Agriculture Organization (FAO, 1999/2000), emphasizing the central role of soil quality in sustaining forest productivity and recovery (Fuwape, 2001; Onyekwelu and Fuwape, 2013).

The socio-economic findings reveal that forest degradation is closely linked to livelihood dependence. In Onipe, Onigambari, and Busogbooro, wood harvesting remains a key economic activity, despite widespread awareness of its ecological consequences. The high proportion of respondents reporting declines in tree cover, wildlife populations, and soil fertility indicates that environmental degradation is both observable and experienced at the community level. However, continued exploitation reflects a classic livelihood–conservation trade-off, where limited economic alternatives compel resource-dependent communities to prioritize immediate survival over long-term sustainability (Fadairo *et al*., 2021; Oyediji and Adenika, 2022).

Institutional constraints further exacerbate this situation. Weak enforcement of forest regulations and limited community involvement in management have allowed unsustainable practices to persist. This aligns with broader assessments of forest governance in Nigeria, where inadequate institutional capacity and poor stakeholder engagement undermine conservation efforts (Oyediji and Adenika, 2022). Without effective governance structures, even well-designed policies are unlikely to yield meaningful outcomes.

Addressing these challenges requires an integrated and context-specific management approach. Regulated harvesting systems should be implemented, particularly within buffer zones, to control the extraction of high-value species and prevent further degradation. Strengthening community-based forest management (CBFM) is essential to enhance local participation, promote stewardship, and align conservation objectives with livelihood needs. In addition, restoration interventions—such as enrichment planting of indigenous species—should be prioritized in degraded areas to accelerate recovery, as supported by previous silvicultural studies (Onyekwelu and Fuwape, 2013). Finally, improving institutional capacity for monitoring and enforcement, alongside the development of alternative livelihood options, will be critical in reducing dependence on unsustainable wood harvesting and ensuring the long-term sustainability of the forest (Fadairo et al., 2021).

Conclusion

The consistent decline in forest structural attributes—tree density, basal area, canopy cover, and tree height—across disturbance gradients reflects significant biomass loss and structural simplification. In addition, the reduction in seedling and sapling densities indicates impaired natural regeneration, suggesting that the long-term sustainability of the forest is under serious threat. The deterioration of soil properties, including reductions in organic matter and essential nutrients, further highlights the extent of ecosystem disruption. These changes not only limit vegetation growth but also weaken the forest's capacity to recover from disturbance. The increasing prevalence of anthropogenic disturbance indicators, such as tree stumps, charcoal kilns, and logging tracks, confirms the intensity and persistence of human pressure within the reserve. Findings from the surrounding communities—Onipe, Onigambari, and Busogbooro—reveal a strong dependence on forest resources for livelihoods. Although there is considerable awareness of environmental degradation, economic necessity continues to drive wood harvesting activities. This underscores the complex interaction between ecological sustainability and rural livelihoods. The study establishes a clear linkage between unsustainable harvesting practices, ecological degradation, and socio-economic dependence on forest resources. Without timely intervention, continued exploitation may lead to further biodiversity loss, reduced ecosystem services, and diminished forest resilience. To ensure the long-term sustainability of the forest, integrated management strategies are needed that combine regulated harvesting, ecological restoration, strengthened institutional enforcement, and community-based forest management. Equally important is promoting alternative livelihood options to reduce pressure on forest resources. Such coordinated efforts are essential to balance conservation objectives with the socio-economic realities of forest-dependent communities.

References

Adekunle, V. A. J., Olagoke, A. O., and Akindele, S. O. (2010). Rate of timber production in a tropical rainforest ecosystem of southwestern Nigeria and its implications on sustainable forest management. *Journal of Forestry Research,* 21(3), 317–323. https://doi.org/10.1007/s11676-010-0037-8

Agbelade, A. D., Onyekwelu, J. C., and Oyun, M. B. (2017). Tree species richness, diversity, and vegetation index for Federal Capital Territory, Abuja, Nigeria. *International Journal of Forestry Research,* 2017, Article 4549756. https://doi.org/10.1155/2017/4549756

Fadairo, O., Adelakun, O., Olutegbe, S., and Adeleke, O. (2021). Climate change, rural livelihoods, and ecosystem nexus: Forest communities in agro-ecological zones of Nigeria. In W. L. Filho, N. Oguge, D. Ayal, L. Adeleke, and I. da Silva (Eds.), *African Handbook of Climate Change Adaptation* (pp. 1–18). Springer, Cham. https://doi.org/10.1007/978-3-030-42091-8_155-1

FAO. (1999/2000). *Workshop on Tropical Secondary Forest Management in Africa: Reality and Perspectives.* Food and Agriculture Organization of the United Nations. https://www.fao.org/4/j0628e/J0628E59.htm

Fuwape, J. A. (2001). The impacts of forest industries and wood utilization on the environment. *Journal of Tropical Forest Resources,* 17(2), 78–90. https://www.fao.org/4/XII/0122-A2.htm

Haastrup, N., Agboje, I., Lawal, M., Fadimu, B., Sangotoyinbo, O., Mangodo, C., Oripelaye, O., Ganiyu, O., and Fadoyin, A. (2020). Composition of tree species in Onigambari Forest Reserve, Oyo State, Nigeria. *Journal of Applied Sciences and Environmental Management,* 24(10), 1815–1819. https://doi.org/10.4314/jasem.v24i10.16

Okon, K. (2018). Sustainability of wood harvesting in the tropical rainforest of Nigeria. *Eurasian Journal of Forest Science,* 6(2), 44–55. https://doi.org/10.31195/ejejfs.427416

Oloyede, J. O., Okimiji, O. P., and Oloketuyi, A. J. (2025). Massive destruction of tropical rainforests and their significant impact on environmental temperatures in southwest Nigeria. *Discover Global Society,* 3, 110. https://doi.org/10.1007/s44282-025-00196-3

Onyekwelu, J. C., and Fuwape, J. A. (2013). A silvicultural approach to volume yield, biodiversity, and soil fertility restoration of degraded natural forest in South-West Nigeria. *International Journal of Biodiversity Science, Ecosystem Services and Management,* 9(4), 282–291. https://doi.org/10.1080/21513732.2013.823464

Onyekwelu, J. C., Mosandl, R., and Stimm, B. (2008). Tree species diversity and soil status of primary and degraded tropical rainforest ecosystems in south-western Nigeria. *Journal of Tropical Forest Science,* 20(3), 193–204. https://www.jstor.org/stable/23616500

Oyediji, O. T., and Adenika, O. A. (2022). Forest degradation and deforestation in Nigeria: Poverty link. *International Journal of Multidisciplinary Research and Analysis,* 5(10), 2837–2880. https://doi.org/10.47191/ijmra/v5-i10-35

EFFECTS OF RECURRENT FIRE ON VEGETATION STRUCTURE AND REGENERATION DYNAMICS IN ONIGAMBARI FOREST RESERVE, NIGERIA

Akinyemi, G. O.; Akinyemi, I. G., and Owoeye, Yewande

Forestry Research Institute of Nigeria (FRIN), Ibadan, Nigeria
Corresponding email: princetosyne@gmail.com

Abstract

Recurrent fire is a major ecological disturbance influencing vegetation dynamics in tropical forest ecosystems, yet its effects remain insufficiently documented in many West African forest reserves. This study assessed the impacts of repeated fire events on vegetation structure, regeneration, and fire severity in Onigambari Forest Reserve. A total of twelve 20 m × 20 m plots were established, comprising six burned plots exposed to recurrent annual fires and six unburned control plots. Vegetation structure was evaluated using tree density, basal area, canopy cover, and litter depth, while regeneration was assessed through seedling and sapling densities within nested subplots. Fire severity was quantified using bark charring, scorch height, and ash depth. Results revealed significant reductions in vegetation structural attributes in burned plots, with lower tree density (214 ± 18 stems ha^{-1} vs. 362 ± 25 stems ha^{-1}), basal area (7.8 ± 0.65 m^2 ha^{-1} vs. 12.4 ± 0.92 m^2 ha^{-1}), canopy cover (38 ± 4.5% vs. 61 ± 5.2%), and litter depth (2.1 ± 0.3 cm vs. 4.6 ± 0.5 cm) compared to unburned plots. Regeneration was also markedly suppressed, as indicated by substantial declines in both seedling (482 ± 37 ha^{-1} vs. 921 ± 44 ha^{-1}) and sapling densities (176 ± 21 ha^{-1} vs. 391 ± 28 ha^{-1}) in fire-affected areas. Fire severity indicators (bark charring: 2.3 ± 0.4; scorch height: 3.2 ± 0.5 m; ash depth: 1.8 ± 0.3 cm) suggested moderate to high intensity, sufficient to impact both mature trees and regenerating individuals. The findings demonstrate that recurrent fire not only alters forest structure but also constrains regeneration processes, thereby reducing ecosystem resilience and potentially affecting long-term carbon storage capacity. Effective fire management and restoration interventions are therefore essential to mitigate these impacts and support sustainable forest conservation.

Keywords: Fire disturbance; vegetation structure; regeneration dynamics; tropical forest; fire severity; forest resilience

Introduction

Fire is a key ecological process influencing the structure, composition, and functioning of many tropical and subtropical ecosystems (Boshoff, 2024). In forest–savanna transition zones, where climatic and ecological conditions permit the coexistence of woody and grassy vegetation, fire plays a particularly important role in regulating vegetation dynamics. Recurrent burning can act as a strong selective force, favoring fire-adapted species while suppressing the establishment and persistence of shade-tolerant, closed-canopy tree species (Hoffmann, 2000; Bond *et al.*, 2002). Through these mechanisms, fire helps maintain distinct vegetation states and can reinforce boundaries between forest and savanna systems. A growing body of empirical and modeling studies highlights the importance of fire–vegetation feedbacks in sustaining alternative stable states within these landscapes. Frequent fires reduce woody biomass and canopy closure,

promoting the growth of flammable grasses that, in turn, increase fire frequency and intensity. Such feedback mechanisms can stabilize open vegetation systems and limit the transition to closed-canopy forest, particularly when disturbance thresholds are repeatedly exceeded (Hoffmann, 2000; Shen *et al.,*2025).

In West Africa, many forest reserves are increasingly exposed to anthropogenic fire regimes driven by activities such as land clearing, hunting, and resource extraction. These human-induced fires often occur at higher frequencies and intensities than natural fire regimes, posing significant threats to forest regeneration and long-term ecosystem stability (Wright & He, 2008; Ribeiro *et al*., 2019). Repeated burning can damage juvenile plants, reduce seed bank viability, and disrupt successional processes, ultimately leading to simplified vegetation structure and reduced biomass accumulation (Cury *et al*., 2020; Kofi *et al.*, 2018). Experimental evidence further indicates that frequent fires can significantly reduce seedling diversity and recruitment, particularly in ecotonal and edge environments where forests are already vulnerable to disturbance (Cury *et al*., 2020). Onigambari Forest Reserve lies within this fire-prone forest–savanna transition zone and represents a critical landscape for understanding the ecological consequences of recurrent burning. Despite its protected status, the reserve experiences frequent fires each year, which may be altering its vegetation structure and limiting its capacity for natural regeneration. However, there is a paucity of site-specific empirical data quantifying these impacts within the reserve.

This study, therefore, examined the effects of recurrent fire on key ecological attributes of the forest. Specifically, it compared vegetation structure measured through tree density, basal area, canopy cover, and litter depth and regeneration dynamics, assessed via seedling and sapling densities, between burned and unburned areas. By providing quantitative evidence of fire impacts, the study aims to inform sustainable fire management and restoration strategies to maintain the ecological integrity and resilience of the forest ecosystem.

Materials and Methods

Study Area

The study was conducted in Onigambari Forest Reserve (Figure 1), situated within the forest–savanna ecotone of southwestern Nigeria. The reserve experiences a tropical climate characterized by distinct wet and dry seasons, with rainfall typically occurring between April and October and a pronounced dry season from November to March. Vegetation within the reserve comprises a mosaic of secondary forest, woodland, and regenerating patches resulting from varying degrees of anthropogenic disturbance. The area is subject to recurrent human-induced activities, including fuelwood harvesting, selective logging, and annual bush burning. These disturbances have contributed to alterations in vegetation structure and composition over time. The ecological significance of the reserve, coupled with its history of recurrent fire events, makes it an appropriate site for examining the effects of recurrent fire on vegetation dynamics and regeneration.

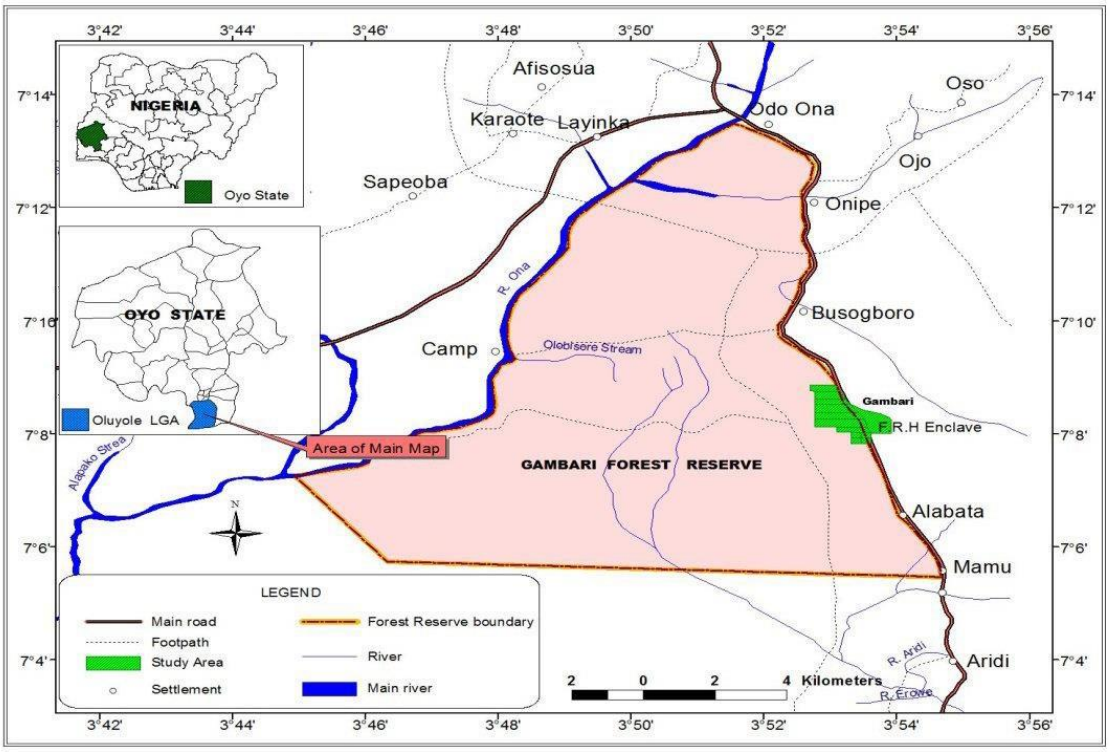


Figure 1: The Map of Onigambari Forest Reserve, Oyo State, Nigeria

Plot Establishment and Fire Regime Classification

A total of twelve square sample plots (20 m × 20 m) were systematically established across the study area. The plots were categorized into two groups based on fire history: six plots located in areas subjected to recurrent annual burning (hereafter referred to as burned plots) and six plots situated in areas without recent fire incidence, serving as unburnt controls. Fire occurrence and classification were determined through a combination of field-based evidence and local ecological knowledge. Indicators such as charred tree bark, scorch marks, ash deposits, and visible fire scars were used to identify previously burned sites. To reduce environmental variability and ensure comparability between treatments, plots were selected to have similar topographic conditions, soil characteristics, and pre-disturbance vegetation attributes.

Vegetation Structure Assessment

Within each 20 m × 20 m plot, all woody plants with a diameter at breast height (DBH) ≥ 5 cm were enumerated and measured. DBH was recorded at 1.3 m above ground level with a diameter tape, and total tree height was measured with a clinometer. Tree density was expressed as the number of stems per hectare, standardized from plot-level counts. Basal area (m^2 ha^{-1}) was calculated for individual trees using standard allometric relationships and subsequently aggregated at the plot level. Canopy cover was estimated using a spherical densiometer at five randomly selected points within each plot, and the average value was computed. Litter depth was measured at 10 systematically distributed points per plot using a graduated ruler, and the mean litter depth was determined for each plot.

Regeneration Assessment

Regeneration was evaluated by enumerating seedlings and saplings within nested subplots. Five subplots measuring 5 m × 5 m were established within each main plot. Seedlings were defined as individuals with a height < 1 m, while saplings were defined as individuals with a height between 1 and 3 m and a DBH < 5 cm. All individuals within these categories were identified to species level where possible and counted. Regeneration density (individuals per hectare) and species composition were derived from these data to assess the influence of fire on recruitment patterns and vegetation recovery.

Fire Severity Assessment

Fire severity within burned plots was evaluated using a set of field-based qualitative and semi-quantitative indicators. Bark charring was assessed on an ordinal scale ranging from 0 (no visible charring) to 3 (severe charring). Scorch height, defined as the vertical extent of fire damage on tree stems, was measured in meters from ground level. Ash depth was measured in centimeters at multiple intervals within each plot and averaged to estimate fire residue intensity. These indicators collectively served as proxies for fire intensity and its potential ecological impact on vegetation structure and regeneration.

Data Analysis

All collected data were subjected to preliminary screening to assess assumptions of normality and homogeneity of variance. Descriptive statistics were computed for all measured variables, including tree density, basal area, canopy cover, litter depth, and regeneration density. Differences between burned and unburnt plots were evaluated using one-way analysis of variance (ANOVA) at a significance level of $p < 0.05$. Where necessary, appropriate data transformations were applied to meet statistical assumptions. All statistical analyses were performed in R, and results were presented in tables and graphical representations to facilitate comparison among fire regimes.

Results and Discussion

Vegetation structural attributes differed significantly between burned and unburned plots (Table 1). Mean tree density in burned plots was 214 ± 18 stems ha^{-1}, which was significantly lower than the 362 ± 25 stems ha^{-1} recorded in unburned plots ($p < 0.05$). A similar pattern was observed for basal area, with burned plots exhibiting 7.8 ± 0.65 m^2 ha^{-1}, compared to 12.4 ± 0.92 m^2 ha^{-1} in unburned plots, indicating a substantial reduction in stand biomass under recurrent fire conditions. Canopy cover was also markedly reduced in burned plots (38 ± 4.5%) relative to unburned plots (61 ± 5.2%), reflecting the structural simplification of the vegetation. In addition, litter depth was significantly lower in burned areas (2.1 ± 0.3 cm) compared to unburned plots (4.6 ± 0.5 cm), suggesting direct consumption of organic material by fire and reduced litter accumulation.

These findings demonstrate that recurrent fire significantly modifies vegetation structure by reducing tree abundance, biomass, canopy closure, and forest floor development. The observed decline in tree density and basal area in burned plots suggests that repeated fire events not only

cause direct tree mortality but also inhibit long-term growth and stand development. This aligns with ecological theory and empirical evidence indicating that fire serves as a key disturbance agent that maintains open vegetation states. In particular, fire can impose ecological thresholds that limit woody plant dominance and promote alternative vegetation states, such as savanna-like systems. Previous studies have shown that fire selectively removes less fire-tolerant species while favoring species with adaptive traits such as thick bark or resprouting ability (Hoffmann, 2000). Furthermore, recent advances in spatially explicit fire–vegetation models demonstrate that frequent burning can reinforce feedback mechanisms between vegetation structure and fire regimes, thereby stabilizing landscapes in alternative states depending on disturbance frequency and intensity (Shen *et al.,*2025).

Table 1: Vegetation structure in burned and unburned plots

Parameter	Burned Plots (Mean ± SD)	Unburned Plots (Mean ± SD)
Tree density (stems ha^{-1})	214 ± 18	362 ± 25
Basal area (m^2 ha^{-1})	7.8 ± 0.65	12.4 ± 0.92
Canopy cover (%)	38 ± 4.5	61 ± 5.2
Litter depth (cm)	2.1 ± 0.3	4.6 ± 0.5

Regeneration patterns varied markedly between burned and unburned plots (Table 2). Mean seedling density in burned plots was 482 ± 37 individuals ha^{-1}, representing a reduction of approximately 48% compared to 921 ± 44 individuals ha^{-1} recorded in unburned plots. A similar trend was observed for saplings, with burned plots supporting 176 ± 21 individuals ha^{-1}, significantly lower than the 391 ± 28 individuals ha^{-1} observed in unburned areas. These reductions indicate a pronounced limitation in recruitment on fire-affected sites, suggesting that recurrent burning disrupts establishment and survival during early life stages. The consistently lower densities of both seedlings and saplings in burned plots highlight a critical regeneration bottleneck, which may compromise long-term forest recovery and structural stability.

The observed decline in regeneration aligns with findings from experimental fire studies in tropical ecosystems, where high-frequency fire regimes have been shown to reduce seedling abundance and diversity, diminish seed bank viability, and shift regeneration strategies toward vegetative resprouting rather than seed-based recruitment (Cury *et al*., 2020). This shift in regeneration mode has important ecological consequences, as repeated top-kill events can prevent juvenile plants from reaching maturity, thereby limiting population turnover and reducing ecosystem resilience. Evidence from Amazonian forest experiments further supports these patterns, demonstrating that recurrent understory fires can promote resprouting while simultaneously causing substantial declines in species richness, particularly among rare and fire-sensitive taxa (Brando *et al*., cited in Cury *et al*., 2020). The patterns observed in this study are consistent with these findings, as the reduced regeneration densities in burned plots suggest that repeated fire events selectively favor fire-tolerant and resprouting species. Over time, such selective pressures may lead to compositional shifts and a gradual erosion of overall biodiversity.

Table 2: Seedling and sapling densities in burned and unburned plots

Parameter	Burned Plots (Mean ± SD)	Unburned Plots (Mean ± SD)
Seedling density (ha^{-1})	482 ± 37	921 ± 44
Sapling density (ha^{-1})	176 ± 21	391 ± 28

Field-based indicators revealed that fire severity within burned plots ranged from moderate to high (Table 3). Bark charring recorded a mean score of 2.3 ± 0.4 on a 0–3 ordinal scale, indicating substantial thermal impact on tree stems. Similarly, mean scorch height reached 3.2 ± 0.5 m, suggesting that flames extended well into the lower canopy layer. Ash depth averaged 1.8 ± 0.3 cm, reflecting considerable combustion of surface fuels. Collectively, these indicators demonstrate that fire intensity was sufficient to affect both mature trees and regenerating individuals. The observed severity levels provide a mechanistic explanation for the reduced vegetation density, lower basal area, and impaired regeneration recorded in burned plots. High-intensity fires are known to cause cambial damage, increase tree mortality, and reduce seedling survival, thereby contributing to the structural and compositional differences between burned and unburned areas.
The structural changes observed in burned plots—particularly reduced canopy cover, diminished litter accumulation, and suppressed regeneration—suggest the emergence of a self-reinforcing vegetation–fire feedback system. Reduced canopy closure increases Light penetration to the forest floor, promoting the proliferation of flammable understory vegetation such as grasses. This, in turn, enhances fine fuel availability, increasing the likelihood and intensity of subsequent fire events. Such feedback mechanisms are central to fire ecology theory and underpin the concept of alternative stable states, in which ecosystems may shift from closed-canopy forests to more open, fire-maintained systems. Once this transition occurs, recovery to the original forest state can be constrained by persistent fire–vegetation interactions (Shen *et a*l., 2025).

Beyond structural implications, recurrent fire regimes may also influence ecosystem carbon dynamics. Modeling studies in southern African landscapes have demonstrated that frequent fires can reduce tree cover, leaf area index, and net primary productivity, ultimately leading to long-term declines in carbon storage (Huang *et a*l., 2021). Although carbon stocks were not directly quantified in this study, the observed reductions in basal area and vegetation density strongly suggest a diminished capacity for carbon sequestration in fire-affected areas. These findings highlight the dual role of fire as both a disturbance agent and a driver of ecosystem state transitions, with significant implications for forest management, biodiversity conservation, and climate regulation.

Table 3: Fire severity indicators in burned plots

Indicator	Burned Plots (Mean ± SD)
Bark charring (0–3)	2.3 ± 0.4
Scorch height (m)	3.2 ± 0.5
Ash depth (cm)	1.8 ± 0.3

Management implications for fire-affected forest systems

The pronounced negative effects of recurrent fire on vegetation structure and regeneration observed in this study underscore the need for proactive, adaptive fire management strategies in the Onigambari Forest Reserve. Without intervention, continued fire disturbance may further

degrade forest structure, suppress recruitment, and reinforce a shift toward more open, low-biomass vegetation states. A range of management approaches can be considered to mitigate these impacts and enhance ecosystem recovery:

1. **Fire regime modification:** Adjusting the frequency and intensity of fire through controlled burning or fire exclusion measures may create favorable conditions for tree regeneration. In managed woodland systems, interventions such as regulated burning and protective measures have been shown to enhance seedling establishment and improve sapling survival rates (Cochrane, 2003; Johansson *et al*., 2021). Carefully designed fire regimes can therefore balance ecological processes while minimizing destructive impacts.
2. **Fuel load management:** The accumulation of fine fuels, particularly grasses and dry litter, plays a critical role in driving fire intensity. Strategic fuel management, such as creating firebreaks, selectively removing combustible materials, or controlled grazing, can reduce fire spread and severity. By limiting fuel continuity, these practices may help disrupt the positive feedback loop that sustains recurrent fire and open vegetation conditions.
3. **Assisted natural regeneration:** Active restoration interventions, including enrichment planting of native late-successional tree species, can accelerate vegetation recovery in degraded or repeatedly burned areas. This approach can enhance structural complexity, improve species diversity, and facilitate the re-establishment of closed-canopy conditions, particularly in areas where natural regeneration is severely constrained.
4. **Long-term ecological monitoring:** Establishing permanent monitoring plots is essential for evaluating vegetation responses under varying fire regimes over time. Continuous monitoring enables the assessment of regeneration trajectories, species turnover, and structural recovery, while also providing early warning signals of potential regime shifts toward fire-adapted, low-diversity systems. Such data are critical for informing adaptive management and evidence-based conservation planning.

Conclusion

This study demonstrates that recurrent fire strongly influences vegetation structure and regeneration dynamics in the Onigambari Forest Reserve. Burned areas were characterized by reduced tree density, lower basal area, diminished canopy cover, and decreased litter accumulation, reflecting a clear decline in structural complexity. In addition, significantly lower seedling and sapling densities in burned plots indicate a pronounced regeneration bottleneck, suggesting that repeated fire events hinder recruitment and limit the progression of juvenile plants to maturity. The combined effects of structural degradation and impaired regeneration point to a trajectory in which continued fire disturbance may shift the ecosystem toward a more open, fire-maintained state. Evidence from fire severity indicators further confirms that fire intensity is sufficient to affect both mature vegetation and early life stages, reinforcing the observed patterns. These conditions, coupled with feedback mechanisms between vegetation openness and fuel availability, may reduce the forest's resilience and constrain its capacity for natural recovery. Overall, the findings highlight the critical role of fire as a driver of ecological change in this forest reserve and emphasize the need for targeted management interventions. Without effective control of fire frequency and intensity, the long-term sustainability, biodiversity, and ecological functioning of the forest may be compromised. Conversely, appropriate fire management strategies and restoration efforts can

enhance regeneration, support structural recovery, and promote the persistence of forest ecosystems under increasing disturbance pressure.

References

Bond, W. J., & Keeley, J. E. (2005). Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems. *Trends in Ecology & Evolution*, 20(7), 387–394. https://doi.org/10.1016/j.tree.2005.04.025

Boshoff, D. S. (2024). Understanding fire regimes: A biogeographical perspective. *Jàmbá: Journal of Disaster Risk Studies, 16*(1), Article a1673. https://doi.org/10.4102/jamba.v16i1.1673

Hoffmann, W. A. (2000). Post-establishment seedling success in the Brazilian cerrado: A comparison of savanna and forest species. *Biotropica, 32*(1), 62–69. https://doi.org/10.1111/j.1744-7429.2000.tb00447.x

Cochrane, M. A. (2003). Fire science for rainforests. *Nature*, 421(6926), 913–919. https://doi.org/10.1038/nature01437

Cury, R. T. S., Montibeller-Santos, C., Balch, J. K., Brando, P. M., & Torezan, J. M. D. (2020). Effects of fire frequency on seed sources and regeneration in southeastern Amazonia. *Frontiers in Forests and Global Change, 3*, 82. https://doi.org/10.3389/ffgc.2020.00082

Huang, H., Xue, Y., Liu, Y., Li, F., & Okin, G. S. (2021). Modeling the short-term fire effects on vegetation dynamics and surface energy in southern Africa using an improved SSiB4/TRIFFID-Fire model. *Geoscientific Model Development, 14*(20), 7639–7655. https://doi.org/10.5194/gmd-14-7639-2021

Johansson, M. U., Abebe, F. B., Nemomissa, S., Bekele, T., & Hylander, K. (2021). Ecosystem restoration in fire-managed savanna woodlands: Effects on biodiversity, local livelihoods and fire intensity. *Ambio, 50*, 190–202. https://doi.org/10.1007/s13280-020-01343-7

Koffi, K. F., N'Dri, A. B., Lata, J.-C., Konaté, S., Srikanthasamy, T., Konan, M., and Barot, S. (2018). Effect of fire regime on the grass community of the humid savanna of Lamto, Ivory Coast. *Journal of Tropical Ecology, 34*(4), 283–293. https://doi.org/10.1017/S0266467418000202

Ribeiro, N. S., Syampungani, S., Matavel, N., Cuvilas, C. A., and Paulo, J. A. (2019). Ecology and management of African savanna woodlands with emphasis on fire management. In *Tropical Forests* (pp. 219–240). Springer, Cham. https://doi.org/10.1007/978-3-030-15516-2_10

Shen, K., Levin, S., & Patterson, D. (2025). Spatial modeling of forest–savanna bistability: Impacts of fire dynamics and timescale separation. *Journal of Mathematical Biology, 92*, 44. https://doi.org/10.1007/s00285-026-02363-9

Uhl, C., & Kauffman, J. B. (1990). Deforestation, fire susceptibility, and potential tree responses to fire in the eastern Amazon. *Ecology*, 71(2), 437–449. https://doi.org/10.2307/1940299

Wright, S. J., and He, F. (2008). Tropical forests. In *Encyclopedia of Ecology* (Vol. 5, pp. 3592–3600). Elsevier. https://doi.org/10.1016/B978-008045405-4.00474-9

Proceedings of the 4th ISTF-NIGERIA International Conference. Held at the Faculty of Renewable Natural Resources Management, College of Agriculture and Renewable Natural Resources, Osun State University, Nigeria, from 19th – 21st of May, 2026.
Theme: Forest Ecosystem Conservation: A Roadmap For Resilient Economies And Environmental Sustainability

EVALUATING THE DRIVERS OF LAND DEMAND AMONG RURAL AND URBAN FARMERS IN OYO STATE, NIGERIA

***Ganiyu, M.O[1], Ezekiel A.A[1], Akinniran N.T[1], Oladeebo, J.O[2], Adesiyan, O. I[1], Dairo, D. A[1], Olarinde A.A[3] and Jabaru, M.O[4]**

[1,2,3,5 & 6]Department of Agricultural Economics, Faculty of Agricultural Sciences, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria
[2]Department of Agricultural Economics and Extension, National University of Lesotho, Roma, Lesotho
[3]Department of Agricultural Economics, University of Ilesa, Osun State, Nigeria
[4]Department of Agricultural and Resource Economics, Federal University of Technology, Akure, Ondo State, Nigeria
Correspondence: moganiyu@lautech.edu.ng (https://orcid.org/0000-0002-3126-9876)

Abstract

The importance of land cannot be overemphasized because it serves as the major asset for human livelihood sustainability. An understanding of the significant driving factors of land demand in both rural and urban areas is vital for sustainable land use planning and the formulation of agricultural land policies. This therefore study examined the drivers of land demand among rural and urban farmers in Oyo state, Nigeria. The descriptive and quantitative research designs were adopted as methodological approaches to achieve the aims of the study. General Household Survey (GHS) panel data were sourced from the National Bureau of Statistics in collaboration with the World Bank data sources. A sample size of 236 rural and urban farmers each was selected using a stratified sampling method, while descriptive statistics, multivariate regression model and sample t-test were employed for the analysis. The results showed that agricultural credit access as well as loan disbursed to women increase land demand for agricultural practices in both rural and urban areas, however hired labor used also complements land demand in the rural settlements. The statistical t-test conducted, reveals a significant difference in land demand by rural and urban users. Thus, the study concluded that agricultural credit drives land demand in both areas, but hired labor utilization drags land demand at the rural area. Based on this result, it is recommended that the stakeholders as well as policy intervention on land use should pay attention to the roles of agricultural finance and hired farm labourer in the context of land demand for agriculture.

Keywords: Drivers, Land demand, Rural versus Urban farmers, Agricultural land use, Oyo state

Introduction

The individual demand for land is complex, given its multifunctional roles (Yifang *et al.,* 2024), and is best understood within the framework of land resource economics. It is commonly described as a derived demand, reflecting the broader economic value that land provides. For example, in land resource economics, land is considered a factor of production, a property, an asset/capital, among others (Omole, 2009). Land is an indispensable resource that is constantly in demand for

agricultural activities worldwide, and, substantively, in several developing countries, land is the primary means of production and livelihood sustainability (Angbo *et al.,* 2018; Ganiyu, 2025). The significance of land cannot be overstressed by human beings (Angbo *et al.,* 2018). Land demand refers to the need or aspiration for land to fulfill specific functions, such as agriculture, residential development, industrial activities, or infrastructure expansion. It embodies the extent or size of land needed to accommodate various human and economic endeavours. The behavior of most people in the development and utilization of land reflects their specific demands for functions derived from the land (Li *et al.*, 2023).

Substantial research emphasizes that, during social and economic development in resource-based cities, factors such as resource extraction, population growth, urban expansion, and changes in industrial and consumption structures drive the transformation of human demand for land use (Yifang *et al.,* 2024). Within the agricultural sector, land demand specifically pertains to the critical need for cultivable land to sustain food production and diverse farming operations in a region. More importantly, a range of factors govern land demand. Population growth is a primary driver, intensifying the need for both food and housing (Chiaka *et al.,* 2024). Urbanization similarly exerts pressure on land resources, frequently leading to the reduction of farmland as urban areas expand (Asselen & Verburg, 2012). Climate change significantly influences both land availability and productivity (Choudhary, 2023). The dimension of land acquisition over the years has reshaped land resource demand and utilization among people in Nigeria (Angbo *et al.,* 2018; Oluwatayo *et al.,* 2019). According to Deutsch *et al.* (2018), land tenure arrangements critically shape access to land and the security with which land users operate. In essence, the competition for arable land in Nigeria is escalating, yet debates on the factors governing land demand and conservation for rural and urban agriculture remain limited as global technology advances.

Moreover, despite the crucial role of agricultural land in food production, employment, and economic stability, land is unevenly distributed due to a range of factors, including socioeconomic, infrastructure, and institutional contexts (International Fund for Agricultural Development (IFAD), 2015). Given that land resources are a control factor in all human economic activities, Yifang *et al.* (2024) propose greater emphasis on the role of land as the nexus between natural environments and human activity. However, a range of challenges, including insecure land tenure, environmental degradation, and competition from non-agricultural land uses such as residential or industrial development (Yifang *et al.,* 2024), undermine their capacity to utilize land effectively. In essence, land is recognized as a prominent pillar and input for agricultural sustainability; for this reason, the study evaluated the significant drivers of land demand among rural and urban farmers by seeking to answer the following research question: What are the demographic characteristics of rural and urban farmers? What are the primary drivers of land demand among farmers in both areas? What is the difference between rural and urban land demand by the users?

Methodology

Study Area

The study was carried out in Oyo State, Nigeria. Oyo State is located in southwestern Nigeria and is One of the country's most historically and economically significant states (Figure 1). Established in 1976, it spans approximately 28,454 square kilometers and is bordered by Kwara, Osun, Ogun, and the Republic of Benin. The state's capital, Ibadan, serves as a major commercial and

educational hub and is historically known as the largest city in sub-Saharan Africa. The state features a tropical climate with a bimodal rainfall pattern, receiving 1,200 mm to 1,800 mm annually, and average temperatures ranging from 25°C to 35°C. These climatic conditions, along with fertile loamy and clayey soils, support a wide range of agricultural activities. Rural areas focus on subsistence and commercial farming, producing crops like maize, cassava, yams, cocoa, and vegetables. Livestock farming, particularly poultry and cattle rearing, is also prevalent. In urban centers like Ibadan and Ogbomoso, land-use competition is more intense due to urbanization, industrial development, and population growth. However, urban farmers engage in innovative practices such as backyard gardening and aquaculture to meet food demand within constrained spaces. Culturally, Oyo State is home to the Yoruba ethnic group, whose communal land-ownership traditions shape rural land access. In contrast, urban areas rely on formal land acquisition systems regulated by government policies and zoning laws. Economically, the state thrives on agriculture, trade, and services, making it a critical contributor to Nigeria's GDP. Oyo State's dual nature of extensive rural farming and rapidly urbanizing centers makes it an ideal case for studying land demand dynamics. The interplay between rural and urban land uses highlights the need for sustainable land management policies to balance agricultural productivity with urban expansion.



Fig 1: Map of Oyo State indicating the local government areas and Agricultural Development Programme (ADP) Zones.

Target Population and Sample Size Selection

The target population for this study comprised all farmers, both rural and urban, in Oyo State, Nigeria. These farmers collectively engage in various agricultural activities, including crop production, livestock rearing, aquaculture and other farming practices. Oyo State, with 33 local government areas, including urban and rural centers, has a population of 60007. This study employed a stratified random sampling procedure to select 472 respondents, comprising 236 rural and 236 urban farmers.

Data Source and Methods of Data Analysis

The secondary dataset used in this study was obtained from the General Household Survey (GHS). GHS data contain information on farming households, including states, enumerated areas, local government areas, demographic characteristics, farm-level characteristics, agricultural inputs, crop cultivation, land costs, loan sources and repayment, land rentage, and so on. Descriptive statistics, such as frequencies, percentages, and means, were used to summarize survey findings. Multivariate regression analysis was used to determine the key drivers of land demand among rural and urban farmers in the study areas. In contrast, the sample t-test was used to test the hypothesis. The multivariate regression model estimates the effects of all factors on the predictor variables simultaneously. It runs like an ordinary least squares regression model. As the name implies, multivariate regression is a technique that estimates a single regression model with more than One outcome variable and is expressed as:

$Yi = \beta_0 + \beta iXi + \mu i$ 1
$Y_1, Y_2, = \beta_0 + \beta iXi + \mu i$ 2

Where Y_1= Land demand for Urban farmers, Y_2=Land demand for Rural farmers, Xi=Vector of explanatory variable, βi =Vector of unknown coefficients, μi= independently distributed error term, i = number of observations = 1, 2, 3…. n.

$Y_1, Y_2 = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + ... \beta_8X_8 + \mu i$ 3

Where: Yi=Land demand, X_1 = Farmer native, X_2 = Crop cultivation (Crocultivat), X_3 = Individual land cost (Indvlandcost), X_4 = Hired labour, X_5 =household land cost, X_6 = Credit source, X_7 = Member paid, X8 = Women access to loan, Constant (intercept term = β0), μi = distributed error term.

Results and Discussion

Demographic Characteristics of Urban and Rural Farmers in Oyo State

The farmers' demographic characteristics captured in the survey data are reported in Table 2, along with summary statistics. The number of observations is 236 respondents for each rural and urban group, for a total of 472 household heads. The average land size (ha), also known as land demand among urban dwellers, is approximately 0.868ha, with a standard deviation of 0.715ha, while a

maximum size reached 6.07 ha. Whereas rural farmers demand 1.11ha on average, with a standard deviation of 1.26 ha and a maximum of 7.46 ha, this finding suggests relatively larger landholdings in the rural context than in the urban context. On average, farmers cultivate approximately 5 plots, with a standard deviation of 1.36; the minimum and maximum are 1 and 7 plots, respectively. Crop cultivation is a variable indicating whether crops are grown, with a mean of approximately 1.05, suggesting that almost all farmers cultivate crops. Similarly, the use of hired labor has a mean of 1.12, indicating that it is commonly used. The average farmers' native value of 1.66 suggests a mix of native and non-native farmers, with some dominance of Yoruba. The average daily wage paid to men is approximately ₦ 1665.25, while the wage received per day by women is slightly higher at ₦ 1668.64. Regarding land costs, the average individual land cost is substantial, at ₦ 7,186,742, with a very high standard deviation of ₦ 10,300,000, indicating significant variation in individual land prices. The maximum reported for individual land costs is ₦37.5 million. Household land cost is lower on average, at ₦ 3,625,386, but also exhibits large variability, given the standard deviation (₦ 5,969,665), with a maximum of ₦ 20 million. The average annual land rent is ₦234,961.9, with a maximum of ₦1.5 million, again showing a considerable range. For agricultural credit access, the mean was 1.487, while the average for women's loan access was 1, indicating that most women have access to loans but need support for their farm production.

Table 2: Summary Statistics of Demographic Factors of Urban & Rural Farmers (N=236)

Variables	Observation	Mean	Std. Dev.	Min	Max
Plot size used in urban(ha)	236	0.868	0.715	0.081	6.0704
Plot size used in rural (ha)	236	1.113	1.259	0.073	7.464
Number of plots	236	5.318	1.364	1	7
Crop cultivation	236	1.051	0.220	1	2
Crop type cultivated	236	1.538	0.919	1	6
Individual hired labour	236	1.119	0.324	1	2
Farmers nativity	236	1.661	0.817	1	3
Men hired	236	1.021	0.144	1	2
Men paid (₦)	236	1665.254	711.950	0	3000
Women hired	236	1.021	0.144	1	2
Women paid (₦)	236	1668.644	580.638	700	5000
Individual land cost (₦)	236	7,186,742	10,300,000	3000	37,500,000
Household land cost(₦)	236	3,625,386	5,969,665	2000	20,000,000
Annual land rent (₦)	236	234,961.9	372,111.6	3000	1,500,000
Agricultural credit	236	1.487	0.501	1	2
Women's access to loans	236	1	0.292	1	2
Land rentage	236	1.525	0.500	1	2

Source: Field survey, 2025

Drivers of Land Demand by Respondents using Multivariate Regression Model

This study revealed the demographic variables influencing land demand among rural and urban farmers in Oyo state, as shown in Table 3. Given the urban model results, the agricultural credit source shows a statistically significant, direct relationship with urban land-use demand (coefficient = 0.4066, p-value = 0.001). This implies that agricultural credit access increases land demand. This could be due to more favorable loan terms from agricultural banks, which are supporting larger land acquisitions or investments in urban farming. Women's access to loans also has a significant effect on land demand (Coefficient = 0.6110, p-value = 0.004). This suggests that greater access to credit for women farmers increases land demand in urban areas, possibly enabling them to acquire or expand their farming plots. It further strengthens women's role in land cultivation to promote agriculture. Other variables, such as farmer nativity, use of hired labor, wages paid to men per day, individual land cost, household land cost, and annual land rent, do not show a statistically significant impact on urban land-use demand at conventional significance levels. This might indicate that these factors, while potentially relevant, do not exert a strong, direct, and measurable influence on urban land demand within this specific dataset.

Consistently, in the rural analysis, agricultural credit access was statistically significant, with a positive effect on land demand (coefficient = 0.3893, p-value = 0.016). This implies that access to agricultural credit leads to improvement in land acquisition, which further enhances farming practices. Women's access to loans has a significant positive effect on land demand (coefficient = 0.5755, p-value = 0.035). This result provides insight into women's empowerment in local areas, as it shows that loan disbursements to women increase land demand for agricultural practices. Use of hired labour was also significant, with a positive coefficient (coefficient = 0.4831, p-value = 0.053). This indicates that the use of hired labour increases the demand for land in rural areas. The result is in line with *prior expectation*s because the availability of hired laborers impacts the majority of farm operations.

Table 3: Results of Multivariate Regression Model indicating the Drivers of Land Demand

Equation	Obs	Parms	RMSE	"R-sq"	F	P
Urbanland demand	236	9	0.9327744	0.1374	4.520778	0.0000
Rural land demand	236	9	1.204629	0.1160	3.723357	0.0004
	Urban Land			Rural Land		
Variables	Coefficients	Std. errors	t-values	Coefficients	Std. errors	t-values
Farmers' native	0.075256	0.0756745	0.99	0.0343098	0.0977296	0.35
Individual hired labour	0.237502	0.1927043	1.23	0.483072*	0.2488676	1.94
Men wage paid	0.000057	0.0000901	0.64	0.000057	0.0001163	0.49
Individual land cost	0.045139	0.0382736	1.18	0.074317	0.0494283	1.55
Household land cost	1.82e-09	1.29e-08	0.14	-2.08e-08	1.66e-08	-1.25
Annual land rent	0.048100	0.049269	0.98	0.083642	0.0636283	1.31
Agricultural credit	0.406633***	0.123616	3.29	0.389262**	0.1596436	2.44
Women's access to loans	0.611039***	0.2102768	2.91	0.575501**	0.2715615	2.12
Constant term	5.96487***	0.5459569	10.93	-2.61664***	0.7050748	-3.71

Source: Field survey, 2025

Difference in Land Use Demand between Rural and Urban Farmers (t-test Result)

As indicated in Table 4, a t-test was conducted to determine if there is a significant difference in land demand between urban and rural farmers in Oyo State.

Table 4: Statistical t-test for the difference between Urban and Rural Land Use Demand

Two-sample variables	Observations	Means	Std. errors	Standard dev.
Urban land demand	236	0.868208	0.0466028	0.7159264
Rural land demand	236	1.112935	0.0819691	0.9514468
Two groups mean (diff)	236	-0.244728	0.0969654	1.489611
diff = mean (Urban land demand) – mean (Rural land demand)			t = -2.5239	
Ho: mean (diff) = 0,			degrees of freedom = 235	
Ha: mean (diff) < 0,	Ha: mean (diff) != 0,		Ha: mean (diff) > 0	
Pr(T < t) = 0.0061	Pr(|T| > |t|) = 0.0123		Pr(T > t) = 1.0000	

The mean urban land-use demand is 0.8682 units, while the mean rural land-use demand is 1.1129 units. The mean difference between urban and rural land-use demand is -0.244728, indicating that the two means are significantly different. The t-statistic for the difference in means is -2.5239, which is also greater than zero, indicating a substantial difference between land demands with 235 degrees of freedom. The p-value for the two-sided hypothesis (Ha: mean (diff)! = 0) is 0.0123 and significant; hence, we reject the null hypothesis that there is no significant difference between urban and rural land use demand. This strongly indicates a statistically significant difference in land demand between urban and rural farmers in Oyo State.

Conclusion

This study evaluates the drivers of land demand between rural and urban farmers in Oyo State, Nigeria. The findings unequivocally demonstrate a significant disparity in land demand between urban and rural farming communities, with rural farmers cultivating substantially larger land areas. The research established that financial accessibility, particularly through agricultural bank credit and women-targeted loans, is a paramount factor influencing land demand in both urban and rural settings. This underscores the critical role of institutional support and inclusive financial policies in enabling farmers to acquire and expand their landholdings, irrespective of their geographical location. Thus, the study concluded that agricultural credit significantly increases land demand in both areas, but hired labor utilization complements land demand in the rural area. Based on this result, it was recommended that stakeholders, as well as policy interventions on land use, should pay attention to the roles of agricultural finance and hired farm labourers in the context of land demand for agriculture.

References

Angbo, Y.B, Attah, E.E and Otso, Y.O (2018). Land Resources Development Model: A Tool for Sustainable National Development in Nigeria International Journal of Advanced Academic Research | Social & Management Sciences, 4(11): 67-79

Asselen, S.V., & Verburg, P. H. (2012). A Land System representation for global assessments and land-use modeling. *Global Change Biology*, *18*(10), 3125–3148. https://doi.org/10.1111/j.1365-2486.2012.02759.x

Bandyopadhyay, S., Jaiswal, R. K., Hegde, V. S., & Jayaraman, V. (2009). Assessment of land suitability for agriculture using a remote sensing and GIS-based approach. *International Journal of Remote Sensing*, *30*(4), 879–895. https://doi.org/10.1080/01431160802395235

Chiaka, J. C., Zhen, L., Xiao, Y., Hu, Y., Wen, X., & Muhirwa, F. (2024). Spatial Assessment of Land Suitability Potential for Agriculture in Nigeria. *Foods*, *13*(4), 568. https://doi.org/10.3390/foods13040568

Choudhary, K. (2023). Agricultural land suitability assessment for sustainable development using remote sensing techniques with the analytic hierarchy process. *Remote Sensing Applications: Society and Environment*, *32*, 101051. https://doi.org/10.1016/j.rsase.2023.101051

Deutsch, C. A., Tewksbury, J. J., Tigchelaar, M., Battisti, D. S., Merrill, S. C., Huey, R. B., & Naylor, R. L. (2018). Increase in crop losses to insect pests in a warming climate. *Science (New York, N.Y.)*, *361*(6405), 916–919. https://doi.org/10.1126/science.aat3466

International Fund for Agricultural Development (IFAD) (2015): Land Tenure Security and Poverty Reduction; Investing in rural people. Paolo di Dono, 44 – 00142 Rome, Italy.www.ruralpovertyportal.org

Liu, Y., Wan, C., Xu, G., Chen, L., Yang, C., (2023). Exploring the relationship and influencing factors of cultivated land multifunction in China from the perspective of trade-offs and synergies. Ecol. Ind. 149, 110171.

Oluwatayo I.B, Timothy, O., & Ojo, A.O (2019). Land Acquisition and Use in Nigeria: Implications for Sustainable Food and Livelihood Security. Intechopen Chapter DOI: 10.5772/intechopen. 79997

Omole F. Land-use violations: Implications for sustainable development: the case study of the Federal Capital City, Abuja, Nigeria. Current Research Journal of Social Sciences, 1(1):31-37

Yifang W, Linlin C, Yang Z, Junqi W, Huizhen Cui, (2024). Evolution of land use functions and their trade-offs/synergies relationship in resource-based cities, Ecological Indicators, Volume 165, 2024, 112175, ISSN 1470-160X, https://doi.org/10.1016/j.ecolind.2024.112175.

THE CAUSES AND CONSEQUENCES OF SPATIAL DISTRIBUTION PATTERNS OF TREE SPECIES IN TROPICAL RAINFORESTS

***Rebecca O. Ogundotun and Oladele F. Falade**

[1]*Department of Forest Production and Products, University of Ibadan, Nigeria.*
[2] *Department of Forest Production and Products, University of Ibadan, Nigeria.*
Corresponding email: rogundotun253170@stu.ui.edu.ng

Abstract

Tropical rainforests are highly rich in tree species compared to other terrestrial plant formations. Species spatial distribution regulates population dynamics within communities, while spatial distribution patterns regulate biological and ecological processes at finer scales. However, the causes and consequences of spatial patterns are not the same. There is limited information on the processes regulating spatial patterns and the consequences of individual spatial patterns for tree species conservation. This review examines the biological and ecological mechanisms that regulate tree species coexistence in tropical forests. Studies from short- and long-term census plots in tropical regions show that most tree species exhibit aggregated patterns, a few exhibit regular patterns. In contrast, rare tree species tend to be more strongly aggregated. These patterns are shaped by interacting species characteristics and ecological processes, including conspecific aggregation, negative density dependence (NDD), seed dispersal mechanisms and limitations, and environmental heterogeneity, which together promote niche differentiation and stabilize species coexistence.The spatial pattern of tree species is mostly regulated by negative density dependence through competition, seed and seedling predation, thereby maintaining tree diversity at various spatial scales. Consequently, spatial patterns shape key ecological outcomes, including forest regeneration dynamics, species turnover, and ecosystem resilience.

Keywords: Spatial distribution patterns, Species coexistence, Tropical Rainforests, Negative density dependence, Ecosystem Resilience.

Introduction

Tropical rainforests harbor the largest proportion of tree species in terrestrial plant formations, supporting approximately 65% of terrestrial taxa (Gardner *et al*., 2009; Gallery, 2014). According to Wright (2002), Amazon forests supported more than 280 tree species per hectare, while forests in Borneo and Ecuador supported approximately 1,100 tree species per hectare with a diameter at breast height (DBH) of at least 10 cm. Therefore, there is variation in tree species density among tropical rainforests. Classic niche theory states that differences in tree species density among rainforests are due to the provision of a high gradient of environmental factors, resulting in subtle environmental variation (Koffel *et al*., 2021). High gradients of environmental factors provide numerous niches for plants and animals. However, in small landscapes, the composition of tree species is strongly influenced by existing climatic and edaphic factors (Baldeck *et al*., 2013; Baňares-de-Dios *et al*., 2022; Richards, 1996).

Tree species distribution regulates community structure and population dynamics (Condit *et al*., 2000; Nathan & Muller-Landau, 2000; Wiegand & Moloney, 2014), while tree spatial pattern

regulates subsequent biological and ecological processes, including competition, regeneration, and resource use (Nathan & Muller-Landau, 2000). The processes that create the patterns and the consequences of those patterns in tree species are not the same. Moreover, spatial patterns are fundamental to species coexistence and are regulated by many processes. For instance, the Janzen–Connell hypothesis explains that seed and seedling predation near parent trees reduces survival, thereby preventing any single species from dominating available space and resources (Bagchi *et al*., 2014; Comita *et al*., 2014). Although dominance of spatial aggregation among tree species is well established, there is still a need to understand how these patterns can assist conservation efforts in tropical tree formations. A detailed understanding of tree spatial structure and interactions is necessary to maintain alpha tree diversity and coexistence, preventing biodiversity loss at multiple scales. Therefore, the objective of this review is to examine the processes regulating spatial patterns and the consequences of these patterns in tropical rainforests with a view to improving tree species conservation.

Discussion

In tropical forests, there are many interacting biological and ecological processes regulating spatial structures, including:

Spatial Aggregation of Trees in Tropical Forests

Studies have shown that approximately 1,768 tree species exhibit a more aggregated distribution than would be expected by chance (Condit *et al*., 2000; Wiegand & Moloney, 2014). This clustering pattern is also observed among mature trees (DBH ≥ 10 cm), indicating that aggregation persists across life stages. Rare species tend to show stronger clustering compared to common species (Condit *et al*., 2000; Fibich *et al*., 2021). Spatial aggregation has important ecological implications, as it influences how tree species compete for resources and interact with other organisms such as herbivores and pathogens. These interactions shape important ecological processes, including reproduction, survival, and competition within forest communities (Yang *et al*., 2024; Condit *et al*., 2000; Nathan & Muller-Landau, 2000).

Many studies have found that tropical tree species are more aggregated rather than randomly distributed (Condit *et al*., 2000; Fibich *et al*., 2021; Harms *et al*., 2001; John *et al*., 2007; Seidler and Plotkin, 2006; Wiegand & Moloney, 2014) while regular distribution is mostly found among tree species in the arid zones. Therefore, a high degree of aggregation within a population is an attribute of tree species in tropical forests, ranging from a few meters to several hundred meters (Datta & Rawat, 2008; Seidler & Plotkin, 2006). Moreover, studies in tropical rainforests such as Panama, Malaysia, and India consistently show that rare species are more aggregated than common species (Condit *et al*., 2000; Fibich *et al*., 2021). Spatial aggregation is also scale-dependent. Wiegand et al. (2009) showed that clustering is strongest at short distances due to limited dispersal and localized recruitment, while patterns observed at larger spatial scales are more strongly influenced by environmental heterogeneity. This demonstrates that multiple ecological processes operate simultaneously across different spatial scales. Wiegand et al. (2009) further explained that many mechanisms may cause this aggregation pattern. They indicated that dispersal limitation was the most important cause of the aggregate pattern among five frugivore-dispersed tree species in the Barro Colorado Island forest, Panama.

Effect of Seed Dispersal Mechanisms on Spatial Patterns among Tropical Tree Species

Seed dispersal mechanisms play a significant role in the structuring of the spatial patterns of tropical tree populations. The mode of seed dispersal of tree species (e.g., animal, wind, or gravity) is associated with the extent of spatial aggregation (Datta & Rawat, 2008; Howe, 2004; Seidler & Plotkin, 2006). Limited dispersal often leads to strong clustering near parent trees, whereas long-distance dispersal results in more diffuse spatial distributions (Seidler & Plotkin, 2006). Sometimes, this causes double clustering and superposition patterns, which explain the occurrence of an aggregate pattern at multiple distances within a population of tree species.

Different dispersal strategies produce distinct spatial outcomes. Tree species with explosive dispersal mechanisms tend to exhibit the highest levels of aggregation, followed by gravity- and wind-dispersed species. In contrast, animal-dispersed tree species exhibit greater spatial spread due to longer dispersal distances. Among these species, fruit size further influences dispersal patterns, as large fruits are typically carried over longer distances by animals. These dispersal-driven patterns reduce competition among species and contribute to spatial segregation, thereby supporting species coexistence. However, dispersal alone does not fully explain spatial patterns. While seed dispersal determines the initial distribution of propagules, subsequent recruitment processes such as seedling establishment and early survival modify these patterns (Wiegand et al., 2009). As a result, the spatial arrangement of adult trees reflects both dispersal and post-dispersal processes.

Negative Conspecific Density Dependent Effects on Recruit Growth Rate and Mortality

Negative density dependence (NDD) is the most important mechanism regulating species diversity in tropical rainforests. The Janzen–Connell hypothesis demonstrates a strong relationship between natural enemies and the maintenance of plant diversity in tropical forests, such that specialized natural enemies maintain diversity by elevating mortality rates where plant species occur at high density or near reproductive adults (Bagchi *et al*., 2014; Chesson, 2000; Comita *et al*., 2014; Davies *et al*., 2025; LaManna *et al*., 2017). These conspecific negative density-dependent effects occur through competition, natural enemies and other biological interactions. These natural enemies, including fungal pathogens and insect herbivores, reduce the survival of seedlings and juveniles in areas with high conspecific density (Bagchi *et al*., 2014). As a result, conspecific density-dependent mortality is more pronounced in abundant, fast-growing species. This process limits dominance and allows multiple species to persist within the same community, thereby contributing to species coexistence and diversity. These findings are consistent with earlier reviews that emphasize conspecific density-dependent processes as an important mechanism regulating species coexistence and maintaining tree species alpha diversity in tropical forests (Falade, 2023). These conspecific density-dependent effects interact with recruitment processes, particularly at fine spatial scales where seedling survival is reduced near conspecific adults (Wiegand et al., 2009). This interaction contributes to shaping spatial structure and limiting excessive aggregation.

Environmental Heterogeneity and Habitat Differentiation in Tropical Rainforests

Environmental heterogeneity is another important factor influencing the spatial distribution of trees. Variations in topography and edaphic factors such as soil type, soil nutrients, and Light availability contribute to non-random spatial patterns (Clark *et al*., 1998; Denslow, 1987; Hofhansl

et al., 2020; John *et al*., 2007; Wright, 2002). These factors determine habitat suitability and create a mosaic of micro-sites that different tree species exploit. At large spatial scales, species distribution is often associated with landscape features such as ridges, slopes, and swampy areas (Harms *et al*., 2001). Soil nutrient availability also plays a critical role, with many species showing strong associations with specific nutrients such as phosphorus, potassium, and magnesium (Baldeck *et al*., 2013; John *et al*., 2007). In addition, canopy gaps create variation in Light conditions, allowing species with different ecological requirements to establish and grow. These environmental gradients promote niche differentiation and enhance species coexistence within tropical forests.

Forest Regeneration and Reproductive Success of Tropical Tree Species

Spatial patterns strongly influence forest regeneration processes. Seedlings often emerge in clustered distributions due to limited seed dispersal, but survival decreases in areas of high conspecific density due to natural enemies. This leads to a thinning process in which only a fraction of seedlings reach maturity, resulting in more dispersed adult populations. Recruitment success is spatially heterogeneous, with establishment occurring only in suitable microsites (Wiegand et al., 2009). This spatial variability contributes to complex regeneration patterns and influences long-term forest composition. Environmental factors such as Light availability further influence regeneration. Canopy gaps create opportunities for both shade-tolerant and light-demanding species, contributing to forest structural complexity. These spatial and biological processes also enhance ecosystem resilience. Diverse and spatially structured forests are better able to withstand environmental disturbances because different species respond differently to stress. This variation ensures the continuity of essential ecosystem functions such as carbon storage and nutrient cycling.

Implications for Conservation

As discussed above, integrating recruitment dynamics with spatial analysis highlights that spatial patterns in tropical forests result from interacting processes operating across multiple scales. Therefore, understanding spatial patterns is essential for effective forest conservation and management. Conservation strategies should account for environmental heterogeneity to ensure protected areas capture the full range of biodiversity. In addition, restoration efforts should incorporate natural spatial patterns, including species-specific dispersal strategies and habitat preferences, to improve the success and sustainability of reforestation. Integrating spatial ecology into conservation planning can enhance biodiversity preservation and strengthen ecosystem resilience.

Conclusion

Spatial aggregation is a fundamental and consistent characteristic of tropical forest tree communities. Most species occur in aggregate patterns rather than random distributions, with rare species often showing stronger aggregation. Based on this review's findings, these spatial patterns are shaped by interacting ecological processes, including seed dispersal limitation, negative density dependence, and environmental heterogeneity. Together, these processes regulate species interactions, promote coexistence, and maintain high levels of biodiversity. Recruitment dynamics further reinforce these patterns by linking early-stage processes, such as seed dispersal and establishment, to the spatial structure observed in mature tree populations. Conservation strategies

and restoration efforts should incorporate spatial ecological principles to improve the sustainability and effectiveness of forest management.

References

Bagchi, R., Gallery, R. E., Gripenberg, S., Gurr, S. J., Narayan, L., Addis, C. E., Freckleton, R. P., & Lewis, O. T. (2014). Pathogens and insect herbivores drive rainforest plant diversity and composition. *Nature*, *506*(7486), 85–88. https://doi.org/10.1038/nature12911

Baldeck, C. A., Harms, K. E., Yavitt, J. B., John, R., Turner, B. L., Valencia R., Navarrete, H., Davies, S. J., Chuyong, G. B., Kenfack, D., Thomas, D. W., Madawala, S., G., N., G., S., B., S., K., S., Y., A., S. M. N. N., Dalling, J. W. (2013). Soil resources and topography shape local tree community structure in tropical forests. Proc R Soc B 280: 20122532. https://dx.doi.org/10.1098/rspb.2012.2532

Baňares-de-Dios, G., Macía, M. J., Carvalho, G. M., and Arellano, G. (2022). Soil and climate drive floristic composition in tropical forests: A literature review. Frontiers in Ecology and Evolution, 10, 866905. https://doi.org/10.3389/fevo.2022.866905

Chesson, P. (2000). *Mechanisms of Maintenance of Species Diversity. Annual Review of Ecology and Systematics.*

Clark, D. B., Clark, D. A., & Read, J. M. (1998). *Edaphic variation and the mesoscale distribution of tree species in a neotropical rain forest*. Vol. 86. No. 1, 101-112. https://www.jstor.org/stable/2648618

Comita, L. S., Queenborough, S. A., Murphy, S. J., Eck, J. L., Krishnadas, M., Beckman, N., & Zhu, Y. (2014). *Testing predictions of the Janzen – Connell hypothesis : a meta-analysis of experimental evidence for distance- and density-dependent seed and seedling survival*. 845–856. https://doi.org/10.1111/1365-2745.12232

Condit, R., Ashton, P. S., Baker, P., Bunyavejchewin, S., Gunatilleke, S., Itoh, A., Lafrankie, J. V, and Lee, H. S. (2000). *Spatial Patterns in the Distribution of Tropical Tree Species*. *May*. https://doi.org/10.1126/science.288.5470.1414

Datta, A., & Rawat, G. S. (2008). *Dispersal modes and spatial patterns of tree species in a tropical forest in Arunachal Pradesh, northeast India*. *1*(3), 163–185.

Davies, T. J., HilleRisLambers J., & Wolkovich E. M. (2025). The Janzen-Connell hypothesis and seed masting. Trends in Ecology and Evolution, 40(2), 1190–1198.

Denslow, J. S. (1987). *Tropical Rainforest Gaps And Tree Species Diversity*. *185*.

Falade, O. F. (2023). Some of the Mechanisms for Coexistence of Tree Species Diversity in Tropical Forests: A Review of Effects of Tree Density Dependence. Open Journal of Forestry, 13, 132-144. https://doi.org/10.4236/ojf.2023.131009

Fibich, P., Novotny, V., Ediriweera, S., Gunatilleke, S., Gunatilleke, N., Molem, K., Weiblen, G. D., & Leps, J. (2021). Common spatial patterns of trees in various tropical forests: Small trees are associated with increased diversity at small spatial scales. Ecology and Evolution, 11, 8085–8095. https://doi.org/10.1002/ece3.7640

Gallery R. E. (2014). Ecology of Tropical Rainforests. Ecology and the Environment. https://doi.org/10.1007/978-1-4614-7501-9_4

Gardner, T. A., Barlow, J., Chazdon, R., Ewers, R. M., Harvey, C. A., Peres, C. A. *et al* (2009). Prospects for Tropical Forest Biodiversity in a Human-Modified World. Ecology Letters, 12, 561–582. https://doi.org/10.1111/j.1461-0248.2009.01294.x

Harms, K. E., Condit, R., Hubbell, S. P., & Foster, R. B. (2001). *Habitat associations of trees and shrubs in a 50-ha neotropical forest plot*. 947–959.

Hofhansl, F., Chacón-Madrigal, E., Fuchs, V. J., Weissenhofer, A., Hietz, P., and Wanek, W. (2020). Climatic and edaphic controls over tropical forest diversity and vegetation carbon storage. https://doi.org/10.1038/s41598-020-61868-5

Howe, H. F. (2004). When seed dispersal matters. BioScience 54(7):651–660. https://doi.org/10.1641/0006-3568(2004)054[0651:WSDM]2.0.CO;2

John, R., Dalling, J. W., Harms, K. E., Yavitt, J. B., Stallard, R. F., Mirabello, M., Hubbell, S. P., Valencia, R., Navarrete, H., Vallejo, M., & Foster, R. B. (2007). *Soil nutrients influence spatial distributions of tropical tree species*. PNAS, 104(3), 864-869. https://doi.org/10.1073/pnas.0604666104

Koffel, T., Daufresne, T. and Klausmeier, C. A. 2021. From competition to facilitation and mutualism: a general theory of the niche. Ecological Monograph 91(3): e0148

LaManna, J. A., *et al*. (2017). Plant diversity increases with the strength of negative density dependence at the global scale. Science, 356(6345), 1389-1392. https://doi.org/10.1126/science.aam5678

Nathan, R., and Muller-Landau, H. C. (2000). *Spatial patterns of seed dispersal, their determinants and consequences for recruitment*. *15*(7), 278–285.

Richards, P. W. (1996). The tropical rain forest: An ecological study. Second edition. Cambridge University Press. 575p

Seidler, T. G., & Plotkin, J. B. (2006). *Seed Dispersal and Spatial Pattern in Tropical Trees*. *4*(11). https://doi.org/10.1371/journal.pbio.0040344

Wiegand, T., Martinez, I., & Huth, A. (2009). Recruitment in tropical tree species: Revealing complex spatial patterns. The American Naturalist, 174(4), E106-E140. https://doi.org/10.1086/605368

Wiegand, T., & Moloney, K. A. (2014). Handbook of Spatial point pattern analysis in ecology. 57(2), 360–361. https://doi.org/10.1002/bimj.201400174

Wright, S. J. (2002). *Plant diversity in tropical forests : a review of mechanisms of species coexistence*. 1–14. https://doi.org/10.1007/s004420100809

Yang, J., Yu, J., Wang, G., & Li, X. (2024). Competition and density dependence in arid mountain forest stands: revealing the complex process from spatial patterns. https://doi.org/10.3389/ffgc.2024.1354240

SUB-THEME 4:
WATERSHED MANAGEMENT AND GREEN ECONOMY

ISTF-NIG 2026

INFLUENCE OF LAND USE TYPES ON WATER QUALITY IN OSUN RIVER WATERSHED ECOSYSTEMS, SOUTHWESTERN NIGERIA

[1]*Akintan, A. O., [2]Akintunde-Alo, D.A., and [2]Jimoh, S. O.

*[1]*Rainforest Research Station, Forestry Research Institute of Nigeria, Ibadan*
[2]Department of Social and Environmental Forestry, University of Ibadan, Nigeria
**Corresponding author: akintanadetinuke@gmail.com/08035309326*

ABSTRACT
The land use systems surrounding the watershed ecosystem of a river has significant impacts on its water quality. In recent decades, Osun watershed has experienced increasing anthropogenic activities that have influenced the land use types and had implications on vegetation structure and water quality. There is a need to identify the effects of these anthropogenic activities on water quality in Osun River (OR). This study assessed the impact of different land use types on the quality of water from OR. The river's Watershed was stratified into Upper Course (UC), Middle Course (MC), and Lower Course (LC) based on the gradient of flow. Three land use types: Forest (FO), Farmland (FL) and Built-up Area (BU) common to UC, MC and LC were purposively selected for water quality investigation. Water samples were collected from a randomly designated point within the river shore and close to each of the three major types of land use once in two months for 24 months. The pH, Turbidity, Dissolved oxygen, Calcium, Magnesium, Total dissolved solid, Total suspended solid, Biological Oxygen Demand, Electrical conductivity, Iron, Faecal and Total coliforms of the water samples were determined using standard procedures. Data were analysed using descriptive and inferential statistics. Turbidity, Iron, Faecal and Total coliforms ranged from 6.52±0.03 to 22.51±0.52 NTU, 0.10±0.01 to 0.35±0.02 mg/l, 152.83±0.42 to 197.94±0.53 mpn/ml and 182.67±0.17 to 209.78±0.89 mpn/ml respectively with highest in BU during rainy season and the lowest values in Forest during dry season. Indicating mean values in BU are above drinking water safety thresholds. Forest land had the lowest mean values when compared to farmland and BU. This implies that forest vegetation plays an essential role in maintaining good water quality.

Keywords: watershed ecosystems, anthropogenic activities, land use types, Osun River water quality

INTRODUCTION
Watershed ecosystems are areas of land that drain rainwater and run off into a common waterbody, like a river, lake or ocean. It is an ecosystem with interacting natural components such as soil, land, climate, flora, fauna, vegetation and humans. These ecosystems are crucial for maintaining water quality, serve as habitat for diverse plant and animal species and regulating the water cycle. They are also important for human communities, providing water for drinking, agriculture and industry. In many developing regions, however, increasing human pressure on watershed ecosystems has led to rapid changes in land use patterns, deforestation, urbanization and intensive agriculture which have raised concerns about their impact on water quality (Asinwa and Olajuyigbe 2019). Globally, there is growing concern over surface water resource contamination, particularly in rivers (Mul *et al*., 2015).

Forests are used in the protection of watershed in order to have adequate water supply in urban and suburban areas (Mfon and Mfon, 2013). Also, forest vegetation determines the amount and quality of water in developing nations (Akinwande *et al*., 2013). However, the effects of human disturbances are already being felt largely in forested watersheds across southwest Nigeria, and this is only going to get worse as the population grows. Riparian vegetation loss weakens river banks, increasing the risk of flooding in low-lying places (Adegboyega, 2018). The water quality, soil, plant diversity, structure, and population features of watershed ecosystems are all significantly impacted when they are converted to other land use systems (Enwelu *et al.,* 2010).

The Oṣun River flows through five Southwestern States of Nigeria: Ekiti, Osun, Oyo, Ogun and discharges into the Lagos Lagoon. The watershed of Osun River accommodates different land use types along its upper, middle and lower courses. Osun River supplies water to international breweries at Ilesha, Coca cola company in Ibadan, Triton fish Production Company, Omo Wood at Ijebu East and the general populace of Ekiti, Osun, Oyo and Ogun States. Unfortunately, the natural features of the river have been impacted by human activity throughout its courses (Anifowose and Oyebode 2019).

Anthropogenic activities like farming, refuse dumping and building constructions are prominent in Osun watershed. Fertilizer use in agriculture leads to leaching of nutrients like nitrogen, potassium, and phosphorus, compromising water quality (Asaad *et al*., 2016 and Akubugw *et al*., 2013). Deforestation in watershed causes turbidity; loss of forest cover will increase effect of upstream, erosion and downstream sedimentation resulting in loss of capacity to regulate run-off (Ogunade *et al.,* 2011). Waste disposed into water bodies contain microbes and toxic substances like heavy metals which contaminate water and make it unsafe for irrigation and drinking usage. Previous studies by Olajire and Imeokparia (2001); Azeez *et al*. (2015) and Anifowose and Oyebode (2019) have assessed Water quality and heavy metals of Osun River respectively in specific parts of the watershed but there is a need for an understanding of how different land use types influence water quality across the ecosystem. Therefore, assessing Osun River's water quality is necessary for conserving its socioeconomic advantages and for efficient management.

The use of land in a watershed has a significant influence on the amount and quality of water available (Li *et al.,* 2014). Recognizing how land usage and river water quality are related enables the identification of potential hazards, facilitating assessments of water safety and determining the extent of pollution in Osun River. Since forests are a major contributor to water quality, thus; reliable data on Osun River's physico-chemical properties and land use types is necessary for effective forest cover management. This will inform strategies for preserving a safe environment, supporting ecosystem and human well-being amidst growing freshwater demands. An assessment of the watershed was undertaken to understand how various forms of land usage affect the quality of the water along the course of the Osun River.

MATERIALS AND METHODS

Study Area

The Osun River meanders through Southwestern Nigeria, along latitudes 6º 45' N and 7º 69' N and longitudes 4º 04' E and 5º 13' E. Igede-Ekiti in the Irepodun/Ifelodun LGA of Ekiti State is where the Osun River originates (Olajire and Imeokparia, 2000). The river flows through five states (Ekiti, Osun, Oyo, Ogun and Lagos) covering 267km (Anifowose and Oyebode, 2019) before

discharging into the Lagos Lagoon (Fig.1). Some of the tributaries are *Erinle, Ajibu, Ogbaagba and Elekunkun* Rivers.

The dry season runs from November to March, whereas the wet season is from April to October. The average amount of rainfall per year falls between 1500 in the north and 1,800 mm in the south. The average annual temperature is high and nearly constant at 30°C (Adediji and Ajibade, 2008). In the north, the mean annual humidity is 55%, whereas in the south, it is 75%. The two types of rocks that make up the geology are sedimentary basins and basement complex rocks.

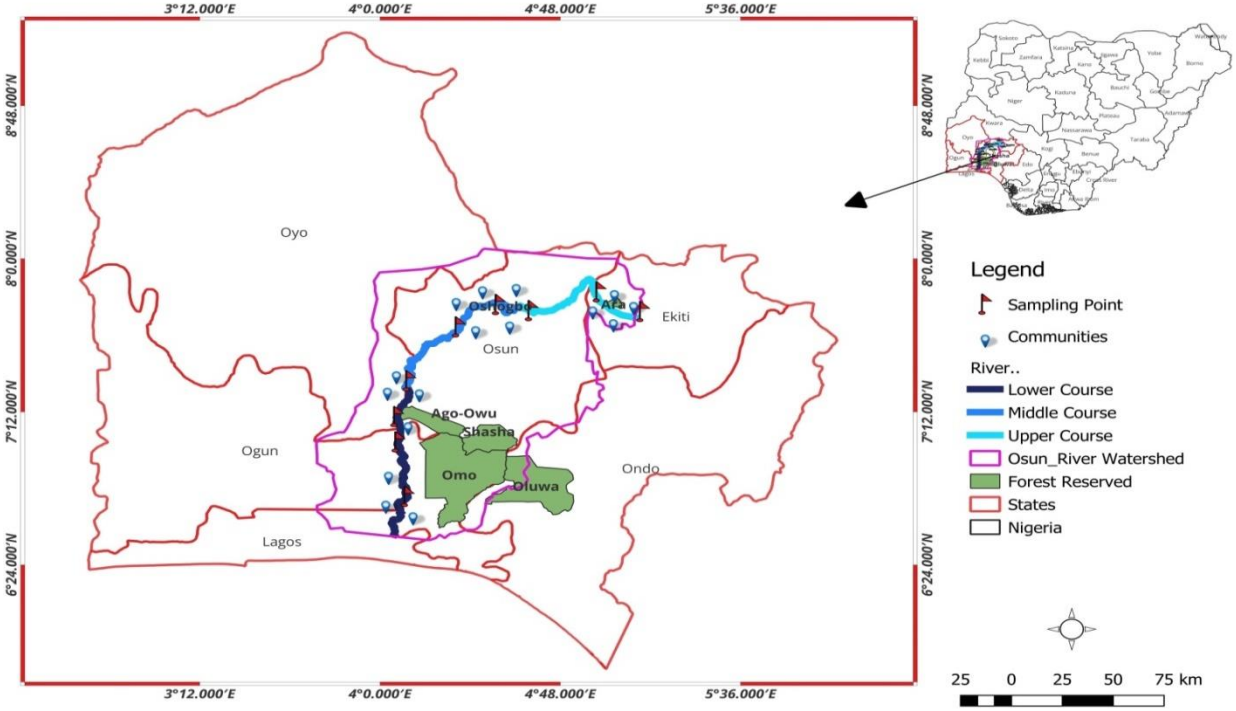


Figure 1: Osun watershed and three river courses through which River Osun flows in southwestern Nigeria. (Auto-generated watershed boundary shape and drainage network using spatial analyst tool in ArcGIS 10.3 and Digital Elevation Model)
(Desk Work, 2021)

Sampling Procedure and Data Analysis

Osun River Watershed (ORW) was stratified into Upper Course (UC), Middle Course (MC), and Lower Course (LC) based on direction of flow. Taking into account how human activities affect the land cover, three land use types: Forest (FO), Farmland (FL) and Built-up (BU) common to UC, MC and LC were purposively selected for water quality investigation. Nine sampling location(s) were selected from the study area (Table 1). Water samples were obtained from a randomly designated point within the river shore and close to each of the three major types of land usage. Coordinate of points were determined for subsequent collection.

Table 1: Locations along the Osun River water course where water sampling was done

		GPS Coordinates	
River Courses	Locations	Latitude (Northing)	Longitude (Easting)
Upper	Odo Ori	7º41'13.47"and 7º42'33.46"	5º07'13.64" and 5º08'10.84"

	Ara	7°44'36.72" and 7°45'08.77"	5°03'48.00" and 5°05'45.76"
	Esa-odo	7°45'26.20" and 7°46'51.98"	4°48'41.92" and 4°51'27.40"
Middle	Osogbo sacred groove	7°43'52.15" and 7°45'21.96"	4°33'01.08"and 4°33'12.00"
	Oke gada	7°44'57.30" and 7°46'18.74"	4°26'09.94" and 4°28'02.77"
	Asejire	7°21'20.96"and 7°23'53.29"	4°07'40.32" and 4°08'39.98"
Lower	Ago Owu	7°07'17.11" and 7°09'29.76"	4°05'21.09" and 4°04'33.26"
	Osun Budepo	7°02'30.12" and 7°04'43.26"	4°04'37.94" and 4°06'65.52"
	Atakobo	6°46' 09.68" and 6°48'18.71"	4°07'13.48" and 4°08'23.61"

Water samples were collected following Asinwa and Olajuyigbe (2019). Samples were taken using a $2^{1}/_{2}$ liters sterilized plastic bottles with a tight-fitting screw top. Prior to collecting the samples, water was skimmed at each location to remove any surface debris. Also, for the purpose of preventing air bubble trapping during collection, sample bottles were dipped to 30 - 50 cm below the surface of water and then tightly covered. Samples were collected once in two months between 7.00 am and 11.00 am at designated points within the river shore and close to the three land use types and for a period of 24 months (September 2019 – August 2021) to capture seasonal variations. Labels were placed on plastic containers indicating the origin and the collection date. The specimens were preserved through freezing method for different parameters measured. Samples were delivered to the laboratory that same day. Thus, three water samples from three major land use types were replicated three (3) times, resulting in an overall of 324 (12months × 9 = 108) x 3) water samples from the three river courses of Osun River.

The following Physico-chemical variables; pH, Turbidity, Dissolved oxygen (DO), Calcium, Magnesium, Total dissolved solid (TDS), Total suspended solid (TSS), Biological Oxygen Demand (BOD), Electrical conductivity (EC), Heavy metals (Iron, chromium, Zinc and lead), Potassium, Nitrate, Phosphate, Sulphate, Chloride residual and microbiological factors; faecal and total coliforms were determined.

A pH meter (PHS-3B Uniscope Model) was used to measure the pH. BOD, DO and TDS were determined by using the iodometric (Wrinkler's) method. Total Suspended Solid was determined gravimetrically, while TS was obtained by summing up the values of TDS and TSS. Optical Turbidimeter (Hach 2100A) was used to determine turbidity. Chloride was determined using the Argentometric method. Total hardness was estimated using EDTA (Ethylenediamine-tetraacetic acid) titrimetric method. Phosphate and Nitrate were obtained using Hanna multiparameter photometer machine. The EC was measured using a conductivity meter. Heavy metals (lead, iron, zinc and chromium) were determined using buck scientific Atomic Absorption Spectrophotometer (model 210/211 VGP), while a flame photometer was used to determine potassium. Microbial contents of the water samples were determined using the multiple tube fermentation method for enumeration of both Total coliforms and Faecal coliforms.

Using 3 x 3 x 2 factorial experiments in a completely randomized design, Analysis of Variance (ANOVA) was utilized to check for variations in the physico-chemical variables of the water samples. Three land use types, three river courses, and two seasons (rainy and dry season) were the first, second, and third factors, respectively. A follow-up test was employed for mean separation where significant differences were found. Values of physicochemical parameters of water samples from each land use type were compared with World Health Organization drinking water standard.

RESULTS AND DISCUSSION

pH, Total Suspended Solid (TSS), Total Dissolved Solid (TDS), Electrical Conductivity(EC), Dissolved Oxygen (DO), Turbidity and Biological Oxygen Demand (BOD) of Water samples from Osun River

Mean values of TSS, TDS, EC, DO, Turbidity and BOD of water samples varied greatly in term of land use types, river courses and seasons while pH is not significant (Table 2). The pH values ranged from slightly acidic (6.50±0.02) in BU at the middle course to slightly basic (7.33±0.06) in FO at middle course during the rainy season. The mean values for pH fell within the acceptable range of 6.5 to 8.5 (WHO, 2011). The pH readings agree with those obtained by Anifowose *et al.* (2015) and Chidya *et al.* (2012) in other rivers.

The highest value (241.11±0.20mg/l) of TSS was obtained in BU at middle course in the rainy season while FO at upper course had the lowest value (155.44±0.34mg/l) during dry season. The high TSS observed may be linked to the rise in runoff of sewage, industrial waste, garbage, and animal wastes' effluence (Bhaduri *et al*., 2000) which may be caused by impermeable surfaces. The TSS value was above 80 mg/L. This is dangerous to aquatic organisms and has negative effect on water quality.

The highest value (227.61±0.87mg/l) of TDS was obtained in BU land of middle course at the rainy season while FO at upper course had the lowest value (126.39±0.43mg/l) during the dry season. Highest TDS could be linked to unregulated human activities including inappropriately pouring of domestic water into water channels and open defecation into waterways (Olusola *et al*., 2018). The mean value of TDS was discovered to be lower than the most ideal range of 600 – 1000 mg/l (WHO, 2022).

Electrical conductivity was greatest (204.83±0.79µs/cm) in BU at the middle course during the rainy season while FO at upper course had the least value (111.72±0.70µs/cm) during the dry season (Table 2). The concentration of dissolved ions is measured using conductivity (Feng *et al*., 2020). Rock, minerals, physical structures, agricultural runoff, urban roads, and sewage wastewater all have an impact on the EC. A high variance in conductivity values suggests that there is water pollution (Dawson *et al*., 2019). The mean value of EC was lower than the drinking water's acceptable threshold i.e. 1000µs/cm (WHO, 2019).

The DO was highest (9.10±0.08mg/l) in FO of upper course during the rainy season while BU at lower course had the lowest value (5.44±0.06mg/l) in the dry season. The greatest DO levels observed in the FO could be due to productivity from aquatic plants. Riparian forests provide a cool microclimate for water bodies, which in turn favours DO. Sufficient DO is required to maintain high water quality and to support aerobic life (WHO, 2010). Lowest values of DO recorded in BU during dry season could be ascribed to water pollution caused by human activities

and might have led to increased temperature and microbial activities. This implied that a larger BU would decrease DO concentrations. This agrees with Xizhi *et al.* 2017 who opined that shift in the BU might impact DO.

The highest value (22.51±0.52 NTU) of Turbidity in water sample was obtained in BU at the middle course in the rainy season while FO at upper course had the lowest value (6.52±0.03 NTU) in dry season. The word "turbidity" refers to the murkiness of water caused by suspended silts and clay, organic particles such as organisms, plant debris, and chemical precipitates like iron, manganese (Health Canada, 2012). Generally, turbidity was lower in the dry season (November to March) than during the rainy season (May to October). The observation supports the claim that turbidity can rise in response to natural occurrences like storms, floods, and severe rains (Borst *et al.,* 2013). The highest turbidity observed in BU suggests that the natural environment of water bodies can be disturbed by human activity. The mean values for turbidity were found to be above the highest desirable level of 4NTU (WHO, 2022). The quantity of oxygen and sunshine available to aquatic organisms for survival is limited by high turbidity which in turns lowers an area's production (Tahiru *et al.,* 2020).

In water sample, Biological Oxygen Demand (BOD) value was highest (72.67±0.37mg/l) in BU at the middle course during the rainy season while FO at the upper course had the least value (44.35±0.15mg/l) during the dry season (Table 2). The highest BOD observed might be related to human activities that influenced the discharge of chemical and plant residues into water bodies. This causes low oxygen concentration in water body owing to larger amounts of oxygen needed by biodegradable organisms. Water with a higher BOD is of lower quality.

ISTF-NIG 2026

Table 2: Mean values of pH, Total suspended solid, Total dissolved solid, Electrical conductivity, Dissolved oxygen, Turbidity and Biological Oxygen Demand of Water samples in the Land Use types of three River courses of Osun River

River Courses	Seasons	Land Use Types	pH	Total suspended solid (mg/l)	Total dissolved solid (mg/l)	Electrical conductivity (µs/cm)	Dissolved oxygen (mg/l)	Turbidity (NTU)	Biological Oxygen Demand (mg/l)
Upper Course	Rainy	Forest	7.18±0.04	184.92±0.67^{i}	152.89±0.39^{g}	165.50±0.44^{g}	9.10±0.08^{a}	13.78±0.38^{de}	54.30±0.42^{h}
		Farmland	6.74±0.07	191.33±0.58^{h}	160.72±0.83^{f}	171.86±0.35^{f}	7.48±0.03^{d}	16.42±0.16^{bcd}	58.08±0.28^{g}
		Built-up	6.59±0.03	199.78±0.49^{f}	167.67±1.26^{e}	182.62±0.96^{d}	6.77±0.03^{fg}	19.02±0.50^{abc}	62.59±0.29^{f}
	Dry	Forest	7.04±0.06	155.44±0.34^{o}	126.39±0.43^{l}	111.72±0.70^{m}	7.91±0.10^{c}	6.52±0.03^{g}	44.35±0.15^{j}
		Farmland	6.82±0.09	162.11±0.49^{n}	132.33±0.73^{k}	124.69±0.23^{k}	6.59±0.03^{gh}	8.36±0.03^{fg}	49.70±0.18^{i}
		Built-up	6.54±0.04	173.89±1.06^{j}	142.17±0.70^{i}	138.89±0.74^{i}	5.58±0.08^{j}	9.85±0.31^{efg}	55.45±1.27^{h}
Middle Course	Rainy	Forest	7.33±0.06	218.22±0.67^{c}	205.83±0.33^{c}	186.28±0.31^{c}	8.59±0.12^{b}	15.98±0.16^{cd}	62.49±0.48^{f}
		Farmland	6.57±0.05	228.61±0.74^{b}	216.00±0.25^{b}	193.86±1.55^{b}	7.44±0.03^{d}	18.73±0.25^{abc}	65.76±0.44^{d}
		Built-up	6.50±0.02	241.11±0.20^{a}	227.61±0.87^{a}	204.83±0.79^{a}	6.85±0.04^{f}	22.51±0.52^{a}	72.67±0.37^{a}
	Dry	Forest	7.18±0.03	166.22±0.28^{m}	142.22±0.45^{i}	125.61±0.78^{k}	7.97±0.03^{c}	8.70±0.02^{fg}	63.53±0.60^{ef}
		Farmland	6.63±0.07	172.17±0.76^{k}	148.61±1.04^{h}	134.89±0.20^{j}	6.44±0.03^{hi}	10.42±0.11^{efg}	64.29±1.02^{de}
		Built-up	6.55±0.02	184.39±1.00^{i}	158.89±0.63^{f}	148.44±0.57^{h}	5.54±0.07^{j}	13.03±0.14^{de}	70.36±0.20^{b}
Lower Course	Rainy	Forest	7.27±0.06	194.22±0.20^{g}	200.33±0.51^{d}	166.06±0.44^{g}	8.76±0.09^{b}	15.02±0.28^{cd}	63.40±0.36^{ef}
		Farmland	6.69±0.05	203.89±0.15^{e}	207.67±1.00^{c}	174.17±0.33^{e}	7.17±0.09^{e}	17.20±0.08^{bcd}	67.42±0.52^{c}
		Built-up	6.57±0.01	212.16±0.44^{d}	217.95±0.86^{b}	187.22±0.31^{c}	6.46±0.05^{hi}	20.71±0.53^{ab}	73.90±0.22^{a}
	Dry	Forest	7.08±0.07	162.94±1.11^{n}	137.56±0.39^{j}	115.53±0.07^{l}	7.51±0.11^{d}	8.58±0.02^{fg}	54.10±0.78^{h}
		Farmland	6.79±0.01	170.22±0.29^{l}	143.61±0.58^{i}	126.55±0.55^{k}	6.37±0.02^{i}	10.40±0.02^{efg}	59.33±0.33^{g}
		Built-up	6.58±0.01	177.22±0.20^{j}	154.22±1.13^{g}	140.34±0.17^{i}	5.44±0.06^{j}	11.51±0.45^{def}	58.15±0.14^{g}

Means in a column that share the same superscript do not differ significantly ($p>0.05$).

Chloride, Sulphate, Phosphate, Nitrate, Total coliform and Faecal coliform of water samples of Osun River.

Chloride, Sulphate, Phosphate, Total coliform and Faecal coliform exhibited notable variations among land use categories, river courses and seasons while Nitrate was not significant (Table 3). Chloride concentration had highest value (173.67±0.58mg/l) in BU at the lower course during rainy season while FO at upper course had the lowest value (85.66±0.44mg/l) all through the dry season. Sources of chloride include; salts from road constructions, that are washed into waterway (Granato *et al.,* 2015), industrial waste, metal plating, and effluent from factory operations like vehicle repairs. Highest value recorded, might be ascribed to urban run-off from road salting, sewage, domestic waste and industrial effluents in Osun watershed. Mean value of chloride was below the acceptable limits for drinking water i.e. 250mg/l (WHO, 2011 and 2019).

Sulphate had the highest value (57.45±0.15mg/l) in FL at the lower course during rainy season while FO at upper course had the lowest value (32.62±0.06mg/l) during the dry season. Sulphate enters waterways through runoff from fertilized soil, sewage treatment plants, organic matter decomposition, mineral weathering, and industrial discharge. The highest concentration of sulphate obtained could be traced to runoff from fertilizer application. The mean value of sulphate was found to be below the drinking water safety requirements i.e. 250mg/l (WHO, 2019).

Phosphate concentration was highest (1.78±0.05mg/l) in FL at the lower courses during rainy season while FO at the upper course had the lowest value (0.31±0.02mg/l) in the dry season. The major activities that could increase phosphate concentration in surface water are industrial effluent, discharge wastes, disposal of municipal, leakage from fertilized soil and abattoir wastes (Taiwo *et al*., 2011). According to Gorgoglione *et al.* (2020), terrestrial vegetation is important for absorbing bioavailable phosphorus. Phosphate concentration above 0.10 mg/L could accelerate plant's growth or algae bloom with subsequent ecological and environmental problems like eutrophication.

Highest concentration value (43.91±0.48 mg/l) of Nitrate was obtained in FL at the middle course during rainy season while FO at upper course had the lowest value (30.73±0.98mg/l) during the dry season. The sources of nitrate in aquatic bodies are fertilizers, atmospheric rainfall, wastewater, animal faeces and urban drainage. Highest nitrate in FL supports the discovery by Kandler *et al*. (2017) that agricultural activities have been associated with increased nitrate levels. Mean values of nitrate were below the drinking water safety requirements i.e. 50mg/l (WHO, 2011 and 2022).

The Total coliform of water sample was highest (209.78±0.89 mpn/ml) in BU at the middle course during the rainy season while FO at upper course had the lowest value (182.67±0.17mpn/ml) during dry season. The faecal coliform of water sample was highest (197.94±0.53mpn/ml) in BU at the middle course during the rainy season while FO at the upper course had the lowest value (152.83±0.42mpn/ml) during dry season (Table 3).

Throughout the period of study, the concentration level of total coliform in the upper, middle, and lower courses of Osun River was very high in BU land during the rainy season. This support the findings of Olalekan *et al.* (2012) 'that the density and quantity of total and faecal coliform in water sources frequently rise during the rainy season as human or animal faeces are washed into creeks, lakes, rivers, ground water, or streams. Bacterial contamination is most strongly linked to

development. High levels of coliform could arise from improper disposal of household and municipal wastes (Tahiru *et al.,* 2020). Total and faecal coliform bacterial had higher mean levels than the desirable limit of 0 mpn /100ml (WHO, 2019). Water contamination by faecal coliform bacteria can lead to loss of potable water, which may have negative social and economic repercussions (EPA, 2000).

ISTF-NIG 2026

Table 3: Mean values of Chloride, Sulphate, Phosphate, Nitrate, Total coliform and Faecal coliform of Water samples in the Land Use types of three River courses of Osun River

River Courses	Seasons	Land Use Types	Chloride (mg/l)	Sulphate (mg/l)	Phosphate (mg/l)	Nitrate (mg/l)	Total Coliform (mpn /100ml)	Faecal Coliform (mpn / 100ml)
Upper Course	Rainy	Forest	100.39±0.68^{n}	37.52±0.66^{g}	0.43±0.00^{ghi}	37.69±0.71	192.67±0.54^{h}	164.67±0.26^{h}
		Farmland	105.91±0.05^{m}	42.77±0.61^{e}	0.53±0.02^{g}	42.58±0.12	196.94±0.34^{fg}	172.61±1.11^{g}
		Built-up	120.94±0.87^{j}	37.99±0.47^{g}	0.45±0.02^{gh}	36.69±0.42	202.83±0.53^{c}	185.50±1.44^{c}
	Dry	Forest	85.66±0.44^{p}	32.62±0.06^{i}	0.31±0.02^{i}	30.73±0.98	182.67±0.17^{j}	152.83±0.42^{j}
		Farmland	97.05±0.55^{o}	36.70±0.26^{g}	0.43±0.02^{ghi}	34.03±1.02	188.33±0.25^{i}	159.78±0.81^{i}
		Built-up	109.39±0.36^{l}	34.36±0.85^{h}	0.34±0.02^{hi}	32.16±0.57	196.17±1.00^{g}	178.61±1.64^{e}
Middle Course	Rainy	Forest	128.61±0.11^{i}	44.45±0.40^{d}	0.99±0.01^{e}	37.84±0.60	198.17±0.26^{ef}	178.61±0.78^{e}
		Farmland	139.11±1.12^{g}	50.06±0.63^{b}	1.65±0.10^{b}	43.91±0.48	201.78±0.22^{cd}	185.67±0.53^{c}
		Built-up	149.28±0.46^{e}	46.78±0.55^{c}	1.26±0.10^{d}	37.81±0.11	209.78±0.89^{a}	197.94±0.53^{a}
	Dry	Forest	107.94±0.53^{l}	36.91±0.04^{g}	1.01±0.03^{e}	31.71±0.07	192.67±0.48^{h}	171.33±1.44^{g}
		Farmland	119.11±0.64^{k}	44.53±0.22^{d}	1.69±0.04^{ab}	35.79±0.27	195.50±0.63^{g}	179.22±0.62^{e}
		Built-up	131.11±0.24^{h}	39.72±0.39^{f}	1.50±0.02^{c}	31.55±0.46	201.11±0.24^{d}	186.17±1.04^{c}
Lower Course	Rainy	Forest	152.39±0.92^{d}	50.72±0.53^{b}	1.23±0.01^{d}	38.11±0.24	196.55±0.43^{g}	175.55±0.55^{f}
		Farmland	162.45±1.15^{b}	57.45±0.15^{a}	1.78±0.05^{a}	43.50±0.35	201.33±0.38^{cd}	182.22±0.46^{d}
		Built-up	173.67±0.58^{a}	50.17±0.44^{b}	1.17±0.05^{d}	37.17±0.42	207.05±0.55^{b}	192.61±0.72^{b}
	Dry	Forest	130.22±1.04^{hi}	34.21±0.57^{h}	0.75±0.01^{f}	35.15±0.21	187.89±0.24^{i}	166.39±0.46^{h}
		Farmland	144.00±0.73^{f}	44.27±0.54^{d}	0.98±0.01^{e}	39.26±0.67	192.17±0.35^{h}	172.28±0.87^{g}
		Built-up	154.39±0.11^{c}	36.70±0.38^{g}	0.79±0.00^{f}	35.93±0.52	198.72±0.68^{e}	185.95±2.07^{c}

Means in a column that share the same superscript do not differ significantly (p>0.05).

Calcium, Magnesium, Potassium, Lead, Zinc, Iron and Chromium of water sample of Osun River

Magnesium, Potassium, Lead, Zinc, Iron and Chromium were not significantly different among land use categories, river courses and seasons while Calcium was significant (Table 4). The greatest value (67.27±0.76 mg/l) of Calcium hardness concentration was obtained in BU land at the lower course in the rainy season while FO at upper course had the least value (40.64±0.29mg/l) throughout the dry season. Also, concentration of magnesium in water sample was highest (8.91±0.17mg/l) in BU at the lower course during rainy season while the forest at the lower course had the least value (3.90±0.10mg/l) at the dry season.

According to Yilmaz and Koc, (2014), rock leaching allows calcium, magnesium, and iron to enter water bodies. Metals in rivers can also come from mining, sewage, waste water treatment facilities, industry effluent, erosion, and sedimentation. The highest levels of calcium and magnesium that accounted for total hardness were recorded in BU land and during the rainy season. The removal of FO vegetation may have contributed to erosion from contaminated soil and sewage discharge in urban areas. Means values were lower than the standard level of 75mg/l for calcium and 30mg/l for magnesium (WHO, 2011).

The highest value (13.80±0.10mg/l) of Potassium was obtained in farmland at middle course during rainy season while forest at lower course had the lowest value (5.69±0.12mg/l) throughout the dry season. The lowest mean value from forest emphasizes the function of forest vegetation in absorbing and removing pollutants from runoff. The highest average value at the rainy season might be related to leaching of fertilizer from farmland. The mean value of potassium was below the drinking water safety thresholds i.e 20 mg/l for Potassium (WHO, 2022).

In water sample, average value of Lead was highest (0.01±0.00mg/l) in built-up at the middle, upper and lower courses during rainy season while forest across the courses had the least value (0.00±0.00mg/l) during rainy and dry seasons. Heavy metals like lead can enter water bodies from a variety of sources, including lead-acid batteries, waste incinerators, industrial effluent, gasoline, paint, pipe fittings, and soldering operations. During the wet season, the highest lead observed in built-up areas corroborate the findings of Olajire and Imeokparia (2001) that lead levels may have increased due to runoff from nearby auto repair shops, torrents from nearby dumps, and welders near the Osun River. The average value of lead was within the acceptable range for drinking water. i.e. 0.01mg/l (WHO, 2022).

The highest value (1.05±0.04mg/l) of Zinc in water sample was obtained in built-up Area at the lower course during rainy season while the forest at upper course had the least value (0.04±0.02mg/l) throughout the dry season. Zinc pollution primarily comes from anthropogenic sources, such as coal-burning power stations, municipal wastewater discharges, metal-based manufacturing processes, and atmospheric fallout. Zinc's The highest concentration of zinc recorded in the built-up Area is in agreement with Anifowose and Oyebode (2019) that the concentration of zinc-galvanized material dissolving and burning increased gradually from Osogbo city's pre-urban settlement to its populated regions. Mean concentration value of Zinc was lower than the drinking water safety threshold i.e. 3.00mg/l (WHO, 2022).

Iron level in the water samples was highest (0.35±0.02mg/l) in built-up Area at the upper course during rainy season while forest at upper course had the lowest value (0.10±0.01mg/l) during dry season. Rivers may contain iron due to anthropogenic actions (such as clearing forest cover for farming) and natural deposits like the leaching of corroded metallic objects. Mean concentration value of iron in built-up areas across the courses slightly exceeded the highest desirable level of 0.3mg/l (WHO, 2022). Water with too much iron can harm human internal organs, produce bacterial infections that can cause serious sickness, clog pores, damage skin cell walls, cause acne, and cause long-term plumbing issues (Abwatertreat, 2020).

The highest concentration value (0.03±0.00 mg/l) of Chromium was obtained in built-up Area at the lower course during the rainy season while forest at upper, middle and lower courses had the lowest value (0.00±0.00mg/l) during rainy and dry seasons (Table 4). Chromium is one of the heavy metals that can leak into soil and water from industrial activities such electroplating, water treatment, tanning, dyeing, and coal ash disposal (Agegnehu and Nigus, 2017). The highest chromium mean value recorded in built-up Areas support the findings of Sánchez-Chardi *et al*. (2007) that anthropogenic activities in urban settings can easily raise the quantities of heavy metals in rivers. The mean value of chromium was found to be below the safe limit for drinking water i.e. 0.05 (WHO, 2022).

ISTF-NIG 2026

Table 4: Mean values of Calcium, Magnesium, Potassium, Lead, Zinc, Iron and Chromium of Water samples in the Land Use types of three River courses of Osun River

River Courses	Seasons	Land Use Types	Calcium (mg/l)	Magnesium (mg/l)	Potassium (mg/l)	Lead (mg/l)	Zinc (mg/l)	Iron (mg/l)	Chromium (mg/l)
Upper Course	Rainy	Forest	46.81±0.23^{k}	4.05±0.26^{i}	9.81±0.65^{e}	0.00±0.00	0.06±0.00	0.18±0.01	0.00±0.00
		Farmland	50.44±0.25^{ij}	5.67±0.30^{de}	12.80±0.53^{b}	0.01±0.00	0.22±0.02	0.27±0.01	0.00±0.00
		Built-up	56.01±0.44^{d}	7.68±0.13^{bc}	9.98±0.41^{e}	0.01±0.00	0.49±0.04	0.35±0.02	0.01±0.00
	Dry	Forest	40.64±0.29^{m}	4.01±0.06^{i}	6.44±0.08^{gh}	0.00±0.00	0.04±0.02	0.10±0.01	0.00±0.00
		Farmland	44.75±0.88^{l}	5.04±0.13fg	7.67±0.04^{f}	0.00±0.00	0.20±0.01	0.16±0.01	0.00±0.00
		Built-up	51.33±0.79^{hi}	7.18±0.20^{c}	7.49±0.09^{f}	0.01±0.00	0.32±0.02	0.26±0.01	0.00±0.00
Middle Course	Rainy	Forest	52.67±0.59^{gh}	4.28±0.01^{hi}	11.06±0.15^{c}	0.00±0.00	0.41±0.01	0.17±0.00	0.00±0.00
		Farmland	59.11±0.49^{d}	6.18±0.22^{d}	13.80±0.10^{a}	0.00±0.00	0.58±0.03	0.30±0.03	0.00±0.00
		Built-up	64.61±0.29^{b}	7.94±0.18^{b}	10.87±0.14^{cd}	0.01±0.00	0.87±0.02	0.31±0.00	0.01±0.00
	Dry	Forest	53.25±0.31^{fg}	4.21±0.22^{hi}	6.44±0.10^{gh}	0.00±0.00	0.40±0.01	0.24±0.09	0.00±0.00
		Farmland	56.72±0.73^{e}	5.88±0.06^{de}	7.82±0.13^{f}	0.00±0.00	0.56±0.03	0.23±0.01	0.00±0.00
		Built-up	63.33±0.29^{bc}	7.82±0.19^{b}	7.33±0.10^{f}	0.01±0.00	0.81±0.04	0.27±0.02	0.00±0.00
Lower Course	Rainy	Forest	59.17±0.19^{d}	4.69±0.11^{gh}	10.12±0.09^{de}	0.00±0.00	0.60±0.01	0.16±0.00	0.00±0.00
		Farmland	62.50±0.54^{c}	7.20±0.21^{c}	12.6±0.43^{b}	0.01±0.00	0.79±0.02	0.31±0.01	0.02±0.00
		Built-up	67.27±0.76^{a}	8.91±0.17^{a}	10.54±0.12^{cde}	0.01±0.00	1.05±0.04	0.33±0.09	0.03±0.00
	Dry	Forest	49.59±0.37^{j}	3.90±0.10^{i}	5.69±0.12^{h}	0.00±0.00	0.53±0.02	0.14±0.00	0.00±0.00
		Farmland	54.24±0.39^{f}	5.49±0.14^{df}	7.07±0.08^{fg}	0.00±0.00	0.71±0.04	0.20±0.00	0.00±0.00
		Built-up	62.33±0.51^{c}	7.51±0.26^{bc}	7.04±0.04^{fg}	0.01±0.00	0.89±0.45	0.26±0.00	0.01±0.00

Means in a column that share the same superscript do not differ significantly ($p>0.05$).

In general, mean values of all the physico–chemical and bacteriological properties were greater at the rainy season as opposed to dry period. This indicates that a considerable amount of the water quality indicators earlier discussed enters water body through runoff water, and the importance of forest vegetation in conserving and protecting water bodies cannot be over emphasized.

Also, forest land had the lowest mean values when compared to farmland and built-up across the seasons, land use types and river courses. This implies that forest vegetation plays an essential role in maintaining good water quality by filtering sediments, regulating the flow of water, absorbing and removing contaminants from soil, runoff and water bodies. McMahon *et al*. (2020) recent study has proven that vegetation can lessen erosion along riverbanks, hence minimizing turbidity. Moreover, built-up land had the highest mean values, followed by farmland in most of the physicochemical and bacteriological properties. This implies that the natural environment can be disturbed by human activity.

Mean values were lowest at the upper course, higher at the middle course and highest at lower course. This shows that the majority of human activities influencing the water quality of the Osun River were from Non – point sources.

CONCLUSION

Higher values recorded for some water quality parameters in Osun River indicate that human activities had an impact on the watershed ecosystem's transition to different land use types. The ongoing deterioration of the water quality in farmland and built-up land at the three river courses illustrate the direct consequences of the removal of forest cover. Thus, the study found that building areas and farming encroachments aggravated water contamination in Osun River. This shows how important forests are to the preservation and protection of the water bodies in the Osun River watershed. In the face of an ever- increasing population, if pollution to Osun River is not checked, access to good and safe water would be impeded. This would invariably threaten human health and affect economic development. It is therefore recommended that agroforestry practices and the use of organic fertilizers should be encouraged on farmland.

REFRENCES

Abwatertreat, 2020. Negative effect of too much iron in your water. Atlantic blue water centre. 1808 Baltimore Blue, Westminister, MD 21157. https://alanticbluewatercenter.com Accessed on 19/01/2025.

Adediji, A. and Ajibade, L.T. 2008. The Change Detection of Major Dams in Osun State, Nigeria using Remote Sensing (RS) and GIS Techniques. *Journal of Geography and Regional Planning* 1(6): 110-115.

Adegboyega, S.A. 2018. Spatio-temporal assessment of riparian vegetation degradation and its environmental consequences in Osogbo City. *Journal of Earth Atmospheric Research*. JEAR 1(1): 61-67.

Agegnehu, A. and Nigus, G. 2017. Assessment of chromium contamination in the surface water and soil at the riparian of Abbay River caused by the nearby industries in Bahir Dar city, Ethiopia. *Water Practice & Technology* Vol 12 No 172 doi: 10.2166/wpt.2017.012.

Akinwande, K, A., Ojo, P.A., Ogunade, J.O., Ogundana, S.A. and Ademisoye, A.O. 2013. Watershed functions and climate change. Proceeding of 36th Annual conference of the

Forestry Association of Nigeria held at Uyo, Akwa- Ibom, Nigeria on the 4th – 9th November 2013. Vol 1, Pp 305-312.

Akubugw, E.I., Nwachukwu, M.I., Odika, P.C., Duru, M.K.C. 2013. Water quality assessment of Njaba River, Nigeria. *Journal of Environmental Science, Toxicology and Food Technology*. 4(6):33-37.

Anifowose, A.J. and Oyebode, A. 2019. Studies on heavy metals contents of Osun River at the pre-urban settlement and across Osogbo City, Nigeria. *Journal of Taibah University for Science* 13(1): 318-323.

Anifowose. A.J., Takeda, K. and Sakugawa, H. 2015. Photoformation rate, steady-state concentration and lifetime of nitric oxide radical (NO) in a eutrophic river in Higashi-Hiroshima, Japan. *Chemosphere*. 2015;119: 302–309.

Asaad, M. A., Abdelazin, N., Oliver, C. S. V. 2016. Groundwater Quality Investigation Using Multivariate Analysis. Case Study: Western Nile Delta Aquifer, Egypt. *International Journal of Environmental Science and Development*, 7 (1):1-9.

Asinwa, I.O. and Olajuyigbe, S.O. 2019. Water quality modification by landuse types in watershed ecosystems of Southwestern Nigeria. *Eurasian Journal of Biosciences* 13:1-9

Azeez, L., Salau, A.K., Adewuyi, S.O., Osineye, S.O., Tijani, K.O., Balogun, R.O. 2015. Safety Evaluation of Osun River Water Containing Heavy Metals and Volatile Organic Compounds (VOCs) in Rats. Niger. *J. physiol. Sci.* 30(1): 103-109.

Bhaduri, B., Harbor, J., Engel, B. and Grove, M. 2000. Assessing watershed scale, long-term hydrologic impacts of land-use change using a GIS-NPS model. *Environmental Manage*. 26(6): 643-658.

Borst, W., Vellinga, T. and Van-Tongeren, O. 2013. "The Monitoring Programme for the Maasvlakte 2 Construction at the Port of Rotterdam – Part II".Terra- Aqua, no. 130, http: //www.iadc-dredging.com Accessed on 4/11/2025.

Chidya, R., Sajidu, S. and Mwatseteza, J. 2012. Evaluation and assessment of water quality in Likangala River and its catchment area. *Physics and Chemisty of the Earth*. 36:865–871.

Dawson, M. R., Hutchins, M., Bachiller-Jareno, N. and Loiselle, S. 2019. The spatial and temporal variation of water quality at a community garden site in an urban setting: Citizen Science in action. *Freshw. Sci.* 38: 352–364.

Enwelu, I.A., Agwu, A.E. and Igbokwe, E.M. 2010. Challenges of participatory Approach to Watershed Management in Rural Communities of Enugu State. *Journal of Agricultural Extension* 14 (1): 69-79.

EPA 2000. Progress in water quality: An evaluation of the national investment in municipal wastewater treatment: Washington, D.C., U.S. Environmental Protection Agency, Office of Wastewater Management, EPA–832–R–00–008.

Feng, W., Qian, H., Xu, P. and Hou, K. 2000. Hydrochemical characteristic of groundwater and its impact on crop yields in the Baojixia irrigation area, China. *Water* 12:1443.

Gorgoglione, A., Gregorio, J., Ríos, A., Alonso, J., Chreties, C., Fossati, M. 2020. Influence of land use/land cover on surface-water quality of Santa Lucia River, Uruguay. *Sustainability* 12(11): 4692.

Granato, G.E., DeSimone, L.A., Barbaro, J.R. and Jeznach, L.C. 2015. Methods for Evaluating Potential Sources of Chloride in Surface Waters and Groundwaters of the Conterminous United States. Open File Report 2015-1080. US Geological Survey, Reston. https://doi.org/10.3133/ofr20151080. Accessed on 16/03/25.

Health Canada 2012. Guidelines for Canadian drinking water quality: guideline technical document – turbidity. Ottawa, Ontario: Water, Air and Climate Change Bureau, Healthy Environments and Consumer Safety Branch, Health Canada (www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/turbidity/index-eng php, accessed 22nd September 2025).

Kandler, M., Blechinger, K., Seidler, C., Pavlu˚, V., Šanda, M., Dostál, T., Krása, J., Vitvar, T. and Štich, M. 2017. Impact of land use on water quality in the upper Nisa catchment in the Czech Republic and in Germany. *Sci. Total Environ*. 586: 1316–1325.

Li, X., Nian, Y., Zhou, J. and Hu, X. 2014. Impact of land use change on water resource allocation in the middle reaches of the Heihe River Basin in North Western China. *J Arid Land* 6(3):273-286

McMahon, M.J., Olley, M.J., Brooks, P.A., Smart, C.R.J., Stewart-Koster, B., Venables, N.W., Curwen, G., Kemp, J., Stewart, M., Saxton, N., Haddadchi, A. and Stout, C.J. 2020. Vegetation and longitudinal coarse sediment connectivity affect the ability of ecosystem restoration to reduce riverbank erosion and turbidity in drinking water. *Sci Total Environ* 707:135904.

Mfon, P. and Mfon, G. 2013. Prospects and challenges of urban Forestry. Proceedings of the 36th Annual Conference of the Forestry Association of Nigeria held at Uyo, Akwa -Ibom State, Nigeria held at 4th – 9th , November, 2013 Vol 1 Pp. 524 – 531.

Mul, M., Obuobie, E., Appoh, R,, Kankam, K., Bekoe-obeng, E., Amisigo, B. and Mccartney, M. 2015. Water resources assessment of the Volta River Basin, vol 166. IWMI, Colombo.

Ogunade, J.O., Adio, A.F., Yakubu, F.B., Abu, J.E., Olayiwola, V.A. and Akamu, O.O. 2011. Sustainable Management of Agbonmagbe Watershed Through Enrichment planting in Popoola, L.; Ogunsanwo, O and Idumah, F. (eds). *Forestry in the Context of the Millennium Development Goals*; Proceedings of the 34th Annual Conference of the Forestry Association of Nigeria held at Osogbo in Osun State, Nigeria. Held between 5th -10th December, 2011. Pg. 95-101.

Olajire, A.A. and Imeokparia, F.E. 2000. A study of the Water quality of the Osun River: Metal Monitoring and Geochemistry. Bull. *Chem. Soc. Ethiop*. 14(1):1-8.

Olajire, A.A. and Imeokparia, F.E. 2001. Water quality assessment of Osun River: studies on inorganic nutrients. *Env. Mon. & Ass*.69: 17-28.

Olalekan, O. I., Oladipupo, S. O., Habeeb, A. Q. and Oluwaseun, A. B. 2012. Influence of Human Activities on the Water Quality of Ogun River in Nigeria. *Journal of Environmental Research* 2 (9):36-49.

Olusola, A., Onafeso, O. and Durowoju, O.S. 2018. Analysis of organic matter and carbonate mineral distribution in shallow water surface sediments. *Osun Geogr Rev* 1(1):106–110.

Sánchez-Chardi, A., López-Fuster, M.J.and Nadal, J. 2007. Bioaccumulation of lead, mercury, and cadmium in the greater white-toothed shrew, Crocidura russula, from the Ebro Delta(NESpain):Sex-andage-dependentvariation. *Environ Pollut*, 145(1):7–14.

WHO 2010. Guideline for Drinking Water Quality. 3rd Edition., World Health Organization, Geneva, Switzerland.

WHO 2011. Guidelines for Drinking-Water Quality. 4th Edition. NLM Classification: WA 675, World Health Organization, Geneva, Switzerland, Pp: 307-433, ISBN: 978 924 1548151.

WHO 2022. Guideline for Drinking Water Quality: fourth edition incorporating the first and second addenda. World Health Organization, Geneva, Switzerland. Pp 614. ISBN 978-92-4-004506-4.

WHO, 2019. World Health Organization Drinking Water Specification. Central pollution Control Board. Ministry of Environmental, Forest and Climate change Government of India. https://cpcb.nic in update on 14th 0ct. 2022.

Tahiru, A.A., Doke, D. A and Baatuuwie, B.N. 2020. Effect of land use and land cover changes on water quality in the Nawuni Catchment of the White Volta Basin, Northern Region, Ghana. *Applied Water Science*. 10:198

Taiwo, A.M., Adeogun, A.O., Olatunde, K.A., Adegbite, K.I. (2011). Analysis of groundwater quality of hand-dug wells inperi-urban areas of Obantoko, Abeokuta, Nigeria for selected physico-chemical parameters. *Pacific Journal of Science and Technology*, 12 (1): 527-534.

Xizhi, L., Jing, H., Peiqing, X., Pan, Z. and Hui, J.X. 2017. Correlation analysis between the water quality and land use composition in Chaobai River basin. *Nature Environment and Pollution Technology*, 16: 307-314.

Yilmaz, E. and Koc, C. 2014. Physical and chemical evaluation for the water quality criteria in a farm on Akcay. *Journal of Water Resources. Vol. 6: 63-67.*

ISTF-NIG 2026

SUB-THEME 5:
FOREST PRODUCTS DEVELOPMENTS, UTILIZATION AND SUSTAINABLE ECOSYSTEMS

ISTF-NIG 2026

MODEL IDENTIFICATION AND SENSITIVITY ANALYSIS OF FACTORS AFFECTING *Clarias gariepinus* DRIED IN A SEMI-AUTOMATED GAS-FIRED DRYER

[1]OGUNSOLA Akinola David, [1]*ADERIBIGBE Abidemi Adetuji, [2]ADEYI Oladayo, [3]ADEYEYE Taofeek Adewale, [1]ADETUNJI Michael Opeoluwa, [1]AJAYEOBA Abiola Olufemi,., [4] SANGOTAYO Emmanuel Olayimika, [1]ALADE Tinuade Racheal

[1]Department of Mechanical Engineering, Ladoke Akintola University of Technology, P.M.B.4000, Ogbomoso, Oyo State, Nigeria.
. [2]Department of Chemical Engineering, Michael Okpara University of Agriculture, P.M.B 7267, Umudike, Abia State, Nigeria.
[3]Department of Mechanical Engineering, Oyo State College of Agriculture and Technology, Igboora, Oyo State, Nigeria.
[4]Department of Biomedical Engineering, Achievers University, Owo, P.M.B 1030, Ondo State, Nigeria.
**Corresponding Email: aaaderibigbe@lautech.edu.ng /+2348032318122*

Abstract

This study entails the development of a mathematical model and a sensitivity analysis of drying factors based on published open-access drying data for *Clarias gariepinus* in a developed semi-automatic gas-fired dryer. The data comprised the relationships among drying Time, drying temperature, energy utilization, and moisture content in *Clarias gariepinus*. The data were preprocessed using Microsoft Excel 2010 software. A suitable mathematical model was developed from the preprocessed data using the multi-gene genetic programming algorithm (MGGP) in MATLAB R2017b. The efficiency of the developed mathematical model was established statistically using root mean square error (RMSE) and coefficient of determination (R^2). A sensitivity analysis of the drying factor was also conducted quantitatively using Monte Carlo simulation in Oracle Crystal Ball. The results showed that the developed mathematical model had an RMSE of 0.023012 and an R^2 of 0.991055. Sensitivity analysis showed that drying time accounted for -88.1 % of the variance in moisture content, while energy utilization and drying temperature accounted for 9.7 % and -2.2 %, respectively. It was concluded that these results would assist in the operation, optimization, and control of the developed semi-automatic gas-fired dryer.

Keyword: Multi-gene Genetic Programming; Monte Carlo simulation; Oracle Crystal Ball; sensitivity analysis; *Clarias gariepinus*

Introduction

Fish is a major source of protein, and it is considered to be One of the most important foods. It is also an important source of food and income to many people in the developing world (Teklu & Lema, 2015). Fish is a highly nutritious food, and it is particularly valued for its high-quality protein, which is superior to that of meat and eggs (Idah & Nwankwo, 2013). The importance of fish in citizens' diets has helped make fish farming One of the fastest-growing agricultural enterprises. Fisheries and fish processing have a significant impact on the nation's economy, including employment generation, poverty alleviation, foreign exchange earnings, and the provision of raw materials for the development of animal feed (Idah & Nwankwo, 2013). Fish is

a highly perishable product, and its quality deteriorates within a few hours after harvesting. Therefore, if fish is not consumed fresh, it must be preserved. Adequate fish preservation lessens post-harvest losses, conserves fish food and generates income, and eliminates incessant catch. The conventional methods for preserving fish include drying, salting, pickling, freezing, and smoking, amongst others (Abakarova *et al.,* 2011); however, in developing countries, fish drying is most widely practiced because of its easy accessibility, low cost, and low operational expertise requirements. Drying of fish is a complex operation that involves the application of heat and the removal of moisture from the material, making it an energy-intensive process (Abakarova *et al.,* 2011; Osofisan, 2007; Gou *et al.,* 2005). Understanding the mechanisms of drying will assist engineers in designing more suitable drying processes, equipment, and dried product qualities. Therefore, drying should be properly prepared and represented for further optimization and control. In practice, drying temperature, humidity, air velocity, nature of the material, process time, equipment design, and pre-treatments, amongst others, are factors contributing to the drying process (Idah & Nwankwo, 2013).

The suitability of artificial intelligence models for representing the complexity and multivariate nature of drying processes, coupled with their high accuracy, has recently drawn attention to these methods. These methods include machine learning and meta-heuristics categories. Successful artificial intelligence methods for drying processes include: Fuzzy Inference System, Artificial Neural Networks, Adaptive Neuro-Fuzzy Inference System, Support Vector Machines, Genetic Algorithms (GA), and others. The application of Multi Gene Genetic Programming (MGGP) to drying processes is still in the early stages. In addition to network structure development, MGGP can develop a mathematical model from data using its symbolic data-mining capabilities. This is an improvement over most artificial intelligence methods, which have only developed networked, structured architectures. In essence, genetic programming is a search algorithm whose behavior closely resembles the adaptive processes of biological systems (Taheri-Garavand *et al.,* 2013). It is an optimization algorithm used to find the maximum or minimum of a function.

The quantification of the dependence of dependent (output) factors on an independent (input) factor is important, at least for guided engineering decision-making. This act of understanding the contribution of each input factor to the output factor's variance, otherwise known as sensitivity analysis, will inform the economic processing of a product. Oracle Crystal Ball (OCB) is a sensitivity and risk analysis tool concerned with forecasting, simulation, and optimization (Hoffman *et al.,* 1994). OCB provides a needed understanding of the important factors affecting a risk (dependent factor). In contrast to traditional probabilistic analysis, OCB provides quantitative information on the realism of a particular forecast or prediction (Rai *et al.,* 1996). Understanding the sensitivity, or degree of importance, of the investigated input factors to the response variance is an important consequence of OCB (Oke *et al.,* 2020).

Several works have been done on artificial intelligence modeling, prediction, and optimization of drying data. For instance, Taheri-Garavand *et al.* (2013) optimized the Feed-Forward ANN structure with GA to model the moisture content of dried Basil under varied conditions; the best GA network obtained had only One hidden layer with 11 neurons. The network predicted the moisture content of dried Basil leaves with a high correlation coefficient. Jafari *et al.* (2015) applied FL and ANN to model and predict the moisture content during the drying of onions, reporting promising results. Ojediran *et al.* (2020) applied ANFIS to predict the moisture content

of yam slices (*Dioscorea rotundata*) in a convective hot-air drier, achieving better performance than empirical models. Kaveh *et al.* (2018) found that ANFIS and ANN models accurately predicted the drying characteristics of potato, garlic, and cantaloupe when dried in a convective hot-air dryer.

Ohijeagbon *et al.* (2018) published experimental data in relation to the performance evaluation of a designed and fabricated semi-automated gas-fired dryer. However, no effort was made to mathematically or otherwise represent the process. The mathematical representation of the process would enable analysis, prediction, optimization, improved dryer equipment design and drying process, and improved control of the process, amongst others. Furthermore, a mathematical representation of the process will enable the understanding of the degree of contribution of each process factor to the process performance indicator. Fortunately, researchers have published such datasets to serve as a framework for improved analysis, as shown by Adeniyi *et al.* (2019). Therefore, the present study aims to consolidate the preliminary work of Ohijeagbon *et al.* (2018) by developing a mathematical model from performance evaluation data obtained during the drying of *Clarias gariepinus* in a semi-automated gas-fired dryer. Complementing the model developed, this work investigated the sensitivity of each process factor (drying Time, drying temperature, and energy utilization) on the moisture content of *Clarias gariepinus* using OCB. The application of the MGGP algorithm to modeling and predicting drying characteristics, and the quantitative understanding or sensitivity analysis of drying factors, are identifiable gaps in the study that the present study strives to fill.

Methodology

Data information and preprocessing

In this study, the open-access experimental data published by Ohijeagbon *et al.* (2018) were used (Table 1). The data were arranged to examine the effects of drying Time, drying temperature, and energy utilization on the moisture content of fish (*Clarias gariepinus*) when dried in a developed semi-automated gas-fired dryer. Traditionally, the drying process for *Clarias gariepinus* involves several steps to produce an acceptable dried product. Figure 1 summarizes the typical procedure for drying *Clarias gariepinus*.

Table 1: Drying data representation

No Of Exp.	Drying Time (min)	Drying Temperature (^{O}C)	Energy Utilization (MJ)	Moisture Content (kg water / kg dry fish)
24	0 - 420	80 - 120	2.310 - 21.070	0.000 - 0.770

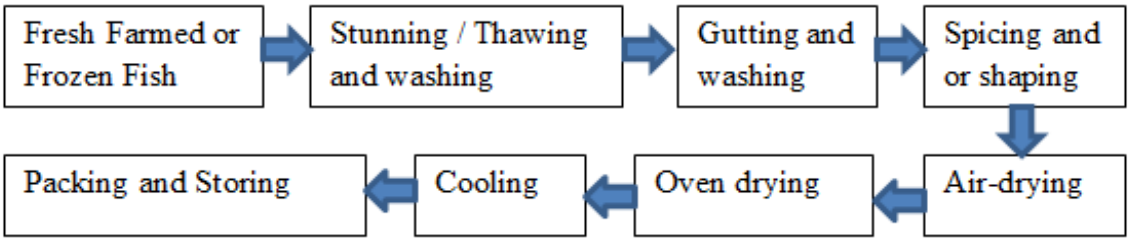


Figure 1. Typical drying procedure of *Clarias gariepinus*

Prior to use, the data were preprocessed by normalization in accordance with the method of Kaveh *et al.* (2018) using Microsoft Excel 2010 Software (Equation 1)

$$X_n = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (1)$$

Where X_n depicts the normalized value of the specific experimental data, X_i depicts the value of each experimental data, X_{max} depicts the maximum value for the specific experimental data, and X_{min} depicts the minimum value of the specific experimental data.

MGGP modeling

The MGGP algorithm is organized to strengthen the simulation process by incorporating modeling requirements that enable the determination of an optimal solution to a task; the genetic programming iteration continues until an optimal solution is established, a termination criterion is met, or both are satisfied. The algorithm then returns the best individual solution throughout the iteration (Orove & Osegi, 2005). The open-source Genetic Programming Toolbox for System Identification of Physical Systems (GPTIPS) was used to develop the MGGP model in MATLAB 2017b. GPTIPS enables the building of data-driven mathematical models. The underlying benefit of GPTIPS is the reduced technical difficulties in the application of the developed model, easy understanding, visualization, and deployment, while also providing highly customizable and robust numerical performance (Ozkan *et al.,* 2019). Table 2 presents the parameter settings for MGGP in this study.

Table 2: Tunable Parameter Setting of MGGP

Tunable Parameter	Value
Population size	500
Number of generations	150
Tournament size	4
Elitism fraction	0.02
Termination value	0.001
Maximum gene	4
Node functions	times, minus, plus, rdivide, psqroot, plog, square, tanh, pdivide, iflte, sin, cos, exp

The efficiency of the established MGGP mathematical model was statistically evaluated using the coefficient of determination (R^2) and root mean square error (R, MSE) in accordance with Adeyi *et al.* (2. Equations 3 were used to determine the best MGGP structure.

$$R^2 = 1 - \left(\sum_{i=1}^{N} \frac{(\text{Pred,i} - \text{Exp,i})^2}{(\text{Pred,i} - \text{AverageExp})^2}\right) \quad (2)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\text{Exp,i} - \text{Pred,i})^2}{N}} \quad (3)$$

Where Pred, i is the ith predicted value, Exp, i is the ith experimental value, and Averaged Exp is the average of all the experimental values. N represents the number of observations.

Sensitivity analysis of drying factors

The sensitivity or significance of each drying factor on moisture content was quantified. This was done using the MGGP-derived mathematical equation in the OCB software through Monte Carlo simulation. Oracle Crystal Ball functions within a defined range of independent variables to construct a probability distribution curve from which the sensitivity and stochastic analyses are established. In this study, drying input factors were assumed within their respective experimental ranges, while moisture content was treated as the forecast factor. Thirty thousand (30,000) iterations were performed to ensure a low mean standard error to determine the input factors' sensitivity analysis. The range of each input factor and the distribution curve used in the simulation are shown in Table 3.

Table 3: Input factors used for sensitivity analysis

Input variables	Designation	Distributions	Range of variables		
Drying Time (min)	x_1	Uniform	0	–	420
Drying Temperature (^{O}C)	x_2	Uniform	80	–	120
Energy Utilization (MJ)	x_3	Uniform	2.31	–	21.07

Results and discussion

MGGP simulation

The resulting multi-gene genetic programming equation in this study is represented in Equation 5.

$$0.018750x_3 - 0.001202x_1 + 2.341000tanhx_3 - \left(\frac{1.097000(x_2+6.919000)(x_1+x_2)}{10^5}\right) - 1.497 \quad (5)$$

The mathematical model of a typical MGGP is a tree structure composed of multiple genes. The genes incrementally reinforce the model's stiffness (objective function) by minimizing the sum of squared residuals from the data. Artificial intelligence methods develop model solutions consisting of weights and biases. Equation 5 showed that the MGGP developed a mathematical model with four genes and a bias term. The order of importance of the gene and bias is represented in Figure 2.

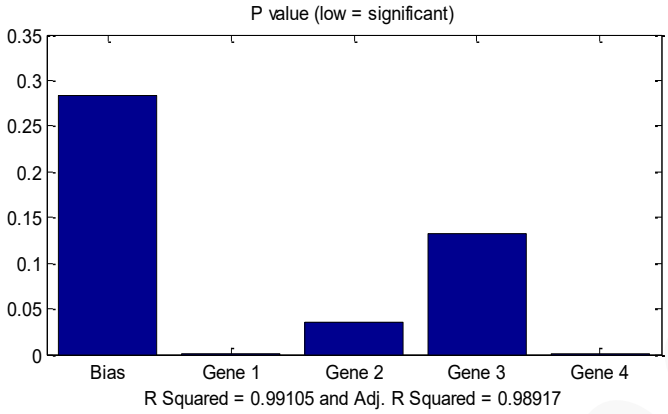


Figure 2. Importance of genes and bias in the model

The figure shows that genes 1 and 4 make the greatest contribution to the effectiveness of the MGGP mathematical model. The trend of effectiveness is followed by gene 2 and gene 3. The bias has the least contribution to the efficiency of the mathematical model developed. The efficiency of the MGGP mathematical model (Equation 5) developed from data of *Clarias gariepinus* dried in a semi-automated gas-fired oven is represented in Figure 3.

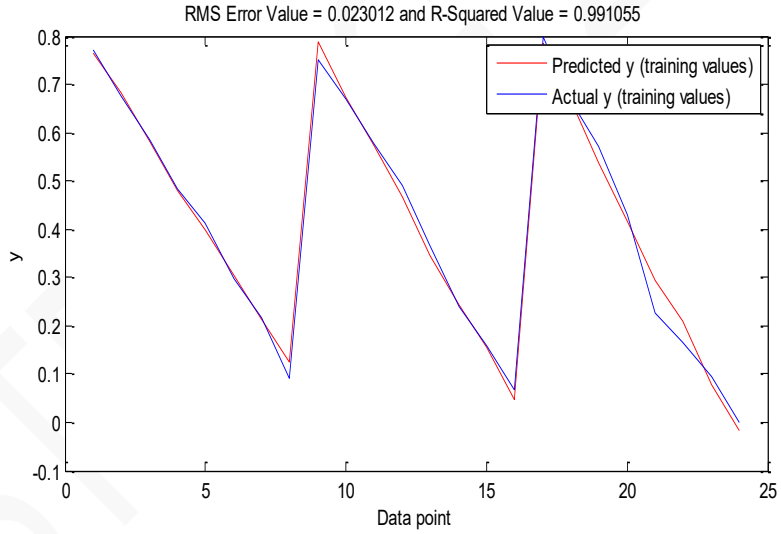


Figure 3. Performance efficiency

The figure shows close agreement between the experimental and MGGP-predicted data. The close equality is supported by the RMSE (0.023012) and R^2 (0.991055) values. In data prediction, the goal is to achieve an RSME value close to zero and an R^2 value close to unity. This result shows that the mathematical model developed using MGGP was efficient. The population spread of the individual solution (genome) in this study is shown in Figure 4, and the individual with red script is the best solution. The best solution has the lowest fitness value among others because the MGGP algorithm was designed to deliver a mathematical model by minimizing the objective (fitness) function. It is also observed that most individual solutions have low diversity, especially on the left-hand side of the figure.

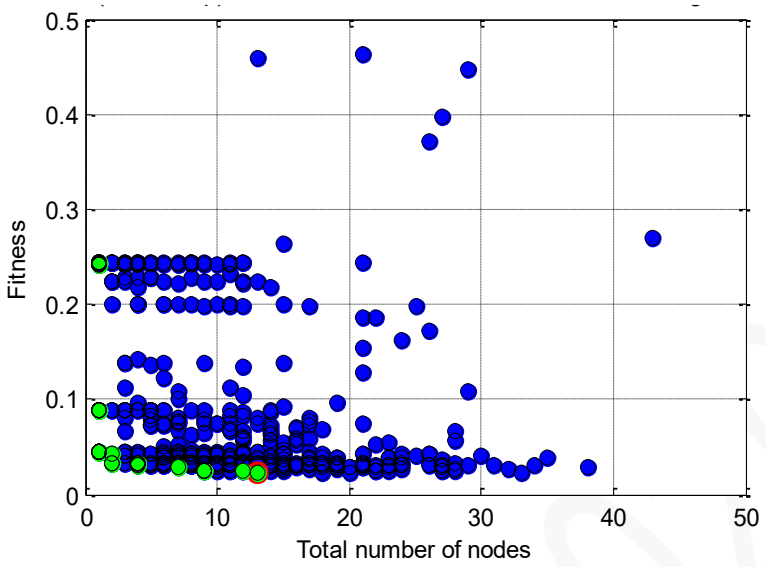


Figure 4: Population of solutions

Sensitivity analysis

The sensitivity analysis of the surveyed input factors for the drying of *Clarias gariepinus* in a semi-automatic gas-fired dryer is shown in Figure 5. The figure showed that drying time has a high influence (-88.10 %) on the moisture content of *Clarias gariepinus.* Negative influence is desirable (a decrease in initial moisture content) because the essence of drying is to reduce moisture content as much as possible, so that the dried product can have extended shelf stability. In contrast to the sensitivity of drying time, energy utilization has a low positive contribution (9.7 %) to the variances of the moisture content of *Clarias gariepinus.* A positive contribution to moisture content variance is not desirable, and this can be related to the higher drying rate associated with increased energy utilization during the drying process. At higher drying rates, there is a high probability of case hardening, in which the surface of *Clarias gariepinus* dries rapidly, forming a crust that prevents heat from penetrating its core. Therefore, at the early stage of drying, the surface had dried, forming a barrier to heat energy from penetrating the wet or yet-to-be-fully dried *Clarias gariepinus* core. Lastly, drying temperature showed a desirable negative sensitivity, or contribution (-2.2 %), to moisture content variance. This occurred because, at higher temperatures, the drying rate increases while drying Time decreases. It is therefore important that the temperature does not surpass the bearable limit of *Clarias gariepinus* fish undergoing drying so that the undesirable case hardening phenomenon does not result.

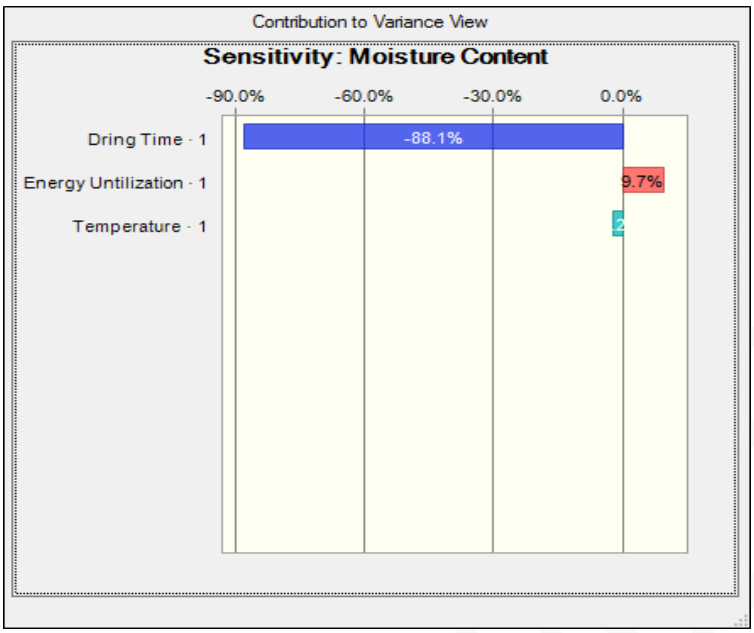


Figure 5. Sensitivity analysis

Conclusion

The interest of this study was to develop the MGGP model from observed drying kinetic data of *Clarias gariepinus* when dried in a developed semi-automatic gas-fired dryer and to quantify the sensitivity to variance (moisture content) of the drying process factors. The results showed that the mathematical model developed by MGGP had an RMSE of 0.023012 and an R2 of 0.991055. The sensitivity analysis established that drying time contributed -88.1% to *Clarias gariepinus* moisture content. In comparison, energy utilization and drying temperature contributed 9.7% and -2.2% to the variance in *Clarias gariepinus* moisture content, respectively. The results indicated that, when using the developed semi-automated gas-fired drying for *Clarias gariepinus*, a longer drying time is desirable to achieve a low moisture content at a moderate temperature, with minimal gas energy consumption. The lower contribution of energy utilization and temperature is well correlated, because at higher gas utilization, temperature is expected to increase. This result will guide the operation, control and analysis of the developed dryer for *Clarias gariepinus* drying.

References

Abakarova A., Jiménez-Ariza H., Correa-Hernandob E., Diezma B., Arranz F.J., García-Hierroc J., Robla J.I., Barreiro J, P. (2011). Control of a Solar Dryer through Using a Fuzzy Logic and Low-Cost Model-Based Sensor

Adeniyi A.G., Ighalo J.O. and Odetoye T.E. (2019). Response surface modelling and optimization of biodiesel production from Avocado plant (Persea americana) oil. Indian chemical engineer. https://doi.org/10.1080/0019 4506.2019.1658546

Adeyi A.J, Durowoju M.O and Adeyi O. (2019). Experimental Studies and Artificial Neural Networks (ANN) Modelling of Moisture Absorption Characteristics of Polyester/*M.*

Augustisepala Fiber Reinforced Composite. *International Journal of Mechanical Engineering and Technology (IJMET)*. 9(11): 1453–1467

Golpour, I. (2018). ANFIS and ANNs Model for Prediction of Moisture Diffusivity and Hot Air Dryer. Info Proc Agri, https://doi.org/10.1016/j.inpa.2018.05.003

Gou P., Comaposada J., Serra E., Corominas M., Poch M., and Arnau J. (2005). Fuzzy Control System in Drying Process of Fermented Sausages. *Drying Technology, 23: 2055–2069, 2005 Copyright Q 2005 Taylor & Francis, Inc. ISSN: 0737-3937 print/1532-2300 online*

Hoffman F.O., & Hammonds J.S. (1994). Propagation of Uncertainty in Risk Assessments: The Need to Distinguish Between Uncertainty Due to Lack of Knowledge and Uncertainty Due to Variability. *Risk Analysis* 14(5): 707–712.

Idah P.A. & Nwankwo I. (2013). Effects of smoke-drying temperatures and Time on physical and nutritional quality parameters of Tilapia (*Oreochromis niloticus*). *Int. J. Fish. Aquaculture.*

Jafari S.M., Ganje M, Dehnad D & Ghanbari V. (2015). Mathematical, Fuzzy Logic and Artificial Neural Network Modeling Techniques to Predict Drying Kinetics of Onion. Journal of Food Processing and Preservation. 40: Pg. 329 – 339

Kaveh M., Sharabiani V.R., Chayjan R.A., Taghinezhad E., Abbaspour-Gilandeh Y., and

Ohijeagbon I.O., Lasode O.A., Adebayo S., Ajayi O.O., Omotosho O.A. (2018). Data on drying kinetics of a semi-automated gas- fired fish dryer. Data in Brief. 18, 641 – 647

Ojediran J.O, Clinton E.O., Adeyi A.J., Adeyi O., Olaniran A.F, George N.E, A.T Olayanju (2020). Drying Characteristics of Yam Slices (*Dioscorea rotundata*) in a Convective Hot Air Dryer: Application of ANFIS in the Prediction of Drying Kinetics. *Cell Press Heliyon, Elsevier*. 6(3)

Oke E.O., Adeyi O., Okolo B.I., Adeyi J.A., Ayanyemi J., Osoh K.A., Adegoke T.S. (2020). Phenolic compound extraction from Nigerian Azadirachta Indica leaves: Response surface and neuro-fuzzy modeling performance evaluation with Cuckoo Search multi-objective optimization. *Results in Engineering*. 8, 100160.

Orove J.O. and Osegi. N.E., 2005. A Multi-Gene Genetic Programming Application for Predicting Students' Failure at School https://www.researchgate.net/publication/273472016

Osofisan P.B. (2007). Fuzzy Logic Control of the Syrup Mixing Process in Beverage Production. *Leonardo Journal of Sciences Issue 11, July-December 2007, pp. 93-108*

Özkan Ö., Cem S., Turgay B., and Aysegül G., 2019. Prediction of Slipper Pressure Distribution and Leakage Behaviour in Axial Piston Pumps Using ANN and MGGP. Mathematical Problems in Engineering.Volume 2019, Article ID 7317520, 13 pages. https://doi.org/10.1155/2019/7317520

Rai S.N., Drewski D. & Bartlett S. (1996). A general Framework for the Analysis of Uncertainty and Variability in Risk Assessment. *Human and Ecological Risk Assessment* 2(4): 972–989.

Taheri-Garavand A., Rafiee S., Keyhani A., & Javadikia P. (2013). Modeling of Basil Leaves Drying by GA –ANN. *International Journal of Food Engineering*. (4): 393– 401. doi 10.1515/ijfe-2012-0224

Teklu D. & Lema A. (2015). Optimization of Time and Temperature for Smoking of Nile Tilapia for a Better Preservation of Protein and Gross Energy Value. *Journal of Nutrition & Food Sciences*

ATTITUDES OF SECONDARY SCHOOL STUDENTS TOWARDS ENVIRONMENTAL CONSERVATION EDUCATIONAL PROGRAMS IN SOME SELECTED SCHOOLS IN OYO STATE, NIGERIA

[1]Olawale Oyetundun Opeyemi, [1]Oke Olugbenga Simeon, [1]Bolaji Kofoworola A, [2]Lawal Elijah and [2]Raymond O. Ademola.

Department of Forestry Economics and Extension Services, Forestry Research Institute of Nigeria, P. M. B. 5054, Jericho Hill Ibadan, Oyo State, Nigeria.
Department of Agricultural Extension and Rural Development, Federal University Oye Ekiti, Ekiti State, Nigeria.
***Correspondence**: okeolugbengas@gmail.com; opeyemioyetundu@gmail.com*

Abstracts

This study assessed secondary school students' attitudes towards conservation education programs in some selected schools in Oyo State, Nigeria. Data were collected from 250 students drawn from urban (n=130) and rural (n=120) schools using structured questionnaire. Descriptive statistic and Chi - square tests were employed for data analysis. The data were analyzed using descriptive and inferential statistics. Findings from this study showed that majority (54.0%) of the students were male and (44.4%) were within the age range of 14-16 years, most of the respondents (65.2%) are from urban area and were in SSS class (58.4%). The result also indicated that teachers (80.4%) were the main source of environmental conservation education. Followed by social media (58.4%). Then, 84.4% of the students expressed willingness to participate in environmental protection activities. Chi- square test revealed significant associations between willingness to participate in environmental conservation (x^2=59.50, p>0.05). Key challenges identified include inadequate teaching materials (61.5%) and insufficient funding (54.4%). The findings highlight the need for improved teachers training, increased resource provision and greater integration of community based environmental initiatives to strengthen conservation education in both rural and urban contexts.

Keywords: Attitude, Education, Environmental conservation, Program, Urban and rural, and Willingness,

Introduction

Environmental degradation has been a major global concern around the globe, particularly in developing nations like Nigeria. Environmental degradation, biodiversity loss, and climate change are major global challenges that threaten sustainable development goals (Denis Vasiliev, 2021). In

Nigeria, these problems are compounded by population growth, urban expansion, unsustainable agricultural practices, illegal logging, bush burning and poor waste management (Rabiu et al., 2020). Such environmental degradation has some unavoidable consequences, such as soil erosion, reduction in forest cover, loss of wild habitats and decrease in agricultural productivity (Fatoba and Aladejana 2014).

Conservation education is widely recognized as a critical strategy for promoting environmental sustainability. It aimed at equipping individuals with knowledge skill and attitudes necessary to protect and manage natural resources effectively. (Akinsemolu and Onyeaka, 2025). Secondary school students represent a crucial target group for conservation education because they are at a formative stage of development, where attitudes and behaviors can shape toward long term environmental sustainability. (Asunlegan et al., 2020). By fostering positive environmental attitudes at this stage, students are more likely to engage in some altitudinal behaviors' such as seedling production, tree planting, waste management, and community sanitation programs.

In Nigeria, environmental education is incorporated into various subjects, include Biology, Agricultural science, Geography and Civic education. (Abun et al., 2017). Additionally, students may also receive information about the environment through environmental clubs, school campaigns, social media platforms and community-based programs. (Ajayi et al., 2024: Umer Abdela, 2022).

Attitude toward environmental conservation is a critical determinant of students' engagement in sustainable practices. In environmental education research, attitude is defined as a learned predisposition to respond positively or negatively toward a specific environmental issue (Walker, 2017; Fabrice Clément, 2026; Daramola, 2023c). Positive attitude toward conservation education is associated with greater willingness to participate in environmental protection activities (Zhang et al., 2024).

The poor state of waste management in the country is caused by inadequate facilities, poor funding, and poor implementation of policies as well as wrong lifestyle. Any good secondary school environment must have environmental characteristics that make them functional, supportive and conducive for learning. (Anyansi, 2010). A functional environment denotes one with provision and management of facilities that promote academics, innovations and entrepreneur.

An environment that is conducive for learning denotes access to classroom, library and laboratory. It is this type of environment that supports the achievement of Sustainable Development Goals (SDGs), particularly SDG 4, which is inclusive and equitable quality education. (Mobolaji et al., 2024).

Economic development, urbanization, improved living standards in cities, and increase in enrolments of school children due to government policies in developing countries increase the quantity and complexity of generated solid waste in schools. If this waste is accumulated, it may

lead to degradation of the urban environment, stresses on limited natural resources, and various health issues. (Adeolu et al., 2014).

These environmental challenges have created inequality and imbalance in optimal development of school activities and in particular diminishes the quality of school environment (UN- Habitat, 2013; Koroye, 2016; Christian and Innocent, 2023). Good environment plays vital role in ensuring intellectual, social, emotional, and physical development in urban environment (Babalola et al., 2016). It promotes convenient working and conducive learning in schools, fast recovery in health sector and comfort in recreational centers (Abdullah et al., 2016).

Studies in relation to environmental quality have focused on amenities that make urban land uses functional, supportive and conducive (Awang et al., 2015). These environmental amenities have been discussed by many scholars in terms of their types and provision. For instance, studies have been carried out on water supply and sanitation (Daramola et al., 2023b). This study is, however, an attempt to understand how students perceived their schools which consequently produces a healthy environment for academic activities.

The major problems facing most secondary schools were unsanitary waste disposals, deteriorated buildings and infrastructure deficit (Adeolu et al., 2014; Egbinola, Amanambu, 2015). These offer an opening for this kind of study and also form bases for the research contribution to knowledge.

This study, therefore examine the attitudes of secondary school students towards environmental conservation educational programs in Oyo State, Nigeria

Methodology

Study Area

This study was conducted in Oyo State. Oyo State is one of the thirty-six states of the Federal Republic of Nigeria. The State has an estimated population of over 5,591,589 people. It is located in the rainforest vegetation belt within longitude 7°23'47"N and 3°55'0"E. Farming was the major occupation of the people in the area. They grow cash crops like cocoa, coffee, oil-palm, maize, yam, cassava, cocoyam, melon, cowpea and vegetables, among others. The state is divided into three senatorial districts namely: Oyo south, Oyo central and Oyo north. The target population for the study was senior secondary students from twelve (12) public and (12) private schools in the three (3) senatorial districts of Oyo-state.

Sampling technique

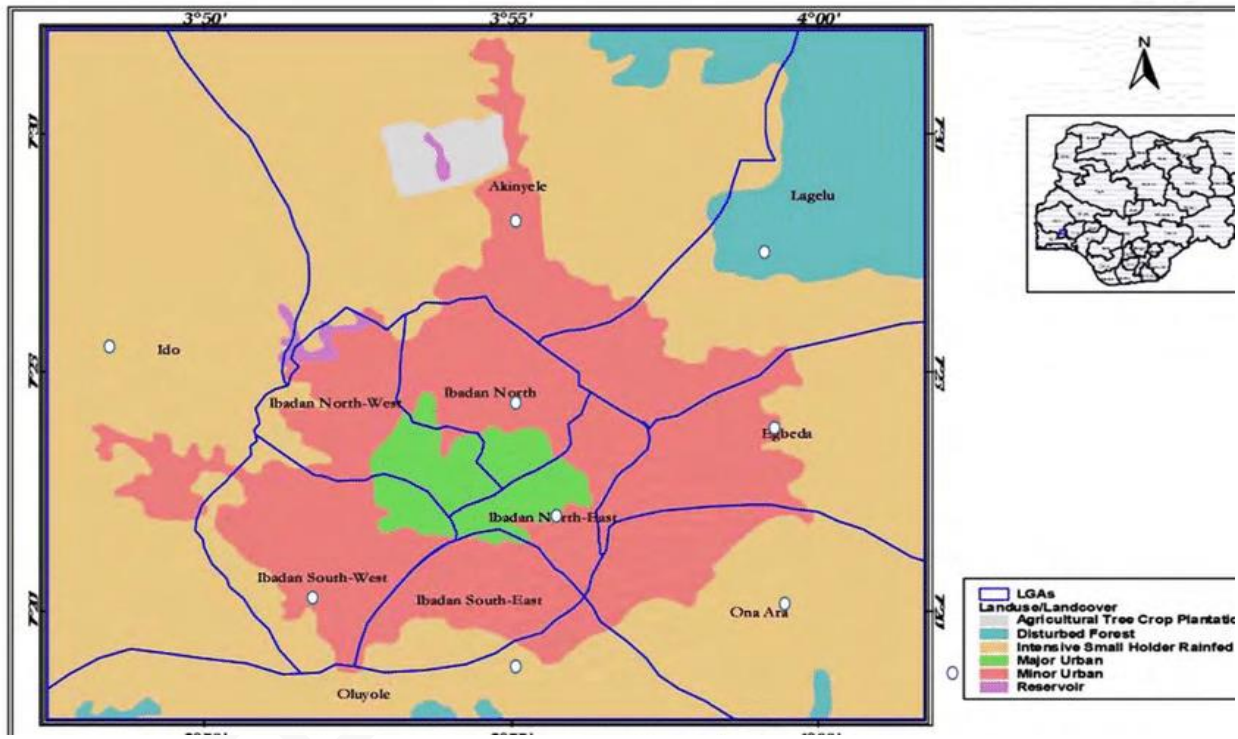
Multistage sampling technique was used to select the sample size for this study. The study area was stratified into three Senatorial Districts of Oyo State. Two Local Government Areas were purposely selected from each Senatorial District based on the number of both public and private schools available in the Local Government Area. Thirteen urbans and twelve rural secondary schools in each of the Local Government Area were randomly selected. Ten (10) students covering both junior secondary schools (JSS1 – JSS3) and senior secondary schools (SSS1 – SSS3) classes were proportionally selected for interview.

Table 1: Distribution of respondents around the Senatorial District in Oyo State

S/No	Sampled Schools	Type of School	Senatorial Districts	Local Govt. Area	No of Respondents
1	Yinbol college,Orogun	Private	Oyo central	Akinyele	10
2	Smith International Baptist Academy	Private	Oyo north	Ogbomoso south	10
3	Leire comprehensive. college	Private	Oyo central	Egbeda	10
4	Distinct Jubilee international college	Private	Oyo central	Akinyele	10
5	De-lord's model college	Private	Oyo central	Egbeda	10
6	All saints' college	Private	Oyo south	Ibadan north west/ ido	10
7	Saint Catherine's college	Private	Oyo south	Ibadan south west	10
8	Best legacy Int'l high School	Private	Oyo north	Ogbomoso north	10
9	Lead city international school	Private	Oyo south	Ibadan north west	10
10	Nesam international school	Private	Oyo south	Ibadan south west	10
11	Olafunmi comprehensive college	Private	Oyo north	Ogbomoso south	10
12	Morenike memorial comp.	Private	Oyo North	Ogbomoso north	10
13	Apata grammar school	Government	Oyo south	Ibadan south west	10
14	Queen's school Apata	Government	Oyo south	Ibadan south west	10
15	Ajibode grammar school	Government	Oyo central	Akinyele	10
16	Urban day secondary school	Government	Oyo south	Ibadan north west	10
17	Eleyele Grammar School	Government	Oyo North	Ibadan north west	10
18	Jericho high school	Government	Oyo south	Ibadan north west	10
19	Aponmode moniya high school	Government	Oyo central	Akinyele	10
20	Oyo state school of science	Government	Oyo north	Ogbomoso north	10
21	Ori Oke community high sch.	Government	Oyo north	Ogbomoso north	10
21	Ogbomoso Baptist high school	Government	Oyo north	Ogbomoso south	10

23	Monatan high school	Government	Oyo central	Egbeda/Lagelu	10
24	Caretaker community high sch.	Government	Oyo north	Ogbomoso south	10
25	Bishop Philips Academy	Government	Oyo central	Egbeda	10
	Total				**250**

Map of Ibadan showing the different local government areas Source



Orisasona et al, 2020.

Data collection

Data was collected by using a semi-structured questionnaire, administered to the respondents in their classrooms under strict supervision.

Data Analysis

Data collected was analyzed by using descriptive statistics and Chi-Square analysis. The descriptive statistics was used in determining student's demographics characteristics, their sources of environmental conservation education, Student's attitude towards environmental conservation education and challenges facing environmental education in the study area. The chi-square analysis

was used in determining the relationship between both student attitudes and willingness to partake in Environmental Education and students' attitudes and school location.

Results and discussion

Demographic characteristics of the respondents

It was revealed in Table 2 that the majority (44.4%) of the students were aged 14 – 16 years, they are at a stage and class, that is SSS1-SSS3 (58.4%) where environmental topics are often introduced in greater depth and which aligns with age group that are most actively engage in secondary school environmental education subjects. Sara et al., (2023), follow by aged 10-13 years and 17-19 years with (31.6%) and (24.0%) respectively. Most of the respondents were male (54.0%), which is an indication that there is slightly higher male representation in conservation education assessment than females (46.0%), This finding agrees with Akomolafe and Adesua (2016) who reported the higher participation of male students in environmental initiatives when compared with the females. Urban school made up 65.2% of the sample, which may give students greater access to environmental programs, as urban areas tend to have better infrastructure and NGOs presence (Rivera and Lopez 2023: Jeffry et al., 2025).

Table 2: Demographic characteristics of the respondents

Demographic characteristic	Frequency (f)	percentage (%)
Age		
10 – 13	79	31.6
14 – 16	111	44.4
17 – 19	60	24/0
Gender		
Male	135	54.0
Female	115	46.0
Class		
JSS 1 – JSS 3	104	41.6
SSS 1 – SSS 3	146	58.4
Location		
Urban	163	65.2
Rur**al**	87	34.8

(n=250)

Sources of environmental conservation education

The result of Table 3 reveals that teachers (80.4%) are the major source of environmental conservation education, as they pass the adequate and necessary information directly to the students. Jose (2023): Comfort et al., (2025) found that the Nigeria school curriculum is a major channel of environmental knowledge transfer. Then the social media (58.4%) also plays a significant role, reflecting the growing influence of digital platforms. However, NGO (28.0%) is relatively low, this indicates that formal education remains the primary channel of environmental knowledge among secondary school students in the study area. (Ifeanyi, U. and Chukwu, M. 2020).

Table 3: Source of environmental conservation education

Source of Information	Frequency	Percentage (%)
Teachers	201	80.4
Radio	119	47.6
Environmental clubs	93	37.2
Social media	146	58.4
Parents	114	45.6
NGO	70	28.0

n= 250

The result of table 4 shows that majority (84.4%) of the students expressed willingness to participate in environmental protection activities, suggesting a favorable attitude towards conservation efforts. This positive disposition is an asset that can be harnessed for program sustainability. However, attitude does not always translate to action without institutional support (Ogunyemi, 2010), to foster pro - environmental behaviors.

Table 4: Students' attitude towards environmental conservation

Willingness to participate in activities that protect environment	Frequency (f)	Percentage (%)
Strongly agree	122	48.8

Agree	89	35.6
Undecided	26	10.4
Disagree	9	3.6
Strongly disagree	4	1.6

n= 250

The result presented in Table 4 indicates the most reported challenge as inadequate teaching material (61.6%). This report was consistent with findings by Grace, B. I. (2025): Zomeren,, (2008). who reported that inadequate teaching aids significantly hinder effective environmental education in Nigeria schools. Lack of funding (54.4%) was also a significant barrier, because schools are unable to procure relevant instructional materials without enough financial aid, and this is a critical component of environmental education. This finding also indicates that limited trained teachers (40.8%) and insufficient in school time schedule (44.8%) is another major challenge that needs to be addressed to enhance the effectiveness of environmental education programs in secondary schools.

Table 4: Conservation education challenges

Challenge	Frequency	Percentage
Inadequate teaching materials	154	61.6
Lack of funding	136	54.4
Poor student interest	62	24.8
Limited trained teachers	102	40.8
Insufficient time in school schedule	112	44.8

n= 250

The Chi –square analysis presented in Table 5 revealed a statistically significant relationship (x^2=59.50, p>0.05) between attitude and willingness to participate in environmental protection activities, The relationship between attitude and school location was not statistically significant (x^2=.92, p>0.05). This indicates that where a student attends school does not determine whether they will have a positive or negative attitude toward conservation education. Additionally,

willingness is strongly influenced by attitude and awareness, as supported by the theory of planned behavior (Ajzen, 1991), which states that behavioral intention is shaped by attitude and perceived control.

Table 5: Chi – square relationship between attitude and location of students

Variable	Urban	Rural	X^2 value	Df	P- value	Decision
Attitude and willingness to participate in protection activities	85.9	81.6	59.50	1	0.000	S
Attitude and school location	65.2	34.8	2.92	1	0.088	NS

n= 250

Conclusion

The findings revealed that students generally demonstrate a positive attitude toward environmental conservation and recognize the importance of protecting natural resources. Age, gender, class and location were the demographic factors influencing attitude of secondary school students toward environmental conservation in Ibadan. Metropolis. The school teachers and social media were identified as the major sources of environmental knowledge. The most reported challenge are inadequate teaching material and lack of funding.

Recommendation

It is recommended that government and school authorities provide adequate teaching materials and increase funding to support effective conservation education in secondary schools.

Schools' management should promote more practical activities such as environmental clubs, tree planting, and sanitation programs to strengthen student's engagement.

Teachers should also receive regular training to improve instructional delivery. Additionally, special support should be given to rural schools to ensure equal access to environmental education resources.

References

Abdullah, H., Azam, M., and Zakariya, S. K. (2016). The Impact of Environmental Quality on Public Health Expenditure in Malaysia. *Asia Pacific Journal of Advanced Business and Social Studies,* 2(2), 365–379. Retrieved from https://apiar.org.au/wp-

Abun Damianus and Alfie P.Racoma.(2017). Environmental Attitude and Environmental Behavior of Catholic Colleges' Employees in Ilocos Sur, Philippines Colleges' employees in Ilocos Sur, Philippines. *Texila International Journal of Academic Research*, 4(1). pp,1-30. https://doi.org/ 10.21522/TIJAR.2014.04.01. Art003.

Adeolu A.T, Enesi D.O and Adeolu M.O. (2014). Assessment of Secondary School Students' Knowledge, Attitude and Practice towards Waste Management in Ibadan, Oyo State, Nigeria. *Journal of Research in Environmental Science and Toxicology,* Vol. 3(5) pp. 66-73, http://www.interesjournals.org/JREST. doi: http://dx.doi.org/ 10.14303/jrest.2014.021.

Ajayi, O.O., Coker, O.M. & Agbon, Z. (2024) Assessing the knowledge, perception, and attitude of wildlife management students toward biodiversity conservation in Nigeria. Wildlife Letters, 2, 23–32. https://doi.org/10.1002/wll2.12028.

Ajzen K. (1991). Environmental Attitudes among Youths: How Much Do the Educational Characteristics of Parents and Young People Matter? *Journal of Sustainability*.15 (15).

Akinsemolu, Adenike A. and Onyeaka,Helen (2025). The role of green education in achieving the sustainable development goals: A review, *Renewable and Sustainable Energy*, Reviews,Volume 210, journal homepage: www.elsevier.com/locate/rser. https://doi.org/10.1016/j.rser.2024.115239.

Akomolafe, C. O. and Adesua, V.O (2016). Environmental awareness and attitude of urban and rural secondary schools' students in Ekiti State, Nigeria. *Journal of Education and Practice*, 7(23), 45 – 51.

Asunlegan, O. A., Akanni, O.F., Olumide-Ojo, O., Ojedokun, C.A. and Agboola, I. S. (2020) Perceptions of Secondary School Students on Forestry and Environmental Science Education

in Oyo-State, Nigeria. *Journal of Research in Forestry, Wildlife & Environment*. Vol. 12(4), 76-84. https://doi.org10.3390/su151511921.

Awang, N. A., Mahyuddin, N., & Kamaruzzaman, S. N. (2015). Indoor Environmental Quality Assessment and Users Perception in Meru Secondary School. *Journal of Building Performance,* 6(1), 105–115. Retrieved http://spaj.ukm.my/jsb/index.php/jbp/index content/uploads/2016/08/29_APJABSS _APCAR_BRR723_BUS-365-379.pdf

Babalola, O. D., Ibem, E. O., Fulani, O. A., & Olotuah, A. O. (2016). Residents' Perception of Quality of Public Housing in Lagos, Nigeria. *International Journal of Applied Environmental Sciences,* 11(2), 583–598. Retrieved from http://www.ripublication.com/

Charlotta . B, Joachim. B, Serah. S, (2024). Environmental Attitude and Effective Motivational Beliefs Towards Sustainabilityo for Secondary School Children in Germany and their Associations with Gender, Age, School Type, Socio – Economic Status and Time Spent in Nature. *Journal of National Library of Medicine,* National center for Biotechnology Information. *National Center for Biotechnology Information.* Volume 19 (5) e 029632710.1371/Journal.pone.029632.

Christian Baribor Ndayor GIAMI and Innocent ALETE-OMONI (2023). Influence of School Environment on Academic Performance of Students in Public Senior Secondary Schools in Yenagoa Metropolis of Bayelsa State. *International Journal of Economics, Environmental Development and Society*, 4(4), 436-447.

Comfort Nkongho AGBOR, Michael Obun ETAN, Raphael Terungwa AKUJI and Comfort Omeri OGBOR (2025), Methods 0f Teaching Environmental Education for Sustainability, *International Journal of Economics, Environmental Development and Society*, 2025, 6(2), 209-233.

Daramola, O., Mobolaji, D., Tajudeen, O., Popoola, O., Igharo, J., & Oyelere, P. (2023a). Environmental Quality in Urban Areas of Developing Countries: The Example of Bodija and Owode Public Housing Estates, Ibadan, Nigeria. *FUOYE Planning Journal*, 1(2), 65–77. Retrieved from https://fpj.fuoye.edu.ng/index.php/fpj/article/view/28.

Daramola, O., Mobolaji, D., & Idowu, K. (2022b). Assessment of Developers' Awareness of Physical Planning Regulations in Ile-Ife, Nigeria. UNIOSUN. *Journal of Engineering and Environmental Sciences*, 4(1), 139–148. Doi: https://doi.org/10.36108/ujees/2202.40.0141.

Daramola, O. P., Mobolaji, D. O., Olatunji, S. A., & Idowu, K. (2023c). Residents' Awareness and Response to Environmental Sanitation Exercise in Ado-Ekiti, Nigeria. *FUOYE Planning Journal,* 1(1), 11–21. Retrieved from https://fpj.fuoye.edu.ng/index.php/fpj/article/view/3.

Denis Vasiliev, (2021) Combating global challenges – climate change, biodiversity loss and poverty simultaneously: Unachievable goal or the only way forward? SHS Web of Conferences 129, *Globalization and its Socio-Economic Consequences*. Pp 1-9. https://doi.org/10.1051/shsconf/202112909022.

Egbinola, C. N. and Amanambu, A. C. (2015). Water supply, sanitation and hygiene education in secondary schools in Ibadan, Nigeria. *Bulletin of Geography. Socio-economic Series,* 2(29), 31–46. Doi: http://dx.doi.org/10.1515/bog- 2015-0023.

Fatoba. J. O and Aladejana A.L (2014). The Attitudes of Biology Teachers and Students Towards the Conservation of Natural Resources in Ekiti State, Nigeria. *European Journal of Educational Science.*1(4):38 – 46.

Fabrice Clément, (2026). Change your attitude. The role of affective social learning in shaping individual attitudes toward their environment, *Acta Psychologica Journal*, Volume 265, pp.1-9. https://doi.org/10.1016/j.actpsy.2026.106572.

Grace Barinaada Ibaba, (2025). Environmental Education and Sustainable Development in Nigeria. *International Journal of Scientific Research in Education*, Vol. 18(2), 239-244.

Habitat, U. N. (2013). *State of the world's cities 2012/2013:* Prosperity of cities. *Routledge Journal.* taylorfrancis.com.

Ifeanyi, U., & Chukwu, M. (2020). Carried out an investigation on collaborative environmental education programs in secondary schools. *Journal of Educational Development*, 9(3), 88- 104.

Jose. M. E (2023). The Gender Gap in Environmental Concern: Support for an Ecofeminist Perspective and the Role of Gender Egalitarian Attitudes. *Journal of sex role journal*. 9(4):610 – 623.

Jeffry Morilla Saro, Jecel Taray, Jemuel Sabas Cinso, Merry Joy A. Enguio's Bonifacio S. Ingaling's and Cynne Paul Besire Hayon, (2025). Level of attitude, behavior, and awareness of senior high school students toward environmental conservation**, (**JPBI) Journal of Research in Forestry, Wildlife & Environment, *Journal Pendidikan Biologi Indonesia.* 11(1):111-124**.** DOI: 10.22219/jpbi. Journal of Research in Forestry, Wildlife & Environmentv11i1.37861.

Koroye, T. (2016). The influence of school physical environment on secondary school, students' academic performance in Bayelsa State. *African Journal of Educational Research,* 2(4), 1-5.

Mobolaji, D., Durotoye, A., Daramola, O. (2024). Students' perception of environmental quality in public Secondary schools of Ibadan Metropolis, Nigeria. *Journal Environmental Problems*, 9(4), 204–212. DOI: https://doi.org/10.23939/ep2024.04.204.

Ogunyemi, B. (2010). Teacher Education and the Challenge of Sustainable Development in Nigeria. *African Journal of teacher Education,* 1(1):209 – 221.

Rabiu. M, Kabiru S. M, Zahradden M.S, Auwal. G (2020). Assessing the drivers of deforestation in Nigeria: Evidence from fully modified Ordinary Least Square. *International, Journal Research and Innovation in Social Science* (IJRISS), 4(6). Pp 466-473.

Rivera, J. D., & Lopez, M. A. (2023). Integrating theoretical knowledge with practical activities: A framework for effective environmental education programs. *Journal of Environmental Studies*, 45(3), 112-128. https://doi. org/10.2013/jes.2023.003.

Sara, F., Ajab, A. L., Shazma, N., Mansoor, A. C. (2023). Assessing Environmental Awareness and Conservation Behavior in Schools for Sustainable Development. Journal of Pakistan. *Journal of Humanities and Social Science*. 11(4): Pp 4086 – 4097. DOI:10.52131/pjhss.2023.1104.0676.

Shittu Lukman Olayinka and Muhammad Ridwan (2025). Influence of School Environment on Senior Secondary School History Students' Academic Performance in Jos South L.G.A. of

Plateau State, Nigeria. *Matondang Journal.* (BIAR Publisher). Vol. 4, No, Page: 81-92. DOI: https://doi.org/10.33258/matondang.v4i2.1374.

Umer Abdela, (2022). Review on School Based Environmental Education Club on Student and General Environment, *Journal of Education and Practice*. Vol.13, No.10, 21-30. www.iiste.org IS`.qaSN 2222-1735 (Paper) ISSN 2222-288X (Online).

Zomeren, M., Postmes, T. and Spears, R. (2008). Toward an Integrative Social Identity Model of Collective Action: A Quantitative Research Synthesis of Three Socio-Psychological Perspectives. *Psychological Bulletin*, 134(4), 504–535. https://doi.org/10.1037/0033-2909.134.4.504.

Walker, C. (2017). Tomorrow's leaders and today's agents of change? Children, sustainability education and environmental governance. *Children and Society*, 31(1), 72–83. https://doi.org/10.1111/chso.12192.

Zhang Y, Hou M-L, Chen C-Q, Liao Z-Y, Guan Y-F, Yuan Y-L, et al. (2024) Attitude and willingness of biodiversity conservation in Chinese university students: Associated factors and the mediation of social support. *Journal of National Library of Medicine*, PLoS ONE 19(7): e0307510. https://doi.org/10.1371/journal.pone.0307510.

ISTF-NIG 2026

ASSESSMENT OF EXPLOITATION PATTERNS AND CONSERVATION STATUS OF INDIGENOUS TIMBER SPECIES IN SAWMILL CLUSTERS OF ODIGBO LOCAL GOVERNMENT AREA, ONDO STATE, NIGERIA

[1]AKOMOLEDE, Lucas Aderemi, [2] HENRY, Christian Asuquo*, [1]AKEREDOLU, Olaniyi Ayoola, [3]AJAYI, Olalekan Kehinde, [1]ATOLAGBE, Oluwafemi Solomon, [4]RUFAI, Samsideen Olabiyi, and [1]OGUNDOYIN, Adeboye Aderoju

[1]Forestry Research Institute of Nigeria, Jericho Hill, Ibadan, Rainforest Research Station, Ore, Ondo State, Nigeria.
[2]Department of Forest Resources Management, Federal University of Agriculture, Abeokuta, Ogun State.
[3] Forestry Research Institute of Nigeria, Jericho Hill, Ibadan, Forest-Based Rural Resource Centre, Ikija, Ogun State.
[4]Forestry Research Institute of Nigeria, Jericho Hill, Ibadan, Department of Bio-medicinal Research Centre, Ibadan, Oyo State.
Corresponding Email: *ask4henrysworld@gmail.com; +2347068625050*

Abstract

Unsustainable timber harvesting remains a major driver of biodiversity decline and forest degradation in tropical ecosystems. Therefore, this study assessed the exploitation patterns and conservation status of indigenous timber species utilized by sawmill industries in Odigbo Local Government Area, of Ondo State, Nigeria. A purposive sampling approach was adopted to select 10 active sawmills, and 120 copies of a structured questionnaire were administered to operators and workers, comprising 80 males and 40 females with an average age of 45 years. Descriptive statistics were used to analyze species occurrence and respondents' socio-economic characteristics. Twenty indigenous timber species belonging to 13 families and 16 genera were identified as frequently processed. The family Meliaceae had the highest representation, with 5 (18.5%), followed by Fabaceae with 4 (14.8%). Conservation assessment indicated that a substantial proportion of the exploited species fall within threatened categories, including vulnerable (11), endangered (10), un-evaluated (4), critically endangered (1) and least concern (1), respectively belonging to the families of (Caesalpinioideae, Meliaceae, Rubiaceae, Combretaceae, Euphorbiaceae and Ochnaceae), (Bombacaceae, Fabaceae, Bignoniaceae, Malvaceae, Leguminosae and Sterculiaceae), (Apocynaceae, Moraceae and Fabaceae), (Santalaceae) and (Boraginaceae). The dominance of high-value hardwood species such as *Milicia excelsa*, *Triplochiton scleroxylon*, and *Khaya* spp. reflects selective logging pressure on commercially valuable taxa. The findings reveal persistent extraction intensity without proportional reforestation efforts, posing long-term ecological and economic risks. Strengthened enforcement of forest regulations, promotion of indigenous species plantations, and improved monitoring frameworks are urgently required to ensure sustainable utilization of forest resources in southwestern Nigeria.

Keywords: Indigenous timber, Forest degradation, Conservation status, Sawmill industry, Sustainable forestry.

Introduction

Forests are among the most critical terrestrial ecosystems, supporting biodiversity, regulating the climate, protecting watersheds, and providing livelihoods for millions of people worldwide. Recent global assessments estimate that forests store approximately 662 billion tonnes of carbon and harbor more than 80% of terrestrial biodiversity, underscoring their central role in climate mitigation and ecological stability (FAO, 2023). However, tropical forests continue to experience alarming rates of degradation, largely driven by timber extraction, agricultural expansion, and infrastructure development. Selective logging of commercially valuable hardwood species has emerged as a dominant driver of structural and compositional forest change across tropical Africa (Curtis *et al*., 2018; Gibson *et al*., 2019). Although selective logging is often perceived as less destructive than clear-cutting, empirical evidence shows that repeated extraction cycles significantly reduce basal area, alter species composition, and impair regeneration of slow-growing climax taxa (Bicknell *et al*., 2015; Burivalova *et al*., 2017). In West Africa, unsustainable timber harvesting has led to a progressive decline in economically important species such as *Milicia excelsa*, *Khaya ivorensis*, and *Pericopsis elata* (Akindele *et al*., 2020; Adekunle *et al*., 2023).

Nigeria is among the most affected countries in sub-Saharan Africa in terms of forest loss. National forest cover has declined significantly over the past two decades due to weak enforcement mechanisms, illegal logging, and increasing domestic timber demand (Nwokoro & Onyekwelu, 2021). According to the IPCC (2022), degradation of tropical forests substantially reduces carbon sequestration capacity and contributes to greenhouse gas emissions, particularly where large-diameter hardwoods are disproportionately removed. Recent studies emphasize that forest degradation often precedes deforestation and may result in long-term biodiversity erosion even when canopy cover remains partially intact (Vancutsem *et al*., 2021). The removal of high-value canopy species disrupts ecological processes such as seed dispersal, nutrient cycling, and forest succession (Edwards *et al*., 2019). Furthermore, regeneration of commercially exploited hardwoods is frequently insufficient under high extraction pressure, leading to demographic bottlenecks (Rozendaal *et al*., 2019).

In southwestern Nigeria, including Ondo State, timber exploitation remains a major economic activity. However, localized empirical documentation of species-specific exploitation patterns within sawmill clusters remains limited. Understanding which indigenous species are most frequently processed and their conservation status is critical for aligning local timber markets with sustainable forest management (SFM) principles and national climate commitments. Therefore, this study assesses the exploitation patterns and conservation status of indigenous timber species processed by sawmill industries in Odigbo Local Government Area. By linking species-level extraction trends with conservation classifications, the study provides empirical evidence to inform sustainable forest management strategies in southwestern Nigeria. Also, it contributes to the current discourse on sustainable tropical forest management in West Africa.

Methodology

Study Area

The study was conducted in the Odigbo Local Government Area (LGA) of Ondo State, southwestern Nigeria. The area lies between latitudes 6.30°N–6.55°N and longitudes 4.26°E–5.14°E and covers approximately 1,710 km² (Gbadebo *et al*., 2014). The region falls within the lowland tropical rainforest ecological zone, characterized by bimodal rainfall of 1,500–2,000 mm annually and mean temperatures between 21°C and 29°C. The vegetation comprises moist semi-deciduous forest with a historically high representation of commercially valuable hardwood species. However, increased timber commercialization has intensified pressure on indigenous taxa.

Sampling Procedure and Data Collection

The study was carried out within selected sawmills from April to November, 2025. A purposive sampling technique was adopted to select ten (10) operational sawmills within Ore and the surrounding communities. Twelve (12) copies of the structured questionnaire were administered at each sawmill, yielding 120 respondents. The selected sawmills in these locations include Alhaji Olurimi Sawmill, New Odigbo Town, Abimbola Sawmill, Araromi Village, Akinmusayo Philip Sawmill, Irele Road, Ore, Erinfolami Sawmill, Ore, God's Sawmill, Ofosu, Iyadunni Sawmill, Ore, IKB Sawmill Ofosu, Makinde Temidayo Sawmill Orita Odibgo, Olufisayo Sawmill Ofosu Benin Road, and Titilayo Sawmill Ore. Respondents included sawmill owners, machine operators, timber merchants, and wood processors. The questionnaire captured: Species processed, Local names, Frequency of occurrence, Perceived availability trends and Socio-economic characteristics. Species conservation status was cross-checked against recent global assessments and contemporary conservation databases.

Data Analysis

Descriptive statistics (Frequency and percentages) were used to summarize socio-economic variables and species occurrence patterns. Family and conservation category grouped species.

Results

Socio-economic Characteristics of the Respondents

Age distributions of the Respondents

The age distribution of the respondents falls within the 10-20 and 71-80 years age groups (Table 1). The highest age range of the respondents involved in the activities falls within ages 41-50 years (22.5%), which indicated that majority of the people involved in the work are purely adults, followed by 31-40 years (19.2%), which shows that active adults are more prominent in the job, also followed by age range of 51-60 (16.7%) which also indicated that experienced adult is actively involved in the work, 15% of the respondents fall within the age of 21-30 years which is an indicator that the set of people within the age group is very agile and fit in to be involved in such activity. However, the 71-80 age group (4.2%) is small, which may be due to their advanced age.

Age 10-20 (8.3%) are the youngest, among whom involvement may be due to a lack of information or a lack of interest in the job.

Table 1: Age Distribution of the Respondents

Age Group	Frequency	Percentage (%)
10-20	10	8.3
21-30	18	15
31-40	23	19.2
41-50	27	22.5
51-60	20	16.7
61-70	17	14.2
71-80	5	4.2
Total	120	100

Source: Field Survey (2025)

Gender Distribution of the Respondents

In Table 2, the gender distribution among respondents showed that males accounted for the largest share (66.7%), twice that of females (33.4%). However, this might be because the job is strenuous and requires more energy.

Table 2: Gender distribution of the respondents

Gender	Frequency	Percentage (%)
Male	80	66.7
Female	40	33.3
Total	120	100

Source: Field Survey (2025)

Marital Status of the Respondents

Table 3 indicates that the majority of respondents (53.3%) are married, while 36.8% are single, 13.3% are widowed, and 2.5% are divorced. This indicated that the respondents in the study area are maritally balanced.

Table 3: Marital status of the respondents

Variables	Frequency	Percentage (%)
Single	43	35.8
Married	64	53.3
Widowed	10	13.3
Divorced	3	2.5
Total	120	100

Source: Field Survey (2025)

Educational Status

The results in Table 4 show that the majority of respondents were secondary school-leavers, comprising 55.8% of the total respondents. 37.5% were primary school-leavers, while 6.7% had completed tertiary Education.

Table 4: Educational distribution of the respondents

Level of Education	Frequency	Percentage (%)
Primary	45	37.5
Secondary	67	55.8
Tertiary	8	6.7
Total	120	100

Source: Field Survey (2025).

Identification/Classification of Commonly Exploited Timber Species

The result presented in Table 5 revealed the status of the local tree species in the study area. Of the twenty-seven tree species, eleven were vulnerable, ten were endangered, four were not evaluated, One was critically endangered, and One was of least concern.

Table 5: Identification/Classification of Commonly Exploited Indigenous Timber Species, Family names, Local names and Status

Timber Species	Family names	Local names	Status
Afzelia africana	Caesalpinioideae	Y: Apa, H: Kawo, I: Akpalatae	Vulnerable
Alstonia boonei	Apocynaceae	Y: Ahun, I: Egbu.	Not Evaluated
Ceiba pentandra	Bombacaceae	Y: Araba, H: Rimi, I: Akpuogwu	Endangered
Erythrina senegalensis	Fabaceae	Y: Ologbosere	Endangered
Hymenocardiaacida	Phyllanthaceae	Y: Orunpa	Endangered
Khaya senegalensis	Meliaceae	Y: Oganwo, H: Maldachi, I: Abubo,	Vulnerable
Khaya grandifolia	Meliaceae	Y: Gedu	Vulnerable
Khaya ivorensis	Meliaceae	Y: Oganwo, H: Onu, I: Male	Vulnerable
Kigelia Africana	Bignoniaceae	Y: Iyan	Endangered
Lovoatrichilioides	Meliaceae	-	Vulnerable
Mansonia altissima	Malvaceae	Y: Ofun	Endangered
Milicia excelsa	Meliaceae	Y: Iroko, I: Oji, H: Loko	
Naucleadiderrichii	Rubiaceae	Y: Opepe, I: Iwu	Vulnerable
Okoubakaaubrevillei	Santalaceae	-	Critically Endangered
Pericopsiselata	Fabaceae	Y: Ebgin	Endangered
Pterocarpus osun	Leguminosae	Y: Osun	Endangered
Sterculia rhinopetala	Sterculiaceae	Y: Kokoigbo	Endangered
Terminalia superba	Combretaceae	Y;Afara	Vulnerable
Terminalia ivorensis	Combretaceae	Y: idigbo, I: Awunshin	Vulnerable

Triplochiton scleroxylon	Sterculiaceae	Y: opepe, I: Okpopo,	Endangered
Ricinodendronheudelotii	Euphorbiaceae	Y: Omodan	Vulnerable
Antiaris africana	Moraceae	Y: Oriro	Not evaluated
Erythrophleum suaveolens	Fabaceae	Y: Eru	Not evaluated
Lophira alata	Ochnaceae	Y: Ekki (ironwood)	Vulnerable
Brachystegialeonensis	Caesalpiniaceae	Y: Eku	Vulnerable
Elainadoxa spp.	Fabaceae	Y: Parapuru	Not evaluated
Cordia millenii	Boraginaceae	Y: Omo	Least concern

Key: Y: Yoruba, I: Igbo, H: Hausa
Source: Field Survey, 2025

Frequency Distribution of the Indigenous Tree Species Family

The results from the frequency distribution of the indigenous tree species family, as presented in Table 6, revealed that twenty-seven (27) families of the tree species were identified in the study area. Meliaceae had the highest number of occurrences (5), followed by Fabaceae (4), while Caesalpinioideae, Sterculiaceae and Combretaceae had the same Frequency of two (2). However, other families were represented by only One species each.

Table 6: **Timber Species Family and their Frequency Distribution**

Family	**Frequency**	**Percentage (%)**
Apocynaceae	1	3.7
Bignoniaceae	1	3.7
Bombacaceae	1	3.7
Caesalpinioideae	2	7.4
Combretaceae	2	7.4
Fabaceae	4	14.8
Leguminosae	1	3.7
Malvaceae	1	3.7

Meliaceae	5	18.5
Phyllanthaceae	1	3.7
Rubiaceae	1	3.7
Santalaceae	1	3.7
Sterculiaceae	2	7.4
Euphorbiaceae	1	3.7
Moraceae	1	3.7
Ochnaceae	1	3.7
Boraginaceae	1	3.7
Total	27	100

Source: Field survey, 2025

Discussion

The findings of this study reveal heavy reliance on commercially valuable indigenous hardwood species, particularly members of the family Meliaceae. This selective harvesting pattern is consistent with broader tropical forestry research demonstrating that high-density, durable timber species are disproportionately targeted due to market preference (Akindele *et al*., 2020; Adekunle *et al*., 2023). Such species are typically late-successional, slow-growing canopy trees whose regeneration cycles may span several decades, making them highly vulnerable to repeated extraction. Empirical evidence indicates that selective logging reduces structural complexity, basal area, and recruitment of target species, especially when harvesting intensity exceeds ecological thresholds (Burivalova *et al*., 2017; Edwards *et al*., 2019). In African lowland forests, degradation associated with selective logging has been shown to persist for over 30 years without active restoration interventions (Rozendaal *et al*., 2019). The high proportion of Vulnerable and Endangered species identified in Odigbo, therefore, signals potential long-term compositional shifts if regeneration is not prioritized.

From a biodiversity perspective, removing large canopy hardwoods can lead to cascading ecological effects. These trees often serve as keystone structural components supporting epiphytes, fauna, and microhabitat diversity (Gibson *et al*., 2019). Their depletion may therefore reduce habitat heterogeneity and compromise ecosystem resilience. Studies comparing logged and intact tropical forests reveal significant declines in species richness and functional diversity following selective harvesting (Bicknell *et al.*, 2015; Vancutsem *et al*., 2021). However, some research argues that reduced-impact logging (RIL) can mitigate ecological damage when properly implemented (Putz *et al*., 2016). Under carefully regulated extraction systems, biodiversity losses may be minimized relative to conventional logging practices. Nevertheless, the persistence of threatened species within sawmill supply chains in this study suggests that such best-practice

systems are either inadequately applied or insufficiently monitored within the study area. Climate implications further reinforce the urgency of sustainable management. Large hardwood species store disproportionately high carbon stocks, and their removal reduces forest carbon density (IPCC, 2022). Tropical forest degradation accounts for a substantial share of land-use emissions, even where deforestation rates appear stabilized (FAO, 2023). Consequently, continued exploitation of high-biomass indigenous taxa may undermine Nigeria's climate mitigation commitments. Socio-economic drivers must also be considered. Timber industries provide employment and income to local populations, as reflected by the predominance of economically active respondents in this study. Previous research emphasizes that sustainable forestry interventions must balance conservation goals with livelihood security (Nwokoro & Onyekwelu, 2021). Community-based Forest management models have shown potential in improving compliance and regeneration outcomes while sustaining rural economies (Akindele *et al*., 2020).

The findings also raise concerns regarding market sustainability. Overdependence on a narrow portfolio of threatened species increases vulnerability to future timber scarcity and economic instability. Diversifying into lesser-known species and establishing indigenous plantations could reduce pressure on natural forests. Plantation development has been recommended as a viable strategy for restoring degraded forest landscapes in Nigeria (Adekunle *et al*., 2023). Overall, this study corroborates a growing body of literature indicating that selective logging of high-value hardwoods without adequate regeneration frameworks leads to progressive biodiversity decline, reduced carbon sequestration, and long-term economic risk. The integration of conservation status assessments into harvesting decisions, strengthening enforcement, and implementing structured reforestation programs is therefore imperative for sustainable forest governance in southwestern Nigeria.

Conclusion and Recommendations

This study demonstrates that sawmill industries in Odigbo LGA heavily depend on indigenous hardwood species, many of which are classified as vulnerable or endangered. The high representation of Meliaceae species signals selective pressure on commercially valuable taxa. Current exploitation trends are ecologically unsustainable and may lead to irreversible biodiversity loss if regulatory enforcement and reforestation efforts are not strengthened. The following policy recommendations are hereby advised based on the findings of this study:

1. Mandatory regeneration quotas tied to sawmill licensing.
2. Establishment of indigenous species plantations through public-private partnerships.
3. Strengthened collaboration between State Forestry Departments and research institutions.
4. Adoption of timber traceability systems aligned with international sustainable forest management standards.
5. Community-based Forest monitoring to reduce illegal harvesting.

References

Adekunle, V. A. J., Olagoke, A. O., & Akinwale, A. A. (2023). Logging pressure and conservation implications for indigenous hardwood species in southwestern Nigeria. *Trees, Forests and People, 12*, 100372. https://doi.org/10.1016/j.tfp.2023.100372

Akindele, S. O., LeMay, V., & Popoola, L. (2020). Sustainable forest management in Nigeria: Status and prospects. *Journal of Sustainable Forestry, 39*(5), 487–503.

Bicknell, J. E., Struebig, M. J., Edwards, D. P., & Davies, Z. G. (2015). Improved timber-harvest techniques help maintain biodiversity in tropical forests. *Current Biology, 25*(16), R805–R806.

Burivalova, Z., Şekercioğlu, Ç. H., and Koh, L. P. (2017). Thresholds of logging intensity to maintain tropical forest biodiversity. *Current Biology, 24*(16), 1893–1898.

Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., & Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science, 361*(6407), 1108–1111.

Edwards, D. P., Tobias, J. A., Sheil, D., Meijaard, E., & Laurance, W. F. (2019). Maintaining ecosystem function in logged tropical forests. *Trends in Ecology & Evolution, 29*(9), 511–520.

Food and Agriculture Organization of the United Nations. (2023). *The state of the world's forests 2023*. FAO.

Gbadebo, J.O.; Akinbi O.J.; Akintan, C.I. and Oseke J.I. (2014): Non-Timber Forest Products: A viable source of income in Odigbo Local Government Area of Ondo State. *Proceedings of the 3rd Annual Conference of the Association of Women in Forestry and Environment (AWIFE) Held at FUTA, Akure, Ondo State. Pp 214–223, 6th May, 2014.*

Gibson, L., Lee, T. M., Koh, L. P., Brook, B. W., Gardner, T. A., Barlow, J., Peres, C. A., Bradshaw, C. J. A., Laurance, W. F., Lovejoy, T. E., & Sodhi, N. S. (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature, 478*(7369), 378–381. https://doi.org/10.1038/nature10425

Intergovernmental Panel on Climate Change. (2022). *Climate change 2022: Impacts, adaptation, and vulnerability*. Cambridge University Press.

Nwokoro, C., & Onyekwelu, J. C. (2021). Forest degradation and governance challenges in Nigeria. *Environmental Management, 68*(3), 345–358.

Putz, F. E., Sist, P., Fredericksen, T., & Dykstra, D. (2016). Reduced-impact logging: Challenges and opportunities. *Forest Ecology and Management, 256*(7), 1427–1433.

Rozendaal, D. M. A., Bongers, F., Aide, T. M., Alvarez-Dávila, E., Ascarrunz, N., Balvanera, P., Becknell, J. M., Bentos, T. V., Brancalion, P. H. S., Cabral, G. A. L., Calvo-Rodriguez, S., Chave, J., César, R. G., Chazdon, R. L., Condit, R., Dallinga, J. S., de Almeida-Cortez, J. S., de Jong, B., de Oliveira, A., and Poorter, L. (2019). Biodiversity recovery of Neotropical secondary forests. *Science Advances, 5*(3), eaau3114. https://doi.org/10.1126/sciadv.aau3114

Vancutsem, C., Achard, F., Pekel, J.-F., Vieilledent, G., Carboni, S., Simonetti, D., & Gallego, J. (2021). Long-term (1990–2019) monitoring of forest cover changes in the humid tropics. *Science Advances, 7*(10), eabe1603.

EFFECT OF MOISTURE SORPTION STATE ON THE TRANSVERSE DIMENSIONAL CHANGE OF *Terminalia ivorensis* A.Chev. WOOD

***[1]Adebayo, J. O., [2]Elesho, R. O., [2]Aluko, A. K., [2]Majekodunmi, O. A., [2]Yusuf, [2]A. A., [2]Adeniran, T., [2]Aderemi. F. T., [2]Adeniji, R. T., [2]Oyelabi, A. A., [2]Akande, A. A., [2]Idowu, A. F., and [2]Oyediran, O. O**

[1]Derived *Savanna Research Station, Al-Hikmah University, Igbaja, Kwara State, Forestry Research Institute of Nigeria.*
[2]Federal College of Forestry, Jericho, Ibadan.
**Corresponding author: ologsoljim@gmail.com; 08029545279*

Abstract

Wood is a renewable raw material generally subjected to fluctuating atmospheric Humidity. There is little information available concerning the effect of the moisture sorption state on the swelling behaviour of tropical hardwoods. This study was therefore carried out with a view to understanding the reaction of wood to variation in relative Humidity. The gravimetric method was used in this study with gradual oven-drying from 50 ^{0}C to 102 ^{0}C for ten days at five relative humidities (33%, 45%, 55%, 75%, and 93% as treatments in a Completely Randomized Design) and 35 ±2 ^{0}C. After completion of adsorption experiments, samples were kept in a desorption mode under the same conditions. They were weighted and measured for the transverse dimensions at each equilibrium condition. Percent radial and tangential dimensional changes were evaluated based on oven-dry dimensions during both adsorption and desorption states. Data were analyzed using descriptive statistics. The characteristic hysteresis loop was evident between the adsorption and desorption curves for dimensional change in both directions. The ratio of tangential to radial swelling (aT/aR) was not constant over the entire range of relative Humidity and was found to increase sharply at high relative Humidity (above 75% RH). State of sorption influences transverse dimensional changes and anisotropies in dimensions. Anisotropy was high during desorption compared to during adsorption with respect to both relative Humidity and moisture content. The difference between the adsorption and desorption curves was more in the tangential direction, depicting a prominent second-order effect in the tangential direction.

Keywords: *Terminalia ivorensis*, Moisture, Swelling, Adsorption, Desorption

Introduction

Wood is a natural, eco-friendly, and renewable raw material widely used for its simple processing and excellent physical and aesthetic properties. These properties allow incorporating wood into lightweight constructions and, in separate cases, replacing metal parts. Furthermore, wood shows good thermal resistance and a relationship between weight and strength. However, in addition to these advantages, there are many disadvantages: moisture causes dimensional changes in wood, and wood shows poor resistance to fungi and pests (Navickas & Albrektas, 2013). Wood used in its final form for furniture, building construction, musical instruments, and other uses is generally subjected to fluctuating atmospheric Humidity. Timber is hygroscopic; it will absorb moisture from the atmosphere when dry and, correspondingly, yield moisture to the atmosphere when wet,

thereby attaining a moisture content in equilibrium with the water vapour pressure of the surrounding atmosphere (Quartey *et al*., 2021).

Wood, being a hygroscopic material, adsorbs or desorbs moisture in response to changes in the relative Humidity and temperature of its surroundings to attain equilibrium moisture content. This moisture movement leads to dimensional changes in wood, namely, swelling during adsorption and shrinkage during desorption (Chauhan & Aggarwal, 2004). The EMC is therefore constantly changing, sometimes periodically and at other times sporadically, such as when wooden decking is exposed to rain (Siau, 1995). Wood exposed to high humidity conditions or to liquid water during use may be subjected to biological deterioration. Where timber is subjected to wide fluctuations in relative Humidity, care must be exercised to select a species that has low movement values. Since environmental conditions never remain stable and ambient relative Humidity and temperature change continuously, moisture adsorbs and desorbs repeatedly, and the moisture content of wood seldom reaches equilibrium with the surrounding environment. There is little information available concerning the effect of the moisture sorption state on the swelling behaviour of tropical hardwoods. Thus, this study aimed to investigate the effect of moisture sorption state on transverse swelling in *Terminalia ivorensis* wood.

Materials and Method

In this study, *Terminalia ivorensis* wood was used. The basic density of these wood species, based on oven-dried weight and green volume, was in the range of 300 kg/m^3 to 460 kg/m^3. True end - matched specimens of size 30 mm (R), 30 mm (T) and 5 mm (L) were prepared from air-dried defect-free boards of each species. To avoid dimensional distortion during initial drying, samples were slowly dried by gradually increasing the oven temperature from 50 ^{0}C to 102 ^{0}C over a period of 10 days. Oven-dried samples that were randomly selected (Completely Randomized Design) were cooled down in a desiccator over calcium chloride. These oven-dried samples were weighed (accuracy—0.001 g) and measured for radial and tangential dimensions using a digital micrometer (accuracy—0.01 mm). Ten specimens of each species were subjected to multistep adsorption at five relative humidities, viz. 33%, 45%, 55%, 75%, and 93% (Table 1). Different relative humidities were achieved in desiccators over selected saturated salt solutions maintained in a constant-temperature chamber at 35 ± 20 °C. Saturated salt solutions were kept under slow stirring using magnetic stirrers to prevent the formation of a water top film due to salt precipitation. When the moisture content in the samples reached equilibrium at each relative Humidity, they were weighed and measured for transverse dimensions. After completion of adsorption experiments, samples were kept over distilled water for a sufficient time so that the wood cell walls became fully saturated with water and the moisture content reached near fibre saturation point.

These samples were placed in desorption mode under the same conditions, weighed, and measured for their transverse dimensions at each equilibrium condition. The time taken to attain equilibrium was 4 weeks. Percent radial and tangential dimensional changes (swelling) were evaluated based on oven-dry dimensions during both adsorption and desorption states by using the following equations:

$$aT = \frac{Tm - Tod}{Tod} x100\% \quad \ldots\ldots\ldots\ldots\ldots 1$$

and $aR=\frac{Rm-Rod}{Rod}x100\%$..... 2 (Chauhan & Aggarwal, 2004).

Where:

aT and aR = Tangential and Radial dimensional changes (in per cent) respectively,

Tm and Rm are tangential and radial dimensions at moisture content "m". T_{od} and R_{od} are the oven-dried tangential and radial dimensions, respectively.

Results and Discussion

Transverse Dimensional Changes as a Function of Relative Humidity (%)

Tangential and radial dimensional changes with respect to relative Humidity are shown in Fig. 1. The characteristic hysteresis loop was evident between the adsorption and desorption curves for dimensional change in both directions. The higher dimensions during desorption may be attributed to the mechanism of water sorption. The ratio of tangential to radial swelling (aT/aR), an indicator of transverse dimensional anisotropy, was determined at all humidity levels to understand the anisotropic behaviour during different states of sorption (Table 2). The aT/aR ratio was not constant over the entire humidity range and increased sharply at high relative Humidity (above 75% RH). This indicates that the dimension in the tangential direction was higher during desorption than during adsorption at all relative humidities. The results demonstrated that dimensional changes in the tangential direction and volume were greater during desorption than during adsorption.

The difference in adsorption and desorption was more pronounced at lower humidity (below 75% RH), suggesting that the mechanism of transverse dimensional movement may depend on the sorption state. The results indicated that the angular deformation in wood is expected to be less at intermediate humidities during moisture adsorption, with a relatively greater rate in the radial direction at higher Humidity. Arevalo and Hermandez (2001) (1967) also observed a similar phenomenon in Mahogany (*Swietenia macrophylla* King), where their results demonstrated that dimensional changes in tangential direction and in volume were greater for desorption than adsorption. This result was also similar to the report of Chauhan and Aggarwal (2004) in their study of *Albizia chinensis*, *Erythrinia variegata*, *Gmelina arborea* and *Lannea coromandelica,* where a difference in prominent adsorption and desorption was observed in the lower Humidity of less <75% RH, indicating that the dimension in tangential was higher during desorption compared to adsorption at all relative humidities. Table 2 showed that the aT/aR ratio was higher during desorption than during adsorption at all relative humidities.

Table 1: Selected Saturated Salts for Different Relative Humidity

Salt	Relative Humidity (%)
$MgCl_2.6H_2O$	33
$MgCl_2.6H_2O$	43
$Na_2Cr_2O_7$	55
NaCl	75
$CuSo_4.5H_2O$	93 (Chauhan & Aggarwal, 2004).

Table 2: Variation in Tangential and Radial Dimensional Ratio (aT/aR**) during Adsorption and Desorption in *Terminalia ivorensis* Wood with Respect to Relative Humidity**

	(aT/aR) (%)	
Relative Humidity (%)	Adsorption	Desorption
33	1.89	2.13
43	1.92	2.15
55	1.99	2.18
75	2.14	2.19
93	2.24	2.27

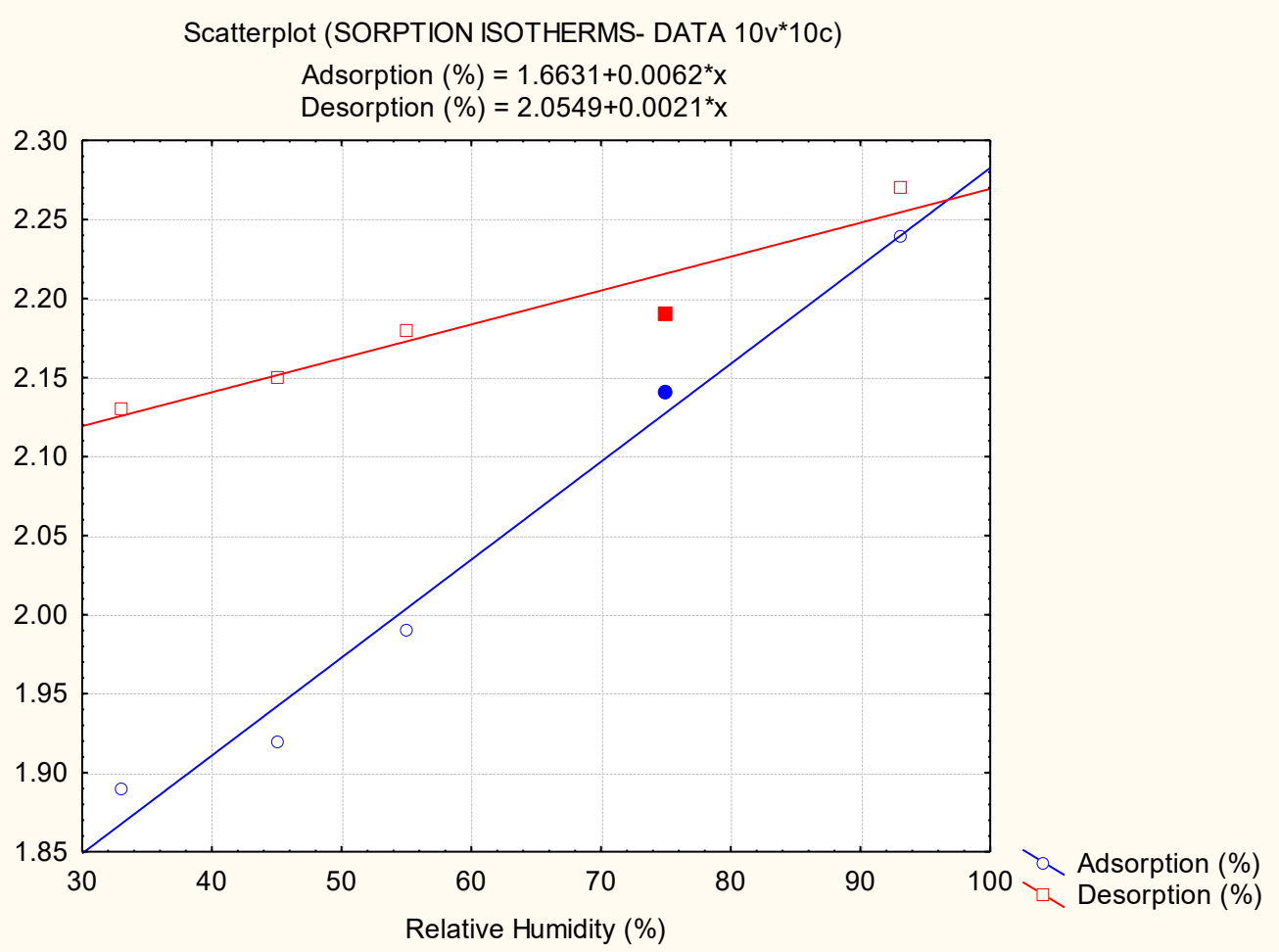


Figure 4: Sorption Isotherms of *Terminalia ivorensis*

Note: x-axis = Relative Humidity, y-axis = Dimensional Change (%).

Conclusion

State of sorption influences transverse dimensional changes. Anisotropy: the aT/aR ratio was not uniform across the entire humidity range and increased sharply at high Humidity. It was found to be higher during desorption than during adsorption, both in relative Humidity and moisture

content. These confirmed the state effect of moisture sorption on dimensional changes and anisotropic behaviour. The difference between the adsorption and desorption curves was more in the tangential direction than in the radial direction, depicting a prominent second-order effect in the tangential direction
direction.

References

Álvarez, J.V. (2012)**.** Sorption and thermodynamic properties of cork from the 35°C and 50°C isotherms.*Bois et forêts des Tropiques* 311 (1): 63-74.

Chauhan, S. S., & Aggarwal, P. (2004). Effect of moisture sorption state on transverse dimensional changes in wood. *Holz Roh Werkst (2004), 62:50-55. DOI 10.1007/s00107-003-0437-y. A. Published online: 17 Dec. 2003 Springer Verlag 2003.*

Fernández, F.G. De Palacios, P.; Esteban, L.G.; Iruela, A.G.; Gonzáles Adrádos, J.R.; López Mohammed, A. I., Ejeh, S. P., Amartey, Y. D., & Ocholi, A (2019). Determined uncertainty models of reference material properties and the EN 338 strength class of Nigerian-grown *Terminalia Ivorensis* (Black Afara) Timber. *Nigerian Journal of Technology (NIJOTECH)* 38, (2): 302-310.

Navickas, P., and Albrektas, D. (2013). Effect of heat treatment on sorption properties and dimensional stability of wood

Quartey, G. A., Eshun, J. F. & Sakyiama, B. (2021). Effect of Microstructure on the Permeability and Sorption of Wood of *Sterculia rhinopetala* and *Albizia ferruginea*. *Journal of Advanced Technology. 1(3): 523-535*

Siau, J, F. (1995). *Wood: Influence of Moisture on Physical Properties. Technology and engineering- 227 pages*. Department of wood science and forest products, Virginia polytechnic institute and state university, Blacksburg, va. ISBN: 9780962218101.

ISTF-NG-2026

ASSESSMENT OF THE INFORMATION NEEDS FOR THE DEVELOPMENT OF TIMBER MARKETING INFORMATION SYSTEM IN SOUTHWESTERN NIGERIA

***Falana, A.R[1]., Akintunde-Alo, D.A[2]., Azeez, I.O[2] and Omotayo F. O[3]**

[1]Department of Forestry and Environmental Technology, Federal College of Forestry, Ibadan, Nigeria
[2]Department of Social and Environmental Forestry, University of Ibadan, Nigeria
[3]Department of Data and Information Science, University of Ibadan, Nigeria
**Correspondence e-mail address: pejusmile@gmail.com; +2348038552927*

Abstract

This study assessed the Information for the development of a timber marketing information system in Southwestern Nigeria. This study aimed to assess the information needs of timber marketers in Southwest Nigeria to develop a standardized TMIS for the region. Primary data were collected from 355 respondents using structured questionnaires and analyzed using descriptive statistics and Chi-square tests. Results revealed that timber marketing is largely male-dominated (62.8%), with high mobile phone ownership (97.7%) and intermediate ICT proficiency (75.0%). The main Information needs assessed for the development of a TMIS in Southwestern Nigeria were: Seller's contact (89.3%), Timber species (89%), Plank sizes (71.5%), Current prices per plank (86.8%), Sources of timber (71.3%), Timber legality Status (61.7%), Machines used for conversion (69.6%), and Season of availability (65.7%). It was revealed that gender significantly influenced current price information need ($\chi^2 = 7.554$). Education level significantly influenced sellers' Contact ($\chi^2 = 16.433$), source of timber ($\chi^2 = 22.479$), timber legality status ($\chi^2 = 13.675$) and machines used for conversion ($\chi^2 = 20.779$). This study concludes that there is a need to develop a reliable and standardized TMIS in Southwestern Nigeria, as this would provide access to timber species availability, enhance market transparency, and connect timber buyers and users to marketers, thereby promoting sustainable forest resource management in the region. The study therefore recommends strong policy support, stakeholder collaboration, and continuous capacity development to ensure effective adoption and long-term sustainability of the system.

Keywords: Information needs, Timber marketers, Southwestern Nigeria, and Information System.

Introduction

Timber production and marketing have significant roles in the economies of many developing countries, including Nigeria. The forestry sector in Nigeria is crucial, not only for economic development but also for employment, rural livelihoods, and environmental sustainability (Akinyemi & Ola, 2021). In Southwestern Nigeria, the timber industry is a vital source of income, contributing to rural development and the broader national economy (Akinyemi & Ola, 2021). In recent years, despite the potential of this sector, the timber market has faced challenges such as limited access, inefficient market information, inadequate infrastructure, inadequate understanding of market dynamics, and underdeveloped technological solutions to facilitate trade (Ogundele & Abiola, 2017). This inefficiency limits timber marketers' ability to make informed decisions, thereby reducing the timber sector's potential to foster economic growth and development (Fakorede, 2020). Information need refers to the desire or requirement for Information to meet specific goals and solve particular problems. The concept has gained significant attention due to

the increasing complexity of information environments, particularly amid rapid technological advancements, digitalization, and the information overload individuals and organizations experience.

A Timber Marketing Information (TMIS) is a structured framework that integrates various data sources to facilitate decision-making in the timber and forest products industry. It encompasses the collection, analysis, and dissemination of relevant Information on timber production, distribution, pricing, and consumer demand, thereby helping stakeholders such as forest managers, timber producers, and marketers make informed decisions. The development of a Marketing Information System (MIS) is increasingly crucial, as the stability and growth of economies depend heavily on the acquisition of data, Information, and knowledge to better understand customers' specific needs. A TMIS could significantly improve overall performance and market efficiency by providing up-to-date, reliable data on timber prices, demand trends, market access and production statistics, thereby improving decision-making for timber producers, traders, and policymakers and consequently resulting in sustainable forest management (Adeyemo & Adetunji, 2023; Ogundele & Abiola, 2017). Such a system would also help address infrastructure gaps in the timber sector by facilitating better communication and coordination among key stakeholders. However, despite the potential advantages, there is limited research on the readiness of timber markets in Southwestern Nigeria to adopt and develop a TMIS. Understanding the information needs of timber marketers is crucial for designing an effective Marketing Information System (MIS) that supports decision-making, enhances market efficiency, and improves performance in the timber sector. This study seeks to assess the information needs required for the development of TMIS in Southwestern Nigeria.

Methodology

Nigeria is a diverse and multi-ethnic nation, home to over 250 ethnic groups who speak more than 500 different languages and exhibit a broad spectrum of cultural traditions. The major ethnic groups, Hausa in the north, Yoruba in the west, and Igbo in the east, account for more than 60% of the population. English serves as the official language, chosen to promote communication and unity at the national level (Akindele *et al.,* 2022).The South West is One of Nigeria's six geopolitical zones, serving as both a geographical and administrative division. This region includes six states: Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo. Ekiti State is located in the Southwest region of Nigeria, sharing boundaries with Kwara State to the north (approximately 61 km), Kogi State to the northeast (about 92 km), Ondo State to the south and southeast, and Osun State to the west (around 84 km). Oyo State is an inland state located in southwestern Nigeria, with Ibadan as its capital. Ibadan is the third most populous city in the country and was formerly the second most populous in Africa (Nenge, 2019). Osun State, also known as the "State of Osun" by the state government, is located in southwestern Nigeria. It is bordered to the east by Ekiti and Ondo States (84 km and 78 km respectively), to the north by Kwara State (73 km), to the south by Ogun State (84 km), and to the west by Oyo State, largely across the River Osun. Ogun State had a population of approximately 3.75 million people (Ogun Smart City, 2021), ranking 16th among Nigeria's states by population (National Results, 2011). With a land area of 16,762 square kilometers, it is the 24th-largest in the country (World Gazetteer, 2018). Ondo State receives approximately 182.94 mm (7.2 inches) of rainfall and records about 266 rainy days annually, representing nearly 73% of the year (Historical Data, 2013; Historical Data, 2014). Lagos State stands out as One of the world's

fastest-growing urban regions and is considered Nigeria's most economically significant state. It hosts the country's largest city and serves as a central financial hub with One of the strongest economies on the African continent (Ekundayo, 2013)

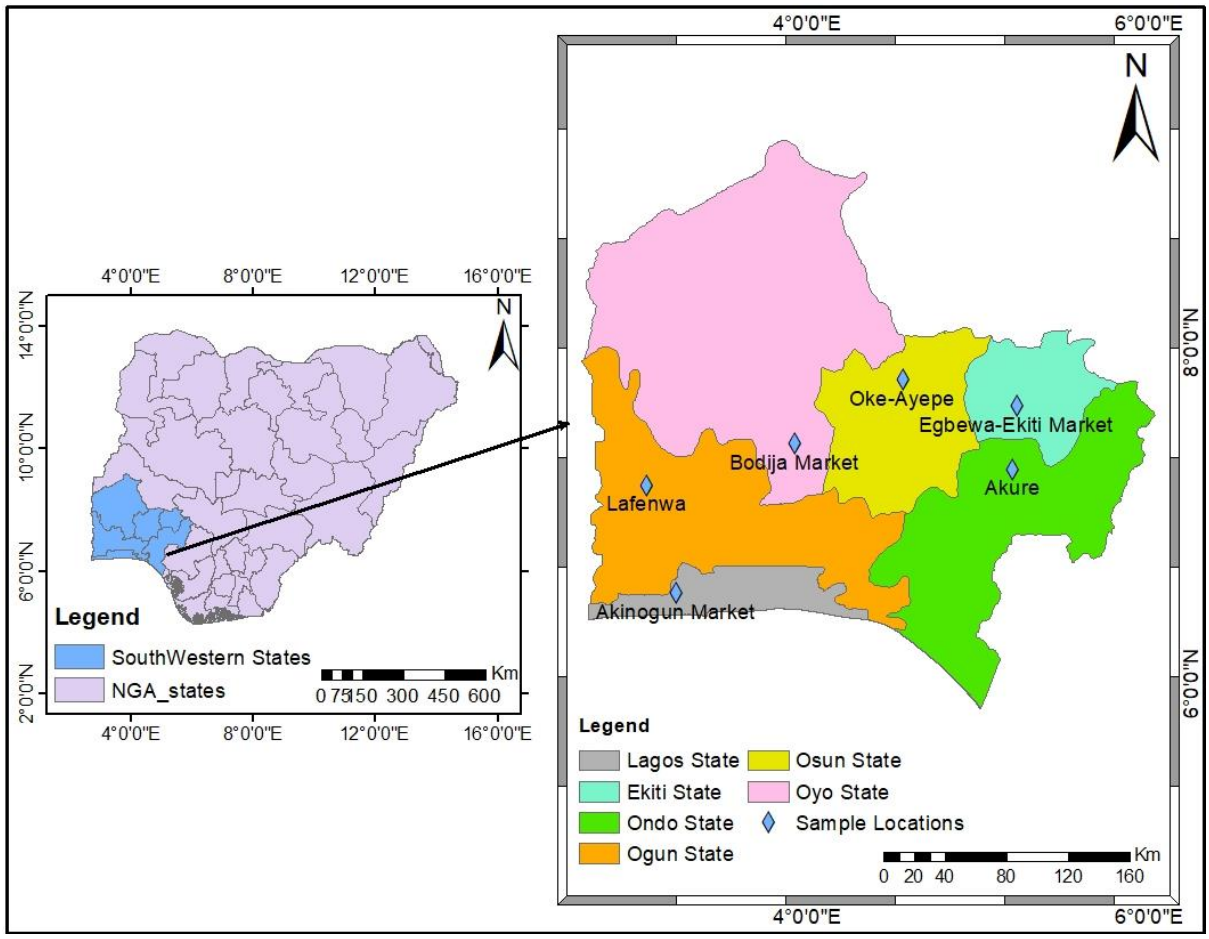


Figure 1. Map of the Study Area
Source: Field Survey, 2025

Sampling Procedure and Sampling Technique

A proportionate-to-size sampling procedure was used to select 379 respondents from the 1895 registered timber marketers' population in the study area, with a 20% sampling intensity based on available data.

Table 1. Sampling procedures for Respondents in Southwest, Nigeria

States	Number of registered Timber marketers	20% sample
Oyo	300	60
Ogun	535	107
Osun	330	66

Lagos	200	40
Ekiti	280	56
Ondo	250	50
Total Sample	**1895**	**379**

Field Survey, 2025

Sources of Data and Instruments for Data Collection
Primary data were collected using a structured questionnaire.

Statistical analysis

The collected data were analyzed using descriptive statistics and the Chi-Square test.

Results and Discussion

The demographic characteristics of the timber marketers in Southwestern Nigeria are presented in Table 1. It showed that 62.8% of respondents were male and 37.2% were female, indicating a greater number of male respondents than female respondents in the plank marketing business in the study area. This is in line with Falana *et al.* (2023), who found that there were more males than females in the planks marketing business, noting that women are usually involved in domestic work. The greater involvement of men in the timber business in the study area may imply that men can manage stress and tedious activities better than women, as men are more muscular (Sekumade & Oluwatayo, 2011).

The respondents' ages showed that 27.7% were between the ages of 41-50, 26% were 51-60 years, 19.2% were 21-30, 16.1% were between 31-40, while 7.3% and 3.4% respectively of the respondents' ages ranged between 60-70 years and above 70 years. This shows that the respondents were within their active age group, agile and resilient to stress, and a source of income for livelihood sustenance. This suggests that mature adults predominantly practice timber marketing. This supports the findings, which consistently show that middle-aged and older individuals dominate the timber trade in Nigeria. According to Alawode *et al.* (2023), most timber marketers fell within the 41–60 years' age range, indicating that experience and established networks play a critical role in sustaining participation in the sector.

It is revealed that the majority (25.6%) of the respondents had an estimated monthly income level of above ₦500,000, 24.5% had an estimated income level of ₦ 100,000 -200,000, followed by 18.6% having an estimated income level of ₦ 401,000 -500,000, while the least was 11.5% with an estimated monthly income of between ₦ 301,000-400,000. It can be deduced that the timber marketing business is a lucrative job and a very good source of livelihood in Southwestern Nigeria, capable of yielding a high monthly income. The economic potential of timber marketing has been documented in prior research by Falana *et al.* (2023) and Idoko (2024), who reported that marketers reported timber trading as a primary source of income capable of supporting household expenditures, Education, and capital investment. This aligns with the conclusions of Adedokun *et al.* (2017) and Aremu *et al.* (2015), who both emphasized that sawn wood production across major sawmills remains a highly lucrative venture with high rates of financial returns (Areo *et al.*, 2024).

Many (59.4%) of the respondents had no other sources of livelihood, while 40.6% had other sources of income other than the timber marketing business. This can be attributed to the business's profitability. This brought to Light that Timber marketers are sufficiently taking care of their families with the income they earn from their business, as it is profitable. This supported Alawode *et al.* (2023), who found that timber marketing significantly contributes to marketers' income, with many relying on it as their main source of livelihood. The few respondents with other sources of income reported that 17.5% were into trading other products besides Planks, 10.5% were building contractors, and 2% were involved in furniture making. Since many of the respondents did not have other sources of livelihood aside from the timber marketing business, the few who did were still in timber (forestry)- related businesses. The engagement of timber marketers in ancillary economic activities such as furniture production and building contracting constitutes a form of horizontal and vertical integration within the timber industry. Rather than representing a departure from timber marketing, these activities reflect strategic diversification that remains embedded within the broader timber value chain. Moreover, this diversification contributes to local employment generation and skill development within the wood-processing sector. Similarly, participation in building contracting represents another avenue through which timber marketers remain functionally connected to the timber economy.

The educational background of timber marketers in Southwest Nigeria is diverse but largely basic. Most respondents (51%) possessed secondary school certificates, indicating that most participants had completed basic formal Education. Additionally, 20.6% had post-secondary qualifications such as Ordinary National Diploma (OND), Higher National Diploma (HND), or Nigeria Certificate in Education (NCE). A smaller segment (12.7%) had only primary Education, while others had Qur'anic Education (3.1%), adult literacy Education (2.8%), and 2.5% had no formal Education. These findings suggest that timber marketing in Southwest Nigeria is accessible to individuals across various educational levels, especially those with basic Education. The dominance of secondary-level Education aligns with earlier research by Alawode *et al.* (2023), which reported that secondary school graduates constitute the bulk of timber traders at the Bodija timber market in Ibadan. This level of Education is often enough to handle the fundamental aspects of timber business operations, such as basic bookkeeping, customer relations, and understanding market dynamics.

Findings showed that all (100%) of the respondents used phones, 17.2% used the internet, while only 8% and 7.3% used the library and laptops, respectively. The phone was the primary information technology the timber marketers used, as it helped them reach their customers and retrieve and disseminate Information within and outside the market environment. This agrees with the findings of Ajewole and Fasoro (2013), who found that the use of mobile phones has significantly simplified communication, enabling sawn wood marketers to carry out business transactions efficiently and quickly with customers.

The marketers are proficient with phones. Intermediate ICT usage typically implies reliance on basic digital tools, particularly mobile phones, for essential communication and coordination. In contrast, more advanced tools such as computers, internet-based platforms, and digital record systems remain underutilized. Mobile phones are used primarily for making calls, price negotiation, and logistics coordination. This corroborates Adeoye and Oke (2019), who observed that in many informal and semi-structured market environments in Nigeria, traders often rely on mobile phones due to their affordability, ease of use, and relevance to daily operations.

Table 1. Demographic characteristics of the Timber marketers in Southwestern Nigeria

Variables	Categories	Frequency	Percent %
1. Gender	Male	223	62.8
	Female	132	37.2
	Total	**355**	**100.0**
2. Age	Less than 20	1	3.0
	21-30	68	19.2
	31-40	57	16.1
	41-50	98	27.7
	51.60	92	26.0
	61-70	26	7.3
	Above 70	12	3.4
	No response	1	3.0
	Total	**355**	**100.0**
3. Estimate Income level	N100,000-200,000	87	24.5
	N201,000-300,000	56	15.8
	N301,000-400,000	41	11.6
	N401,000-500,000	66	18.6
	Above N500,000	91	25.6
	No response	14	3.9
	Total	**355**	**100.0**
4. Have other Sources of Income?	Yes	144	40.6
	No	211	59.4
	Total	**355**	**100.0**
5. Other sources of livelihood	Artisanship	18	5.1
	Building Contracting	37	10.4
	Furniture making	7	2.0
	Trading other products	62	17.5
	Farming	10	2.8
	No response	221	62.2
	Total	**355**	**100.0**
6. Academic Qualifications of Respondents	No formal Education	9	2.5
	Adult Literacy Class	10	2.8
	Qur'anic Education	11	3.1
	Pry Sch Cert	45	12.7
	Sec Sch Cert	181	51.0
	OND/HND/NCE	73	20.6
	Univ. Degree	26	7.3
	Total	**355**	**100.0**

Variables	Categories		Frequency	Percent %
7. Types of Information Technology/Systems	Mobile phone	Yes	347	97.7
		No	8	2.3
		Total	**355**	**100.0**
	Laptop	Yes	26	7.3
		No	329	92.7
	Total		355	100.0
	Internets	Yes	61	17.2
		No	294	82.8
	Total		355	100.0
	Library	Yes	3	8.0
		No	352	99.2
	Total		**355**	**100.0**
8. Proficiency of the Respondents in using information technology	Novice		20	5.6
	Intermediate		266	75.0
	Highly proficient		69	19.4
	Total		**355**	**100.0**

Source: Field Survey, 2025

Tables 2 and 3 show the Information needs assessed for the development of an effective and reliable TMIS in Southwestern Nigeria. Nwafor *et al.* (2020) emphasized that identifying the precise information requirements of farmers is crucial to enhancing productivity and market participation, ultimately contributing to poverty reduction. It is also pertinent to understand timber marketers' Information needs to develop an efficient TMIS in Southwestern Nigeria. Seller's Contact (89.3%), Timber Species (89.0%), Current Prices of Timbers (86.8%), Plank sizes (71.5%), Sources of Timber (71.3%), Machines used for conversion (69.6%), Season of availability of Timbers (65.7%), and Timber Legality Status (61.7%). The very high proportion of respondents (89.3%) who indicated sellers' contact information as a critical information need underscores the central role of communication and linkage in timber marketing in Southwestern Nigeria. This finding suggests that timber marketers place great ValueValue on having reliable, up-to-date contact details for timber sellers to facilitate transactions, negotiate prices, arrange supply, and reduce uncertainties in sourcing timber products. The lack of a structured platform for accessing sellers' contact information often results in high search costs, procurement delays, missed market opportunities, and increased susceptibility to middleman exploitation.

The price of timber is an information need for the development of an effective Marketing Information System, which gives room for negotiating Power. With real-time timber price data, sellers are in a stronger position when negotiating with buyers. They can justify their prices with concrete data showing market trends, supply shortages, or demand surges. If a seller knows that market prices are higher due to limited supply, they can use this Information to defend their pricing decisions during negotiations. Regular updates on timber prices reduce confusion among buyers when they reach the market. When prices are updated regularly, buyers can compare and weigh which markets offer the best purchase price, even after accounting for transportation costs (Agwu *et al*., 2012; Akinbami, 2020).

Current price data helps set real-time prices, negotiate sales, and avoid exploitation while assessing profitability. Regular updates on prevailing market prices empower sellers to make evidence-based pricing decisions, reducing the risk of underpricing or overpricing. Reliable, timely price data minimizes transaction inefficiencies and supports higher income for marketers (Ogunleye & Oladeji, 2007). Timber price information is likely to enhance market efficiency in Nigeria's timber sector. The integration of price data is essential in dynamic markets, particularly in countries like Nigeria, where the timber industry faces significant challenges due to fluctuating prices, trade policies, and market volatility. This followed Suialignsyi and Oyeleke (2016), whose study investigated the role of price information in enhancing market efficiency in Nigeria's timber sector, highlighting how price transparency improves market competition and decision-making, ultimately benefiting both buyers and sellers

Information about timber species is critical because of varying quality, strength, and market value. Knowledge of species supports customer satisfaction, processing techniques, and pricing. Accurate identification aids quality control, grading, and matching customer preferences. As noted by Ayuba *et al.* (2013), species-specific Information enhances both technical handling and market performance, especially in a diverse tropical environment like Nigeria. The finding that 71.5% of respondents identified plank size information as a critical information need highlights the importance of standardization and specification in timber marketing in Southwestern Nigeria. Plank sizes constitute a key quality and technical attribute that directly influences pricing, end-use suitability, processing efficiency, and buyer satisfaction in timber markets. This result is consistent with the findings from forest product marketing studies, which show that a lack of reliable product specification information undermines market transparency and reduces operational efficiency (FAO, 2017). In many developing-country timber markets, including Nigeria, plank sizes are often determined using informal measurement techniques rather than standardized grading rules, leading to significant variability in product quality (Adekunle *et al.*, 2013). Consequently, marketers require accurate size information to match supply with customer requirements, particularly in construction, furniture-making, and carpentry applications. In TMIS development, standardized plank-size data would enable marketers to compare products, set appropriate prices, and plan logistics more effectively. Also, access to plank size information has implications for pricing efficiency and cost reduction.

Information on timber sources is another information need. It highlights the importance of knowledge of supply origins in timber marketing in Southwestern Nigeria. Timber marketers operate within a complex supply environment involving natural forests, forest reserves, plantations, and private lands, often with limited formal documentation. Inadequate Information on timber sources increases uncertainty in procurement planning, transportation costs, and supply reliability, thereby constraining market efficiency (FAO, 2016). From a marketing information systems perspective, access to reliable source-related Information enhances transparency, supports informed sourcing decisions, and reduces transaction risks. Knowledge of timber origin also has implications for sustainability and regulatory compliance, as traceability to source is increasingly recognized as a key mechanism for promoting legal and sustainable timber trade (Tacconi *et al.*, 2016). Integrating Information on timber sources into a Timber Marketing Information System (TMIS) would therefore improve supply chain coordination, reduce market uncertainty, and support sustainable timber marketing practices in Southwestern Nigeria.

Marketers need Information on the machines used for conversion, processing techniques, milling quality standards, and value-added options to improve product quality and competitiveness. Information on best practices in sawnwood processing, including machine use and defect reduction, improves product quality and profitability (Ogunwusi & Onwualu, 2013). The finding that 69.6% of respondents identified machines used for conversion as an information need highlights the importance of processing technology in timber marketing systems. Timber conversion machines such as bandsaws, circular saws, and portable mills determine not only the productivity and efficiency of processing operations but also the quality and marketability of finished products (Mafimisebi & Okuneye, 2014). Integrating Information on conversion machinery into a Timber Marketing Information System (TMIS) supports efficiency gains across the timber value chain by facilitating technology matching and knowledge transfer.

Seasonality greatly affects timber availability, especially with poor road networks and rain-related access issues, with certain species more available in dry seasons than rainy ones. Awareness of seasonal trends helps with procurement planning and inventory control (Ogunwusi, 2013). Marketers need this Information for scheduling procurement and managing stock levels. Knowing when forests are accessible, due to dry or rainy seasons, policy restrictions, or operational schedules, is essential for planning harvesting and supply operations. This Information is important for inventory management and logistics. A moderately high percentage (61.7%) of respondents identified timber legality status as a key information need, highlighting its importance in timber marketing and value-chain governance in Southwestern Nigeria. Timber legality refers to whether a product has been harvested, processed, transported, and traded in compliance with applicable laws and regulations (e.g., forest policies), a matter central to market legitimacy, forest sustainability, and access to international trade (FAO, 2021). In many tropical timber markets, including West Africa, weak enforcement of forest laws and opaque supply chains have enabled widespread illegal logging, undermining economic returns, contributing to deforestation, and eroding stakeholder trust (Forest Trends, 2023). For timber marketers, knowing the legal status of timber products is crucial for avoiding transactions that could expose them to regulatory sanctions, loss of business reputation, or exclusion from markets with strict legality requirements.

Integrating legal Information into a Timber Marketing Information System (TMIS) enhances market transparency and risk management by linking buyers and sellers through verifiable documentation of compliance (FAO, 2021). International frameworks, such as the EU Timber Regulation and FLEGT Voluntary Partnership Agreements, exemplify how legal verification systems are used globally to restrict illegal timber from entering formal markets and to support sustainable trade practices (EU Timber Regulation, 2025). In this context, a TMIS that includes verified legality status would enable local marketers to align with international norms, support traceability, and reduce the prevalence of illegally sourced timber in domestic and export markets. Collectively, such features can improve competitiveness, strengthen governance, and promote sustainable forest use in Southwestern Nigeria.

Table 2. Information Needs for the Development of Timber Marketing System in Southwestern Nigeria

S/N	INFORMATION NEEDS	AGREE (%)	DISAGREE (%)	NOT SURE (%)
1	Timber Species	89	3.1	7.9

2	Current prices of timber	86.8	7.3	5.9
3	Sellers Contact	89.3	4.3	6.4
4	Sources of Timber	71.3	15.2	13.5
5	Timber Legality Status	61.7	22.8	15.5
6	Machine used for Conversion	69.6	14.4	16
7	Season of availability of timber species	65.7	18	16.3
8	Planks Sizes	71.5	14.1	14.4

Source: Field Survey, 2025

Table 3. Ranking of Information Needs for the Development of Timber Marketing System in Southwestern Nigeria

S/N	INFORMATION NEEDS	AGREE	RANKING
1	Sellers' Contact	89.3	1st
2	Timber Species	89.0	2nd
3	Current prices of timber	86.8	3rd
4	Plank Sizes	71.5	4th
5	Sources of Timber	71.3	5th
6	Machines used for Conversion	69.6	6th
7	Season of availability of timber species	65.7	7th
8	Timber Legality Status	61.7	8th

Source: Field Survey, 2025

Tables 4 and 5 show the inferential analysis of Socio-demographic characteristics and information needs for TMIS development. Chi-square tests of independence were conducted to examine the associations between socio-demographic characteristics (Gender and Education level) and timber marketers' Information needs for the development of a Timber Marketing Information System (TMIS). The Information needs assessed included sellers' Contact Details, timber species, plank sizes, current prices, timber sources, timber legality status, machines used for conversion, and Season of availability. Descriptive statistics showed high demand for sellers' Contact (89.3%), timber species (89.0%), current prices (86.8%), plank sizes (71.5%), sources of timber (71.3%), machines used for conversion (69.6%), season of availability (65.7%), and timber legality status (61.7%). Chi-square tests examined the relationship between gender, Education level, and these information needs.

Inferential analysis revealed that gender (Table 4) significantly influenced current price information need ($\chi^2 = 7.554$, $p = 0.023$), while no significant associaions were observed for other information needs ($p > 0.05$). This suggests that gender does not substantially influence most information needs for the development of the Timber Marketing Information System (TMIS), except for current price information. Education level (Table 5) significantly influenced sellers' Contact ($\chi^2 = 16.433$, $p = 0.002$), source of timber ($\chi^2 = 22.479$, $p < 0.001$), timber legality status ($\chi^2 = 13.675$, $p = 0.008$), and machines used for conversion ($\chi^2 = 20.779$, $p < 0.001$). No significant associations were found between Education level and timber species ($\chi^2 = 4.117$, $p = 0.390$),

current price ($\chi^2 = 6.104$, $p = 0.192$), Season of availability ($\chi^2 = 4.702$, $p = 0.319$), and plank sizes ($\chi^2 = 5.809$, $p = 0.214$).

Table 4. Summary of Chi-Square Test of Association Between Gender and Information Needs for TMIS Development (N = 355)

S/N	Information Need	χ^2 ValueValue	Df	p-value	Decision (α= 0.05)	Interpretation
1	Timber Species	2.516	2	0.284	Not Significant	No association
2	Current Price	7.554	2	0.023	**Significant**	Association exists
3	Sellers' Contact	3.849	2	0.146	Not Significant	No association
4	Source of Timber	4.844	2	0.089	Not Significant	No association
5	Timber Legality Status	3.785	2	0.151	Not Significant	No association
6	Machines Used for Conversion	5.271	2	0.072	Not Significant	No association
7	Season of Availability	4.863	2	0.088	Not Significant	No association
8	Plank Sizes	4.887	2	0.087	Not Significant	No association

Source: Field Survey, 2025

Table 5. Summary of Chi-Square Test of Association Between Education Level and Information Needs for TMIS Development (N = 355)

S/N	Information Need	χ^2 ValueValue	Df	p-value	Decision (α = 0.05)	Interpretation
1	Timber Species	4.117	4	0.390	Not Significant	No association
2	Current Price	6.104	4	0.192	Not Significant	No association
3	Sellers' Contact	16.433	4	0.002	**Significant**	Ass. exists
4	Source of Timber	22.479	4	0.000	**Significant**	Ass. exists
5	Timber Legality Status	13.675	4	0.008	**Significant**	Ass. exists
6	Machines Used for Conversion	20.779	4	0.000	**Significant**	Ass. exists
7	Season of Availability	4.702	4	0.319	Not Significant	No association
8	Plank Sizes	5.809	4	0.214	Not Significant	No association

Source: Field Survey, 2025

Conclusion and Recommendation

The study identified key information needs for developing a Timber Marketing Information System (TMIS) in Southwestern Nigeria, with sellers' Contact, timber species, and current prices ranking highest. Timber marketers demonstrate high mobile phone usage and moderate ICT capacity, indicating readiness for system adoption. Socio-demographic factors, particularly Education, significantly influence specific information needs. Overall, a standardized TMIS is essential to improve market transparency, efficiency, and sustainable timber resource management.

It is therefore recommended that a mobile-based TMIS be developed to promote stakeholder collaboration in system design and management, and to enhance capacity building and digital literacy among marketers.

References

Adedokun M.O., Ojo, T.M., Dairo, G.S. 2017. Economic Importance and Marketing of Timber Species in Oyo Town. *International Journal of Scientific & Engineering Research* 8 (11):263-272.

Adekunle, V. A. J., Olagoke, A. O., & Ogunsanwo, O. Y. (2013). Timber utilization and Wood waste generation in Nigeria. *Journal of Forestry Research*, 24(2): 343–351.

Adeoye, A. S., & Oke, O. O. (2019). Accessibility of Non-Timber Forest Products (Medicinal Plants) Collectors of Information and Communication Technologies in Gambari Forest Reserve, Oyo State, Nigeria. *Journal of Research in Forestry, Wildlife and Environment* 11(2): 1–10.

Adeyemo, T. A., & Adetunji, A. I. (2023). Technological advancements and the future of Agricultural Marketing in Nigeria. *African Journal of Agricultural Economics* 50(2): 123-137.

Agwu, M. E., Emeti, C. I., & Ayoade, A. E. (2012). Challenges of marketing Products in Nigeria: A case study of Cross River State. *International Journal of Business and Social Science* 3(17): 192–198.

Ajewole, I.O., and Fashoro. O. 2013. Market and Marketing Information of Bodija Plank Market in Ibadan Metropolis, Ibadan, Oyo State, Nigeria. *Nigerian Journal of Forestry* 43(1): 13-39

Akinbami, C. A. O. (2020). Timber pricing and policy dynamics in Nigeria. *Journal of Sustainable Development in Africa.* 22(4): 1–15.

Akindele, J. A., Oladepo, O. J., & Akano, R. (2022). *Linguistic diversity, Nigerian indigenous Languages and the choice of English for Nigeria's national sustainability.*

Akinyemi, O. T., & Ola, D. A. (2021). Challenges and opportunities in timber marketing In Nigeria: A case study of Southwest Nigeria. *Journal of Forestry Research* 35(1), 15-30.

Alawode, G. L., Jimoh, S. O., Oluwajuwon, T. V., & Daniel, O. I. (2023). Socio-cultural determinants of timber marketing contribution to the income of timber marketers in the Bodija sawn wood market, Ibadan, Nigeria. *Journal of Agriculture and Environment* 19(2): 156-165

Aremu, F.J., Olugbire, O.O., Adebayo, D.A and Apata, O.V. 2015. Socio-economic Characteristics of the Bodija sawnwood market in Ibadan, Oyo State, Nigeria. *Journal of Social Sciences and Public Policy* 7(2): 94-103

Areo, O. S., Omole, A. O., Amoo-Onidundu, O. N., Adejoba, A. L., and Oyewumi, O. R. (2024). Appraisal of women's participation and contributions to wood plank marketing in Nigeria: A review. *Agriculture, Food, and Natural Resources Journal* 3(2): 358–367.

Ayuba, P. A., Ogbodo, E. N., & Isa, H. M. (2013). The economics of timber marketing in Benue State, Nigeria. *Journal of Economics and Sustainable Development* 4(13): 100–106.

Fakorede, O. A. (2020). Market inefficiencies and technological gaps in the timber industry of Nigeria. *African Journal of Forest Economics* 14(4): 65–80.

Falana, A. R., Ojo-Fakuade, F. F., Joseph, A. F., Adelusi, F. T., Oke, O. O., Majolagbe, M.O., and Adesokan, F. B. 2023. Economic Analysis of Sawnwood Marketing in Isokan Local

Government Area, Osun State, Nigeria. *Journal of Applied Sciences and Environmental Management* 27(4): 763-773.

Food and Agriculture Organization of the United Nations (FAO). 2016. *State of the world's forests 2016: Forests and agriculture—Land-use challenges and opportunities*. FAO.

Food and Agriculture Organization of the United Nations (FAO). (2017). *Voluntary guidelines on national forest monitoring systems*. FAO.

Food and Agriculture Organization of the United Nations. (2021). *Increasing legality and transparency in the timber trade*. FAO.

Forest Trends. (2023). *Illegal logging and associated trade: Nigeria country overview*. Forest Trends.

Historical data. (2014). Ondo, NG Climate Zone, Monthly Weather Averages and Historical Data. weatherandclimate.com. Retrieved May, 2024.

Historical data. (2013). Ondo, NG Climate Zone Monthly Weather Averages and Historical Data". tcktcktck.org. Retrieved May, 2024.

Idoko, S. S. (2024). Effects of some demographic attributes of sawn wood marketers on their income in Benue State, Nigeria. *Journal of Research in Forestry, Wildlife and Environment* 16(4): 45–53.

John M. O. Ekundayo. (2013). Out of Africa: Fashola: Reinventing Servant Leadership to Engender Nigeria's Transformation. Author House. p. 135. ISBN 9781481790406.

Mafimisebi, T. E., & Okuneye, P. A. (2014). *Forest resource economics and Management: Issues and approaches*. Springer.

National Results (PDF). (2011). Archived from the original (PDF) on 19 May 2011. Retrieved 2021-12-10.

Nenge, K. (2019). Which is the largest city in Africa: Lagos or Ibadan? Legit.ng

Nwafor, Christopher Ugochukwu, Ogundeji, Abiodun A., and van der Westhuizen, Carlu. (2020). Adoption of ICT-Based Information Sources and Market Participation among Smallholder Livestock Farmers in South Africa. *Agriculture* 10(2): 44

Ogun State, Nigeria, (2021). Encyclopedia Britannica. Retrieved 2021-09-23. Ogun State. Ogun Smart City. Retrieved 2024-05-20

Ogundele, O., & Abiola, S. (2017). Assessing the timber trade in Nigeria: Trends, challenges, and policy issues. *Nigerian Forestry Journal* 40(3): 111-126.

Ogunleye, A. J., & Oladeji, O. A. (2007). Socio-economic implications of lumbering and Marketing of timber products in Nigeria. *Journal of Social Sciences* 15(1): 79–84.

Ogunniyi, A. I., & Oyeleke, O. A. (2016). The Role of Price Information in the Timber Market Efficiency: Evidence from Nigeria. *African Journal of Agricultural Economics* 11(1): 45-54

Ogunwusi, A. A. (2013). *Wood waste generation in the forest industry in Nigeria and prospects for its economic utilization. Civil and Environmental Research* 3(10): 125–134.

Ogunwusi, A. A., and Onwualu, A. P. (2013). Developing the wood and wood products sector for job Creation and wealth generation in Nigeria. *Journal of Research in Industrial Development* 1(1): 2–12.

Sekumade, A. B. and Oluwatayo, I. B. (2011). Economic Analysis of Plank Production in Gbonyin Local Government Area of Ekiti State, Nigeria. *International Journal of Agricultural Economics and Rural Development* 4(1):36-42

Tacconi, L., Cerutti, P. O., Leipold, S., Rodrigues, R. J., Savaresi, A., and To, P. X. (2016). *Deforestation-free supply chains: The role of legality, sustainability, and traceability*. CIFOR.

World Gazetteer: Nigeria administrative divisions (per geographical..." archive.ph. 2013-01-05. Archived from the original on 2023-01-05. Retrieved 2025-12-10.

ISTF-NIG 2026

TROPICAL TREE BREEDING AND GENETIC IMPROVEMENT IN CLIMATE-RESILIENT FORESTRY: A BIBLIOMETRIC ANALYSIS

AWOSAN Elizabeth Adetutu[1,2*] ADIGUN Basit Akolade[2,3], OLOYEDE Olayinka Ezekiel[4], AKALA Abisayo Oluwarotimi[4], DAVID Esther Oluwafunmilayo[4], and AYEBOGUN Oluwatimilehin Harry[5]

[1]Forestry Research Institute of Nigeria, P.M.B. 5054, Jericho Hill, Ibadan, Oyo State, Nigeria.
[2]Faculty of Food Science and Agrotechnology, Universiti Malaysia Terengganu, 21030, Kuala Nerus, Malaysia.
[3]Department of Science and Environmental Studies, The Education University of Hong Kong, Tai Po, New Territories, Hong Kong.
[4]Biotechnology Department, Forestry Research Institute of Nigeria, P.M.B 5054, Dugbe, Ibadan, Nigeria
[5]Department of Chemistry, Federal University of Technology, P.M.B 704, Akure, Ondo State, Nigeria.
Correspondence: funmitutu@yahoo.com; +2348038863870

Abstract

Tropical forests constitute a significant global carbon pool and are increasingly vulnerable to climatic stressors that threaten their long-term stability. Genetic enhancement of tropical trees is a timely approach to increasing adaptive capacity, yield, and carbon retention under climate change. Nevertheless, the conceptual and theoretical evolution of breeding studies of tropical trees in a climate-resilient forestry ecosystem has not been systematically assessed. This study analyses 604 articles on tropical tree breeding and genetic improvement published between 2000 and 2026 and indexed in the Scopus database. The bibliometric records examined using the R package bibliometrix were assessed with respect to publication dynamics, distribution of source geography, a network of co-occurring keywords, and the centrality of the themes. Conceptual structure mapping and thematic analysis were used to identify major, new, and emerging areas of underdeveloped research.Findings indicate a sharp rise in scientific output since 2017, which is linked to the widespread adoption of genomics-based technologies, such as genome-wide association studies, single-nucleotide polymorphism analyses, and breeding prediction models. Co-occurrence network analysis shows that genetics, breeding, and genotype–phenotype integration form the core of the research field, whereas tropical genetic improvement remains central but less tightly clustered. Explicit climate-resilience language is not dominant, suggesting that climate-related goals are often implicitly embedded in genetic improvement studies rather than set out as separate thematic priorities. The results indicate the need for further interconnections among genomic prediction, selection of physiological traits, and multi-environment trials to enhance adaptive breeding approaches in tropical forestry. Enhancing collaboration networks and integrating quantifiable climate change-adaptive bills into breeding schemes will be crucial to achieving climate-resilient tropical forest systems.

Keywords: Tropical tree breeding, Genetic improvement, Climate-resilient forestry, Forest genetics, Genomic selection, Bibliometric analysis

Introduction

Tropical forests are among the greatest terrestrial carbon sinks, which are key to global carbon cycling and climate regulation (Pan et al., 2011). Nevertheless, rising climatic variability (such as extreme temperatures, prolonged droughts, and changes in precipitation regimes) poses significant threats to forest productivity and structure (Allen et al., 2010; IPCC, 2021). To establish a climate-resilient forestry system, the adaptive potential of tropical tree species must be strengthened, as these species harbor vast amounts of genetic variation that underlie breeding and genetic enhancement programs. Genetic diversity also supports the long-term health of the forest, enhances the performance of plantations, and helps conserve forest biodiversity (Oluwajuwon et al., 2022).

The breeding and genetic improvement of forest trees have been improved by the traditional methods of progeny testing and selection to more sophisticated methods based on molecules and genomes, such as marker-assisted and genomic selection, which have the capability of breeding faster and more accurate selection of complex traits like growth and drought resistance (Chakrabarty & Kulheim, 2025). Despite the growing body of literature in forest genetics and tree improvement, research on tropical tree breeding remains fragmented across disciplines, including molecular biology, quantitative genetics, and forest management. This fragmentation limits the development of integrated strategies for advancing climate-resilient forestry systems. Furthermore, although climate change adaptation is increasingly emphasized in forestry research, it remains unclear to what extent climate-resilience concepts are explicitly incorporated into tropical tree breeding studies. Existing reviews have largely focused either on genetic improvement techniques or on broader climate–forest interactions, with limited attention to the intellectual structure, thematic evolution, and research dynamics that specifically link tropical tree breeding with climate-resilient forestry.

Consequently, there is a lack of a comprehensive, systematic synthesis that integrates tropical tree breeding research into a climate-resilient forestry framework. Addressing this gap is essential for understanding how the field has evolved, where its conceptual strengths lie, and which areas require further development to support climate-resilient forestry systems. To address this gap, this study aims to provide a comprehensive bibliometric analysis of tropical tree breeding and genetic improvement research within the context of climate-resilient forestry, mapping the intellectual structure, thematic evolution, and emerging research directions of the field. Bibliometric analysis, which may be defined as the quantitative analysis of the patterns and networks of scientific publications, provides a robust mapping of scientific development, outstanding and emerging research clusters, and the discovery of intellectual frameworks within a field (Aria & Cuccurullo, 2017; Albrecht, 2023).

Based on this, the following study will contribute by analyzing the global publication trends and scientific output from 2000 to 2026, examine the intellectual structure and thematic evolution of the field using keyword co-occurrence and thematic mapping techniques, and identify research gaps and emerging directions for advancing climate-resilient breeding strategies in tropical forestry systems.

Methodology

Data Source and Search Strategy

The Scopus database provides broad coverage of peer-reviewed literature in forestry, plant sciences, and environmental studies. The titles, abstracts, and keywords were searched using a structured query focused on tropical tree breeding and genetic improvement. TITLE-ABS-KEY (("tropical tree*" OR "forest tree*" OR "tropical forestry") AND ("tree breeding" OR "forest tree breeding" OR "genetic improvement" OR "forest genetics" OR "tree improvement") AND ("genetic variation" OR "genomics" OR "genomic selection" OR "GWAS" OR "single nucleotide polymorphism" OR "SNP" OR "molecular breeding")) AND PUBYEAR > 1999 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")).

The initial search had retrieved 968 records. A further filter was applied to the records to show only peer-reviewed journal articles published in English from 2000 to 2026. A final dataset of 604 articles was ultimately retained following the use of document-type and language filters, and non-relevant document categories (e.g., conference abstracts, editorials, notes) were removed to be used in bibliometric analysis. Since a bibliometric mapping method was used to investigate structural patterns in this study, no screening of the full texts was conducted. The database filtering and search strategy were designed to ensure thematic relevance and data set consistency.

Data Export and Processing

Scopus bibliographic data was exported in CSV format, including complete records and reference citations. The dataset included citations, bibliographic metadata, abstracts, authors' keywords, indexed keywords, and reference lists. The data were then imported into the R statistical computing software (RStudio version 2025.09.2+418; Posit Software, PBC) and analyzed using the bibliometrix package (Aria & Cuccurullo, 2017) via its web interface, Biblioshiny. Data cleaning processes were performed to harmonize keywords, standardize author keywords, and eliminate non-informative indexing terms, thereby enhancing the clarity of conceptual networks.

Bibliometric Analysis

Descriptive bibliometric measures were computed, including annual scientific production, source allocation, geographic contribution, and citation metrics. To examine the main, emerging, and weakening research topics, the conceptual structure analysis was based on the keyword co-occurrence network and thematic mapping. Author keywords were used to create co-occurrence networks to reduce indexing noise, and network visualization parameters were set to emphasize central research clusters. Thematic maps were created to determine the density and centrality of the research areas, which allowed subdivision into the motor, basic, emerging, and niche themes. The purpose of the analysis was to uncover the structural patterns, the development of the research, and the strategic gaps in tropical tree breeding research within the larger context of climate-smart forestry.

Results and Discussion

Descriptive background of the dataset.

Based on the Scopus database, 604 peer-reviewed journal articles published from 2000 to 2026 were selected and included in the bibliometric analysis (Figure 1). The number of publications

distributed across 272 scientific sources reflected the interdisciplinary background of tropical tree breeding and genetic improvement. This dataset included 3,143 authors and 12 single-authored documents, which is rather indicative of a collaborative research organization. There were 5,393 in-text citations in the corpus, averaging 22.31 per document, indicating a medium level of impact in the chosen literature. The total annual growth rate was -0.85%, likely due to the latest year not being fully indexed. Publications with international co-authorship went to 35.1 percent, indicating that cross-border collaboration is growing in tropical forestry and genetic improvement studies.



Fig 1. Descriptive statistics of the bibliometric dataset of tropical tree breeding publications (2000–2026).

Annual Scientific Production

The trend in annual scientific production demonstrates the clear progressive development of research on tropical tree breeding throughout the study period. In the early years (2000-2008), the volume of publications was comparatively low and erratic, averaging less than 15 articles annually, and this may be seen as a phase of consolidation in which traditional breeding methods, such as provenance trials and phenotypic selection, were predominant (Fig. 2). Between 2009 and 2016 (Fig. 2), a consistent upward trend indicates that research momentum is increasing and that its methodology is improving. This period has coincided with the growing use of molecular markers, quantitative trait analysis, and enhanced screening of physiological traits, as the focus shifted to molecular-assisted breeding models in tropical species.

After 2017, a strong acceleration is expected, with publication output increasing significantly, peaking in 2024-2025. This growth period correlates with increased global interest in climate change adaptation, forest resilience, and sustainable restoration. The increasing integration of genomics, genome-wide association studies (GWAS), single-nucleotide polymorphism (SNP) analysis, and predictive breeding methods indicates a shift toward genetically based climate-adaptive improvement. The recent all-time high underscores the strategic value of breeding

tropical trees to increase carbon sequestration potential, enhance resilience to abiotic stress, and support sustainable forest management. Such an apparent decrease in 2026 cannot be interpreted as a structural decline in research activity, as it likely reflects incomplete indexing of the previous year rather than a true decline in scientific output (Fig. 2).

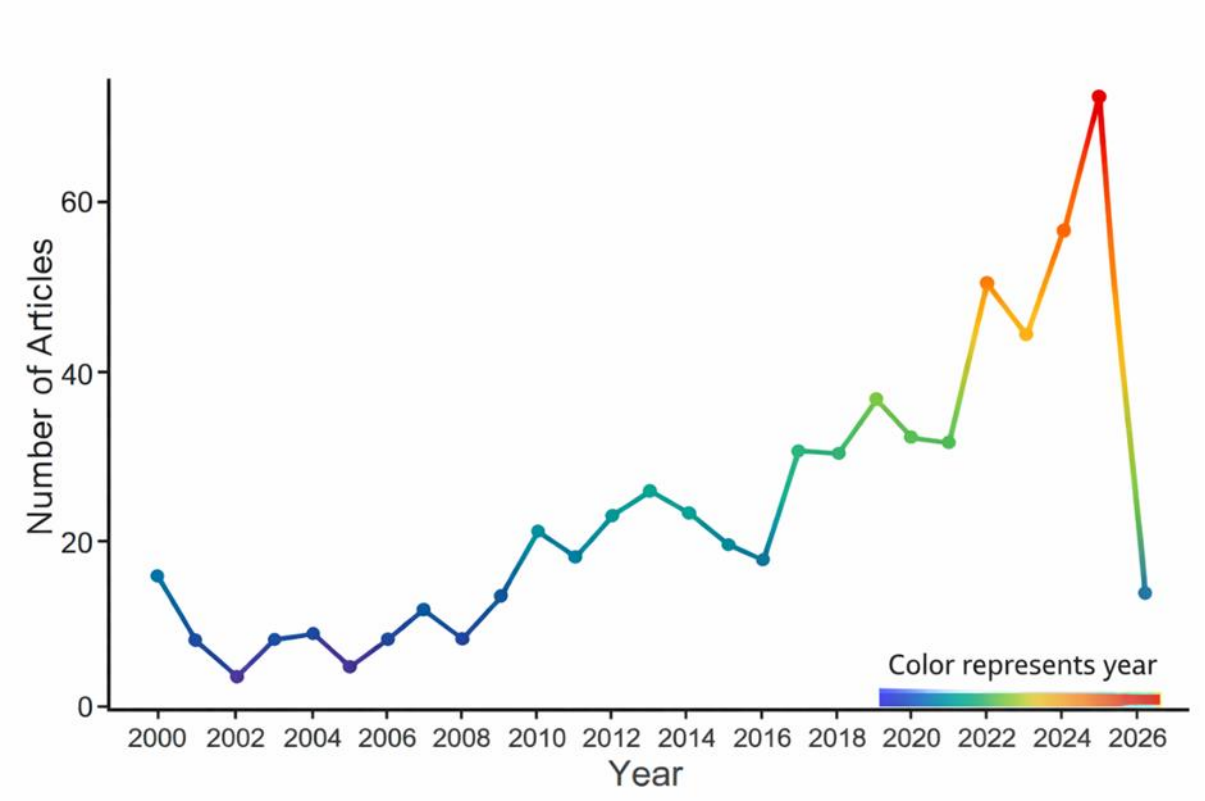


Figure 2. Annual scientific production of tropical tree breeding publications (2000–2026).

Major Journals and Research Sources.

The source distribution analysis shows that research on the breeding and genetic enhancement of tropical trees is focused on high-impact journals in plant science, genetics, and forestry (Fig. 3). Frontiers in Plant Science emerged as the most productive source (n = 25), followed by Euphytica (n = 17), reflecting a strong orientation toward plant breeding and genetic improvement. Journals like BMC Genomics and Genetics, and Molecular Research, which focus on molecular and genomic research, tend to show how well-advanced genomic tools have been embraced in research on tropical forests. The applied aspect of breeding research is displayed in the forestry-related journals such as Forest Ecology and Management. The spread of the 272 sources reflects the interdisciplinary nature of the discipline across plant genetics, quantitative breeding, molecular biology, and climate-responsive forestry (Fig. 3).

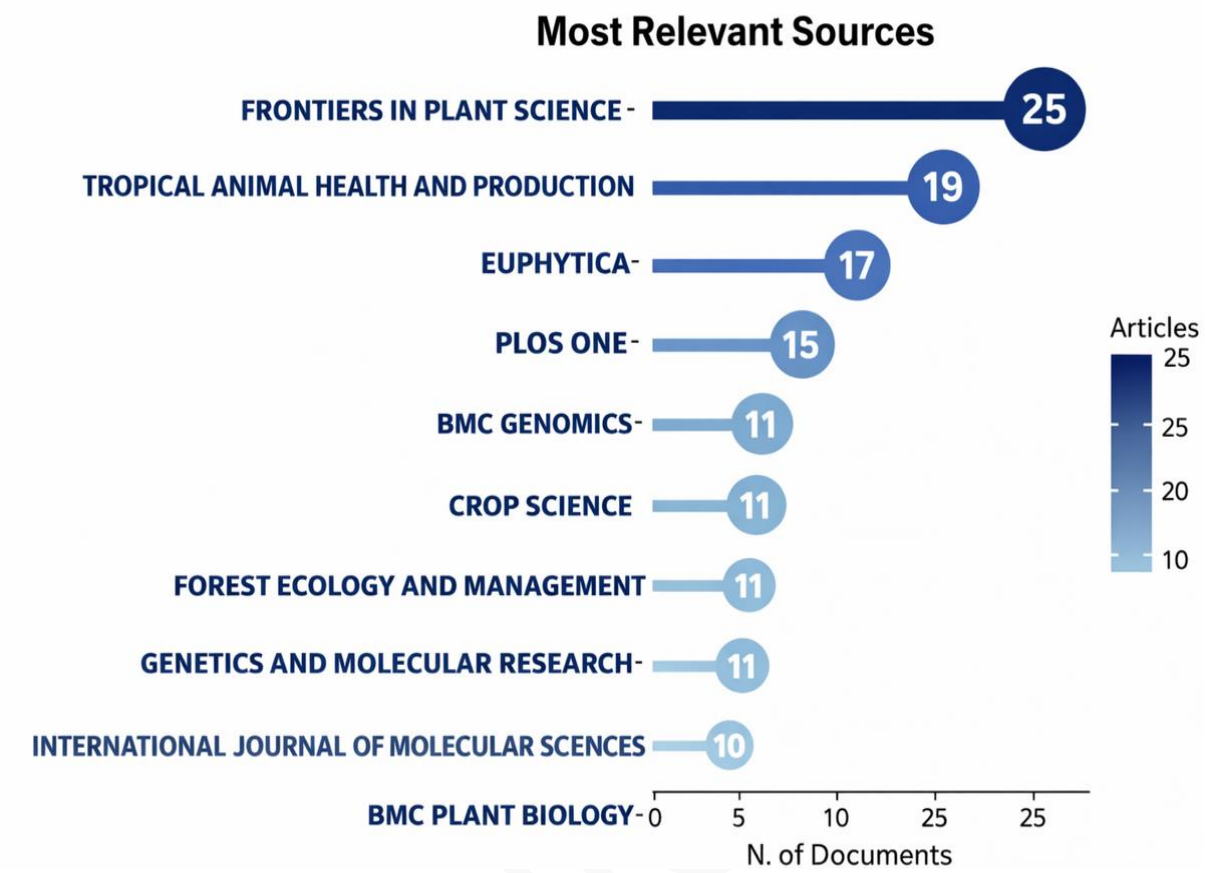


Figure 3. Most productive journals contributing to tropical tree breeding research (2000-2026)

Geographic Distribution of Research.

The scientific production is geographically spread across different continents, as evidenced by the high level of research output in Brazil, China, the United States, India, and Australia (Fig. 4). Brazil became One of the top contributors, which demonstrates the strategic value of tropical forestry in the Amazon ecosystem and its long-term investment in the forest genetic improvement initiatives. Also, China and India are characterized by a high level of research activity, indicating an increasing capacity in breeding and climate-adaptation research on tropical and subtropical trees. The availability of the United States and Australia indicates the incorporation of advanced genomic methods and quantitative breeding techniques into tropical and subtropical forest systems. The 35.1% data on international collaboration indicates moderate but growing international partnerships in the research of tropical tree improvement. Nevertheless, the involvement of several tropical regions, especially Sub-Saharan Africa and Southeast Asia, is relatively low, suggesting the need to strengthen research and capacity-building networks in underrepresented biodiversity-rich areas (Fig. 4).

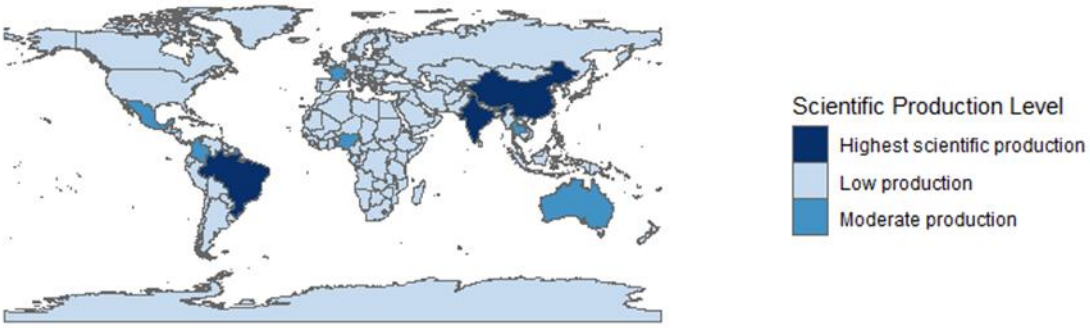


Figure 4. Global distribution of scientific production in tropical tree breeding research (2000–2026).

Keyword Analysis and Research Evolution.

The frequency analysis of the keywords shows that the terms with a genetics-oriented nature dominate strongly, and the most repeated author keywords are the terms of genetics, genetic improvement, breeding, genotype, and genetic variation (Fig. 5). This implies that studies of tropical trees are still essentially rooted in genetic enhancement schemes. The prominence of the term phenotype further underscores that trait-based selection remains relevant in breeding programs.

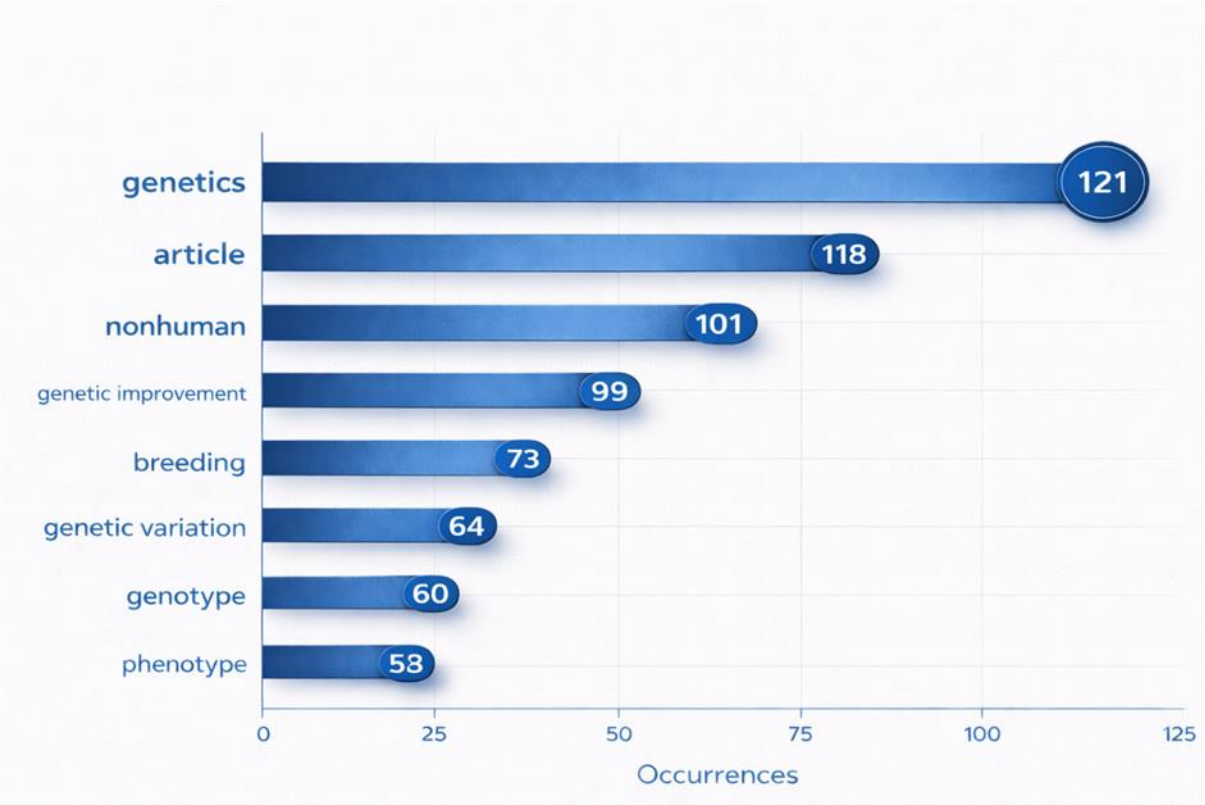


Figure 5: Frequency of the most relevant keywords in tropical tree breeding publications (2000–2026).

The analysis of the keywords over time reveals the evident evolutionary path in the field. Classical breeding concepts such as provenance trials, genetic variance, and phenotypic evaluation dominated early research (2000-2008). Molecular markers and quantitative trait analysis were introduced between 2009 and 2016, leading to a shift to molecular-assisted selection (Fig. 5). More recently (2017-2025), terms related to genomics, such as GWAS, SNPs, predictive breeding, and genotype-phenotype integration, have become prominent. Such a change reflects the growing use of high-throughput genomics and analytical techniques in the breeding of tropical trees. It is interesting that, although terms related to climatic conditions are present in the data, they are not as dominant as core genetic terms, suggesting that the concept of climate-smart framing is implicitly conveyed rather than explicitly expressed in breeding studies.

Conceptual Organizing the Field (Co-occurrence Network).

The co-occurrence network analysis of author keywords shows that three large thematic clusters organize the area of research on tropical tree breeding (Fig. 6). The main and primary cluster is based on the topics of genetic improvement, provenance, heritability, and adaptation, which implies the historical centre of breeding programs of the tropical forestry, which was oriented on the principles of population-based selection and performance trials. The second eminent group focuses on genetics, breeding, genotype, and phenotype, in line with the synthesis of quantitative genetics and ornamental enhancement methods. This cluster shows a strong correlation between phenotypic assessments and genetic parameters in tropical species.

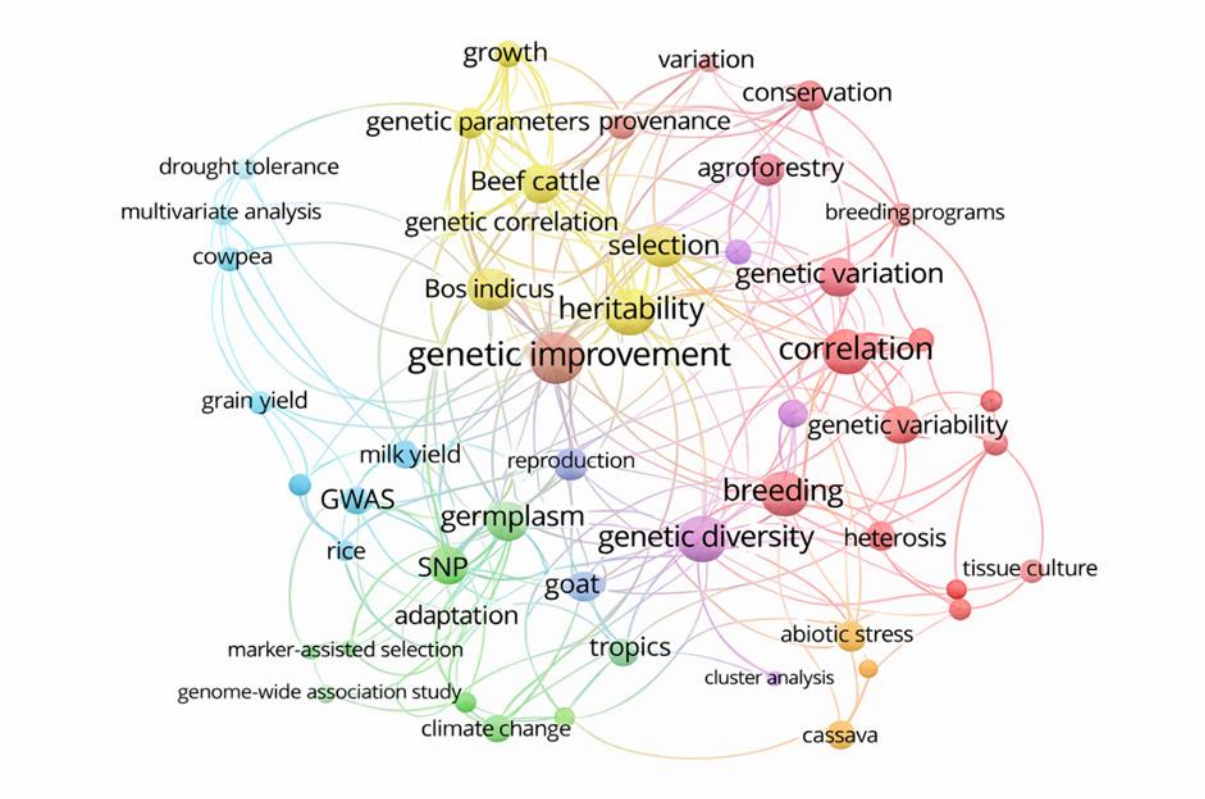


Figure 6. Keyword co-occurrence network illustrating thematic clustering in tropical tree breeding research (2000- 2026)

A third developing cluster comprises terms related to genomics, including GWAS, SNPs, gene expression, and predictive methods, suggesting an increasingly sophisticated approach to molecular breeding and genomic selection systems (Fig. 6). The network organization indicates that, as genomics and molecular technologies are increasingly integrated into tropical tree improvement, some form of thematic fragmentation exists between field-based breeding programs and high-throughput genomic studies. One opportunity to improve climate-smart forestry is to enhance the effectiveness of combining assessments of physiological characteristics with genomic forecasting and climate-resilience goals.

Structure of Author Collaboration

The co-author network of the authors demonstrates that there are two main areas of collaboration, which shows the existence of different research teams in the area (Fig. 7). The biggest cluster, which is around Peng Ming and Wang Wenquan, has good internal connectivity and high collaboration links, which indicate a stable and productive research group. The other team of researchers with relatively low external collaboration is a smaller circle of Xia Zhiqiang, Shi Haitao, and Wei Yunxie. Despite certain inter-cluster ties, cooperation seems to be more focused on institutional or regional clusters than on the entire network.

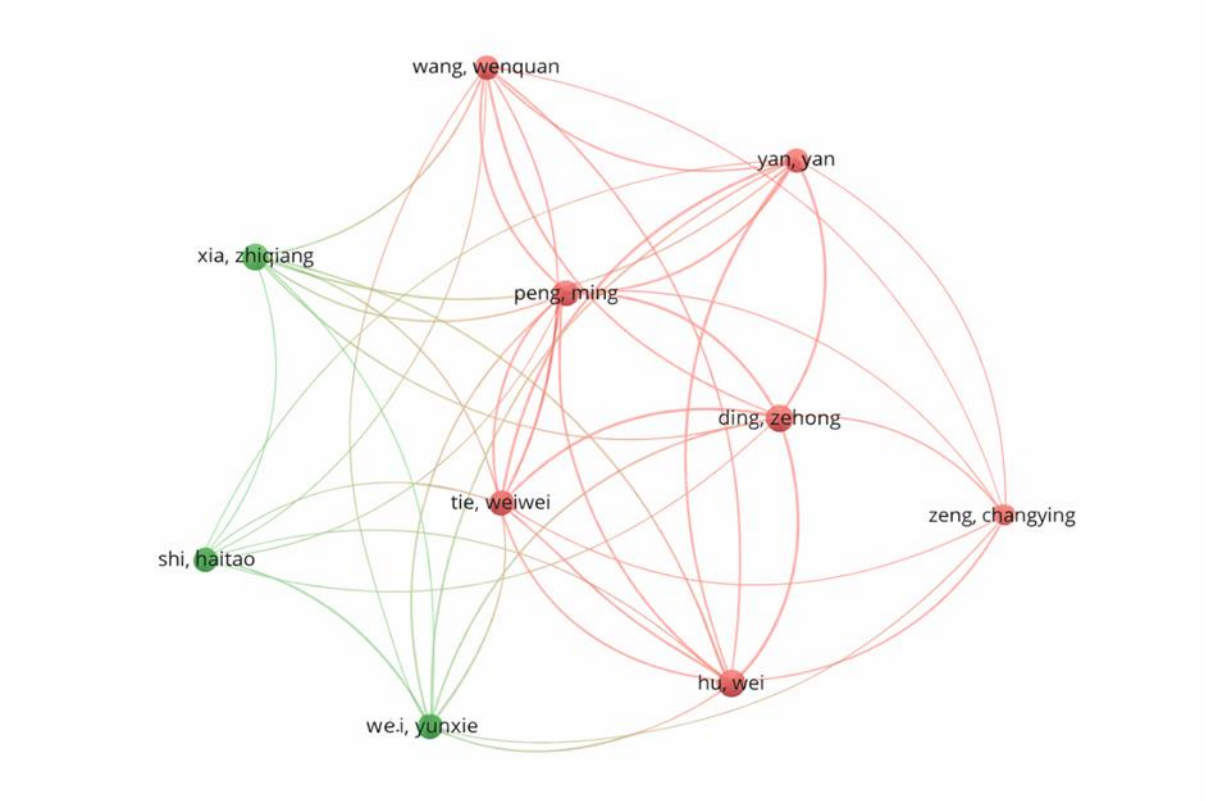


Figure 7. Author co-authorship network in tropical tree breeding research (2000 - 2026)

Thematic Structure and Maturity of Research Domains

The thematic map analysis provides insight into the maturity and centrality of the research themes in tropical tree breeding (Fig.8). The high centrality and high-density quadrant of motor themes is typified by the use of genetics, breeding, and genotype, which in turn suggests that these are the intellectual mainstream pushing the field. Their dense nature indicates high internal development, and their high centrality indicates their strategic value within the larger research system. The basic themes group comprises "genetic improvement," "genetic variation," and "tropics," indicating that the themes are basic and closely linked to other domains of research. However, they remain relatively underdeveloped as coherent, climate-specific research fields. This stance suggests that tropical genetic improvement studies are primary, yet they are maturing in the sophistication of their methodologies and in their integration of themes.

It is interesting to note that no explicit climate-oriented terminology emerges as a dominant motor theme, and climate-smart forestry goals are frequently incorporated into breeding research but not expressed as self-contained thematic drivers. This highlights a critical conceptual loophole: whereas genetic enhancement promotes climate resilience and carbon capture goals, the actual implementation of climate-smart plans in breeding studies remains insufficient in the tropical setting. In general, the conceptual framework appears to be a transition from a traditional quantitative breeding framework to genomics-based, adaptation-focused frameworks. However, it still demands greater incorporation of physiological trait selection and climate-resilience indicators into tropical forestry systems.

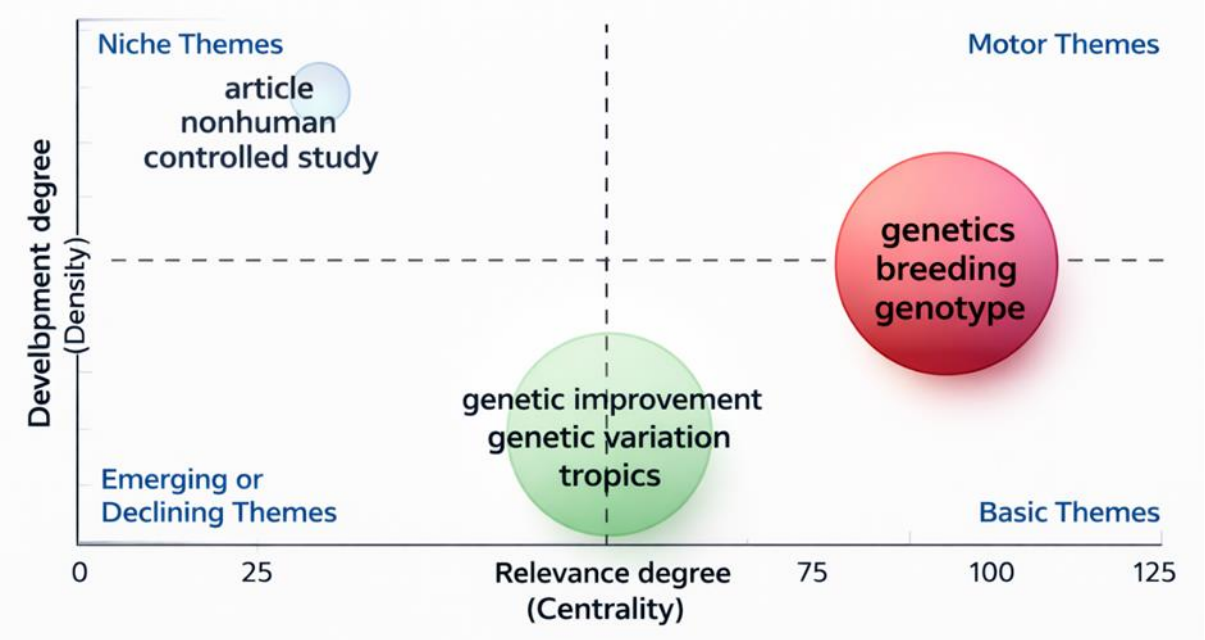


Figure 8. Thematic map showing density and centrality of research domains.

According to this bibliometric analysis, the study of tropical tree breeding has also undergone a clear methodological shift over the last two decades. However, even the overall annual growth rate is slightly negative (-0.85%), which probably indicates indexing lag in the latest year rather than actual shrinkage in research activity. More to the point, the activity in publications has been especially accelerated since 2017, when the world started paying more attention to the issue of climate change and methods of forest adaptation, which is also manifested in the dendrochronological literature on the topic of tree growth reaction to climatic change (IPCC, 2021; Li et al., 2025). The thematic section attests that the field's intellectual core remains based on genetics, breeding, genotype, and genetic improvement. These motor themes indicate the timeless significance of quantitative genetic concepts, such as heritability estimation and genotype-phenotype associations, in long-term forest improvement programs (White et al., 2007; Isik et al., 2017; Ray et al., 2022).

Meanwhile, the growing popularity of genomics-related concepts, such as GWAS and SNP analysis, reflects the widespread adoption of high-throughput molecular technologies (Asif et al., 2025). Genomic selection has been identified as a groundbreaking method that can hasten breeding and enhance the prediction accuracy of complex adaptive traits in perennial species (Resende et al., 2012; Isik et al., 2017; Ray et al., 2022; Sharma et al., 2024). According to the co-occurrence network, though, genomics is becoming increasingly integrated; complete integration of molecular research with field-based climate-adaptive breeding has yet to be achieved. One remarkable discovery is that the explicit terminology of climate resilience does not emerge as a dominant thematic driver. Instead, climate-related goals seem to be incorporated in larger-scale genetic enhancement studies. This implies that breeding programs play a role in indirectly adapting to climate change via productivity and stress tolerance, but quantifiable resilience metrics may not directly capture this. Considering the growing urgency suggested by climate change, the protracted

breeding times of forest trees, and the focus on metrics of adaptation that drought and heat tolerance represent suggested by the IPCC (2021), the adoption of genomic selection and the overt incorporation of climate-resilience criteria into the breeding goals have been suggested as the key tactics to enhance rapid development of stress-resistant genotypes and the ability to align with global climate adaptation frameworks (Sharma et al., 2024; Asif et al., 2025).

Nevertheless, the relative underrepresentation of various tropical regions with biodiversity implies uneven global research coverage. The development of collaborative networks and the integration of genomics into underrepresented areas would enhance global adaptive breeding capacity. Effective application of genomic selection in forest trees also relies on robust phenotyping systems and cost-effective implementation strategies (Sharma et al., 2024), suggesting that infrastructure constraints can partially explain the unequal implementation patterns. In general, the study of tropical tree breeding is in a transitional phase: it is based on a solid quantitative genetic foundation but increasingly uses genomics-based approaches. To develop climate-resilient forestry, a better integration of genomic prediction, physiological trait assessment, and trials across multiple environments will be crucial (Li et al., 2024). Combined with proper phenotyping and economic analysis, genomic selection has been shown to increase genetic gain per unit time and improve breeding efficiency in long-lived trees (Sharma et al., 2024). Integrating specific climate-adaptation indicators into breeding systems and increasing global cooperation will also enhance the role of tropical tree improvement in sustainable forest management and long-term ecosystem stability (Ray et al., 2022).

Conclusion

The given bibliometric analysis provides an overview of global research on tropical tree breeding and physiological traits in the context of climate-smart forestry. The results indicate that the discipline is largely motivated by genetic enhancement and quantitative breeding models, with a shift over the last ten years toward genomics-based and predictive breeding models. Although this has been achieved, there is still limited explicit incorporation of climate-smart forestry terms and indicators of measurable climate resilience. Thematic analysis shows that, whereas the concept of tropical genetic improvement is at the core of the research field, a better balance is needed among genomics, physiological trait assessment, and the climate adaptation agenda. Future climate-resilient tropical forestry will require a combination of genomic transformation and field experimentation, the introduction of physiological performance indicators into the breeding goal, broadening partnerships with underrepresented tropical areas, and the use of predictive analytics and artificial intelligence. On the whole, the process of breeding tropical trees is at a serious crossroads between genetic innovation and climate change. By explicitly orienting breeding programs toward climate-smart goals, they will become more effective in increasing their contribution to carbon sequestration, ecosystem resilience, and sustainable forest management during climate change.

Implications and Future Research Directions.

The results of this bibliometric review also reveal key research gaps and avenues for future research in tropical tree breeding as part of climate-resilient forestry. The bibliometric evidence suggests that breeding studies of tropical trees are increasingly underpinning genomics-based methodologies. However, the combination of physiological trait assessment and extended multi-environment field experiments remains unequal. It will be necessary to strengthen the linkages

among genotypes, phenotypes, and environments to enhance predictive accuracy under climate variability. Even though genetic enhancement is the heart of the subject, the explicit climate-resilience framing has not been as well established, which is why adjustable indicators of adaptation, including drought tolerance, heat resistance, and carbon allocation efficiency, should be formally introduced into breeding programs.

Geographic concentration of research products also reveals differences in global research capacity, especially in areas rich in biodiversity in the tropics. The growth of collaborative networks and genomic infrastructures in low-represented areas would improve adaptive breeding globally. Also, new predictive modeling strategies offer perspectives towards incorporating artificial intelligence, remote sensing, and high-throughput phenotyping into the tropical tree genomic improvement. Altogether, these guidelines remind us of the need to realign genomic innovation, physiological trait integration, and climate-resilient goals to enhance sustainable tropical forestry systems.

References

Allen, C.D., Macalady, A.K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kitzberger, T., Rigling, A., Breshears, D.D., Hogg, E.T., & Gonzalez, P. (2010). A global overview of drought- and heat-induced tree mortality reveals emerging climate-change risks for forests. Forest ecology and management, 259(4), 660–684. https://doi.org/10.1016/j.foreco.2009.09.001

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Asif, M., Raza, Z. H., Munir, A., & Wang, M. (2025). The Role of Bioinformatics in Genetic Improvement and Tree Breeding for Sustainable Forestry. Global Research Repo, 1(2), 56–85. https://doi.org/gjus.2.1.2025.70-100

Chakrabarty, S., & Külheim, C. (2025). Trends in tree improvement methods: from classical breeding to genomic technologies. Tree Genetics and Genomes, 21(3). https://doi.org/10.1007/s11295-025-01698-6

de Medeiros Albrecht, M., & Nayara, F. (2023). Bureaucrats, interest groups, and policymaking: a comprehensive overview from the turn of the century. Humanities and Social Sciences Communications, 10(1), 565. https://doi.org/10.1057/s41599-023-02044-8

Feng, J., Dan, X., Cui, Y., Gong, Y., Peng, M., Sang, Y., Ingvarsson, P. K., & Wang, J. (2024). Integrating evolutionary genomics of forest trees to inform future tree breeding amid rapid climate change. Plant Communications, 5(10), 101044. https://doi.org/10.1016/j.xplc.2024.101044

Li, Q., Li, J., Au, T. F., & Li, T. (2025). From correlation to mechanism: A bibliometric analysis of dendrochronological research evolution on tree growth responses to climate change. Dendrochronologia, 126440. https://doi.org/10.1016/j.dendro.2025.126440

Li, Y., Yuan, Y., Hu, Z., Liu, S., & Zhang, X. (2024). Genetic Transformation of Forest Trees and Its Research Advances in Stress Tolerance. Forests, 15(3), 441. https://doi.org/10.3390/f15030441

Oluwajuwon, T. V., Attafuah, R., Offiah, C. J., & Krabel, D. (2022). Genetic Variation in Tropical Tree Species and Plantations: A Review. Open Journal of Forestry, 12, 350–366. https://doi.org/10.4236/ojf.2022.123019

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G. & Ciais, P. (2011). A large and persistent carbon sink in the world's forests. science, 333(6045), pp.988–993. https://doi.org: 10.1126/science. 1201609

Ray, D., Berlin, M., Alia, R., Sanchez, L., Hynynen, J., González-Martinez, S., & Bastien, C. (2022). Transformative changes in tree breeding for resilient forest restoration. Frontiers in Forests and Global Change, 5, 1005761. https://doi.org/10.3389/ffgc.2022.1005761

Sharma, U., Sankhyan, H.P., Kumari, A. et al. Genomic selection: a revolutionary approach for forest tree improvement in the wake of climate change. Euphytica 220, 9 (2024). https://doi.org/10.1007/s10681-023-03263-5

ISTF-NIG 2026

POTENTIAL IMPACT OF INTEGRATED PEST MANAGEMENT STRATEGIES FOR CONTROLLING INSECT PESTS OF *Balanites aegyptiaca* Linn. AT SEEDLINGS STAGE

Soba T.M[1]., Sani S.M[2]., Ndagi H.I[1], Yusuf A.M.[3], Masok L.J.[4], Mairafi H.H[1]., Umar A.D.[1], Ashe C.B[3], Solomon E.A.[5,] Liman F.M.[1].and Salami K.D.[2]

[1]Department of Forestry, Wildlife and Ecotourism, Nasarawa State University, Keffi, Nigeria
[2]Department of Forestry and Wildlife Management, Federal University Dutse, Nigeria
[3] Department of Forestry Technology, College of Agriculture, Science and Technology, Lafia, Nasarawa State
[4]Department of Geography, Federal College of Education, Odugbo, Benue State, Nigeria
[5] Department of Agriculture Education, Nasarawa State College of Education, Akwanga
Corresponding Email: tukuramohammedsoba@gmail.com +2348062765849

Abstract

Balanites aegyptiaca seedlings are severely damaged by insect pests, reducing establishment and domestication potential. Chemical control is costly and ecologically harmful. This study evaluates integrated pest management (IPM) strategies to identify effective, sustainable, and eco-friendly methods for controlling insect pests at the seedling stage, thereby improving survival and growth and promoting agroforestry adoption in dryland regions. Mature *Balanites aegyptiaca* seeds were collected from Federal University Dutse Campus, viability-tested by water flotation, and air-dried. Seeds were cold-water scarified for 48 hours before sowing at a depth of 2–3 cm in black polythene pots filled with topsoil from the university site. The experiment used a Completely Randomized Design with nine treatments and ten replications. Treatments included biological controls (2% neem and 10% eucalyptus leaf extracts), chemical controls (neonicotinoid, pyrethrins), mechanical controls (net application, crop residue removal), cultural controls (tillage, cover crop) (T9), and a control (T9). Seedlings were watered regularly, weeded, and monitored for pest incidence. Significant differences were observed in plant height and number of leaves among nine treatments, with T4 recording the highest values at approximately 290 cm and 450 leaves, followed by T3 (Application of net; mechanical) T6 (Removal of crop residue; mechanical); T2 (Eucalyptus leave extract; Biological), T7 (Clearing/Tillage; Cultural), and T8 (Planting of cover crop; Cultural) showed moderate growth, while T9 had the lowest performance. In contrast, the number of damaged leaves, the types of insect attack, and the weeks of observation did not vary significantly, indicating that pest incidence was independent of treatment. Among insects, aphids caused the most serious damage at 35%, followed by beetles at 26% and caterpillars at 24%, while mites caused minimal damage at 5%, highlighting the need for targeted IPM strategies. IPM strategies significantly improved *Balanites aegyptiaca* seedling height and leaf growth, though pest damage was unchanged. Aphids caused the most damage. Nursery managers should adopt combined biological, cultural, and mechanical controls, use chemicals only above economic thresholds, and target aphids. Training on IPM is recommended, with further studies on long-term effects across agro-ecological zones.

Keywords: Potential Impact, Integrated Pest Management, Strategies, Insect Pests, *Balanites aegyptiaca* and Seedlings

Introduction

Balanites aegyptiaca Del. (Zygophyllaceae), known as 'desert date,' is a spiny shrub or tree up to 1010 m tall, widely distributed in dryland areas of Africa and South Asia (Wakawa *et al.,* 2018). It is traditionally used to treat various ailments, including jaundice, intestinal worm infection, wounds, malaria, syphilis, epilepsy, dysentery, constipation, diarrhea, hemorrhoids, stomach aches, asthma, and fever (Salami *et al.,* 2024; Lema *et al.,* 2022). It contains protein, lipid, carbohydrate, alkaloid, saponin, flavonoid, and organic acid. (Katerere *et al.,* 2026). It is One of the most common but neglected wild plant species in the drylands of Africa and South Asia. This tree is native to much of Africa and parts of the Middle East. In India, it is particularly found in Rajasthan, Gujarat, Madhya Pradesh, and Deccan. This is One of the most common trees in Senegal. It can be found in many kinds of habitats, tolerating a wide variety of soil types, from sand to heavy clay, and climatic moisture levels (Alkandari *et al.,* 2026)

Balanites aegyptiaca, also known as the Egyptian balsam, is a valuable multipurpose tree species found in arid and semi-arid regions of Africa and Asia. Its fruits, seeds, leaves, and bark have various medicinal and economic uses, making it a vital resource for local communities (Salami *et al.,* 2019). However, the cultivation of *Balanites aegyptiaca* is often hindered by insects that can significantly reduce yield and quality, posing a major challenge to sustainable production (Ibrahim *et al.,* 2026). The tree species is a drought-tolerant, multipurpose tree that holds significant economic and ecological value in arid and semi-arid regions (Medina-Serrano *et al.,* 2026). Existing pest management practices are often reactive, relying on broad-spectrum insecticides, which can lead to environmental pollution and the potential development of resistance in pest populations (Rahman *et al.,* 2026). Moreover, the lack of readily accessible and user-friendly information on pest identification and control methods further complicates effective pest management (Chen *et al.,* 2026)

The decision support system will provide farmers and stakeholders with a comprehensive tool for identifying insect pests, understanding their biology and ecology, and selecting appropriate control strategies based on specific environmental and crop conditions. By incorporating expert knowledge, scientific and decision rules, leading to improved pest control efficacy, reduced pesticide use, and economic returns (Zhao & Li, 2026). Aqueous extracts of fruits showed spermicidal activity without local vaginal irritation in humans, with up to 4% of sperm becoming sluggish on contact with the plant extract and then immobile within 30 s; the Effect was concentration-dependent. Protracted administration of the fruit pulp extract produced hyperglycemia-induced testicular dysfunction in dogs. Seed is used as an expectorant, an antibacterial, and an antifungal. Fruit is used in whooping cough, leucoderma, and other skin diseases. Bark is used as a spasmolytic.

In Senegal, Nigeria, Morocco, and Ethiopia, *B. aegyptiaca* is used as a purgative for colic and stomachache. In Chad, fresh twigs are placed on the fire to keep insects away. For intestinal worms, the fruits are dried and mashed into millet porridge, which is then eaten. In Libya and Eritrea, leaves are used to clean infected wounds. In Sudan and Chad, the bark of *B*. *aegyptiaca* is used to make soap. The use of kernel oil for wound treatment has been reported in Nigeria. For contraception, in Nigeria, a mixture of dried leaf powder of *B. aegyptiaca* and *Ricinus communis* is made in water. In Somalia, the bark and the root are crushed and mixed with two glasses of water, which is then filtered (Cocian & Pocol, 2026). The research focused on the integrated pest

management of *Balanities aegytiaca* at the early stage in view of recommending the best management practice

Materials and Method

Description of the Study Area

The study was carried out at Forestry Nursery of the Department of Forestry and Wildlife Management, Federal University Dutse, Jigawa State. It lies between latitudes 11.00°N and 13.00°N and longitudes 8.00°E and 10.15°E (Gidado *et al.,* 2023). The study area is covered by the Sudan area and characterized by a hot, wet summer and a cool, dry winter, with an average rainfall season of 3-5 months (644 m) (Jigawa State Ministry of Agriculture and Natural Resources, 2016). Sunshine hours indicate that the town receives 10-11 hours of sunshine per day, depending on the season. The topography is characterized by a high land area of almost 750m. Soil tends to be fertile, ranging from sandy loam (Salami & Lawal, 2018). The area's mean annual temperature supports the growth of a variety of plants. The area's relatively uniform climate and soil conditions ensured that the study's results were reliable and applicable to similar agroecological zones. The area's topography is generally flat, with a high point of approximately 750 meters. The soil type in this region is predominantly sandy-loam, as reported in previous studies (Garba *et al*., 2021). This soil type is characterized by a mix of sand, silt, and clay, providing a suitable medium for plant growth

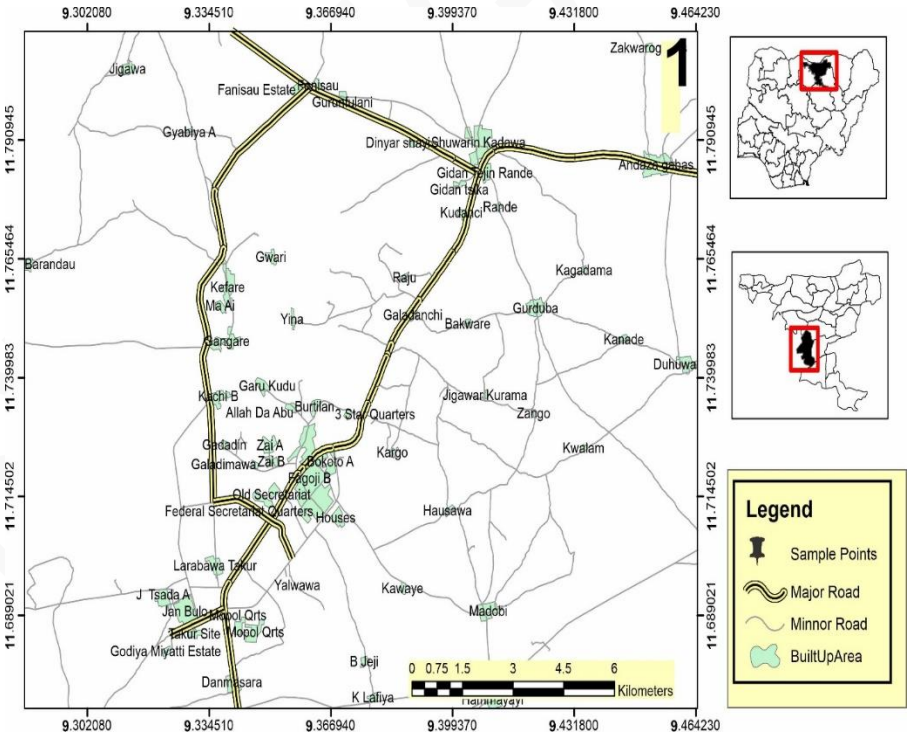


Fig 1: Showing the Map of Dutse Local Government

Source: Salami *et al*., 2023

Data Collection and Procedure

Data collection

Mature seeds of *Balanites aegyptiaca* were collected directly from the tree stand of the mother tree at Federal University Dutse Campus. A seed's viability was tested by placing the seeds in water and separating the floating seeds. Fresh, mature fruits of *Balanites aegyptiaca* were collected and air-dried under normal atmospheric conditions (Salami *et al*., 2019). Cold-water scarification was employed to break the base, as previously reported (Salami *et al*., 2019). The topsoil was collected from Federal University Dutse, Jigawa State. Black polythene pots were collected from the university's nursery.

Procedure

The propagation of Balanites aegyptiaca begins with seed preparation, during which mature fruits are collected, and the seeds are extracted and cleaned to remove any pulp. Prior to sowing, the seeds are soaked in water for 48 hours to soften the seed coat and enhance germination. The treated seeds are then sown directly into a nursery bed at a depth of 2-3 cm. Balanites aegyptiaca can adapt to various soil types but grows best in well-drained soil, and seeds should be spaced appropriately to allow for healthy development. Regular watering is essential, particularly during dry periods, though care must be taken to avoid overwatering. Once seedlings are established, maintenance involves weeding and protecting them from pests and diseases to ensure vigorous growth.

Sampling Design

A Completely Randomized Design (CRD) was applied with nine treatments and ten replications. Treatment 1 and 2 are biological methods (Neem and Eucalyptus leaf extract), Treatment 3 and 4 are chemical methods (Neonicotinoid and Pyrethrins), Treatment 5 and 6 are mechanical methods (Application of net and removal of crop residue), Treatment 7 and 8 are culture methods (Clearing/Tillage and Planting of cover crop) and control, which makes nine treatments.

SN	Method	Treatment code	Treatment	Quantity	References
1	Biological	T1	Neem leaf extract	2%	Tokpah *et al*., 2026
		T2	Eucalyptus leaf extract	10%	Pinto, *et al*., 2026
2	Chemical	T3	Neonicotinoid	Depends on the pest you are trying to control.	Fu *et al*., 2026
		T4	Pyrethrins	Depends on the product formulation.	Basrah, 2023
3	Mechanical	T5	Application of net		Nil Nil

		T6	Removal of crop residue	Nil
4.	Cultural	T7	Clearing/Tillage	Nil
		T8	Planting of cover crop	Nil
5	Control	T9	Control	Nil

Results

The table presents the mean performance of nine treatments (T1–T9) across various growth and pest-related parameters of the plants. The findings revealed that plant height varied significantly across treatments, ranging from 17.50 cm in T9 to 27.58 cm in T4. Treatments T3, T4, and T6 produced taller plants compared to others, and the P-value of 0.000 indicates that the difference was statistically significant ($p< 0.05$). This implies that the treatments had a substantial influence on plant height, with T4 producing the tallest plants. Similarly, the number of leaves differed significantly among treatments, ranging from 23.80 in T9 to 40.20 in T4. Treatments T3, T4, T5, and T6 had higher leaf numbers, suggesting better vegetative growth. The P-value of 0.000 also confirms that the Effect of the treatments on leaf production was statistically significant, with T4 again showing the highest performance.

In contrast, the number of damaged leaves showed little variation across treatments, ranging from 2.50 to 2.70, with a P-value of 0.995, indicating no significant difference ($p > 0.05$). This suggests that the treatments did not have any meaningful impact on reducing or increasing leaf damage, and pest pressure was generally uniform across all treatments. Similarly, the types of insects attacking the plants were not significantly influenced by the treatments, as the mean values ranged from 1.60 to 2.50, and the P-value (0.722) indicated no significant difference. The weeks of observation were the same across all treatments (4.00 ± 0.71), with a P-value of 0.100, confirming no variation among them.

The bar chart in Figure 2 shows the comparative effects of nine treatments (T1–T9) on plant height. Treatment T4 recorded the highest value, reaching nearly 290 units, indicating the greatest positive Effect on the measured parameter. Treatments T3 and T6 also performed strongly, with values above 250, showing good growth response. Treatments T1, T2, T7, and T8 had moderate effects, ranging from 200 to 240 units. Treatment T9 recorded the lowest value (around 180), suggesting it had the least Effect among all treatments.

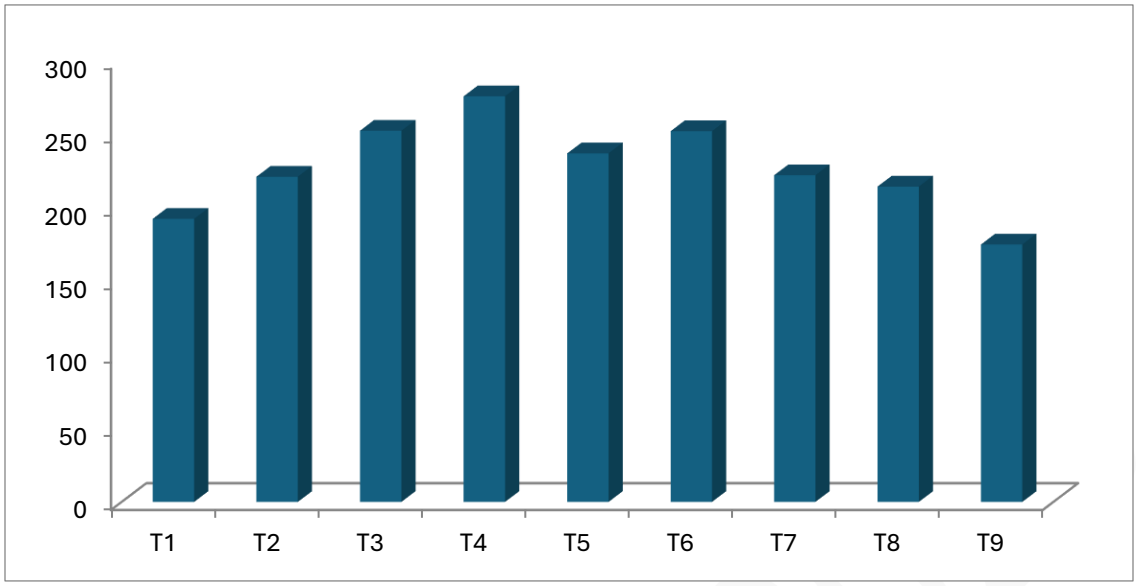


Figure 2: Showing the mean plant height(cm)

The bar chart in Figure 3 shows the Effect of nine treatments (T1–T9) on the number of leaves. Treatment T4 produced the most leaves, reaching about 450, indicating the best vegetative growth among all treatments. Treatments T6 and T5 also recorded relatively high leaf counts (around 380–400), indicating strong plant performance. Treatments T2, T3, T7, and T8 had moderate numbers of leaves (around 300–330). Treatment T9 had the fewest leaves (about 240–250), suggesting poor growth.

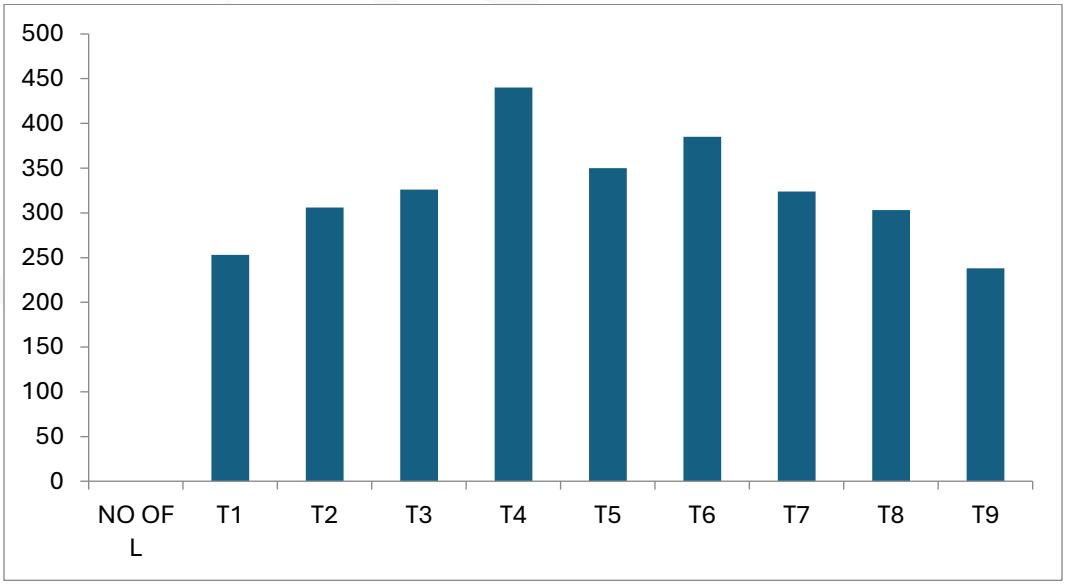


Figure 3: Showing the mean number of leaves

Table 1: Effect of various pest control methods for *Balanites aegyptiaca.*

Parameter	T1	T2	T3	T4	T5	T6	T7	T8	T9	PV
Plant height (cm)	19.25± 0.25 ^{e}	22.11± 0.27 ^{d}	25.24± 0.27 ^{b}	27.58±0.47^{a}	23.70±0.37 ^{c}	25.21±0.42 ^{b}	22.21±0.34 ^{d}	21.44±0.42 ^{d}	17.50±0.17 ^{f}	0.000
No. of Leave (cm)	25.30±0.59 ^{e}	30.60±0.75 ^{d}	36.40±0.56 ^{c}	40.20±0.84 ^{a}	35.00±0.94 ^{c}	38.50±0.96 ^{ab}	32.40±1.01 ^{d}	30.30±1.06 ^{d}	23.80±0.61 ^{e}	0.000
Damaged Leave	2.50±0.17 ^{b}	2.50±0.16 ^{b}	2.50±0.17 ^{b}	2.50±0.16 ^{b}	2.50±0.17 ^{b}	2.51±0.16 ^{b}	2.50±0.16 ^{b}	2.52±0.53^{b}	2.70±0.15^{a}	0.995
Types of insects attacked	1.60±0.27^{c}	1.80±0.29^{c}	2.50±0.43 ^{a}	2.20±0.42 ^{b}	2.30±0.40 ^{b}	2.50±0.43 ^{a}	2.30±0.40 ^{b}	2.20±0.42 ^{b}	1.90±0.38^{ab}	0.722

a,b,c mean in the same row with different superscripts are significant at ($p<0.001$)

ISTF-NIG 2026

The bar chart titled "Insect Damaged" shows the extent of damage caused by different types of insects: aphids, beetles, mites, and caterpillars. Among these, aphids caused the most damage, with a value of 35, indicating they are the most destructive insect in this group. Beetles follow with a damage level of 26, while caterpillars caused slightly less damage at 24. The mites caused the least damage, registering only 5. Overall, the chart suggests that aphids are the primary contributors to insect damage, while mites have a minimal impact compared to the other insects.

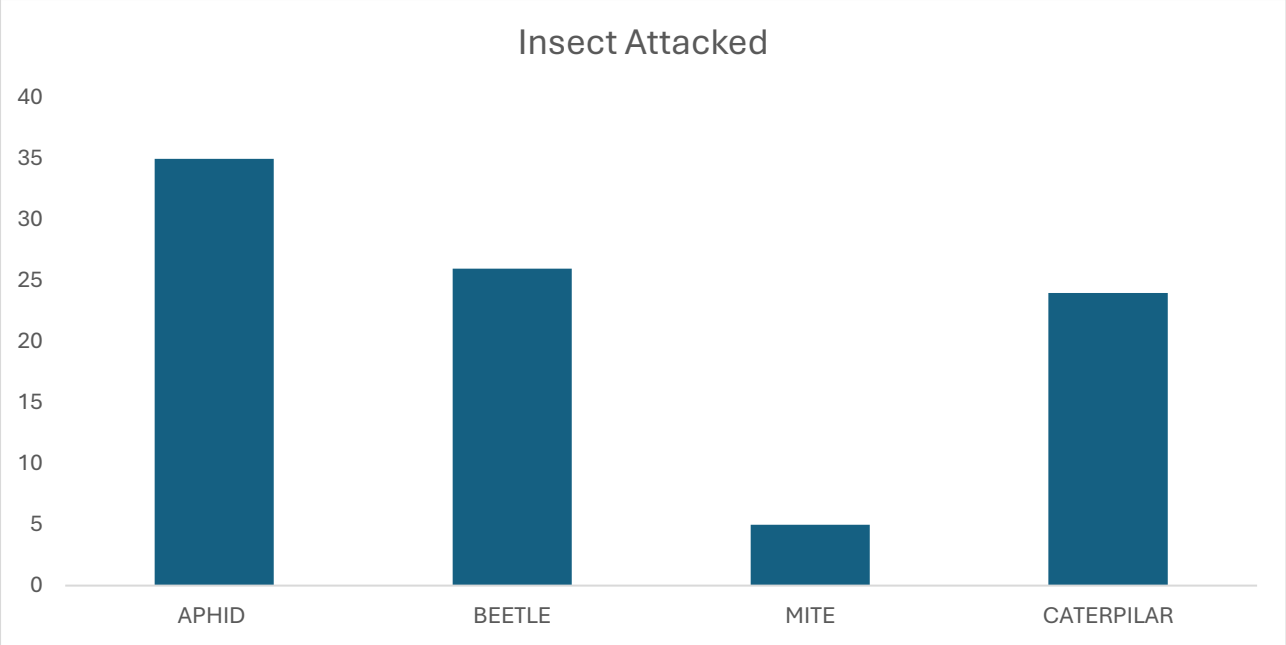


Figure 4: Showing the mean number of insects attacked

Discussion on the Effect of Various Pest Control Methods of *Balanites aegyptiaca*

The results of this study revealed significant differences in plant height and leaf number among treatments. In contrast, the number of damaged leaves, types of insect attack, and weeks of observation showed no significant variation. The observed differences in growth parameters (plant height and leaf number) indicate that the treatments had a positive effect on vegetative growth. Specifically, treatments T3, T4, and T6 produced taller plants and more leaves, with T4 showing the highest performance. The significant increase in growth under T4 could be attributed to its enhanced nutrient composition, better soil conditioning, and improved moisture retention, which collectively promote vigorous vegetative development. According to Adebayo *et al*. (2020), plant growth and leaf formation are directly influenced by the availability of essential nutrients, particularly nitrogen and phosphorus, which stimulate cell elongation and chlorophyll synthesis. Similarly, Usman *et al*. (2021) reported that treatments improving soil structure and root development significantly enhance plant height and leaf number. This aligns with the present findings, where treatments presumed to improve soil fertility (such as T4) resulted in better growth performance. The observation is also consistent with the work of Aliyu and Abubakar (2022), who found that nutrient-enriched treatments significantly increased the growth rate of *Balanites aegyptiaca* seedlings under field conditions.

In contrast, the number of damaged leaves and types of insect attacks did not vary significantly among treatments, suggesting that the treatments had little or no effect on pest incidence or insect diversity. This implies that the factors influencing plant damage were more likely related to external pest pressure rather than treatment composition. Olayemi and Mohammed (2021) reported similar findings in their study on pest impact on crop leaves, where variations in fertilizer and soil treatments had minimal influence on pest damage levels. Likewise, Ibrahim *et al.* (2020) emphasized that pest population dynamics are largely dependent on climatic conditions, crop variety, and field sanitation rather than growth-enhancing treatments. Therefore, the uniformity in leaf damage across treatments suggests that pest pressure was evenly distributed and not treatment-dependent.

Furthermore, the non-significant difference observed in the weeks of observation confirms that all treatments were assessed over the same time frame, ensuring uniformity in data collection. The consistency across the observation period validates the reliability of the experimental design. The study demonstrated that while the treatments substantially improved vegetative growth parameters, such as plant height and leaf number, they did not affect pest-related variables. This indicates that growth-promoting treatments alone may not provide pest control benefits. Hence, integrating effective treatments, such as T4, with appropriate pest management strategies could further enhance plant growth and resistance to insect damage. This finding supports the conclusion of Ndungu *et al.* (2026) that integrated soil fertility management combined with pest control practices yields better plant performance than single-treatment applications. The chart shows that different insect species cause varying degrees of crop damage. Among the four insects observed, aphids caused the greatest damage (35%), suggesting a significant impact on plant health and productivity. Aphids feed on plant sap, which can reduce growth and transmit viral diseases, ultimately lowering yield quality (Blackman & Eastop, 2023). Beetles and caterpillars also caused considerable damage, with 26% and 24% respectively, likely due to their chewing feeding habits that destroy leaf tissue and reduce photosynthetic capacity. On the other hand, mites caused the least damage (5%), indicating that their population or feeding behaviour may be less aggressive under the conditions of the study. These findings emphasize the importance of integrated pest management (IPM) strategies to control high-impact pests, such as aphids and beetles, and minimize crop loss while maintaining sustainable agricultural production.

Conclusion

The results of this study underscore the effectiveness of Integrated Pest Management (IPM) strategies in improving the growth and resilience of *Balanites aegyptiaca* seedlings. The combined use of biological, chemical, and mechanical approaches resulted in significant improvements in plant height and leaf development compared with untreated controls. Although pest diversity and damage levels were not markedly reduced, the improved plant vigor suggests that IPM strategies strengthen seedling tolerance to pest attacks. Aphids emerged as the most destructive pest, underscoring the need for targeted control measures against sap-sucking insects. Integrating preventive cultural practices with selective biological or chemical control measures provides an environmentally friendly and sustainable approach to pest management in *B. aegyptiaca* nurseries. Therefore, adopting IPM is essential for sustainable tree cultivation, improved seedling survival, and environmental protection.

Recommendations

Based on the findings of this research, it is recommended that nursery managers and farmers adopt integrated pest management approaches that combine biological, cultural, and

mechanical control methods to suppress pests effectively with minimal environmental impact. Given that aphids are the most damaging pests, specific monitoring and control programs should be implemented to manage their populations. Chemical pesticides such as pyrethrins and neonicotinoids should be applied only when pest populations exceed economic thresholds to prevent resistance buildup and protect beneficial organisms. Furthermore, extension agents and research institutions should organize regular training programs for farmers on IPM techniques, pest identification, and nursery sanitation to promote sustainable pest management practices. Finally, future studies should focus on the long-term effects of different IPM components on pest population dynamics and on the growth performance of B. aegyptiaca across diverse agroecological conditions.

References

Adebayo, O. S., Yusuf, A. M. & Haruna, M. A. (2020). Effect of nutrient composition on the vegetative growth of selected arid zone crops in northern Nigeria. *Nigerian Journal of Agronomy*, 37(1), 45–53.

Aliyu, M. A., & Abubakar, L. S. (2022). Response of Balanites aegyptiaca seedlings to organic and inorganic soil amendments under field conditions. *Savanna Journal of Agriculture,* 18(3), 212–220.

Alkandari, A. J., Alsayegh, M. A., & Abdulraheem, A. A. (2026). Climate Change-Induced Variation in Ecosystem Structure in Arid Lands Countries. In *Fostering Arid Lands Agriculture in the Face of Climate Change: Mitigation and Adaptation Synergy* (pp. 339–367). Cham: Springer Nature Switzerland.

Basrah J. (2023). Spraying Technology and Foliar Application Result in a Smooth Layer of the Spray: a Literature Review. Agric. Sci., Basrah *Journal of Agricultural Sciences E-*ISSN: 2520-0860 Majid H. R. Alheidary. 36(2), 334–374, 2023

Blackman, R. L., & Eastop, V. F. (2023). *Aphids on the world's crops: An identification and information guide* (3rd ed.). Wiley-Blackwell.

Chen, T., Wang, Y., Dang, J., Zhang, F., & Wang, C. (2026). Detection technologies and sensing systems for crop pest identification and infestation severity prediction: a review—*Frontiers in Plant Science*, *17*, 1765363.

Fu, H., Qiu, T., Bao, S., Jiang, Y., Lu, Y. & Shi, X. (2026). High-throughput analytical method for simultaneous detection of pest control agents and specific metabolites in human urine. *Microchemical Journal*, 117402.

Ndungu, S. M., Kesamreddy, L., Ayenan, M. A., Othim, S., Mkuhlani, S., Liu, Y. H. & Pawera, L. (2026). Agronomic practices for climate-resilient okra production in agroecological systems: a review—*Frontiers in Agronomy*, *8*, 1771721.

Garba, A., Salami, K. D., & Akanbi, W. B. (2021). Assessment of Endangered Economic Tree Species and Conservation Techniques in Jigawa State, FUDMA *Journal of Agriculture and Agricultural Technology*, Vol. 7(2), 116-123

Gidado, H. A., Salami, K. D., Kareem, A. A., Jibo, A. U., Adam Fatima, & Oginni, D. O. (2023). Effect of frequencies of watering and water volumes on the growth performance of *Adansonia digitata* (Linn) Seedlings. *Australian Journal of Science and Technology* ISSN Number (2208–6404) Volume 7, Issue 1, March 2023 Australian

Ibrahim, M. T., Bala, A. G. & Tanko, H. S. (2020). Influence of climatic variables and management practices on pest population dynamics of arid crops. *African Journal of Environmental Research,* 14(4), 98–108.

Ibrahim, N. A., Rathore, D., Janiyani, K., Gupta, A., Sulieman, A. M. E., Tahir, H. E., & Surti, M. (2026). A comprehensive review on plant-derived bioactive saponins as promising antimicrobial agents: from bioavailability challenges, molecular mechanistic insights to

therapeutic applications. *Naunyn-Schmiedeberg's Archives of Pharmacology*, *399*(2), 1657–1687.

Katerere, D. R., Brendler, T., Feiter, U., Mahomoodally, M. F., & Phillips, L. D. (Eds.). (2026). *African Herbal Pharmacopoeia*. CRC Press.

Lema, A., Bangou, M. J., Sawadogo, M., Thiombiano, H. M., & Ouoba, H. Y. (2022). Medicinal plant recipes used in the management of peptic ulcers in Burkina Faso: Ethnobotanical study. *Int. J. Sci. Res. Arch*, *6*, 263–278.

Medina-Serrano, N., Bagnères, A. G., Ndiaye, M. M., Vrecko, V., McKey, D., & Hossaert-McKey, M. (2026). Seasonal variation in insect assemblages at flowers of Balanites aegyptiaca, an ecologically and socially important tree species in the Ferlo region of Senegal's Great Green Wall corridor. *Peer Community Journal*, *6*.

Olayemi, K. D. & Mohammed, R. U. (2021). Impact of fertilizer and soil treatments on insect pest damage in field crops. *Journal of Agricultural and Biological Sciences*, 15(2), 76–85.

Pinto, M., Soares, C., Nadais, P., Valente, I. M., Tavares, F. and Fidalgo, F. (2026). Eucalyptus leaf aqueous extract–a promising biopesticide for managing bacterial spot disease in tomato plants. *Pest Management Science*, *82*(3), 2387-2401.\

Rahman, M. T., Bakibillah, A. S. M., Hossain, A., Ahasan, A., Basher, M. N., Oyshe, K. U., & Mariam, A. (2026). The Role of AI-Integrated Drone Systems in Agricultural Productivity and Sustainable Pest Management. *Agric Engineering*, *8*(4), 142

Salami K. D., Adeniyi, K. A., Abdullahi, A. Y., Moshood, F. J. & Kankomi, D. A. (2024). Morphological Responses of *Balanities eagyptica* (Linnaeus) Del. Seedlings: Unveiling: The Interplay Between Physical Factors and Seedlings Architecture *FUDMA Journal of Agriculture and Agricultural Technology* 10 (2):40-47

Salami, K. D., and Lawal, A. A (2018). Tree Species Diversity and Composition in the Orchard of Federal University Dutse, Jigawa State. *Journal of Forestry Research and Managemen*t. ISSN 0189-8418, www.jfrm.org.ng,Vol 15(2):112-122

Salami, K. D., Bellu, Z., Jibo, A. U., & Nazil, A. (2020). Influence of Different Mulching Materials on Growth of *Adansonia Digitata* Linneous Seedlings. NL *Journal of Agriculture and Biotechnology Volume* 3 Issue 2 April 2026

Salami, K. D., Odewale, M. A., Gidado, A. H., & Adam, Z. A (2019). Pre-germination Treatments on Seeds of *Balanites aegyptiaca* (L) Delile and Influence of Potting Mixtures on the Early Growth. *Journal of Forestry Research and Management.* Vol. 16(1).107-117; 2019, ISSN 0189-8418. www.Jfrm.org.ng IBADAN\

Salami K. D., Alao, J. S. Abubakar, U., & Fatima Adam (2023). Ethno-botanical Survey of Plants Applied for the Treatment of Sexually Transmitted Diseases in the Sudan Savannah Region of Nigeria. *Journal of Advances in Biology & Biotechnology* 25(11-12) :55-63.

Tokpah, D. P., Isbilen, O., & Mahari, A. (2026). Evaluation of bio extracts and potential antagonistic bacterial isolates to control fall armyworm (Spodoptera frugiperda) on Maize—*Journal of Plant Diseases and Protection*, *133*(3), 63.

Usman, A. Y., Garba, M. S. & Idris, N. A. (2021). *Effect of soil amendments on plant height, leaf number, and biomass of selected cereal crops in semi-arid regions.* International *Journal of Agricultural Research and Development*, 10(1), 33–42.

Wakawa, A. I., Sambo, A. B. & Yusuf, S. (2018). Phytochemistry and proximate composition of root, stem bark, leaf and fruit of desert date, Balanites aegyptiaca. *J. Phytopharmacol*, *7*(6), 464–470.

Zhao, Y., & Li, C. (2026). The application progress and development trends of artificial intelligence technology in crop variety improvement and yield enhancement. *Advances in Resources Research*, *6*(2), 1230-1248.

POSSIBLE APPLICATION OF SECONDARY RECOVERED WOOD FOR THE MANUFACTURING OF SPACE MANAGEMENT ENHANCEMENT HOUSEWARE

***Ugbong, Emmanuel Akomaye**

Department of Wood Products Engineering, University of Cross River State, Calabar, Nigeria
*Correspondence Email: *Ugbongemmanuel3333@gmail.com*

Abstract

This study investigates the possible application of secondary recovered wood for the manufacturing of space management enhancement housewares, specifically a dual-purpose chair-to-ladder model. The use of recovered wood aligns with sustainable material utilization, waste reduction, and innovative household solutions for limited spaces. Experimental analyses were conducted to assess the material's performance in terms of moisture content, load-bearing capacity, dimensional accuracy, and user feedback on functionality, Stability, comfort, and design appeal. Results showed that the test wood samples maintained a moisture content of 16%, which falls within acceptable ranges for structural applications. The chair configuration supported loads between 59.62 kg and 85.23 kg, while the ladder configuration held between 65.35 kg and 90.25 kg, demonstrating reliable strength. Dimensional checks confirmed a precise length of 900 mm, ensuring design accuracy. User evaluation revealed high acceptance: 84% affirmed functionality, 88% rated stability as stable or very stable, and 84% rated comfort from comfortable to very comfortable. The design appeal was also positively rated, though 76% of respondents provided modification suggestions. The findings confirm that secondary recovered wood is suitable for multifunctional house, warehouse, and household ware production, with potential to improve urban living through compact, durable, and sustainable furniture designs.

Keywords: Recovered, Wood, Manufacturing, Houseware

Introduction

In recent years, global attention has increasingly focused on sustainable practices in material sourcing and product development. Among these, the reuse and recycling of wood, specifically secondary recovered wood, have gained momentum due to growing environmental concerns, depletion of forest resources, and the rising cost of virgin wood (*Dahiya et al., 2020b*). Secondary recovered wood refers to timber reclaimed from post-consumer or post-industrial sources such as old furniture, demolished buildings, or manufacturing scraps, which is then repurposed for new uses (Architecture Digest, 2021, Bofylatos *et al., 2017a*; Bofylatos *et al., 2017b*). At the same time, the issue of space management in modern housing, especially in urban settings, has become critical. With the surge in urban population and reduced living spaces, there is an increasing demand for furniture and household items that not only serve their functional purpose but also enhance spatial efficiency (Lee & Lee, 2021; Amigo, 2007). This has led to a rising interest in multifunctional, foldable, stackable, and modular furniture systems. The intersection of these two trends, sustainable material usage and space-conscious design, presents an opportunity to innovate within the houseware industry. According to *Olufemi et al.* (2024), recovered wood, with its unique aesthetic, durability, and eco-friendliness, can be engineered into furniture that effectively manages space, especially in compact living environments. By leveraging design thinking and eco-conscious material

selection, manufacturers and designers can offer products that align with the principles of sustainability and functional design (Fuad-Luke, 2019 and Bessuau *et al., 2020*).

Moreover, the use of secondary recovered wood in the development of foldable furniture, such as tables and chairs, can provide a viable solution for maximizing spatial flexibility. Foldable wooden furniture made from reclaimed materials combines sustainability with practicality, allowing users to optimize space without compromising on strength or visual appeal. Based on this, Zhang and Liu (2023) argue that these furniture pieces can be easily stored or reconfigured to meet the spatial needs of different settings, making them ideal for small apartments, offices, and dynamic living spaces. This dual emphasis on sustainability and adaptability makes foldable wooden furniture an important focus for both designers and researchers interested in sustainable houseware innovation (Hernandez *et al.*, 2021). Dahiya *et al.* (2020a) commend that despite the abundance of wood waste generated globally, much of it is discarded or burned, contributing to environmental degradation, pollution and dirt. At the same time, the production of housewares and furniture continues to rely heavily on virgin timber and structural wood, which exacerbates deforestation and resource depletion (European Environment Agency, 2018). Additionally, urban dwellers face the ongoing challenge of maximizing limited living spaces, often resulting in cluttered or inefficient home layouts.

In respect to Nyemba *et al.* (2018), they observed that current household solutions often fail to integrate sustainable materials and efficient space-saving features, creating a gap between environmental responsibility, practical home living, and eco-friendly values. This research addresses the problem of underutilized recovered wood and its potential role in manufacturing eco-friendly, space-optimizing and enhancing houseware products. This research holds significance on multiple fronts. Environmentally, it reduces wood waste by promoting the reuse of secondary materials, aligning with circular economy principles. Socially, it supports urban households by providing practical solutions to space constraints. For the wood product engineering and furniture manufacturing industries, this study offers insights into sustainable design practices and material innovation. Furthermore, the research could influence policies on waste management and sustainable product design, and it could inspire local artisans, startups, and entrepreneurs to consider recovered wood as a viable material for eco-conscious production. This study addresses the dual challenges of environmental degradation caused by wood waste and the lack of efficient, space-saving furniture solutions in urban homes. By focusing on foldable tables made from recovered wood, the study presents an innovative approach that addresses both sustainability and practical living needs. The research fills a gap in existing literature and practice by demonstrating the functional and aesthetic potential of secondary recovered wood in houseware applications.

Materials and Method

Research Design

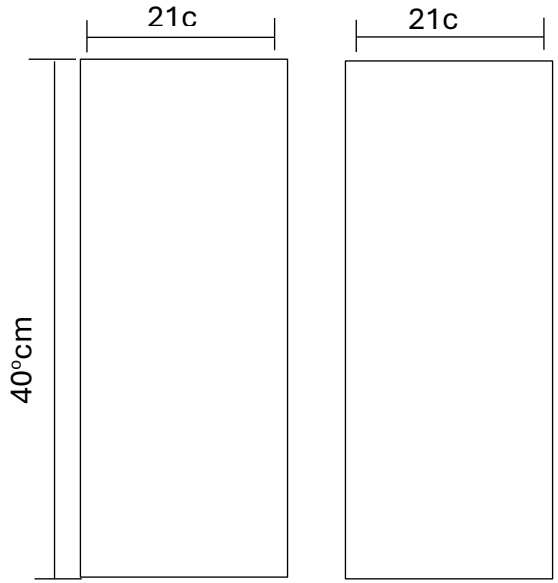
This study adopts a prototype-based experimental research design to develop and assess the functionality, durability, and sustainability of a single foldable chair-to-ladder unit constructed from secondary recovered wood. The design strategy was selected to align with time constraints and material availability, while still ensuring the production of meaningful data that reflects the practical viability of reclaimed wood for compact, multifunctional furniture.

The research is structured in three sequential and interrelated phases:

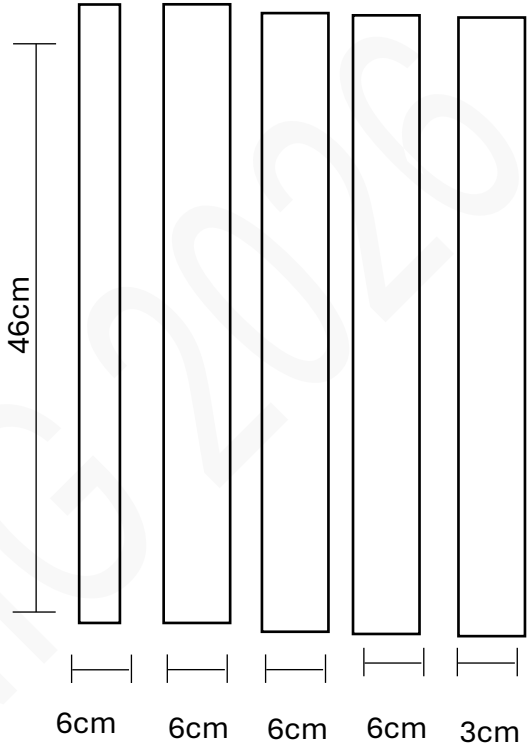
1. **Material Characterization Phase** – This initial phase involved sourcing and selecting appropriate reclaimed wood materials. The materials were subjected to basic physical inspection for moisture content, structural defects, grain direction, and overall integrity. Only samples that met the selection criteria (moisture content ≤15%, absence of warping or decay, and adequate strength) were processed for use.
2. **Prototype Design and Construction Phase** – In this stage, the conceptual design was modeled in SketchUp, enabling accurate virtual visualization, dimensioning, and motion simulation of the convertible unit. Once validated, the digital design was translated into a physical prototype using manual fabrication techniques such as measuring, sawing, drilling, joinery, and hinge installation, as shown in the transition structures below:

ISTF-NIG 2026

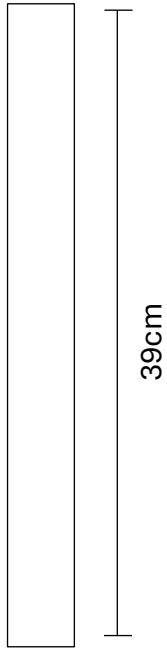
CHAIR CONFIGURATION STRUCTURES



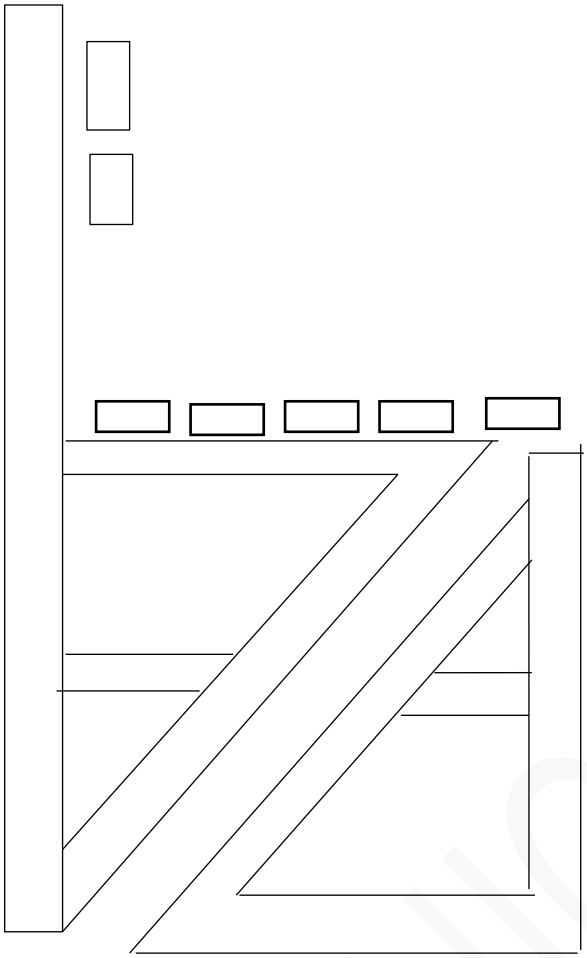
2 Pieces



4 Pieces

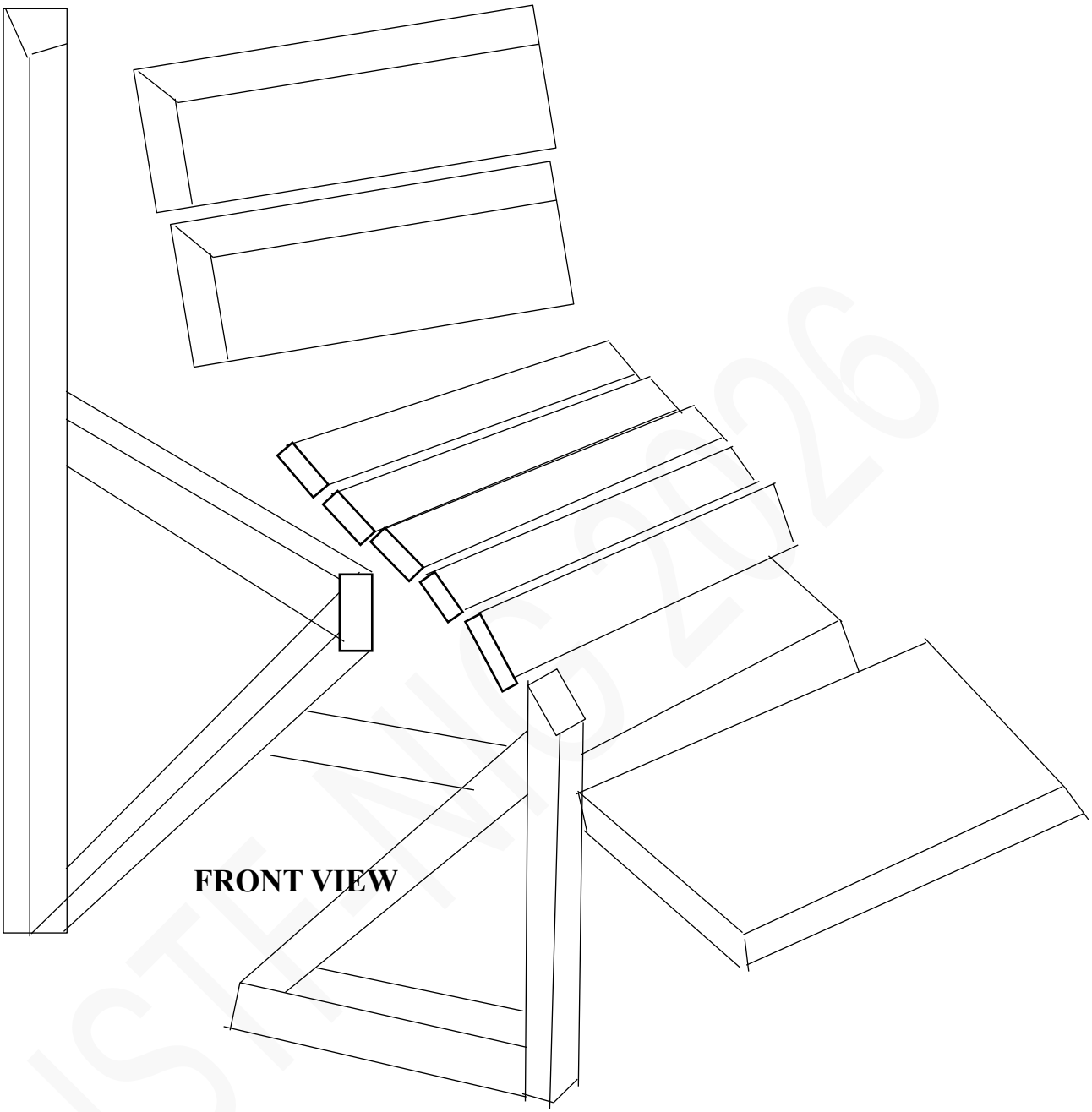


ISTF-NIG2026



Side view

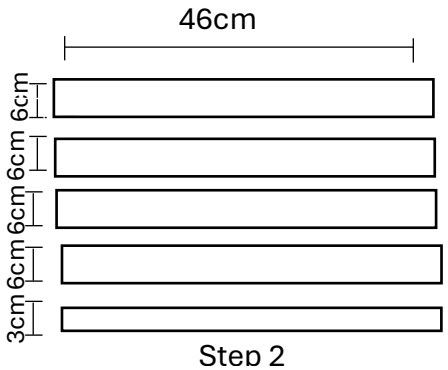
ISTF-NG 2026

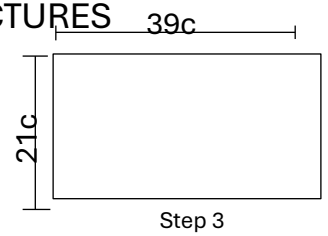


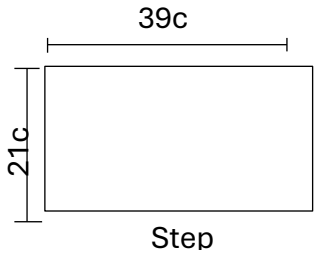
FRONT VIEW

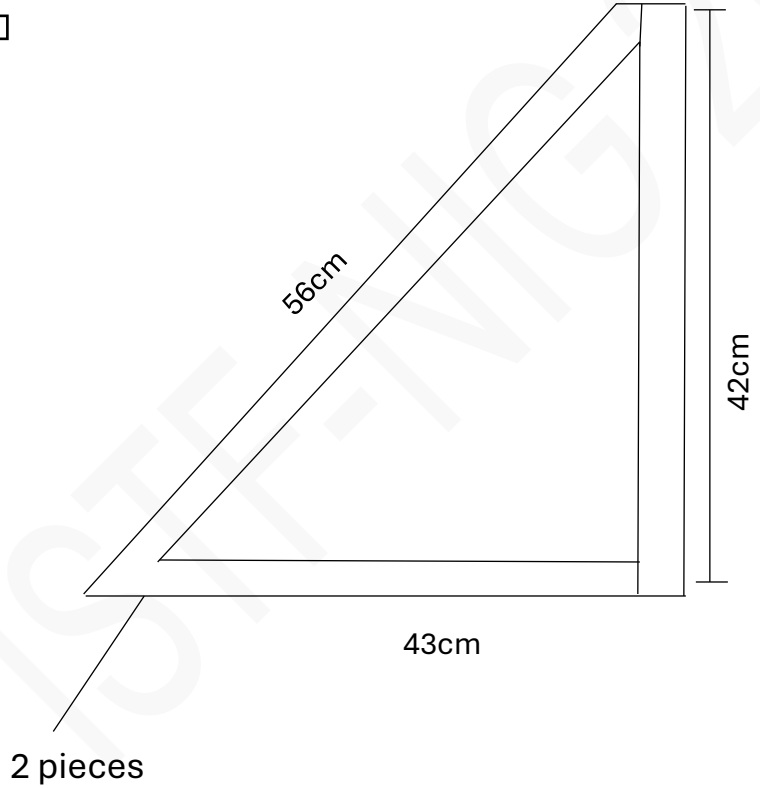
ISTF-NG 2026

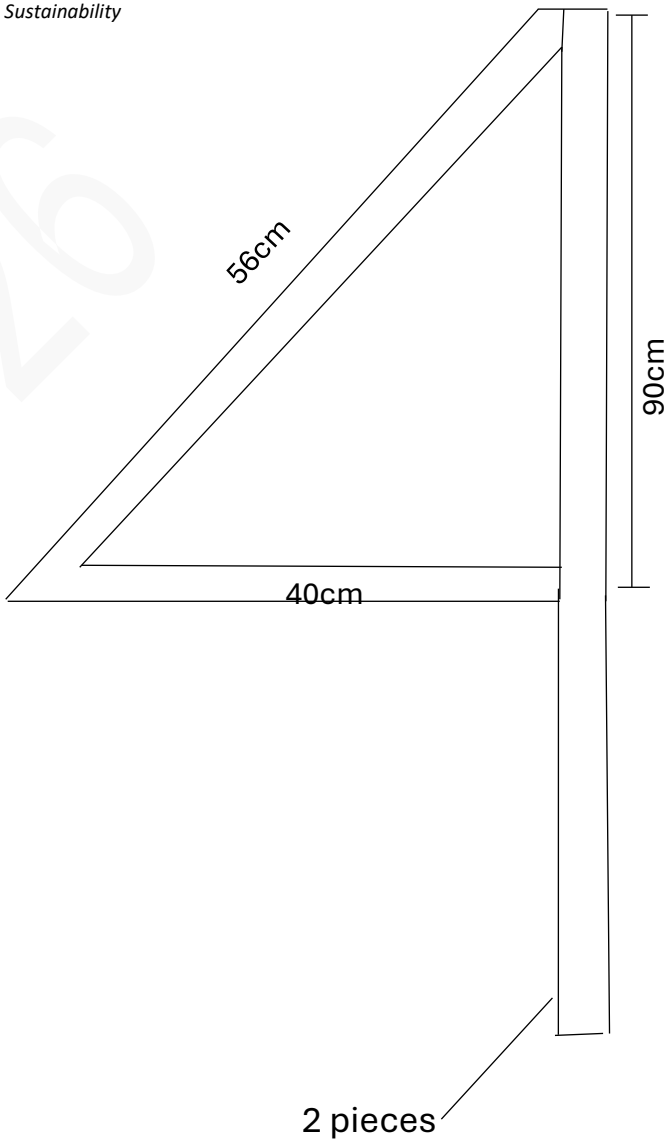
LADDER CONFIGURATION STRUCTURES



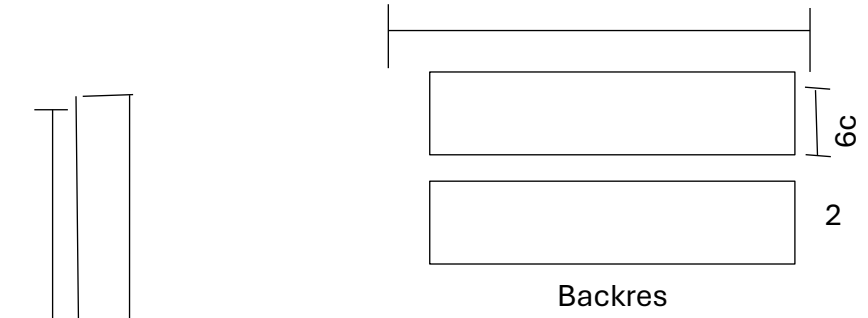


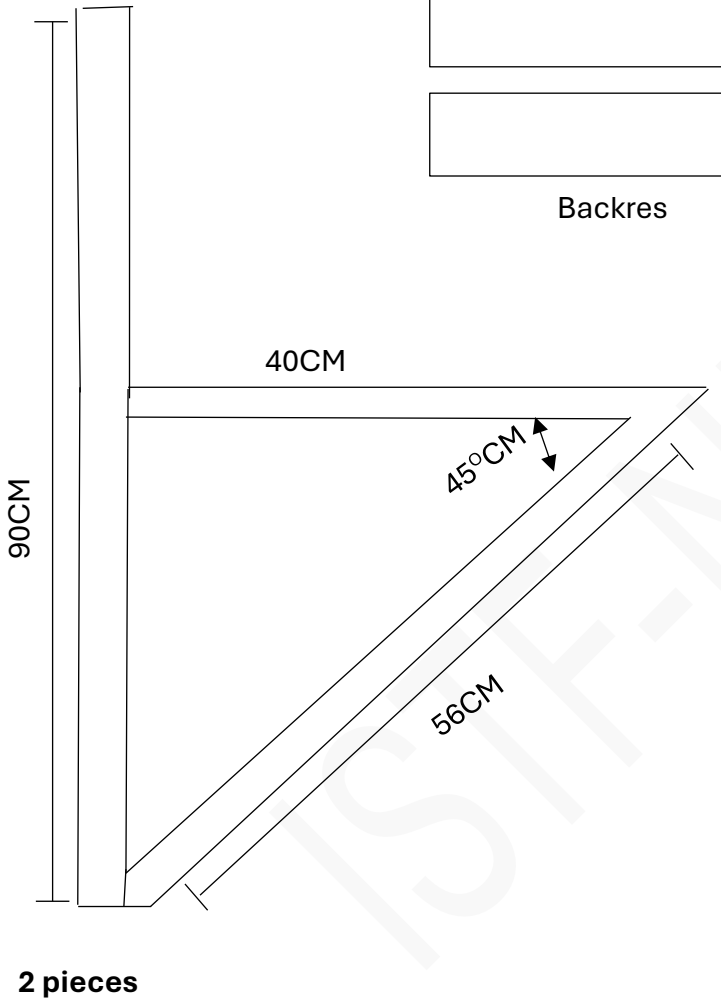






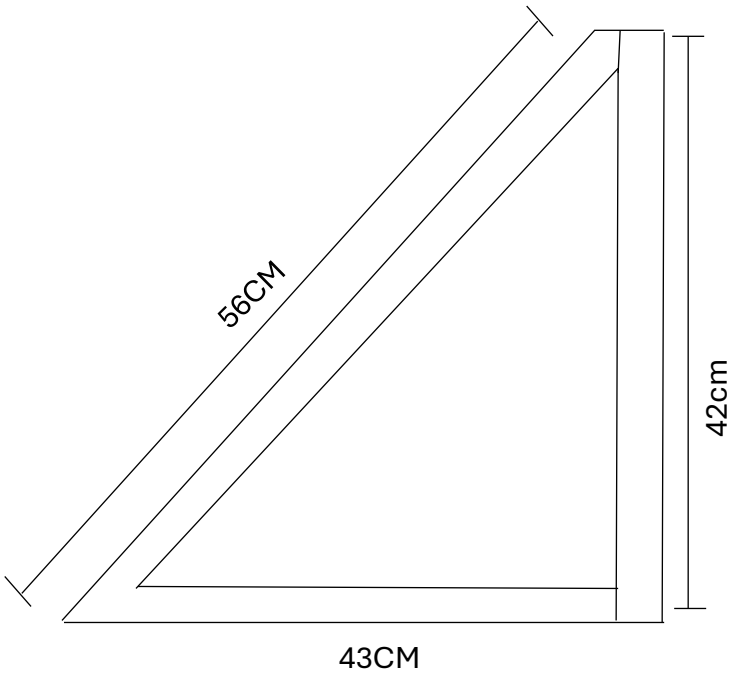
ISTF-NIG2026





2 pieces

2 Pieces



ISTF-NIG 2026

3. **Performance Testing and Evaluation Phase** – The final stage involved subjecting the completed prototype to a series of real-world tests, including load-bearing assessment, transformation trials (folding/unfolding cycles), and dimensional accuracy checks. Additionally, user feedback was collected to evaluate the unit's ergonomic and aesthetic qualities.

Materials Collection

The primary material for this project is secondary recovered wood, sourced directly from ongoing construction of the Information and Communication Technology (ICT) center at the University of Cross River State (UNICROSS), Calabar, which Africa Choice International Service Limited, Nigeria are constructing. Sources include local post-consumer and industrial waste streams, such as discarded furniture, dismantled pallets, demolition timber, sawmill offcuts, and surplus timber from manufacturing operations. This targeted sourcing approach ensures the use of sustainable materials, minimizes environmental impact, and supports the study's commitment to resource efficiency.

- **Chair Dimensions (Unfolded)**: 900 mm (height) × 450 mm (width) × 400 mm (depth)
- **Ladder Dimensions (Deployed)**: 900 mm height with three rungs spaced 250 mm apart, and Key design principles applied included Compactness, Stability and Ergonomics

Table 1: Feedback Response Form

Section	Question	Response Options
Functionality	Does the chair-to-ladder transition smoothly between modes?	Yes / No
Stability	How stable does it feel in both configurations?	Very Stable / Stable / Unstable
Comfort	Is the Chair comfortable for seating?	Very Comfortable / Comfortable / Uncomfortable
Design Appeal	How would you rate the visual appeal?	Excellent / Good / Fair / Poor
Suggestions	What changes or improvements would you suggest?	Open-ended

Results and Discussion

Performance testing and evaluation of materials properties

Moisture Content

Moisture tests conducted on four pieces of 2x4x12 recovered wood indicated an average moisture content of 16%, measured using a digital moisture meter. This falls within the recommended range for furniture applications (8–16%), reducing susceptibility to shrinkage, swelling, or warping during use. The result confirms that of Moeve (2025), Springer (2024), and RMCAD (2025) recovered wood can be effectively repurposed without compromising structural performance with an average moisture level of the wood used: Number of sizes of wood 3 pieces, Dimension '2x4x12', moisture content (%) 16%.

Load Bearing Capacity test: Impact test

Chair Configuration Structure

Load-bearing tests were conducted with 10 individuals of varying body weights. Results showed a minimum capacity of 59.62 kg and a maximum of 85.23 kg under impact loads varying from scale 1–10. These values demonstrate and validate the work of Santos (2007), Yang and Zhu (2021), and Hernandez *et al*. (2021a), showing that the chair configuration can support average adult weights, validating its practical use in domestic settings. However, structural reinforcement may be recommended for loads above 90 kg (Fig. 1).

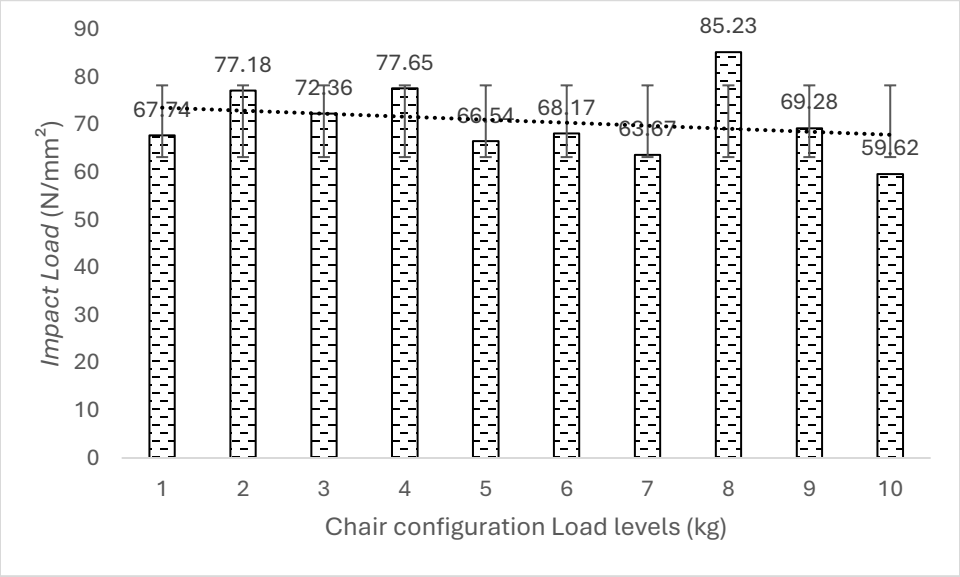


Figure 1: Weight variation of Chair-ladder ware

Ladder configuration Structure

For the ladder configuration, impact loads varied from 1 to 10, with a maximum recorded capacity of 90.25 kg and a minimum of 65.35 kg. These results confirm that the model can withstand climbing and standing loads typical of household tasks such as cleaning high walls or accessing elevated storage. The higher load threshold compared to the chair configuration highlights its strength under vertical load applications, as shown in Figure 2 below.

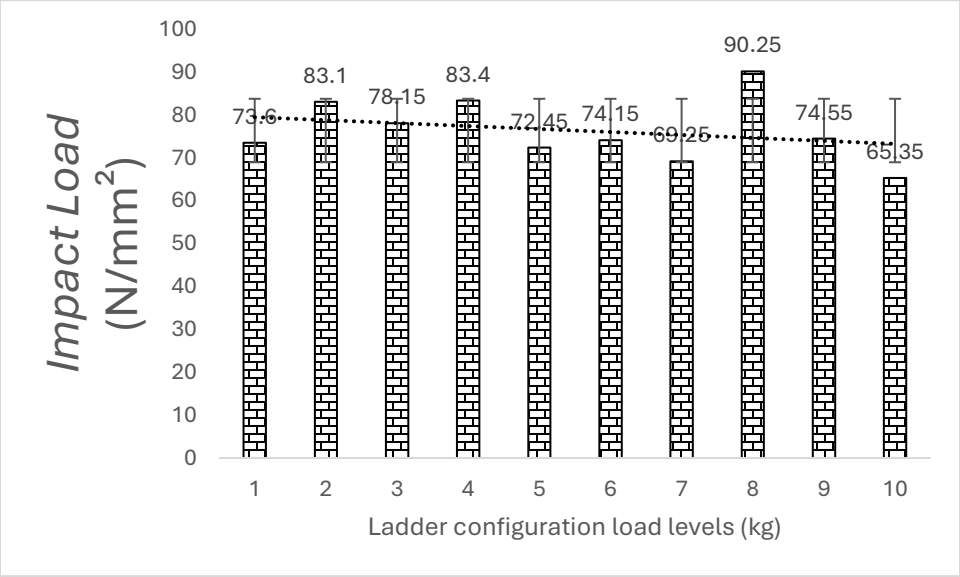


Figure 2: Weight variation of Chair-ladder ware

Dimensional accuracy

The measured total length of both the Chair and the ladder was 90 cm (900 mm), confirming dimensional precision in the processing of the recovered wood. This accuracy ensures structural balance and Stability, essential for multifunctional furniture subjected to both seating and climbing stress. These different-sized pieces of wood were put together like a puzzle, forming the vertical structure of the Chair and ladder.

900mmx2

430mmx2

400mmx2 with 45% cut on side

560mmx2 with 45% cut on both sides

530 mm x 2 with 45% cut on both sides.

These were put together in 4 different sections with a frame structure below:

User feedback mechanism models

Functionality of the Chair to ladder transition

Of 50 respondents, 42 (84%) confirmed that the chair-to-ladder was functional, while only 8 (16%) disagreed. This demonstrates general acceptance of the product's intended dual-purpose use, as shown in Figure 3 below.

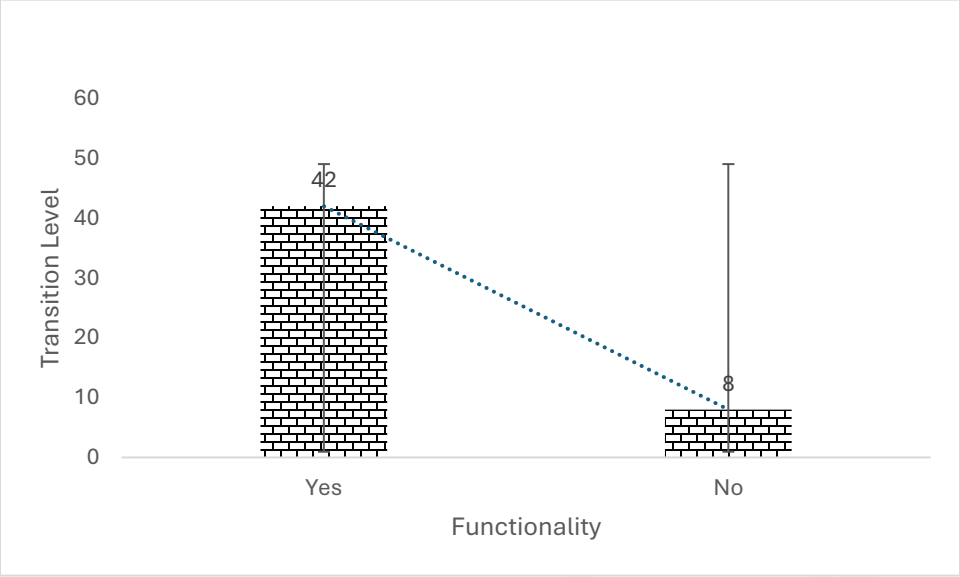


Figure 3: Functionality of the Chair to ladder transition

Chair to ladder Stability

33 (66%) rated it very stable, 11 (22%) rated it stable, and 6 (12%) rated it unstable.

This indicates high reliability, although the small percentage reporting instability suggests a need for design reinforcement.

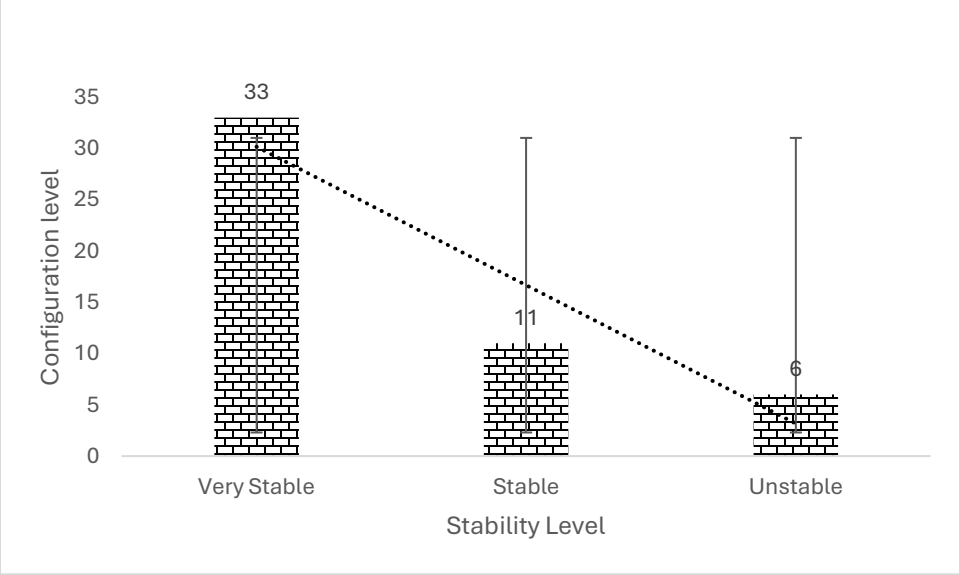


Figure 4: Chair to ladder Stability

Comfort for the seating of the Chair to the ladder

19 (38%) rated very comfortable, 23 (46%) comfortable, and 8 (16%) uncomfortable.

The results show overall user satisfaction with comfort, though further ergonomic adjustments could improve the seating experience, as shown in Figure 5 below.

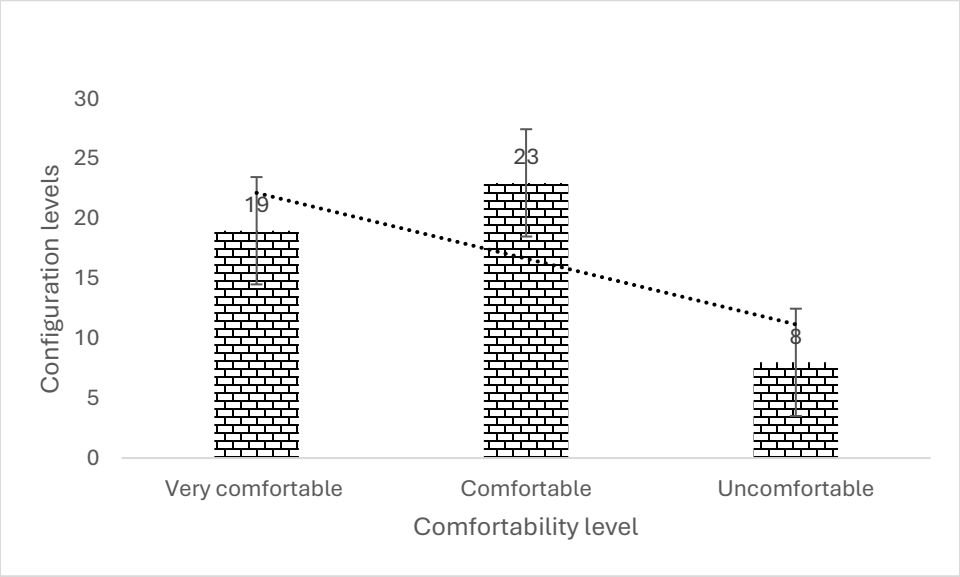


Figure 5: Comfort level of the seating of the Chair to the ladder

Design appeals of the Chair to the ladder model

5.4 Design Appeal, 22 (44%) rated excellent, 24 (48%) rated good, 3 (6%) fair, 1 (2%) poor. The majority found the design visually and functionally appealing, aligning with market competitiveness, as shown in Figure 6 below.

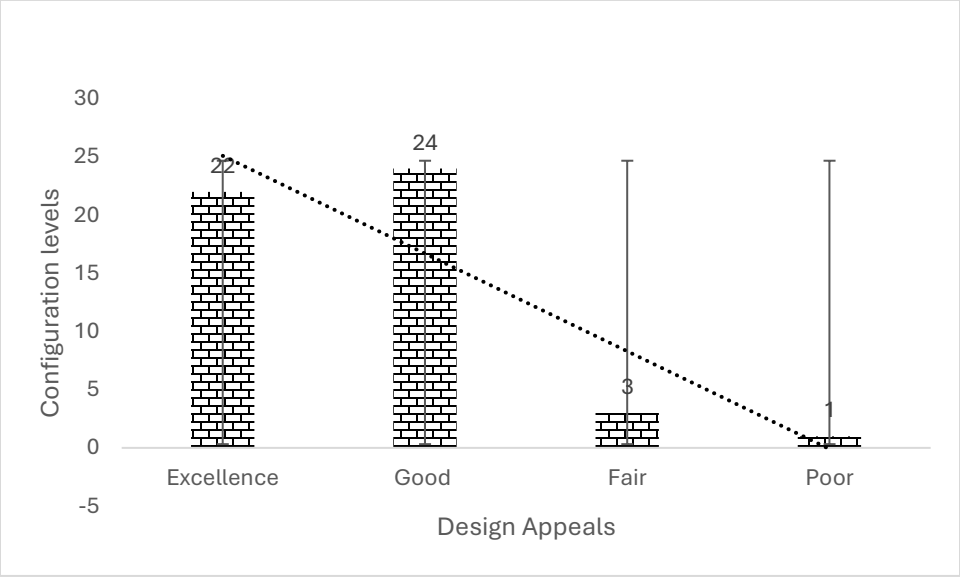


Figure 6: Design appeals of the Chair to the ladder model

Suggestion for modification

38 respondents (76%) provided open-ended suggestions. In contrast, 12 (24%) gave closed-ended feedback, indicating a strong willingness among users to see improvements and customization options for broader functionality, as shown in Figure 7 below.

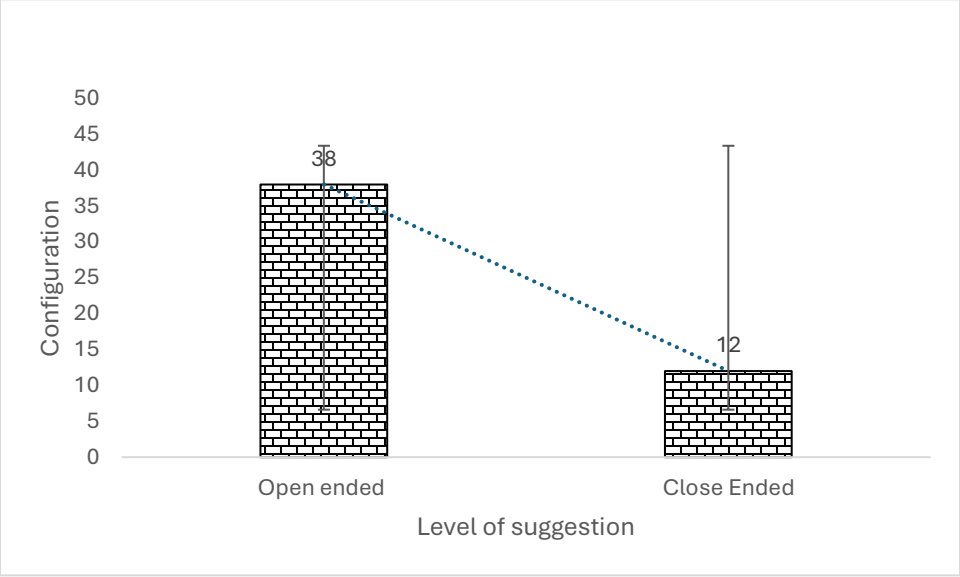


Figure 7: Suggestion for modification

Conclusion

Secondary recovered wood demonstrated promising performance in terms of moisture stability, load-bearing capacity, and impact resistance. Reusing household items, such as chairs, shelves, and storage units, offers both environmental benefits and cost efficiency. Therefore, secondary recovered wood can be considered a reliable alternative material for sustainable houseware manufacturing. The study confirms that secondary recovered wood is a viable material for multifunctional houseware production, particularly for compact furniture designs such as the chair-to-ladder model. Its acceptable moisture content, structural strength, and positive user feedback support its application in space management solutions. However, minor improvements in comfort, reinforcement for higher load capacity, and integration of user-suggested modifications could enhance product performance and adoption. Moisture content: the average of 16% indicate the wood was adequately seasoned for use, reducing the risk of warping or microbial attack

Load-bearing capacity: The highest recorded value was 85.23kg, while the minimum was 59kg, suggesting the wood can safely support moderate human weight.Impact-resistant, the chair-to-ladder demonstrated consistent strength performance, confirming its ability to withstand functional stress in household furniture applications. Reinforce joints and critical stress points to increase load-bearing capacity beyond 90 kg, enhance ergonomics for greater comfort during prolonged seating, explore modular design features for increased versatility, and integrate user-driven design modifications to broaden market appeal.

References

Amigo, C. R. (2007). Design applied to reusing leftover certified native wood in a furniture manufacturer (Bachelor's thesis). University of São Paulo.

Architectural Digest. (2021). At Cabn, furniture offers a future. https://www.architecturaldigest.com/story/at-cabn-furniture-offers-a-future

Besseau, P., Graham, S., & Christophersen, T. (2020a). Restoring forests and landscapes: The key to a sustainable future. UN Environment Programme.

Bofylatos, S., Kachrimani, C., & Zacharopoulos, N. (2017b). Upcycling reclaimed wood: A preliminary analysis. In EKSIG2017 Alive. Active. Adaptive. Delft, the Netherlands.

Bofylatos, S., Papadopoulos, A., & Polydoropoulou, A. (2017b). Product design and reuse: Exploring user perceptions of reclaimed wood furniture. *Journal of Sustainable Product Design, 9*(3), 45–57.

Dahiya, A., Sharma, S., & Rao, P. (2020b). Categorizing reclaimed timber for reuse in furniture and construction. *Journal of Cleaner Production, 255*, 120283.

Dahiya, S., Singh, R. P., & Yadav, V. (2020a). Waste wood management and recycling—*Journal of Environmental Management, 263*, 110404.

European Environment Agency. (2018). Wood recycling in Europe: Challenges and opportunities. https://www.eea.europa.eu

Fuad-Luke, A. (2019). *The eco-design handbook: A complete sourcebook for the home and office*. Thames & Hudson.

Hernandez, L., Ocampo, R., & Ayala, M. (2021b). Comparative analysis of grain structure in reclaimed versus new hardwoods. *Wood Science & Technology, 55*(3), 707–725.

Hernandez, R. E., Koubaa, A., & Beaulieu, J. (2021a). Mechanical durability of old-growth wood: Evidence from reclaimed timber. *Wood Science and Technology, 55*(1), 93–108.

Inside Out Contracts. (2025). Reclaimed wood: A sustainable choice for furniture design. https://insideoutcontracts.com/us/blog/reclaimed-wood-a-sustainable-choice-for-furniture-design

Lee, J., & Lee, S. (2021). Compact living and furniture design: Impacts on space-saving in urban homes. *Journal of Interior Design and Innovation, 12*(2), 55–68.

Metropolis Magazine. (2025). Sustainable furniture designs from Spain. https://metropolismag.com/products/7-sustainable-furniture-designs-from-spain/

Moeve. (2025). Sustainable furniture made from reclaimed ocean wood. https://www.moeveglobal.com/en/planet-energy/sustainable-innovation/sustainable-furniture-reclaimed-ocean-wood

Nyemba, W. R., Hondo, A., Mbohwa, C., & Madiye, L. (2018). Unlocking economic value and sustainable furniture manufacturing through the recycling and reuse of sawdust. *Procedia Manufacturing, 21*, 510–517.

Olufemi, A., Okafor, P., & Balogun, T. (2024). Structural performance evaluation of recovered wood for home furniture manufacturing. *International Journal of Wood Products Engineering, 12*(1), 60–75.

RMCAD. (2025). Maximizing space: Creative storage solutions for modern homes. https://www.rmcad.edu/blog/maximizing-space-creative-storage-solutions-for-modern-homes/

Santos, M. C. L. (2007). *Design applied to reusing leftover certified native wood in a furniture manufacturer* [Bachelor's thesis]. University of São Paulo.

Springer. (2024). Determining the quantity and quality of wood recovered from structural parts of wooden buildings. https://link.springer.com/article/10.1007/s00107-024-02170-3

Superior Hardwoods. (2025). Is reclaimed wood sustainable? Facts, benefits & uses. https://superior-hardwoods.com/how-reclaimed-wood-helps-save-the-earth/

Yang, D., & Zhu, J. (2021). Recycling and value-added design of discarded wooden furniture. *BioResources, 16*(4), 6954–6964.

Zhang, X., & Liu, Y. (2023). Surface modification of reclaimed timber for enhanced adhesion in furniture applications—*Journal of Cleaner Production, 382*, 135139.

ECOLOGICAL AND AXIAL VARIATION IN THE DENSITY OF *Eremospatha macrocarpa* (G.MANN & WENDL.) WENDL. RATTAN IN TWO NIGERIAN ECOLOGICAL ZONES.

***Ogutuga, S.O. and Okanlawon, F.B.**

Department of Wood and Paper Technology, Federal College of Forestry, Forestry Research Institute of Nigeria, P.M.B 5054, Jericho, Ibadan, Oyo State, Nigeria
**Corresponding Author Email: tugalord001@yahoo.com; Tel: +2347037766692*

Abstract

This study investigated the influence of ecological location and sampling height on the density of Eremospatha macrocarpa obtained from freshwater swamp and rainforest zones in Nigeria. Three mature wild rattan stems were collected from each ecological location and sectioned into base, middle, and top sections. Samples for the density test were prepared in accordance with ASTM D143-52 (ASTM, 1972) with slight modifications, while density determination followed ASTM D2395-17 (ASTM, 2017). The experiment was arranged in a 2 × 3 factorial in a Completely Randomized Design (CRD) with five replicates, and data were analyzed using descriptive statistics and ANOVA at $p<0.05$. From the results, the overall mean density of E. macrocarpa was 546.89 ± 95.85 kg/m³. Results showed that both ecological location and sampling height had significant effects on density ($p < 0.05$), whereas their interaction was not significant. Density decreased from the base to the top of the rattan stem, with samples from the base exhibiting the highest density. Rattan samples collected from the rainforest had significantly higher density than those collected from the freshwater swamp. The findings indicate that both axial position and ecological location are important determinants of density in *E. macrocarpa* rattan. Samples from the base and middle, especially from the rainforest, are more suitable for structural applications, while samples from the top are better suited for flexible uses. In general, E. macrocarpa demonstrates characteristics of a medium-density rattan species with great potential for various industrial applications.

Keywords: Eremospatha macrocarpa, rattan density, ecological influence, axial variation, ecological zones.

Introduction

Rattans represent a vital category of non-timber forest products (NTFPs) within tropical ecosystems, providing significant economic value (Akpenpuun *et al.*, 2017) and ecological benefits second only to timber and bamboo. Globally, approximately 600 species of rattan across 13 genera have been identified (Sunderland, 2001), with the vast majority indigenous to South and Southeast Asia. In West and Central Africa, the diversity is more specific, with 20 identified species belonging to four endemic genera: *Calamus*, *Eremospatha*, *Oncocalamus*, and *Laccosperma* (Sunderland, 2001). In Nigeria, these resources are dominantly found in tropical rainforests. They are ranked by availability, with *Calamus deerratus* being the most abundant, followed by *Eremospatha macrocarpa*, *Oncocalamus manni*, and *Laccosperma secundiflorum* (Obiukwu & Igboekwe, 2020). The increasing pressure on traditional timber resources for construction (Ogutuga *et al*., 2015; Aguda *et al*., 2020) has necessitated the investigation of alternative natural biomass, such as rattan, which possesses excellent potential for furniture, craft products, and

housing (Olorunnisola & Adefisan, 2002). Rattan is particularly valued for its lightweight durability and, to a certain extent, flexibility (Ogutuga *et al*., 2021). However, the successful integration of rattan into the construction industry as a structural material depends heavily on its physical and mechanical properties (Abd. Latif, 1991; Abd. Latif, 1992). Among these, density is a critical performance indicator, as it directly influences strength, hardness, natural durability, and many other physical and mechanical properties (Yang *et al.*, 2020).

Density in rattan is determined not only by genetic characteristics but also by external ecological factors (Ogutuga *et al.,* 2021). Bhat and Mohan (1991) reported that rattan density variation is determined by climate, soil, and hydrology. Furthermore, internal variations along the stem (the axial direction) play a major role. Despite the economic importance of rattan species such as *Eremospatha macrocarpa* in Nigeria, there remains a notable scarcity of systematic data on how different ecological zones influence their physical properties, such as density. Most existing research has focused on trade and furniture utilization rather than the fundamental material science required for structural applications. Understanding the interplay between ecological factors and density is vital for developing suitable utilization technologies and ensuring the sustainable management of these forest resources. This study, therefore, aims to evaluate the ecological factors influencing the density of *Eremospatha macrocarpa* rattan canes harvested from two different ecosystems in Nigeria. By investigating variations across different ecological locations and axial positions, this research seeks to provide basic data to support the cultivation and appropriate utilization of *E. macrocarpa* rattan.

Materials and Methods

Sample Collection and Identification

Three mature wild canes of *Eremospatha macrocarpa* were harvested from two contrasting ecological zones in Nigeria. The freshwater swamp samples were collected from Arapagi Village in Ibeju-Lekki Local Government Area of Lagos State, located on latitude 6^0 30' 21.24" N and longitude 3^0 45' 40.68" E. In comparison, rainforest samples were collected from Nicholas Village in Ovia North-East Local Government Area of Edo State, located on latitude 6^0 39' 0.798" N and longitude 3^0 25' 28.099" E. Following the collection, the rattans were carefully examined based on their morphological characteristics to ensure correct identification. This verification was carried out by comparing the specimens with authenticated rattan collections available at the Herbarium of the Department of Forest Conservation and Protection, Forestry Research Institute of Nigeria (FRIN), Ibadan, Oyo State. Each rattan stem was subsequently divided into three portions along its length, namely the base, middle and top, to account for variation along the culm.

Preparation and Testing of Samples

Test specimens for density determination were prepared from the base, middle and top sections of each rattan stem collected from both ecological zones. The preparation procedure followed ASTM D143-52 (ASTM, 1972), with slight adjustments to suit the peculiarities (structural characteristics) of rattan species. The study considered two factors: rattan source (freshwater swamp and rainforest) and sampling height (base, middle, and top). Each treatment combination was replicated 5 times, yielding a total of 30 samples for density evaluation. Density measurements were conducted in accordance with ASTM D2395-17 (ASTM, 2017).

Experimental Design

A 2 × 3 factorial arrangement was adopted in a Completely Randomized Design (CRD), with five replicates per treatment combination.

Data Analysis

The data obtained were subjected to Analysis of Variance (ANOVA) using SPSS Statistics version 20.0 at a 5% level of significance. This analysis was performed to assess the influence of rattan source and sampling height on density. Where significant differences were detected, Duncan's Multiple Range Test (Duncan, 1955) was applied to separate the means.

Results And Discussion

Rattan Density

The density values for *Eremospatha macrocarpa* from the two ecological locations are presented in Fig. 1, with an overall mean of 546.89 ± 95.85 kg/m³. A noticeable decrease in density was observed from samples collected at the base towards the top of the rattan stem. This trend corroborates the findings of Ogutuga *et al*. (2021) for *Laccosperma secundiflorum* across different ecological zones in Nigeria. Similar patterns have also been documented for other rattan species such as *Calamus manan*, *Calamus scipionum*, *Calamus palustris*, *Korthalsia rigida* and *Plectomiopsis griffithii* (Abd. Razak *et al*., 1995).

The reduction in density along the stem is largely associated with internal structural differences. In the basal region, fibres tend to have thicker cell walls and are more densely packed with vascular bundles, which contributes to the relatively higher density recorded in this portion (Abd. Latif and Norralakman, 1993). Evidence from other lignocellulosic materials, such as *Borassus aethiopum* (Ojo *et al*., 2014) and Bambusa vulgaris (Areghan *et al*., 2018), points to the same pattern. These findings suggest that samples collected at the base of the rattan stem have a higher density than those from the middle and top. A clear difference was also noticed between locations, with rainforest samples showing higher density values than those from the freshwater swamp. Statistical analysis confirmed that this difference was significant ($p<0.05$), indicating that ecological location, in addition to sampling height, affected density (Table 1). However, the interaction between ecological location and sampling height was not significant ($p>0.05$), indicating that the pattern of density variation along the rattan stem was similar across both locations.

The significant effect of sampling height on the density of rattan stem ($p<0.05$) highlights the importance of axial position in determining the physical properties of rattan. Results from the Follow-up Test, presented in Table 2, showed that the samples obtained at the base had the highest density values. However, these were not significantly different from the samples obtained at the middle portion. In contrast, samples obtained at the top exhibited significantly lower density than those obtained at the base and middle sections. The observed axial variation can be linked to the inherent structural arrangement of tissues within the rattan stem. The samples from the base, being more mature, contain a greater proportion of thick-walled fibres and densely distributed vascular bundles, which enhance density and mechanical strength (Abd. Latif and Norralakman, 1993; Ahmad, 2000). Functionally, this is important because the lower part of the stem can withstand greater mechanical loads due to its higher fibre concentration and density. In contrast, the upper portion exhibits lower density due to reduced fibre content and thinner cell walls, leading to decreased stiffness and greater flexibility (Dixon & Gibson, 2014; Sharma *et al.,* 2015).

The significant effect of ecological location indicates that density in *Eremospatha macrocarpa* rattan varies across the ecological zones studied. This suggests that, in addition to inherent species characteristics, environmental conditions play a vital role in influencing density. The relatively higher density recorded in samples collected from the rainforest may be linked to more balanced and favourable growth conditions, including adequate but well-regulated moisture availability and richer soil nutrient status. Such conditions are likely to promote optimal fibre development and a higher concentration of vascular bundles (Areghan *et al*., 2018). The combined effect of axial position and ecological location observed in this study are in line with previous findings on rattan and related species. While variation along the stem remains a major factor influencing physical and strength properties, environmental conditions have also been shown to contribute significantly to these variations (Ojo *et al.*, 2014; Ogutuga *et al*., 2021).

From an application perspective, density is a critical parameter in determining material performance. It is closely linked to strength properties, such as bending resistance and compressive strength, and is widely regarded as a reliable indicator of overall material quality (Kubler, 1980; Ahmad, 2000). Consequently, samples from the base and middle of *E. macrocarpa*, which show higher density, are more suitable for structural and load-bearing applications. In contrast, samples from the less dense top portion may be better suited for applications requiring flexibility, such as lightweight components and weaving. The mean density value obtained in this study (546.89 kg/m³) places *E. macrocarpa* in the medium-density category (Bandon, 2005) of rattan species, suggesting its suitability for a wide range of uses. This is consistent with earlier reports by Lucas and Dahunsi (2004), who documented comparable density values for related rattan species, as well as Abd. Razak *et al*. (1995) reported similar ranges for other tropical rattan species.

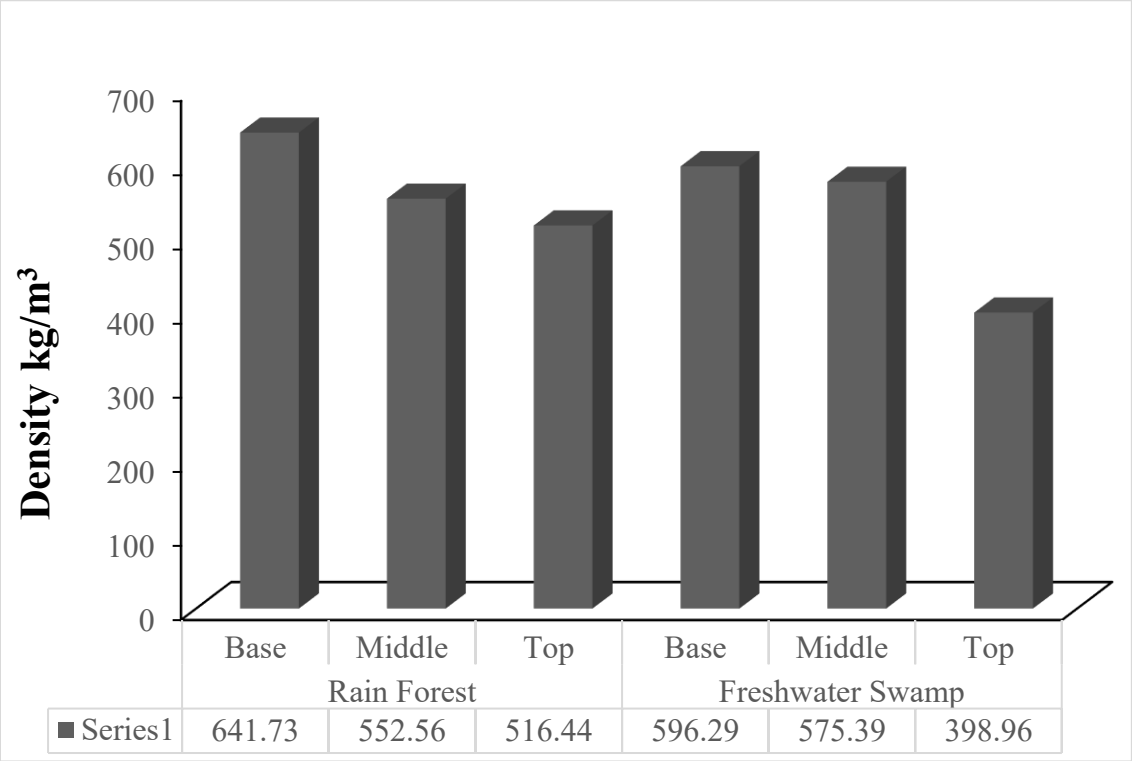


Fig. 1: Density of *Eremospatha macrocarpa* Rattan Samples.

Table 1: Analysis of Variance for Density

Source of variation	Df	SS	MS	F-cal	Sig.
Ecological Location	1	16357.142	16357.142	4.315*	0.049
Sampling Height	2	134476.150	67238.075	17.738*	0.000
Ecological Location * Sampling Height	2	24614.580	12307.290	3.247^{ns}	0.056
Error	24	90973.979	3790.582		
Total	29	266421.850			

** Significant at p<0.05 and **ns**= not significant at p>0.05*

Table 2: Follow-up Test for Sampling Height

Variables	Density Mean±SDV
Ecological Location	
Rainforest	570.24^{a}±88.21
Freshwater Swamp	523.54^{b}±100.40
Sampling Height	
Base	619.01^{a}±81.50
Middle	563.97^{a}±46.96
Top	457.70^{b}±76.24

Means with the same alphabet in the same column are not significantly different (p<0.05) from One another.

Conclusion

This study examined the influence of ecological location and axial position on the density of *E. macrocarpa* rattan in the freshwater swamp and rainforest ecological zones of Nigeria. Density decreased from the base to the top of the rattan stem, confirming the strong influence of axial variation. Ecological location also had a significant effect on density, with rattan samples from the rainforest exhibiting higher density values than those from the freshwater swamp. The results of this study showed that both inherent structural characteristics and environmental conditions play important roles in determining the density of *E. macrocarpa* rattan. In terms of utilization, the denser basal and middle portions, especially those sourced from rainforest, are more suitable for structural and load-bearing applications. In contrast, the less-dense top portions may be more appropriate for uses that require flexibility and lighter weight. Based on the classification of Bradon (2005), *Eremospatha macrocarpa* can be regarded as a medium-density rattan species. Bradon classified wood density at approximately 12% air-dry moisture content as follows: exceptionally Light (<300 kg/m³), Light (300–450 kg/m³), medium (450–650 kg/m³), heavy (650–

800 kg/m³), and very heavy (800–1000+ kg/m³). Further research on additional strength properties and a wider range of ecological conditions would provide deeper insight into its potential for industrial applications.

References

Abd. Latif, M. (1991). Guidelines for the Selection and Preparation of Rattan for Industrial Use. Rattan Information Centre Handbook 2: 1 – 27.

Abd. Latif, M. (1992). Processing of Rattans. *In:* W.M. Wan Razali, J. Dransfield & N. Manokaran (*eds.*). Guide to the Cultivation of Rattan, pp. 239–260. Malayan Forest Record 35. Forest Research Institute of Malaysia.

Abd. Latif, M. and Norralakman, Y.S. (1993). Anatomical Characteristics of Five Malaysian Canes and Their Relationship with Physical and Mechanical Properties. *In:* S. Chand

Basha and K.M. Bhat (*eds.*). Rattan Management and Utilization, pp. 207–213. Proceedings of the Rattan (Cane) Seminar, India. January 29th – 31st, 1992. Trissur, Kerala, India.

Abd. Razak, M.A., Abd. Latif, M., Khoo, K.C. & Kasim, J. (1995). Physical Properties, Fibre Dimensions and Proximate Chemical Analysis of Malaysian Rattans. *Thailand Journal of Forestry.* Vol. 14:59 – 70.

Areghan, S.E., Ojo, A.R. & Ogutuga, S.O. (2018). Density Evaluation of Raw and Laminated *Bambusa vulgaris* Schrad. With a view to assessing its Structural Application Potentials. *Journal of Forestry Research and Management.* Vol. 15(3):57–70.

ASTM D143-52 (1972). Standard methods of testing small clear specimens of timber, West Conshohocken.

ASTM D (2395).-17 (2017). Standard Test Methods for Density and Specific Gravity (Relative Density) of Wood and Wood-Based Materials, ASTM International, WestConshohocken, PA, 2017.

Aguda, L., Ajayi, B., Areghan, S., Olayiwola, Y., Kehinde, A., Idowu, A. & Aguda, Y. (2020). Mechanical Properties of *Ficusvallis-choudae* (Delile), A Lesser Utilized Species in Nigeria. *BioResources* 15(3): 6550 – 6560.

Ahmad, M. (2000). Analysis of Calcutta bamboo for structural Composite materials. A Ph.D thesis in Wood Science and Forest Products, Virginia Polytechnic Institute and State University. August 11, 2000, Blacksburg, Virginia. Pp. 210.

Akpenpuun, T. D., Adeniran, K. A. and Okanlawon, O. M. (2017). Rattan Cane Reinforced Concrete Slab as a Component for Agricultural Structures. *Nig. J. of Pure and Appl. Sci.*, 30 (1): 3007 – 3013.

Bandon, J. (2005). Properties of Wood. Builder's Guide to Aircraft Materials: Wood, Plywood and Adhesives Modules. AUF Australia. pp 9.

Bhat, K.M. & Mohan, V. (1991). Anatomical basis for the density and shrinkage behavior of the rattan stem. *J. of the Inst. Wood Sci.* 12(3):123–130.

Dixon, P.G. & Gibson, L.J. (2014). The structure and mechanics of Moso bamboo material. *Journal of the Royal Society Interface*, Vol. 11: 1–12. http://dx.doi.org/10.1098/rsif.2014.0321

Kubler, H. (1980). Wood as a Building and Hobby Material. John Wiley and Sons, New York. 245pp.

Lucas, E.B. & Dahunsi, B.I.O. (2004). Characteristics of three Western Nigerian Rattan Species in Relation to their Utilisation as Construction Material. *Journal of Bamboo and Rattan*. 3(1):45 – 56.

Obiukwu, O. and Igboekwe, J. (2020). Abrasion and Physical Properties of Rattan Cane (*Calamus deerratus*) Fibre-Based Epoxy Composites. Int. J. of Eng. and Tech., Vol. 19, pp 23 – 31.

Ogutuga, S.O., Ogunsanwo, O.Y. and Adebayo, S.O. (2015). Influence of Laminate Thickness on Selected Properties of Glue-Laminated Bamboo. Nig. J. of For. 45 (2): 65–69.

Ogutuga, S. O., Ojo, A.R., Areghan, S.E. & Aguda, L.O. (2021). Density and Selected Strength Properties of *Laccosperma secundiflorum* (P. BEAUV.) Rattan from Two Different Ecological Zones in Nigeria. *Pro Ligno* Vol. 17(2): 36 – 44.

Ojo, A.R., Adebayo S.O. & Ogutuga, S.O. (2014). Site Factor and Intra-Tree Variations in the Density of *Borassus aethiopum* mart. Woods in Savannah Zones of Nigeria. *Journal of Forestry Research and Management.* Vol.11: 99–111.

Olorunnisola, A.O. & Adefisan, O.O. (2002). Trial Production and Testing of Cement-Bonded Particle Board from Rattan Furniture Waste. *Wood and Fiber Science* 34(1):116–124.

Sharma, B., Gatoo, A., Bock, M. & Ramage, M. (2015). Engineered bamboo for structural applications. *Construction and Building Materials*, Vol. 81: 66–73. http://dx.doi.org/10.1016/j.conbuildmat.2015.01.077

Sunderland, T.C.H. (2001). Rattan Resources and Use in West and Central Africa, *Unasylva* ol. 52(205):18–23.

Yang, S., Xiang, E., Shang, L., Liu, X., Tian, G., & Ma, J. (2020). Comparison of Physical and Mechanical Properties of Four Rattan Species Grown in China. *Journal of Wood Science,* 66(3): 1 – 8. https://doi.org/10.1186/s10086-020-1850-0

ISTF-NIG 2026

UTILIZATION OF ANIMAL-DERIVED LIPIDS AS AN ALTERNATIVE MEDIUM FOR OIL HEAT TREATMENT

[1]ADEJOBA, Adewale Lukeman*, [2]OMOLE, Ayodeji Oludare and [1]OLAYIWOLA, Yetunde Bolarinwa

[1]Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria.
[2]Department of Forest Production and Products, University of Ibadan, Nigeria.
**Corresponding email: adewajoba@gmail.com*

Abstract

Non-durable wood is adversely affected by deteriorating agents and is characterized by failure in service. Preservatives are essential; however, the use of synthetic chemicals is no longer favoured, so attention is shifting to other methods to achieve durability. Wood treatment in hot oil has become One of the alternatives being considered; the use of vegetable oil has gained acceptance and has been commercialized in some countries. Active fatty acids in the oil have shown that oleic acid, palmitic acid, and linoleic acid play significant roles in influencing the desirable properties of wood. Using edible vegetable oil for wood treatment will exacerbate pressure on its use, create a food-versus-materials conflict, and drive up vegetable oil prices. The presence of this fatty acid in animal fat makes it an alternative to vegetable oil and also provides the daily requirement for protein. Thus, there is a need to investigate its efficacy in oil heat treatment of wood.

Keywords: Fatty acid, Weight loss, Durability, Oleic acid, Palmitic acid

Introduction

Wood, as a degradable natural material, is One of the most abundant renewable materials and has been put to several uses, including industrial applications, building and engineering construction, and household items such as furniture and kitchen utensils (Wacker, 2010; Rowel *et al.,* 2012; Kaplan *et al.,* 2018). Despite the advantages of wood as a renewable natural resource, its use is negatively affected by deteriorating agents, especially in non-durable species. Although some wood species are very durable, their scarcity owing to overexploitation has led to the use of less durable species for Light construction, resulting in failures in service. To forestall this challenge, wood protection becomes imperative; however, the use of synthetic wood preservatives has also been questioned due to environmental concerns (Lee *et al.,* 1990). Against this, protecting wood with eco-friendly materials is being advocated.

Wood Treatment with Heat

Wood treatment with biodegradable plant-based extracts has been investigated and found to be effective (Adetogun *et al.,* 2003; Omole *et al.,* 2015). Wood treatment with heat is One that is gaining attention among wood scientists in recent times. Wood modification, the treatment of wood with heat in the absence of oxygen, is done to achieve desirable properties such as water resistance and resistance to wood-decaying agents. One material used for heat treatment is vegetable oil as a heat-transfer medium, but this is not without its challenges. Edible oils such as soybean, palm, and sunflower are staple foods. Diverting a large volume of such vegetable oil for wood treatment may compete directly with human consumption, leading to higher costs and eventually limiting its

availability. The performance of oil being liquid at room temperature may also constitute leaching, which may inadvertently cause a sticky surface. Thus, using edible vegetable oil in wood treatment will create a food-versus-materials conflict and raise the price of vegetable oil, thereby improving food security.

This paper aims to review the use of vegetable oils in wood heat treatment, with a view to exploring the potential of animal fats as alternatives to plant-based oils. Wood modification is the chemical, biological, or physical alteration of wood cells, resulting in desirable properties such as extending the service life of wood (Hill, 2006). Mandraveli *et al.* (2024) noted that modifications can be classified according to the process used. This has been broadly grouped into four: chemical modification, hydro/thermo modification, electromagnetic modification, and other processes, such as biological processes and metabolite treatment. According to Hill *et al.* (2021), treating wood below 150 °C is referred to as thermal ageing, while treating wood above 150 °C and below 240 °C is referred to as thermal modification. Treatment done above 240 °C is referred to as thermal degradation of wood. Heating wood at a low temperature over a longer period tends to plasticize it, making it more water-resistant, whereas heating at a higher temperature induces stress in the wood. According to Endo *et al.* (2016), heating wood for 48 hours at 120 °C resulted in 0% dimensional changes compared to untreated wood.

Fungicidal Property of Fatty Acid

Fungi are ubiquitous microorganisms that can occupy a wide range of environments in the gaseous, liquid, and solid phases (Dix & Webster, 2012). It is estimated that 1.5 to 5.1 million fungal species exist, but only approximately 120,000 have been identified (Hawksworth & Lucking, 2017). Some fungi, such as yeast, are opportunistic and can cause significant losses, while others may be beneficial. The disadvantages of fungi are not limited to living plants and animals but also to stored crops and wood in service (Brown *et al.*, 2012). Oils or lipids are primarily composed of fatty acids in the form of triacylglycerol, where three fatty acids are attached to a glycerol molecule. The position and type of fatty acids attached to the glycerol determine the properties of the oil, such as its melting and boiling points (Lunn & Theobald, 2006; Guimaraes & Venancio, 2022). According to Guimaraes and Venancio (2022), using fatty acids as fungicides offers benefits over synthetic chemicals. Fatty acids are natural and eco-friendly alternatives to synthetic chemicals, useful for controlling plant disease, mopping up environmental hazardous chemicals, and are less likely to be resisted by fungi. Fatty acids offer an added advantage by allowing recovery from waste materials, promoting sustainability and the circular economy (Altieri *et al.,* 2007; Nobili *et al.,* 2019).

Guimaraes and Venancio (2022) noted that the main proposed mechanism of action against fungal activity is that fatty acids penetrate and disrupt the lipid bilayers of fungal membranes, thereby compromising their integrity and leading to the uncontrolled release of intracellular electrolytes and proteins. This inadvertently led to cytoplasmic disintegration of fungal cells (Avis & Bélanger, 2001). Thibane *et al*. (2012) noted that several polyunsaturated fatty acids (PUFAs) may increase the unsaturation ratio of the fungal cell membrane, thereby leading to the accumulation of intracellular reactive oxygen species (ROS) and, eventually, the loss of mitochondrial membrane. However, according to Suzuki *et al.* (2000) and Yonezawa *et al.* (2001), fungal activity may be inhibited by topoisomerase I, an enzyme involved in the breaking and repairing of DNA, as well as in replication, transcription, and recombination (Pommier, 2006). According to Suzuki *et al.* (2000), the type of fatty acids and the position of the fatty acids influence the efficiency of the

topoisomerase I, noting that Cis-monounsaturated fatty acids are the most effective in inhibiting topoisomerase I. The work of Li *et al*. (2003) found that 2-hexadecynic acid influences the elongation of saturated and unsaturated fatty acids, and, as a result of these changes, topoisomerase I becomes impeded. The work of Xu *et al.* (2012) also indicated that 6-nonadecynoic acid interferes with sphingolipid biosynthesis. This sphingolipid regulates critical cellular processes, including signaling and proliferation, while constituting a significant portion of the plasma membrane.

Bergsson *et al.* (2001) reported that capric and lauric acids are cytotoxic against *Candida albicans* at 2.5 and 10 mM, respectively, leading to disintegration of the plasma membrane due to intracellular hydrostatic turgor pressure. According to Clausen *et al.* (2010), pentanoic acid at 6% concentration was effective in inhibiting mold fungi. Furthermore, it was reported that formulating caprylic acid with a phosphate ester as an emulsifier and L-lactic acid resulted in 100 percent inhibition of mold fungi (*Aspergillus niger*, *Penicillium chrysogenum*, and *Trichoderma viride*) and sapstain fungus (*Aureobasidium pullulans*) on pressure-treated wood.

Oil Heat Treatment on Wood Durability

Rapp and Sailer (2001) reported a significant reduction in weight loss of Pine and Spruce when treated with linseed oil at 180 ºC, 200 ºC, and 220 ºC, and in hot air, compared to untreated samples exposed to *Coniophora puteana.* The percentage weight loss of oil-treated samples was lower than that of hot-air-treated samples for both species. An increase in temperature from 180 ºC to 220 ºC resulted in increased weight loss, with 2% and 1% weight loss in pine and spruce, respectively, at 200 oC. Bazyar (2012) treated Aspen wood with linseed oil at 190 ºC, 205 ºC, and 220 ºC; the bioassay showed that the samples treated at 220 ºC had the lowest weight loss when inoculated with *Coriolus versicolor* and *Coniophora puteana.* Falemara *et al.* (2015) *recorded the lowest weight loss for the wood of *T. scleroxylon* treated in hot oil than in cold treatment (18.20 ± 8.73 and 21.04 ± 8.15, respectively) when inoculated with *Sclerotium rolfsii* and *Pleurotus sajorcaju*. Var *et al.* (2021) reported treating pine with castor and flaxseed oil at 110 °C for 6 hours, then immersing it in cold oil for 2 hours, and measuring weight loss after inoculation with *Trametes versicolor* (white rot). *Neolentinus lepideus* (brown rot) shows that castor oil as a standalone treatment was not significantly different from the untreated sample. However, flaxseed oil was significantly more effective than either castor oil alone or a mixture of the two oils. The result suggests that castor oil may not contain an unsaturated fatty acid that is deleterious to the two fungi used, as the treated wood samples showed higher weight loss than the untreated wood samples (32% compared to 26.47% and 28.22%, respectively). Thus, flaxseed may contain more polyunsaturated fatty acids than castor oil, since its presence inhibits the growth of fungal mycelia (Thibane *et al*., 2012). Gandova *et al.* (2023) reported that fatty acids with significant amounts in flaxseed oil are oleic, linoleic, α-linolenic, palmitic and stearic acid.

Fatty Acid Profile in Animal Fat

Fatty acid composition is One of the important attributes that determine the nature of most natural lipids (Marikkar *et al.,* 2021*;* Guimaraes & Venancio, 2022). Abonyi *et al.* (2018) investigated the fat profile in pigs, goats, ts, and cattle, with consideration not limited to the viscera, also including the fats in the brain. The amounts of fatty acids in the liver, kidney, intestine, muscle, and skin were evaluated for cholesterol levels and triglyceride concentrations. Table 1 shows that the

accumulation of fatty acids is highest in the kidney of the pig and higher in the liver of cattle than in the liver of the pig and the goat, respectively, but it is the least in the skin of cattle.

Table 1: Concentration of triglyceride (mg/dL) in pig, goat and cattle

Organ/tissue	Pig	Goat	Cattle
Liver	4.30	3.89	4.80
Kidney	5.14	3.86	4.43
Intestine	2.28	2.89	2.69
Brain	4.38	3.09	3.28
Muscle	2.68	2.04	2.29
Skin	2.55	1.55	1.44

Source: Abonyi *et al.,* (2018)

Marikkar *et al.* (2021) extracted fat from adipose tissue of pigs, sheep and cattle. They noted that the fatty acid composition revealed that oleic acid was highest in pig fat than in the other animal fats. Oleic acid was generally higher than all other identified fatty acids. Palmitic acid was the next most abundant fatty acid identified. At the same time, capric acid was not identified in the cattle fat; it was present in pig and sheep fat. Lauric acid was the least present in cattle fat in Table 2. However, stearic acid was in abundance in sheep fat, with 16.53% in cattle fat.

Table 2: Fatty acid composition (%) in pig, goat and cattle

Fatty acid	Common name	Pig fat	Goat fat	cattle fat
C10:0	Capric acid	0.08	0.29	
C12:0	Lauric acid	0.19	0.46	0.11
C14:0	Myristic acid	2.28	6.40	6.15
C15:0	Pentadecanoic acid	0.05	0.76	0.46
C16:0	Palmitic acid	24.64	27.38	31.07
C16:1	Palmitoleic acid	1.07	0.52	2.56
C17:0	Margaric acid	0.25	1.85	0.82
C18:0	Stearic acid	11.53	30.90	16.53
C18:1	Oleic acid	42.62	29.82	35.70
C18:2	Linoleic acid	17.29	1.61	6.5

Source: Marikkar *et al.* (2021)

Table 3 shows the results of the investigation into the characterization of fat from the intestinal organs of cattle obtained from Iwo town. The table shows that gamma-linolenic acid was abundant

in the rendered fat (232.47 mg/L). Oleic acid, pentadecylic acid, margaric acid, z-heptadec-10-enoic acid and palmitic acid were present in large concentrations. While capric acid was not detected in the work of Marikkar *et al.* (2021), 0.16 mg/L of caprynic acid and 1.29 mg/L of caprylic acid were present in the rendered fat. A small amount of lauric acid (0.41 mg/L) was present in the investigation, compared with 0.11% in Table 2.

Table 3: fatty acid composition from rendered cattle fat

Sn	Fatty Acid	Retention time	Quantity mg/L	Structure	Name
1	Octanoic acid	4.019	1.29	$C_8H_{16}O_2$	Caprylic acid
2	Capric acid,	5.193	0.16	$C_{10}H_{20}O_2$	Caprylic acid
3	Undecanoic acid	5.599	0.94	$C_{12}H_{24}O_2$	Undecylenic acid and hendecanoic acid
4	Dodecanoic acid	6.131	0.41	$C_{13}H_{28}O_2$	Lauric acid
5	Tridecanoic acid	6.514	0.45	$C_{14}H_{28}O_2$	Tridecylic acid
6	Methyl myristoleate	6.875	1.05	$C_{15}H_{28}O_2$	Methyl cis-9-tetradecenoate and myristoleic acid
7	Methyl tetradecanoate	6.932	1.32	$C_{15}H_{30}O_2$	Methyl myristate, myristic acid
8	cis-10-Pentadecenoic acid,	7.596	3.6	$C_{15}H_{28}O_2$	10z-pentadecenoic acid
9	Pentadecanoic acid,	7.659	60.02	$C_{15}H_{30}O_2$	Pentadecylic acid
10	9-Hexadecenoic acid,	7.596	3.7	$C_{16}H_{30}O_2$	Palmitoleic acid
11	Hexadecanoic acid,	7.659	20.25	$C_{16}H_{32}O_2$	Palmitic acid
12	cis-10-Heptadecenoic acid	7.813	22.74	$C_{17}H_{32}O_2$	(z)-heptadec-10-enoic acid
13	Heptadecanoic acid	8.26	49.76	$C_{17}H_{34}O_2$	Margaric acid
14	gamma-Linolenic acid	8.242	232.47	$C_{18}H_{30}O_2$	Gamolenic acid
15	Oleic acid	8.26	75.72	$C_{18}H_{34}O_2$	Oleic acid
16	Methyl stearate	8.311	6.03	$C_{19}H_{38}O_2$	Stearic acid methyl ester

17	Arachidonic acid	8.712	27.35	$C_{20}H_{32}O_2$	Arachidonic acid
18	5,8,11,14,17-Eicosapentaenoic acid	8.712	24.15	$C_{20}H_{30}O_2$	Epa
19	cis-11,14-Eicosadienoic acid	8.809	42.70	$C_{20}H_{36}O_2$	di-homo-linoleic acid
20	cis-11-Eicosenoic acid	8.803	14.01	$C_{20}H_{38}O_2$	Gondoic acid
21	Eicosanoic acid	8.849	3.97	$C_{20}H_{40}O_2$	Arachidic acid
22	Heneicosanoic acid	9.124	2.15	$C_{21}H_{42}O_2$	Heneicosylic acid
23	4,7,10,13,16,19-Docosahexaenoic acid	9.284	6.65	$C_{22}H_{32}O_2$	Cervonic acid
24	13-Docosenoic acid	9.364	1.06	$C_{22}H_{42}O_2$	Erucic acid
25	Docosanoic acid	9.41	0.34	$C_{22}H_{44}O_2$	Behenic acid
26	Tricosanoic acid	9.724	0.27	$C_{23}H_{46}O_2$	Tricosylic acid
27	15-Tetracosenoic acid	9.856	2.03	$C_{25}H_{48}O_2$	Nervonic acid, Selacholeic acid
28	Tetracosanoic acid	10.005	0.26	$C_{25}H_{50}O_2$	Lignoceric acid

Source: Laboratory investigation on fat from the visceral organs of cattle

Conclusion

The higher concentrations of fatty acids of particular interest: oleic acid, palmitic acid, linoleic acid, stearic acid and linolenic acid present in fat from domestic animals are a potential source of fatty acids for oil heat treatment in wood treatment. Cattle, being the largest slaughtered animal across the country, will provide a ready source of wood for treatment. Secondly, the issue of competition for land meant for arable crop cultivation would have been mitigated with fatan as an alternative to vegetable oil for oil heat treatment. Thirdly, sustainable land use for crop cultivation to feed cattle will both mitigate human food insecurity and meet the demand for protein, while providing oil for wood treatment. Thus, the efficacy of using animal fat as an alternative to vegetable oil in oil heat treatment needs to be investigated with respect to wood enhancement, such as resistance to decay, aesthetics, and wood stability.

Reference

Abonyi, F. O., Ogbu, I. J. & Unigwe, C. R. (2018). Comparative study of lipid profile of pigs, goats and cattle slaughtered at Nsukka Municipal Abattoir, Enugu State, Nigeria. *Nigerian Journal of Animal Production*. 45(1): 164 - 171

Adetogun, A. C., Aina, O. M. & Ogunsanwo, O. Y. (2003). Evaluation of Cashew nut shell liquid (CNSL) as a wood preservative using crushing strength. ASSET. An. Int. Series A 3(4): 55-61 UNAAB

Altieri, C., Cardillo, D., Bevilacqua, A., and Sinigaglia, M. 2007. Inhibition of *Aspergillus* spp. and *Penicillium* spp. by fatty acids and their monoglycerides. *J. Food Prot.* 70: 1206–1212.

Avis, T. J. & Bélanger, R. R. (2001). Specificity and mode of action of the antifungal fatty acid cis-9-heptadecenoic acid produced by *Pseudozyma flocculosa*. *Appl. Environ. Microbiol.* 67: 956–960.

Bazyar, B. 2012. Decay resistance and physical properties of oil-heat-treated aspen wood. *BioResources* 7(1): 696-705. https://ojs.cnr.ncsu.edu/index.php/BioRes/article/view/BioRes_07_1_0696_Bazyar_Decay_ Resistance_Properites_Oil_Heat_Treated_Aspen

Bergsson, G., Arnfifinnsson, J., Steingrímsson, O., & Thormar, H. (2001). *In vitro* killing of *Candida albicans* by fatty acids and monoglycerides. *Antimicrob. Agents Chemother.* 45: 3209–3212.

Brown, G. D., Denning, D. W., & Levitz, S. M. (2012). Tackling human fungal infections. *Science 336*: 647

Clausen, C. A., Coleman, R. D. and Yang, V. W. 2010. Fatty acid-based formulations for protection against mold and sapstain. *Forest Products Journal.* 60(3): 301-304. https://doi.org/10.13073/0015-7473-60.3.301

Dix, N. J. & Webster, J. (2012). *Fungal Ecology*; Springer Science: Berlin/Heidelberg, Germany.

Endo K, Obataya E, Zeniya N, Matsuo M (2016). Effects of heating humidity on the physical properties of hydrothermally treated spruce wood. *Wood Sci Technol* 50:1161–1179. https://doi.org/10.1007/s00226-016-0822-4

Falemara, B. C., Ampitan, T. and Oyeleye, I. O. 2015. Effects of Hot and Cold Treatment Techniques on Preservative Absorption of *Triplochiton Scleroxylon* (Obeche) Against Fungal Attack. *Appl. Trop. Agric J* 20(1): 146-151

Guimarães, A.and Venâncio, A. 2022. The Potential of Fatty Acids and Their Derivatives as Antifungal Agents: A Review. *Toxins* 14: 188. https://doi.org/10.3390/ toxins14030188

Hawksworth, D.L. & Lücking, R. (2017). Fungal diversity revisited: 2.2 to 3.8 million species. *Microbiol. Spectr. 5*: 10.

Hill, C., Altgen, M., & Rautkari, L. (2021). Thermal modification of wood: a review: chemical changes and hygroscopicity. *Journal of Materials Science*, *56*(11), 6581–6614. https://doi.org/10.1007/s10853-020-05722-z

Hill, C.A.S. (2006). *Wood Modification: Chemical, Thermal and Other Processes*; John Wiley & Sons, Ltd.: Hoboken, NJ, USA,

Kaplan, L., Kvietková, M. S., & Sedlecký (2018). M. Effect of the interaction between thermal modification temperature and cutting parameters on the quality of oak wood. *BioResources* 13: 1251–1264.

Lee, D. H., Tsunoda, K. & Takanashi, M. (1990). Laboratory evaluation of triiodoallyl alcohol as a wood preservative. *Mat. Und. Org.* 25 Band 1990 Heft, 2: 145–159.

Li, X. C., Jacob, M. R., ElSohly, H. N., Nagle, D. G., Smillie, T. J., Walker, L. A., & Clark, A.M. (2003). Acetylenic acids inhibiting azole-resistant *Candida albicans* from *Pentagonia gigantifolia*. *J. Nat. Prod.* 66: 1132–1135.

Lunn, J. & Theobald, H. E. (2006). The Health Effects of Dietary Unsaturated Fatty Acids. *Nutr. Bull.* 31:178-224.

Mandraveli, E., Mitani, A., Terzopoulou, P., Koutsianitis, D. (2024). Oil Heat Treatment of Wood: A Comprehensive Analysis of Physical, Chemical, and Mechanical Modifications. *Materials.* 17: 2394. https://doi.org/10.3390/ma17102394

Marikkar, N, Alinovi, M. and Chiavaro, E. 2021. Analytical approaches for discriminating native lard from other animal fats. *Italian Journal of Food Science,* 33 (1): 106-115 DOI 10.15586/ijfs.v33i1.1962

Nobili, C., De Acutis, A., Reverberi, M., Bello, C., Leone, G.P., Palumbo, D., Natella, F., Procacci, S., Zjalic, S., & Brunori, A. (2019). Buckwheat hull extracts inhibit *Aspergillus flavus* growth and AFB1 biosynthesis. *Front. Microbiol.* 10: 1997.

Pohl, C. H., Kock, J. L. F., & Thibane, V. S. (2011). Antifungal Free Fatty Acids: A Review. In *Science Against Microbial Pathogens: Communicating Current Research and Technological Advances*; Méndez-Villas, A., Ed.; Formatex Research Center: Gigiri, Nairobi, Kenya, 3: 61–71.

Pommier, Y. Topoisomerase I inhibitors: Camptothecins and beyond. *Nat. Rev. Cancer* **2006**, 6: 789–802.

Rapp, A. O. & Michael Sailer, M. (2001). Oil-heat-treatment of wood - process and properties. *Drvna Industrua Journal* .52 (2): 63-70

Rowell, R., Pettersen, R., Tshabalala, M. (2012). *Handbook of Wood Chemistry and Wood Composites: Cell Wall Chemistry*, 2nd ed.; CRC Press: Boca Raton, FL, USA,

Suzuki, K., Shono, F., Kai, H., Uno, T., and Uyeda, M. 2000. Inhibition of topoisomerases by fatty acids. *J. Enzym. Inhib.*, 15*:*357-366.

Thibane, V. S., Ells, R., Hugo, A., Albertyn, J., Van Rensburg, W. J. J., Van Wyk, P. W., Kock, J. L., and Pohl, C. H. 2012. Polyunsaturated fatty acids cause apoptosis in *C. albicans* and *C. dubliniensis* biofilms. *Biochim. Biophys. Acta Gen. Subj.* 1820: 1463-1468.

Var, A. A., Yalçin, M., Yalçin, Ö. Ü. & Demir, M. (2021). Effects of hot-cold oil treatment on biological resistance and physical properties of Brutia Pine sapwood. *Maderas. Ciencia y tecnología* (23): 42, DOI: 10.4067/s0718-221x2021000100442

Wacker, J. P. (2010). Use of Wood in Buildings and Bridges. In *Wood Handbook: Wood as an Engineering Material*; Chapter 17, Centennial ed.; General Technical Report FPL; GTR-190; U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: Madison, WI, USA, pp. 17.1-17.13.

Xu, T., Tripathi, S. K., Feng, Q., Lorenz, M. C., Wright, M. A., Jacob, M. R., Mask, M. M., Baerson, S. R., Li, X.-C., Clark, A. M. (2012). A potent plant-derived antifungal acetylenic acid mediates its activity by interfering with fatty acid homeostasis. *Antimicrob. Agents Chemother.*, 56*:* 2894–2907.

Yonezawa, Y., Hada, T., Uryu, K., Tsuzuki, T., Eitsuka, T., Miyazawa, T., Murakami-Nakai, C., Yoshida, H., & Mizushina, Y. (2005). Inhibitory effect of conjugated eicosapentaenoic acid on mammalian DNA polymerase and topoisomerase activities and human cancer cell proliferation. *Biochem. Pharmacol.*, 70*:* 453–460.

OPTIMIZING SEED GERMINATION OF CHRIST'S THORN JUJUBE (*ZIZIPHUS SPINA*- CHRISTI (L.) DESF. USING PRIMING TECHNIQUES IN KADUNA NORTHERN GUINEA SAVANNA ECO-ZONE, NIGERIA.

Rasheed, F.M[1], Sodimu, A.I[*2], Bayo, D[3]., and Yakubu, M.H[2]

[1]Federal College of Forestry Mechanization, Forestry Research Institute of Nigeria, PMB 2273, Afaka-Kaduna, Nigeria.
[2]Savanna Forestry Research Station, Forestry Research Institute of Nigeria, PMB 1039, Samaru – Zaria, Kaduna, Nigeria.*
[3]Northern Guinea Research Station, Forestry Research Institute of Nigeria, Nasarawa, Nigeria.

Abstract

Many seeds are adversely affected by seed coat dormancy, which makes germination difficult and reduces potential crop productivity. The objective of this study was to evaluate the effectiveness of seed priming methods for germination of Christ's thorn Jujube (*Ziziphus spina-Christi (L) Desf.*). Seeds were sourced from the Savannah Forestry Research Station, Samaru, Zaria. Treatments consisted of soaking seeds in water at a maintained temperature of 100 ºC for 10, 15, or 20 minutes; soaking seeds in diluted sulphuric acid (H_2S_{O4}) for 10, 15, or 20 minutes; and a control (no priming). Ten seeds from each treatment were sown in germination boxes containing sterilized riverbank sand, and the experiment was replicated three times. The experiment was laid out in a completely randomized design (CRD). Results showed that both priming methods adopted significantly enhanced seed germination ($p<0.05$). However, seed soaked in diluted sulphuric acid (H_2S0_4) for 20 minutes (77.60±7.34) gave the best result compared to that soaked in hot water for 20 minutes (47.67±14.68). Seeds in the control had the lowest overall germination rate (3.20±7.34). Therefore, for effective and rapid multiplication of *Christ's Thorn* Jujube seedlings, soaking the seed in diluted sulphuric acid (H_2S_{O4}) for 20 minutes is recommended at the nursery level.

Keywords: River bank sand, Germination, Sulphuric acid, Multiplication, Optimizing.

Introduction

Many seeds of certain forest tree species are difficult to propagate owing to extensive seed dormancy, which compromises germination and leads to low population densities (Danthu *et al*., 1992). In the affected tree species, seeds germinate slowly and sometimes fail to germinate (Dogodaji, 2002). This is because the seeds easily lose viability, as exhibited through the evolution of oxygen and water to the embryo (Nwoboshi, 1982). This is also caused by either, or a combination of, immaturity of the embryo, impermeability of seed coats, mechanical resistance of seed coats to the growth of the embryo, metabolic blocks within the embryo, and secondary dormancy (Villiers, 1972). Pre-germination treatment is important to mitigate the risks associated with sowing seeds with low germinability. Pre-treatment of seeds enhances the accessibility of water and oxygen into the seeds, thus augmenting the germination process.

Germination is critical to regeneration, and dormancy limits seed germination and seedling availability for afforestation, domestication, multiplication, reforestation, and biodiversity

conservation. (Dahunsi *et al.*, 2020) Pre-germination treatment is important to mitigate the risks associated with sowing seeds with low germinability. Pretreatment of seeds enhances the accessibility of water and oxygen into the seeds, thus augmenting the germination process and avoiding the wastage of time, money, and energy. Planters need to use appropriate priming methods to overcome seed dormancy and improve seedling growth in the nursery. (Adelani *et al.,* 2021). Among the most affected tree species is *Ziziphus spina–christi (Kurna)*, which derives its name "spina-christi" from the legend that Jesus Christ was crowned with the branches of this *Ziziphus* species (Amanuel, 1994). It is widespread in the North-eastern part of Nigeria and in the dry areas of northern Africa, from sea level up to 1900 m in wooded grassland. In arid and semi-arid regions, desert encroachment resulting from excessive deforestation led to dwindling agricultural fields and poor soil conditions (Abubakar, 2002). Consequently, communities are no longer able to meet the upsurge in demand for forest products, food, fodder, fuelwood and other minor forest products. Therefore, there is an urgent need to explore methods for seed pregermination, raising, and tending of indigenous species so that most of them are protected from extinction due to the threat of surging anthropogenic activities. Meanwhile, the neglect of these species results in the loss of information on more efficient methods for pretreating indigenous seeds to promote the rapid germination of tree species for plantation establishment. The objective of the study was to enhance seed germination of *Ziziphus spinosa Christi* (L.). Desf. using priming techniques with a view to easy multiplication of the seedlings in the nursery for plantation establishment.

Materials and methods

Study area

This study was conducted at the Savanna Forestry Research Station nursery (SFRS), situated on the Institute for Agricultural Research (I.A.R) farm at Samaru, in Kurumi Bomu village, in the Kaduna Northern Guinea Savannah Eco- Zone of Nigeria. The station is located at latitude 12º13'and 11º11' N and longitude 8º39' and 7º38' E; 686 m above sea level. The vegetation of the area is the Northern Guinea Savannah woodland type, characterized by short, scattered, drought-resistant trees, with undergrowth of grass that serves as fuel for bushfires in the long dry seasons, with mean annual rainfall of 1000 – 1500 mm, temperature of 25.6 ^{0}C (78.1ºF), and humidity of 69% (Sodimu *et al.*, 2021).

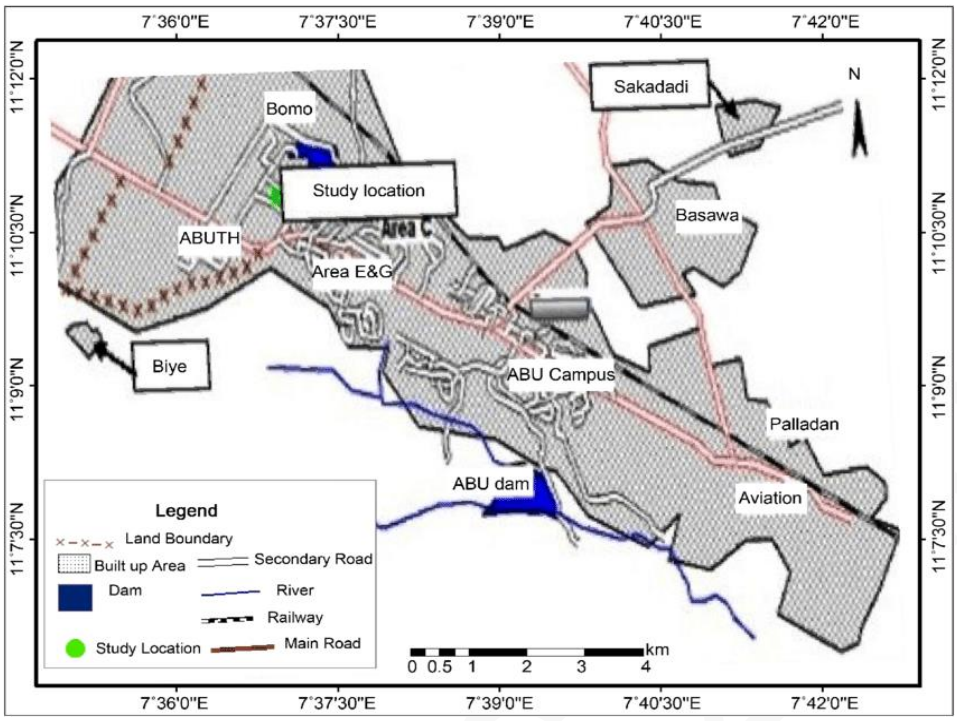


Figure 1: Showing the Study location of the SFRS, Nursery
Source: Sodimu (2025)

Treatments and experimental design

Treatments consisted of boiling water (100 ºC) for 10, 15, and 20 minutes; diluted sulphuric acid (H_2S_{O4}) soaking for 10, 15, and 20 minutes; and a control without priming. Ten seeds were soaked in each of the three treatments, arranged in a completely randomized design (CRD). All seeds from each treatment were sown in germination boxes containing sterilized riverbank sand, and the experiment was replicated three times.

Experimental Procedure

Water was boiled to attain and maintain a boiling point of 100 ºC, and seeds were soaked in the boiling water for 10, 15, and 20 minutes. The seeds were then removed and allowed to cool. Other seeds were soaked in diluted sulphuric acid (H_2S0_4) for three different periods (10, 15, and 20 minutes). After soaking, the seeds were removed, washed and rinsed in sterilized water to remove any remaining acid. A control treatment was included in which *Ziziphus spina–Christi* seeds were sown without any pre-germination treatment.

Data collection and analysis

Seed germination was monitored for 40 days, and data were collected on days to seedling emergence (number of days to the first seedling emergence), germination rate (number of seeds germinated) and germination percentage. Percent seed germination (PG) and germination rate (GR) were estimated using Equations 1:

$$\boldsymbol{GP = \frac{SG}{TS} \times 100} \text{..... Equation 1}$$

Where: GP = germination percentage,

SG = seed germinated, and

TS = total number of seed germinated.

$$\boldsymbol{GR = \frac{GP}{GT} \times 100} \text{ ..... Equation 2}$$

Where: GR = Germination rate,

GP = Germination percentage

GT = Germination time

Data were analyzed using descriptive statistics and Analysis of Variance (ANOVA) in the Statistical Package for the Social Sciences (SPSS). Significant means were compared using the Least Significant Difference (LSD) test at the ($P<0.05$) level.

Results and Discussion

Priming by the hot water treatment method

All pre-germination treatments involving soaking in water at 100^0C increased seed germination rates (Table 1), with soaking for 20 minutes resulting in the highest germination rate (47.67±14.68). Similar results were also reported by Duguma *et al.* (1998), who noted that hot-water treatment was the most effective technique for improving seed coat permeability in *Leucaena leucocephala*. This also aligns with the results of Owonubi *et al.* (2005) for *Azadirachta indica* seeds and Ibrahim and Otegbeye (2004) for *Adansonia digitata* seeds. This, however, contradicts the case of *Calliandra prototricensis seeds,* which failed to germinate in heated water (Gill *et al*., 2006). Therefore, from these results, it can be inferred that soaking in water at 100 ^{0}C for 20 minutes produced a significant increase in seed germination rates of Christ's thorn Jujube *(Ziziphus spina-Christi)*

Table 1: Hot water (100 °C) seed pretreatment in relation to germinability of Christ's thorn Jujube *(Ziziphus spina-Christi)*

Treatment (minutes)	Number of days for first emergence	Number of seeds germinated	Germination percentage
10	15.00±0.00[a]	0.3233	32.33±7.34[c]
15	16.83±0.65[a]	0.3764	37.64±7.34[c]
20	15.00± 0.00[a]	0.4767	47.67±14.68[c]
	0.00		0.00

Means with the same letters along the same column are not significantly different from each other (P>0.05).

Priming by soaking in dilute sulphuric acid

Soaking seeds of Christ's thorn Jujube in dilute H_2S_{O4} resulted in significantly higher germination values (Table 2), though at levels much lower than those in the hot-water treatments. Similarly, soaking for 20 minutes again yielded the best germination values (77.60±7.34%) compared to other exposure times (Table 2). This result agreed with the work of Aduradola *et al. (*1998), who worked on *Enterolobium cyclocarpum* and *Pilostigma reticulatum*, and Adio *et al.* (2006), who worked on *Adansonia digitata*, who also noted that treatment with the acid significantly promoted seed germination. Dachung and Verinumbe (2006) also contended that acid treatment of seeds removes the waxy layer of the seed coat by chemical decomposition of its components, resulting in faster seed germination. Overall, however, although seed priming by this procedure is effective in improving the germinability of Christ's thorn Jujube *(Ziziphus spina-Christi),* the comparative superiority of hot water, which is environmentally safer and economically cheaper to use, may edge out the former for scaling up to mass producers.

Table 2: Dilute sulphuric acid seed pretreatment in relation to germinability of Christ's thorn Jujube *(Ziziphus spina-Christi)*

Treatment (Minutes)	Number of days for first emergence	Number of seeds germinated	Germination percentage
10	15.00±0.00[a]	0.721	72.10±11.34[b]
15	16.43 ±1.25[a]	0.752	75.20±12.34[b]
20	12.00± 0.00[ab]	0.776	77.60±7.34[b]
SE ±	0.00		16.00

Means with the same letters along the same column are not significantly different from each other (P>0.05).

Control (no priming)

The lowest germination rate was observed in the untreated seeds (no priming), serving as the control (3.20±7.34%) (Table 3). This contrasted with the results reported by El-Nour *et al.* (1991), who found that control, untreated *Balanite aegyptiaca* seeds had significantly higher germination than those boiled in hot water.

Table 3: Untreated control in the assessment of priming methods of Christ's thorn Jujube *(Ziziphus spina-Christi)* seed

Treatment	Number of days for first emergence	Number of seeds germinated	Germination percentage
Control	8.42±12.23[b]	0.0323	3.20±7.34[d]
SE ±	8.415		0.367

Means with the same letters along the same column are not significantly different from each other (P>0.05).

Conclusion and Recommendations

It is clear from this study that the germinability of Christ's thorn jujube (*Ziziphus spina-christi*) benefits significantly from the different priming pretreatments used. Overall, however, priming seeds in diluted sulphuric acid for 20 minutes was the most outstanding, followed by soaking seeds in hot water for 20 minutes. For the regeneration of planting materials at a commercial scale, however, it is imperative that a more extensive economic evaluation be performed, particularly under farmer nursery conditions. Based on the results, it is recommended that, for the easy multiplication of seedlings of Christ's thorn jujube (*Ziziphus spina-christi***)** for plantation establishment, nursery workers adopt diluted sulphuric acid (soaking for 20 minutes) as a pre-sowing treatment to promote better germination of the species.

References

Abubakar, M. (2002). Effects of Mycorrhiza and Watering Regime on *Acacia senegal (Linn)* Wild in a Semi-Arid Environment*. M.Sc. Dissertation (Unpublished). Usmanu Danfodiyo University, Sokoto, Nigeria.*pp 73.

Adelani, D.O., Ariyo, O.C., Olorukoba, M.M., Suleiman, R., & Balogun, O.S. (2021). Effects of priming methods and organic fertilizers on the germination and early seedling growth of three indigenous agroforestry tree species. *Journal of Forestry Research and Management* 18 (1): 11 – 23.

Aduradola, A.M., Adeodola, B.F. & Adedire, M.O. (1998). Enhancing germination in seeds of African Star apple, *Chrysophyllum albidium G. Don*. *Journal of Food, Agriculture and Environ*ment 3:285-287.

Adio, A. F., Odigie, G.A. & Imran, G.T. (2006). The influence of pretreatments on germination of seeds of *Adansonia digitata* (Baobab). *Journal of Forest and Management* 5(3):23-29.

Amanuel, G. (1994). Indigenous trees and shrubs of Eritrea. Department of Forestry, Wildlife and Environment, Ministry of Agriculture, Asmara, Eritrea. 49pp.

Dahunsi, O.M., Baba, G.O., Olaifa, R.K., Erhabor, T.A. & Sodimu, A.I. (2020). Effect of different pre-germination treatments on germination and early growth of *Balanites aegyptiaca* seeds in Northern Guinea Savanna Agrological zone, Nigeria**.** *South Asian Research Journal of Biology and Biosciences* 2(6):121-126

Danthu, A., Roussel, J. & Saar, A. (1992). Effect of Different Pretreatments on the Germination of *Acacia senegal* Seeds. *Seed Science and Technology* 20(1):111-117

Dogodaji, A. (2002). Effects of Pre-Sowing Treatment on Seed Germination of Three Indigenous Tree Species in a Semi-Arid Environment. M.Sc. Dissertation (unpublished). *Usmanu Danfodiyo University, Sokoto, Nigeria.* 59pp.

Dachung, G. & Verinumbe, I. (2006). Effects of water and Acid pretreatment on the Germination of *Prosopis africana* seeds. Proceedings of the Paper Presented at the 31st Annual *Conference of the Forestry Association of Nigeria* held in Makurdi, Benue State, Nigeria. pp.11–18

Duguma B, Kang, B.T, & Okali, D.U. (1998). Factors Affecting the Germination of *Leucaena leucoph*ylla Seeds. *Science and Technology*. 16:489-500.

El-Nour, M., El-Khalifa, K., Massimo, K., & ElHassen, B. (1991). Preliminary Study on Seed Pre - germination. pp. 23.

Gill, L., Onyibe, H.I. & Asemota, B.P. (2006). Studies on the Germination of Callian draportoricensis (Benth)—*the Nigerian Journal of Forestry* 22:53-57.

Ibrahim, A. & Otegbeye, G. O. (2004). Methods of Achieving Optimum Germination in *Adansonia digitata*. *Bowen Journal of Agriculture* 1:53-58.

Nwoboshi, L.C. (1982). Principles of Tropical Silviculture and Techniques. Oxford University Press, Ibadan, Nigeria. pp.210.

Owonubi, J. J., Otegbeye, G. O. & Nwokedi, C. (2005). A Development of Pre-Germination Technique for *Azadirachta indica*: Preliminary Investigation. In: Sustainable forest Management in Nigeria: Proceedings of the Papers Presented at *30th Annual Conference of the Forestry Association of Nigeria*, held in Kaduna, Kaduna State, Nigeria. 29-39.

Otegbeye, G.O., Owonubi, J.J. & Oviasuyi, P. K. (2001). Interspecific Variation Growth of Eucalyptus growing in Northern Nigeria. Proceedings of Paper Presented at *the 27th Annual Conference* of the *Forestry Association of Nigeria.* Pp. 12–16.

Sodimu, A. I., Olaifa, R.K., Baba, G.O., Lapkat, G. L., Olorukooba, M.M., Olumuyiwa, S.A., Salau, L.O. and Rasheed, F.M. (2021). Effects of Boiled Water on Germination Potential and Early Growth of Faidherbia albida. (Del.) A. Chev. Seeds in Kaduna Northern Guinea Savannah Agrological Zone of Nigeria. *Ethiopian Journal of Environmental Studies and Management.* 14 (2):208 – 222.

Sodimu, A.I. (2025). Pre-sowing treatments pathways for enhancing *Milletia thonningii* (Schum and Thonn.) seed germination in the Kaduna Northern Guinea Savanna Ecology Zone of Nigeria. *Journal of the Kenya National Commission for UNESCO,* 6 (1), 1 – 10. ISO 9001: 2015 Certified. ISSN: 2958 – 7999 – 6467.

Villiers, T. A. (1972)."Seed dormancy. Kozlowski, T.T (Ed.). Academic Press, New York and London. 2: 219 -281.

GERMINATION DYNAMICS OF *Prosopis africana* GUILL. AND PERR. SEEDS AS INFLUENCED BY PRE-SOWING TREATMENTS IN KADUNA NORTHERN GUINEA SAVANNA ECOLOGY ZONE OF NIGERIA.

Bayo, D[1], Sodimu, A. I[2*], Rasheed, F.M[3] and Salau, I. O[2]

[1]Northern Guinea Research Station, Forestry Research Institute of Nigeria, Nasarawa, Nigeria.
*[*2]Savanna Forestry Research Station, Forestry Research Institute of Nigeria, P.M.B 1039, Samaru – Zaria, Kaduna, Nigeria.*
[3]Federal College of Forestry Mechanization, Forestry Research Institute of Nigeria, P.M.B 2273, Afaka – Kaduna, Nigeria
***Corresponding author**: tunsod88@gmail.com ; sodimu.ai@frin.ng*

ABSTRACT

Seed germination is a vital stage in plant development and can be considered a determinant for plant productivity. Forest tree species across the tropics can be effectively domesticated and conserved for various afforestation programmes after overcoming dormancy in their seed coats. Germination dynamics of *Prosopis africana* Guill. and Perr. Seeds influenced by Pre-Sowing Treatments in the Kaduna Northern Guinea Savanna Ecology Zone of Nigeria were studied. Seeds were sourced from Savannah Forestry Research Station, Samaru - Zaria, which were divided into 5 replicates of 20 seeds, each sown in a separate germination box in 10 treatments: H_2SO_4 for 15, 25 and 35 minutes; hot water (100^0C) for 7, 14 and 28 hours; cold water for 4, 7 and 9 days; and control with no treatment. Seedlings were arranged in a Completely Randomized Design (CRD). The treated seeds were sown in a germination box containing sterilized riverbank sand, and each replicate was replicated 5 times. Germination count was based on the emergence of the radicle daily from sowing up to 20 days after sowing. Percentage germinations for each treatment were arcsine transformed, subjected to ANOVA and were separated using DMRT at ($P \leq 0.05$). The results revealed significant differences in germination ($P \leq 0.05$). However, seeds soaked in cold water for 7 days, 9 days, and seeds with no treatment at all, had the same number with no germination. The study concluded that soaking Prosopis africana seeds in H2SO4 for 35 minutes breaks their dormancy and enhances germination, resulting in 85.4% germination; hence, it was recommended for uniform and improved seed germination in the Kaduna Northern Guinea Savanna Ecozone of Nigeria.

Keywords: Germination, pre-sowing, Prosopis africana, afforestation, nursery, dormancy.

Introduction

The Fabaceae family includes the genus Prosopis, which comprises about 45 species of spiny trees and shrubs that grow in tropical and subtropical climates in South Asia, Africa, Western Asia, and the Americas. African mesquite, iron tree, and gele (Malinke) Sombtree or Djembe wood are some of its common names. *Prosopis africana* is a deciduous tree that grows between 4 and 20 meters tall. It has an open crown and drooping branches. The tree mostly grows in the savanna regions of western Africa (Fasidi *et al.*, 2000). Its economic value makes it relevant to foresters. *Prosopis africana* has significant social, economic, cultural, medicinal, and agricultural value. In Nigeria,

fermented *Prosopis africana* seeds are used to make "Daddawa," "Kpaye," or "Okpeye," which are fermented foodstuffs used as sauces (Aremu *et al.*, 2006). *Prosopis africana* fixes nitrogen into the soil, produces high-protein leaves, and its sugar pods are fed to ruminants in Nigeria (Annongu *et al.*, 2004). This species is drought-resistant, frequently grows well in arid soil, and may form incredibly deep root systems. The pods' pulp has an energy value of 1168 J and is composed of 53% carbohydrates, 3% fat, and 9.6% protein (FAO, 2003). *Prosopis africana* is utilized in the production of sausages and cakes, as well as in the cooking of foods like soup and baked goods. Due to overexploitation, *Prosopis africana* is losing its range through stem and branch cutting, thereby reducing its natural regeneration capacity (Pasiecznik, 2004). Farmers use the bark and roots to treat illnesses, and the leaves and pods to make animal feed. Termites and fungi cannot penetrate the dense wood (Nygård & Elving, 2000; Gérardin, 2004). In addition, it has rich red-brown sapwood that is gray and extremely resistant. Its wood, used for building, poles, planks, mortars, and handles for agricultural tools, has been reported to have good physical properties, including dimensional stability and strength (Jone & Taupiac, 2004). Blacksmiths greatly value charcoal production from wood for making fire because of its high calorific value (Sotelo-Montes, 2011).

The fact that the majority of tropical forest tree seeds display some dormancy, which is One of the main issues with afforestation initiatives in the tropics (Ajboye & Adegboola, 2008). The tree's rich value makes it relevant to foresters. Though its seed coat is hard (dormant), the seeds must be pre-treated to enhance germination. Seed germination is a crucial process in plant growth and development (Oyebamiji *et al.*, 2014). Seeds of *Prosopis africana,* like most leguminous plants, possess a hard seed coat that hinders water imbibition **and** gaseous exchange and harbors inhibitors that suppress germination, a condition referred to as dormancy (Mwase & Mvula, 2011). Seeds of *Prosopis africana* exhibit physical dormancy caused by a water-impermeable seed coat; dormancy is broken when this barrier is disrupted by acid or hot-water scarification. The conditions necessary to allow seeds to break dormancy and germinate can be highly variable among species, within a species, or among seed sources of the same species (Luna *et al.,* 2009). Hard seed coat type and size have been identified by Agboola (1996) and Agbogidi *et al.* (2007) as attributes that affect the germination and growth of *Prosopis africana*. Dormancy in a seed could be considered simply as a block to the completion of germination of an intact or viable seed under favourable conditions (Finch-Savage & Leubner-Metzger, 2006). Such barriers are commonly removed using several scarification methods, including treatment with Tetraoxosulphate (VI) acid and steeping in hot water, as described by Azad *et al.* (2011), to make the seed permeable to water and hasten germination. Once dormancy has been broken, the period of active germination is usually less than 30 days. A possible exception to the above is a fresh collection of *Prosopis africana* seeds that has not been dried; without losing viability or long-term viability, such seeds may germinate promptly without pretreatment (Vautier *et al.*, 2007). *Prosopis africana* seeds exhibit orthodox seed behavior, meaning they can be dried and stored in cool, dry conditions (10 – 15 °C, 30 – 40% Relative Humidity) for long periods (5 – 10 years) (Agboola, 2004; Anshwange *et al.*, 2020). However, temperature has been observed to strongly influence seed germination in tropical forest trees, including *Prosopis africana* (Pearson *et al.,* 2002). Older seeds experience reduced germination rates and increased physical dormancy (Anshwange *et al.,*2020)

Seed germination is a vital stage in plant development and can be considered a determinant for plant productivity (Vickery & Vickery, 2007). To sustain good seedling development, seed stores food reserves mainly as proteins, lipids, and carbohydrates. Protein and oil bodies are the major

reserves in the oilseed of *Prosopis africana*, which represent a source of energy, carbon, and nitrogen during seedling establishment (Orji *et al.*, 2000). As the physiology of reserve mobilization in *Prosopis africana* during germination and post-germination events remains poorly understood, extensive studies are needed to elucidate the metabolic mechanisms of reserve food mobilization, providing insights into the ability to use such seeds as planting material (Zida *et al.*, 2005). Physiological and biochemical changes, followed by morphological changes, during *Prosopis africana* germination are strongly related to seedling survival rate and vegetative growth, which in turn affect yield and seed quality (Atiku *et al.*, 2013). Some methods to overcome physical dormancy in seeds include acid scarification, mechanical scarification, and water immersion (Baskin & Baskin, 2004). Acid and mechanical scarification are more costly and labor-intensive than hot- or cold-water treatments. These species, like *Prosopis africana*, generally possess hard seed coats that impose physical dormancy; hence, they respond to acid scarification and water-soaking treatments. These, including *Faidherbia albida and Acacia spp: Terminalia chebula, Tetrapleura tetrapetra* and *Adansonia digitata* (Oyebanji *et. al.* 2022).

Seed pretreatments are methods of treating seeds to enhance germination vigor. Given *Prosopis africana*'s potential, its germination and growth rates without seed pretreatment are very slow. However, it is worth notingworth noting that the most suitable pre-sowing treatment to stimulate seed germination and enhance seedling growth of *Prosopis africana* seeds has yet to be identified. A dormant seed does not have the capacity to germinate in a specified period of time under any combination of normal physical environmental factors that are otherwise favourable for its germination, that is, after the seed becomes non-dormant (Baskin & Baskin, 2004). This study, therefore, aimed to identify suitable pre-sowing seed treatment methods for uniform germination of high-quality *Prosopis africana* seedlings, thereby boosting seedling output for plantation establishment and other economic uses in the Kaduna Northern Guinea Savanna ecozone of Nigeria.

Materials and Methods

Study area

The study was conducted at the Savanna Forestry Research Station nursery, located on the Institute for Agricultural Research (I.A.R) farm in Samaru, Kurumi Bomu village. Located at Latitude 12º13'and 11º11ˈN / Longitude 8º39' and 7º38ˆE and 686m above sea level (Figure 1). It is located in Sabon–Gari Local Government Area of Kaduna State. The vegetation in the local Government Area is the Northern Guinea Savannah woodland type, characterized by short, scattered, drought resistant trees with undergrowth of grass and forage that serves as fuel for bushfires in the long dry season with mean annual rainfall of 1000mm – 1500mm, temperature of 25.6ºC (78.1ºF), precipitation of 1,117.6mm and humidity of 69% respectively (Sodimu *et al.*, 2021).

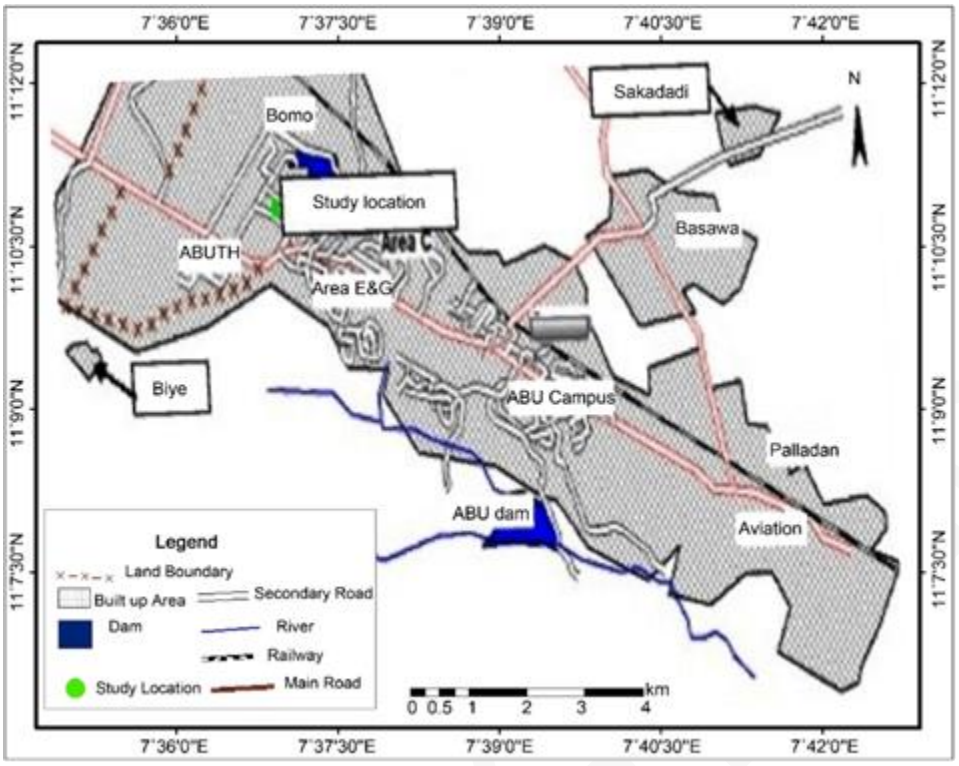


Figure 1: Showing the Study location of the SFRS, Nursery

Source: Sodimu (2025)

Experimental procedure and design

Mature seeds of *Prosopis africana* were procured from the Savanna Forestry Research Station, Forestry Research Institute of Nigeria, Samaru, Zaria. The seeds were subjected to a viability test using the floatation method described by Amusa (2011). The seeds were dropped in a beaker containing water. The seeds that floated were not viable. Such seeds were removed and replaced. A total of 100 viable seeds were used per treatment, for a total of 1000 across all treatments. The experiment was laid in a completely randomized design (CRD) involving ten (10) treatments (T): soaking in 98% concentration of tetraoxosulphate (VI) acid (H_2SO_4) for 15 minutes (T1), 25 minutes (T2) and 35 minutes (T3); soaking in hot water (Seeds were immersed in water initially at 100 °C, removed from the heat and left to cool, and remained immersed) for 7 hours (T4), 14 hours (T5) and 28 hours (T6) and soaking in cold water for 4 days (T7), 7 days (T8) and 9 days (T9) and no treatment (T10). One hundred (100) seeds each were soaked in ten treatments: tetraoxosulphate (VI) acid (H_2SO_4) for 15, 25 and 35 minutes; hot water for 7, 14 and 28 hours; cold water for 4, 7 and 9 days; and seeds with no treatment at all of the same number. For each treatment, 20 seeds per lot werelot were used, which were replicated 5 times. Thus,100 seeds per treatment; however, for 10 treatments, 1000 seeds were used in all. Germination count was based on the emergence of the radicle daily from sowing up to twenty (20) days after sowing. Seed germination counts under different pre-sowing treatments were analyzed using descriptive statistics, and germination percentage per box was used as the experimental unit for analysis of variance (ANOVA). For the analysis of variance, the percentage values were transformed to

arcsine values. The means with significant differences were separated using the Duncan multiple range test at ($P \leq 0.05$).

Data Collection and Analysis

Germination count was based on the emergence of the radicle daily from sowing up to twenty (20) days after sowing. Germination percentage was calculated as the ratio of germinated seedlings to the total number of seeds planted, multiplied by 100.

$$\textbf{Germination \%} = \frac{\textbf{Number of Seeds Germinated}}{\textbf{Total Number of Seeds Planted}} \times \mathbf{100}$$

Results and Discussion

Results

The result of mean germination for *Prosopis africana* seeds under different pre-sowing treatments showed that seeds treated with tetraoxosulphate (VI) acid for 35 min (T3) had the highest germination percentage (85.4%), followed by the seeds treated with hot water for 7 hours (T4) and 14 hours (T5) (35.2% and 15.2%, respectively). Seeds soaked in cold water for 4 days (T7) had a germination percentage (12.5%). However, no germination was recorded in seeds treated with cold water for 7 days (T8), 9 days (T9), or no treatment (T10) (0%). The details of germination percentages for other treatments are shown in Figure 2.

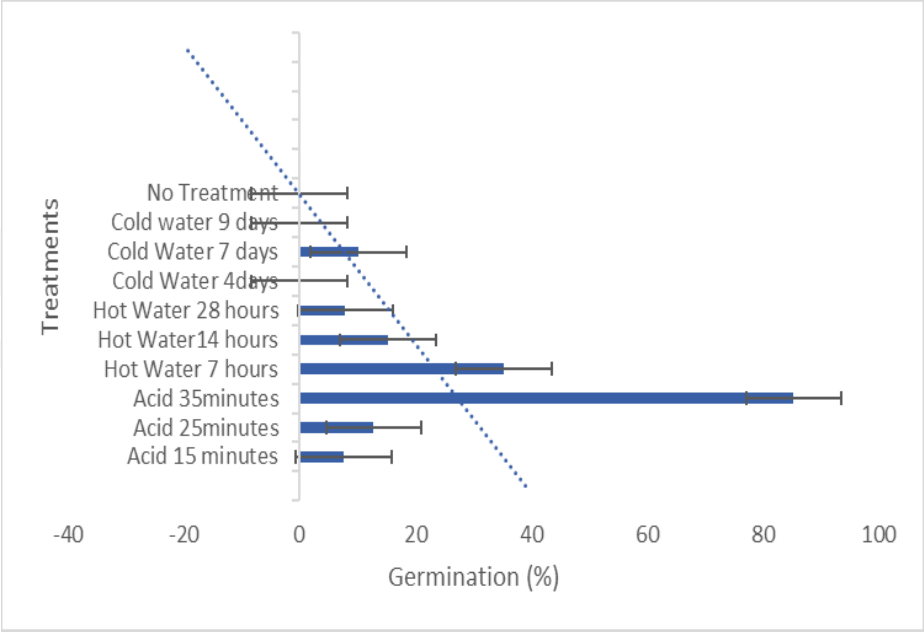


Figure 2. Seeds germination of *Prosopis africana* under various pre – sowing treatments

Means are back-transformed percentages; ANOVA was carried out on the arcsine-transformed data, and the results showed a significant difference ($P \leq 0.05$) in the germination of *Prosopis africana* seeds subjected to different pre-sowing treatments. However, DMRT result for the pre-sowing treatments showed that the seeds with acid treatment for 35minutes (T3) had the highest mean of 78.814± standard deviation (SD) of 9.882, followed by the seeds with hot water treatment for 7 hours (T4) with 29.744±8.879. The seeds with hot?? Water treatment for 28 hours exhibits the lowest mean of 11.509±0.004. Moreover, the seeds with cold water treatment for 7 days, 9 days and with no treatment at all had no mean (Table 1)

Table 1. Seed germination Results for different treatments with back-transformed means percentage

Allotted Treatments Number	Treatments	Mean ± Std. Deviation
T1	Acid 15 Minutes	11.573 ± 0.005^{c}
T2	Acid 25 Minutes	17.636 ± 4.586^{bc}
T3	Acid 35 Minutes	78.814 ± 9.882^{a}
T4	Hot water 7 hours	29.744 ± 8.879^{b}
T5	Hot water 14 Hours	18.937 ± 7.415^{bc}
T6	Hot water 28 Hours	11.509 ± 0.004^{c}
T7	Cold Water 4 days	17.208 ± 0.003^{bc}
T8	Cold Water 7 days	NG
T9	Cold Water 9 days	NG
T10	No treatment	NG

Means followed by the same letter(s) within the same treatment column are not statistically different at the 5% level of probability (*P=0.05)* using Duncan Multiple Range Test (DMRT). (NG means not germinated)

Discussion

Based on the results above, among the diverse pre-sowing treatments applied, tetraoxosulphate (VI) acid (H_2SO_4) for 35 minutes recorded the highest germination percentage, which helps remov*e the waxy layer of the seed coat by chemically decomposing seed coat components, thereby accelerating germination*. This is in agreement with the report by Ulleh and Fagbemi (2017). Similarly, Dachung and Verinumbe (2006) stated that acid treatment of seed helps remove the waxy layer of the seed coat by chemically decomposing seed coat components, similar to breakdown processes occurring during microbial attack. Mwase and Mvula (2011) also revealed that soaking seeds in hot water makes the seed coats permeable to water, allowing the seeds to imbibe and swell as they absorb water. Meanwhile, seeds that stayed in acid for a long time may have had their embryos destroyed, thereby preventing germination, as confirmed by Ariana *et al.* (2011) and Kumar e*t al.* (2018). The lowest seedling growth observed in hot water indicates that hot water treatment is detrimental to the growth of *P. africana* seedlings. Soaking seeds in acids should also be regulated to avoid cotyledon consumption, which may invariably hamper seed germination. This is also in alignment with (Ajiboye *et al.*, 2014; Oyebamiji *et al.*, 2019). Seeds soaked in water at room temperature and in hot water performed worse than expected compared to the acid treatment, and some seeds failed to germinate in the cold-water treatment. One possible explanation, which would need further study, is seed imbibition, which could have ruptured the cotyledons or affected the embryo in a way that would have impaired rapid, better germination. The poor germination observed in the control treatment indicates that *P. africana* seeds require presowing treatments to enhance germination, thereby promoting seedling growth.

Conclusion

It is concluded that seeds treated with acid performed better than those treated with hot or cold water. The acid presowing treatment, among others, significantly enhanced seedling growth in *P. africana*. Although other pre-sowing treatments were very vital, acid presowing treatment of seeds with 98% concentration of H_2SO_4 for 35 minutes was concluded to be the best presowing treatment for *Prosopis africana* (78.814 ± 9.882) and therefore recommended for improved seedling growth and development of *P. africana* seeds in the Kaduna Northern Guinea Savanna ecozone of Nigeria.

Recommendation

Based on the results above, it is recommended that for easy multiplication of seedlings of *Prosopis africana* for plantation establishment and afforestation projects, the nursery workers should adopt the use of acid treatment **(**98% concentration of tetraoxosulphate (VI) acid for 35 minutes) as a pre-sowing method to promote and enhance better germination of the species.

References

Agbogidi O.M, Bosah B.O., and Eshegbeyi, O.F (2007). Effects of acid pretreatment on the Germination and Seedling growth of African pear (*Dacryodes edulis* Don. G.Lam H. J). *International Journal of Agricultural Research*. 2:952-958. DOI: 10.3923/ijar.2007.952.958

Agboola, D. (2004). *Prosopis africana* (Mimosaceae): Stem, Roots and Seeds in the Economy of the Savanna Areas of Nigeria. *Economy Botany* 58, 34–42.

Agboola, D. (1996). Effect of storage humidity on seed longevity and sowing depth on seed germination of *Prosopis africana* (Guill and Perr). Taub. *Bangladesh Journal of Forest Science.*25(1&2):65-70

Ajiboye A.A, and Agboola, D.A (2014). Effects of seed size and phytohormone on the germination of seeds of two forest tree species, *Prosopis africana* (Guill) and *Dialium guineensis* (Wild)—Proceedings of Third Conference on *Science and National Development. 3:145-150.*

Amusa, T. (2011). Effects of three pretreatment techniques on dormancy and germination of seeds of *Afzelia africana* (Sm. Ex pers). *Journal of Horticulture and Forestry 3(4):96–103.*

Annongu A.A, Joseph J.K. and Liebert F (2004). Effect of anaerobic fermentation and Lyle-treated *Prosopis africana* seed meal on the nutritional and hematological responses of Harco chicks. *Journal of Raw Materials Research. 1: 33–41.*

Ariana, O.M, Ojas, R., Re'chiga, A., Aria, K., Guilar, M.A.A., Jardan, G., Olubov Maria., Andujano, G.M. (2011). Effect of Gibberellic Acid on the germination of seeds of five species of cacti from the

Chihuahuan Desert, Northern Mexico. *The Southwestern Natural.* 56(3):393–400.

Aremu M.O, Olonisakin A, Atolaye B.O, and Ogbu C.F (2006). Some nutritional and functional studies of *Prosopis africana*. *Elec J Env Agri Food Chem. 5: 1640–1648.*

Atiku M, Bello A.G, and Alao J.S (2013). Study of some tree characteristics at Tangaza North Forest Reserve in Sokoto State, Nigeria. *Agric. Sci. Res. J.* 3(10): 318–323.

Azad S, Manik M.R, Hasan S, and Matin A (2011). Effect of different pre-sowing treatments on seed germination percentage and growth performance of *Acacia auriculiformis. Journal of Forestry Research.* 22(2):183–188.DOI: 10.1007/s11676-011-0147-y

Baskin, C., & Baskin, J.M. (2004). Seeds: Ecology, Biogeography and Evolution of Dormancy and Germination. *Academic Press, San Diego*. 29: 11–20.

Dachung G, & Verinumbe I (2006). Effect of water and acid pretreatment on the germination of *Prosopis africana* seeds. Proceedings of the 31st Annual Conference of *the Forestry Association of Nigeria, Makurdi. 2006;11-18*

FAO (2003) Non-wood forest products and nutrition, Food and *Agriculture Organization of the United Nations, Quebec City, Canada. 2003.*

Fasidi I.O, Samani T, Kadiri M, and Agboola D.A (2000). "Dormancy types and water uptake in seeds of *Parkia biglobosa. J. Nat. Appl. Sci*. 1: 14–20.

Finch-Savage & Leubner-Metzger (2006). Seed dormancy. Retrieved from http://www.ehow.com from, http://www.ingentaconnect.com

Gérardin P, Neya B, Dumarçay S, Pétrisanns M, Serraj M, Huber F (2004). Contribution of gums to the natural durability of *Prosopis africana* heartwood. Holzforschung. 58:39-44.

Jone N, & Taupiac C (2002). Notes on main findings on Prosopis sp. Prosopis Workshop (2002). Accessed 25 June 2020) Available: http://www.vetiver.com/OTprosop is.htm.

Kumar N, Handa A.K, Dev I., Ram A, Uthappa AR. and Shukla A (2018). Effect of pre-sowing treatments and seedling growth of Abizia lebbeck (L) Bench. Journal of Applied and Natural Science. 10 (3)860 – 863

Luna T, Wilkinson K, & Dumroese R.K (2009). Seed germination and sowing options. In: Dumroese, R.K., Luna, T., and Landis, T.D.(Eds): Nursery manual for native plants: A guide for tribal nurseries - Volume 1: Nursery management. Agriculture Handbook 730. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 133–151.

Mwase W.F and Mvula T (2011). Effect of seed size and pretreatment methods of Bauhinia thonningii Schum. On germination and seedling growth, *Afr. J. Biotech*. 10(26): 5143-5148.

Nygård, R., & Elving, B (2000). Stem basic density and bark proportion of 45 woody species in young savanna coppice forests in Burkina Faso. *Annals of Forest Science*. 57 (3), 143–153.

Orji CU (2000). Evaluation of the physical properties of breadfruit seeds *(Treculia africana)* necessary for shelling. *J. Agric. Engineer. Tech*. 8: 55–58.

Oyebamiji N.A, Fadimu O.Y, and Adedire M.O (2014). Best pre-germination techniques on *Spondias mombin* Linn, seed for plantation establishment. *American-Eurasian J. Agric. Environ. Sci*. 14(6): 575-579.

Oyebamiji N.A, Adelani D.O, and Ojekunle OO (2022). Breaking Seed Dormancy of Prosopis africana Seeds and Its Effects on Seedlings Growth under Two Different Savanna Soil Conditions. *J. Appl. Sci. Environ. Manage* 26 (11) 1765-1770

Pearson T.R.H, Burslem D.F.R, Mullins P.C.E, and Dalling JW (2002). Germination Ecology of Neotropical pioneers: Interacting effects of environmental conditions and seed size. Ecology, 83, 2798–2807. http://dx.doi.org/10.1890/00129658(2002)083%5b2798:GEONPI%5d2.0.CO;2pentandra by *pteropodid bats. Journal of Mammalogy, 85,415-417* http://dx.doi.org/10.1644/1545-1542(2004)085%3c0001:NFAPCF%3e2.0.CO;2

Pasiecznik N.M, Harris P.J.C, and Smith S.J. (2004). Identifying tropical Prosopis species: a field guide, HDRA, Coventry, UK. Pp 6.

Sotelo-Montes C, Silva D.A, Garcia R.A, Muñiz G.I.B and Weber, J.C (2011). Calorific value of *Prosopis africana* and *Balanites aegyptiaca* wood: relationships with tree growth, wood density and rainfall gradients in the West African Sahel. *Biom Bioen*. 35: 346-353. 5.

Sodimu, A.I, Olaifa, R.K., Baba, G.O, Lapkat, G.L, Olorukooba, M.M, Olumuyiwa, S.A., Salau, L.O., Rasheed, F.M. (2021). Effects of Boiled Water on Germination Potential and Early Growth of *Faidherbia albida. (Del.) A. Chev.* Seeds in Kaduna Northern Guinea Savannah Agrological Zone of Nigeria. *Ethiopian Journal of Environmental Studies and Management*. 14 (2): 208 – 222.

Sodimu, A.I. (2025). Pre-sowing treatments pathways for enhancing *Milletia thonningii* (Schum and Thonn.) seed germination in the Kaduna Northern Guinea Savanna Ecology Zone of Nigeria. *Journal of the Kenya National Commission for UNESCO,* 6 (1), 1 – 10. ISO 9001: 2015 Certified. ISSN: 2958 – 7999 – 6467 DOI: https://doi.org/10.62049/jkncu.v5i1.441.

Uleh M, & Fagbemi T (2017). Progeny trial of *Prosopis africana* in Benue State, *Nigeria. Journal of Research in Forestry, Wildlife and Environment*. 9(1):61-66

Vautier H, Sacande M, Schmidt L. *Prosopis africana* (Guill. & Perr.) Taub. Seed Leaflet. 2007; (132). (Accessed 29 March 2023) Available:https://curis.ku.dk/ws/files/20496789/*prosopis_africana*_132.pdf

Vickery, M., & Vickery, B. (2007). Plant Product of Tropical Africa, Macmillan International College Edition. Macmillan Press Limited, London. Pp35

Zida D, Tigabu M, Sawadogo L, & Oden, P.C (2005). Germination requirements of seeds of four woody species from the Sudanian savanna in Burkina Faso, West Africa. *Seed Sci. Tech*. 33:

EFFECTS OF SELECTED INTEGRATED SOIL FERTILITY MANAGEMENT ON THE EARLY GROWTH PERFORMANCE OF *Adansonia digatata* Linneus SEEDLINGS

[1]Iroko, O. A. and [2]Salami, K. D

[1]*Forestry Research Institute of Nigeria, P.M.B. 5054 Jericho, Ibadan, Oyo State*
[2]*Department of Forestry and Wildlife Management, Federal University Dutse, Jigawa State, Nigeria*
**Corresponding Email: foristsalam@yahoo.com; 07034294371*

Abstract

Adansonia digitata exhibits slow early growth and poor establishment in nutrient-depleted savanna soils, limiting its domestication for nutrition and income. Integrated Soil Fertility Management options remain unevaluated for baobab nurseries. This study investigated the effects of selected integrated soil fertility management: Poultry manure, Green Manure (*Tamarindus indica* leaf extract), Mulching (decayed sawdust) and control (no application) on the growth performance of *Adansonia digitata* seedlings to identify cost-effective, sustainable amendments that improve vigor, enhance field survival, and support climate-resilient agroforestry in drylands. A Completely Randomized Design (CRD) with four treatments and five replications was used. One-way Analysis of Variance was used to analyze the data during the study. Growth parameters assessed were plant height, stem diameter, and leaf count. The results revealed significant differences among treatments. Poultry Manure and Green Manure improved seedlings' growth more than Compost, with Poultry Manure producing the highest leaf count and Green Manure promoting better stem girth. Results showed that Poultry Manure had the highest Plant height (13.0±0.34), Leaf Count (8.6±0.21), and Stem Diameter (10.24±0.32), followed by green manure. However, the control recorded a slightly higher mean height. The results suggest that organic soil amendments enhance seedling development and should be incorporated into nursery and reforestation practices to support the sustainable growth of *Adansonia digitata.*

Keywords: Integrated Soil Fertility Management, Growth Performance, *Adansonia digatata* and Seedlings

Introduction

Silviculture encompasses the art and science of controlling the establishment, composition, growth, and quality of forest stands to meet diverse needs and values, including timber production, biodiversity conservation, and soil protection (Hegde *et al.,* 2025). Appropriately integrated soil fertility management can profoundly influence soil function by altering organic matter dynamics, nutrient cycling, and the structural properties of the forest floor and mineral soil layers (Nair *et al.,* 2021). Among common soil management practices, fertilizer application, Mulching, green manuring, and conventional planting regimes are employed to enhance soil fertility and forest productivity. However, their comparative impacts on soil physical (bulk density, moisture retention), chemical (pH, nutrient availability), and biological (microbial biomass) properties have not been fully quantified across many forest ecosystems. Mid-rotation fertilization is widely used to boost nutrient availability in intensively managed plantations. For example, over 150,000 ha of

loblolly pine plantations in the U.S. received fertilizer annually by the mid-1990s, with significant increases in soil nitrogen and phosphorus levels reported One season post-application (Prem *et al.,* 2020).

Organic and inorganic mulches, such as dried sawdust, help conserve soil moisture, regulate temperature, and add organic matter upon decomposition. In tropical yam cultivation, organic mulches improved soil moisture retention and increased soil organic carbon by up to 20% compared to un-mulched plots. In dryland settings, plastic-film mulching has been shown to reduce soil evaporation and enhance water storage, thereby improving nutrient availability for crops. Salami *et al.* (2026) reported that the mulches evaluated had significant effects on *Adansonia digitata* seedling parameters. Based on the mean values recorded for all parameters at 10 weeks after treatment, sawdust emerged as the best-performing mulching material. Seedling shoot height ranged from 26.08 cm to 35.62 cm, stem diameter from 0.58 cm to 0.75 cm, leaf area from 38.50 cm^2 to 43.92 cm^2, and number of leaves from 19.5 to 32.25 across the different mulch treatments in the study conducted in the Sudan savannah. Incorporation of leguminous green manure crops can enrich soil nitrogen through biological fixation and improve soil structure. In walnut orchards, green manure application enhanced rhizosphere nutrient levels and microbial activity, resulting in better tree growth. In rice systems, combining plastic-film mulching with hairy vetch green manure raised soil NH_4^+–N levels and reduced reliance on chemical fertilizers. Conventional planting without soil amendments often serves as a baseline, yet soil fertility in plantations rarely returns to levels observed under undisturbed natural forests. Despite widespread adoption of various silvicultural practices, comparative data on their cumulative effects on soil health within a single experimental framework are scarce. Forest managers lack clear guidance on which practice or combination thereof optimizes soil fertility and long-term stand productivity. Therefore, the study focused on the impacts of selected integrated soil fertility management practices on the early growth performance of *Adansonia digitata* seedlings, with a view to prescribing the best soil management practices for nursery attendants and plantation establishment.

Materials and Methods

Description of study site

The study was carried out at Forestry Nursery of the Department of Forestry and Wildlife Management, Federal University Dutse, Jigawa State. It lies between latitudes 11.00°N and 13.00°N and longitudes 8.00°E and 10.15°E (Gidado *et al.,* 2023). The study area, Dutse, is covered by the Sudan and characterized by a hot, wet summer and a cool, dry winter, with an average rainfall season of 3-5 months (644 m) (Jibo *et al.,* 2022). Sunshine hours indicate that the town receives 10-11 hours of sunshine per day, depending on the season. The topography is characterized by a high land area of almost 750m. Soil tends to be fertile, ranging from sandy loam (Salami & Lawal, 2018). The area's mean annual temperature supports the growth of a variety of plants. The area's relatively uniform climate and soil conditions ensured that the study's results were reliable and applicable to similar agroecological zones. The area's topography is generally flat, with a high point of approximately 750 meters. The soil type in this region is predominantly sandy-loam, as reported in previous studies (Garba *et al*., 2021). This soil type is characterized by a mix of sand, silt, and clay, providing a suitable medium for plant growth

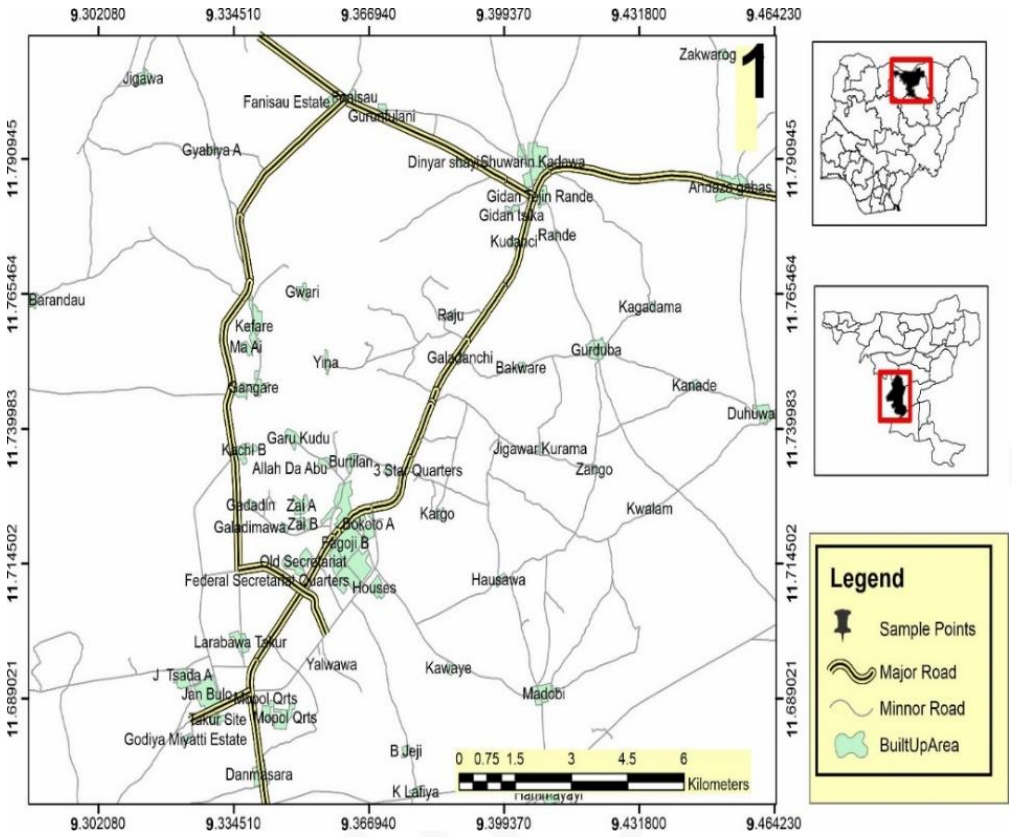


Fig 1: Map of Dutse Local Government

Source: Salami *et al*., 2020

Data Collection

Seeds were collected from mother trees at Federal University Dutse, Jigawa State, to obtain genetically pure seed material. Healthy, uniform-sized seeds were selected and subjected to pre-sowing treatments. After germination, two-week-old uniform seedlings were selected and transplanted into polybags. Non-destructive sampling was done at 15-day intervals. Primary data on the effects of different plant extracts on various vegetative growth parameters were collected through pot experiments conducted under nursery conditions, following standard procedures. Observations on shoot height, stem girth, and leaf production were recorded at regular intervals using non-destructive methods on sample plants from each treatment and replicate.

Sampling design

A Completely Randomized Design (CRD) was employed with five (5) replications for each treatment. Therefore, four treatments were examined: Poultry Manure, Green Manure, Mulching and a control treatment.

Data Analysis

Data collected was subjected to inferential and descriptive statistics, two-way Analysis of Variance) based on the data obtained from morphological characteristics with the aid of the Statistical Package for the Social Sciences (SPSS) version 19





Plate 1: Effect of chicken manure on the sp**ecies. Plate 2:** Effect of Green manure on the species





Plate 3: Effect of Mulching on the species. **Plate 4: Control** Effect on the species

Results and Discussion

Results

The results in Table 1 showed that the growth performance of *Adansonia digitata* seedlings varied under the different soil treatments. The Control treatment recorded the highest mean height (13.4 cm), followed closely by Poultry Manure (13.0 cm) and Green Manure (12.4 cm). The lowest height (10.0 cm) was observed under Mulching. The highest mean leaf count was obtained from Poultry Manure (8.6) and Green Manure (8.4), while both Mulching and Control had lower mean leaf numbers (7.2). The highest stem diameter was recorded under Green Manure (10.36 mm), followed by Poultry Manure (10.24 mm) and Control (10.20 mm). Mulching produced the lowest value (8.98 mm).

Table 1: Showing the Growth Parameters of *Adansonia digitata* Seedlings under Different Soil Treatments

Variables	Chicken Manure	Green Manure	Mulching	Control
Plant height (cm)	13.0 ± 0.34^{a}	12.4 ± 0.22^{ab}	10.0 ± 0.32^{b}	13.4 ± 0.34^{a}
Leaf Count	8.6 ± 0.21^{a}	8.4 ± 0.10^{a}	7.2 ± 0.11^{ab}	7.2 ± 0.11^{ab}
Stem Diameter(mm)	10.24 ± 0.32^{a}	10.36 ± 0.32^{a}	8.98 ± 0.21^{ab}	10.2 ± 0.32^{a}

Discussion

Integrated Soil Fertility Management (ISFM) enhanced *A. digitata* growth, with organic + NPK yielding morphological attributes due to improved nutrient availability and soil moisture, supporting cost-effective baobab domestication. The present study evaluated the effects of different organic soil treatments on the early growth performance of *Adansonia digitata* seedlings, and the results demonstrate that organic amendments significantly influence key morphological parameters. However, the magnitude and direction of effects vary with treatment type. Poultry manure, green manure, Mulching, and control treatments produced statistically distinct responses in plant height, leaf count, and stem diameter, reflecting differences in nutrient availability, release dynamics, and soil physical modification. Control seedlings were tallest, similar to chicken manure, suggesting adequate native soil nutrients initially. Mulching yielded the lowest growth, likely due to delayed nutrient release. This pattern suggests that the experimental soil had considerable inherent fertility prior to treatment application, enabling rapid initial uptake of residual nutrients by control seedlings. Similar observations were reported by Kareem (2022) and Jibo *et al.* (2023) in Parkia biglobosa seedlings, where control plots outperformed some organic treatments in height during the first 8 weeks due to existing soil nitrogen pools. Nevertheless, height alone does not fully capture seedling vigor or establishment potential, because balanced development of foliage and stem girth is critical for photosynthetic capacity and mechanical

stability in savanna environments. In terms of leaf count, chicken manure supported the highest mean of 8.6±0.21 leaves per seedling, followed by green manure at 8.4±0.10, while both Mulching and control recorded 7.2 leaves. The superior leaf production under chicken manure is consistent with its high total nitrogen content, readily available ammonium and nitrate forms, and rapid mineralization within 2–4 weeks of incorporation, all of which directly enhance chlorophyll synthesis and vegetative growth (Sulieman *et al.,* 2026). Adejumo *et al*. (2020) also noted that poultry manure increased leaf area and leaf number in *Moringa oleifera* by 28–34% compared to unamended soils, attributing this effect to improved N uptake and enhanced cytokinin activity, which promote cell division in shoot meristems.

Green manure performed comparably to chicken manure for leaf count, which aligns with findings by Choudhary *et al*. (2020) that incorporation of leguminous green manures such as Mucuna pruriens and *Crotalaria juncea* increases soil nitrogen by 40–80 kg N/ha through biological nitrogen fixation, while simultaneously raising soil organic carbon by 0.15–0.3% within One season. The gradual decomposition of green biomass also improves cation exchange capacity and water-holding capacity, creating a rhizosphere environment that sustains a steady nutrient supply during the critical seedling establishment phase. Stem diameter, a key indicator of seedling sturdiness and survival under field conditions, was highest under green manure at 10.36±0.32 mm, followed by poultry manure at 10.24±0.32 mm and control at 10.2±0.32 mm, with Mulching again recording the lowest value of 8.98±0.21 mm. The increase in stem girth under green manure likely reflects enhanced root proliferation and secondary xylem development driven by improved soil porosity and aggregate stability. Studies by Manono and Mwami (2026) in Ghana demonstrated that green manuring increased bulk density reduction and infiltration rates by 15–22%, facilitating root penetration and nutrient interception in Vitellaria paradoxa seedlings. Furthermore, green manures supply auxins and other growth-promoting substances during decomposition that stimulate cambial activity (Asghar & Kataoka, 2022). Poultry manure's comparable effect on diameter corroborates reports by Olubode *et al.* (2021) that poultry manure application at 10 t/ha increased stem girth of *Tamarindus indica* seedlings by 18% relative to control, owing to the combined provision of N, P, K, and micronutrients such as Zn and Cu that are essential for lignin biosynthesis. Mulching consistently performed worst across all measured parameters, despite its well-documented benefits for soil moisture conservation and temperature moderation.

The reduced growth under mulch may be attributed to the slow mineralization of lignified materials such as sawdust or crop residues, which immobilize nitrogen during the initial 6–10 weeks as microbial populations utilize available N to break down high C: N ratio substrates (Rashid, B., Malik *et al.,* 2026). Work by Macdonald and Everett (2026) confirmed that wood-based mulches with C: N >50:1 can cause temporary N deficiency in seedlings unless supplemented with inorganic N or low C: N amendments. In addition, thick mulch layers may create a physical barrier that delays emergence and reduces the diffusion of soil oxygen, particularly in heavy-textured soils, thereby constraining root respiration (Tobeskanian, 2026). Although Salami *et al.* (2026) found sawdust to be the best-performing mulch for *A. digitata* in terms of shoot height and leaf area, that study used partially composted sawdust with a lower C: N ratio and monitored seedlings to 10 weeks, whereas fresh mulch materials often require 12–16 weeks to contribute net nutrients. The relatively balanced growth observed under chicken and green manure treatments indicates better physiological activity and nutrient use efficiency. Enhanced leaf count and stem diameter under these treatments suggest greater allocation to photosynthetic and structural tissues, which is critical for *A. digitata* given its slow initial growth

and sensitivity to drought stress in the Sudano-Sahelian zone. Adejumo *et al.* (2020) emphasized that integrated soil fertility management using organic inputs improves not only macronutrient supply but also soil microbial biomass and enzyme activities such as dehydrogenase and phosphatase, which correlate with nutrient cycling and seedling vigor. The present findings agree with Motbaynor *et al.* (2026), who reported that *A. digitata* seedlings amended with poultry manure and Gliricidia green manure exhibited 25% higher survival after transplanting, due to improved root: shoot ratios and stem lignification.

Beyond N, P, and K, organic amendments supply calcium and magnesium that are vital for cell wall stability in baobab, a species known to accumulate Ca oxalate crystals (Assogbadjo *et al.,* 2012). The control treatment's high plant height, lower leaf count, and moderate diameter imply etiolated growth driven by rapid vertical extension in search of Light, potentially at the expense of sturdiness, a phenomenon described by Asadu (2026) in unfertilized tropical tree seedlings. For sustainable baobab domestication and restoration programs, therefore, manure-based amendments offer clear advantages over mulching alone during the nursery phase, particularly when seedling quality rather than height alone is the target. However, Mulching should not be discarded because its long-term benefits for soil moisture retention, weed suppression, and erosion control are critical after outplanting, especially amid increasing climate variability in West Africa (Demo & Asefa, 2024). A combined approach where decomposed organic manure is incorporated at sowing and Light organic mulch is applied after establishment may optimize both nutrient supply and moisture conservation, as recommended by Abbas and Arshad (2026) for agroforestry systems. Future studies should evaluate nutrient release curves of different treatments and monitor field survival for at least 24 months to determine carry-over effects. Cost-benefit analysis is also needed, since poultry manure availability may be limited and green manure requires land and labor, whereas crop residues for Mulching are often abundant. In conclusion, chicken manure and green manure enhanced the overall seedling quality of *A. digitata* by improving leaf development and stem thickening, whereas mulching underperformed in the short term due to slow nutrient release. These results support the inclusion of readily mineralizable organic inputs in nursery protocols for baobab and highlight the need to match amendment type to species requirements and production objectives.

Conclusion

Organic amendments significantly influenced early growth of *Adansonia digitata,* with poultry manure and green manure producing superior leaf counts and stem diameters compared to Mulching, despite the control seedlings being tallest. The enhanced foliage and sturdiness under manure treatments indicate better seedling quality and establishment potential, driven by rapid nutrient release and improved soil conditions. Mulching underperformed short-term due to slow mineralization and possible nitrogen immobilization. Therefore, well-decomposed poultry manure or green manure should be prioritized in baobab nursery protocols to improve vigor and survival. At the same time, Mulching is better suited for post-planting moisture conservation rather than early nutrient supply.

Recommendations

To optimize early growth and seedling quality of *Adansonia digitata*, nursery managers should incorporate well-decomposed poultry manure or leguminous green manure into the potting media at sowing to enhance leaf production, stem girth, and overall vigor. Fresh, high C: N ratio mulches should be avoided during the nursery phase due to slow nutrient release and the potential for nitrogen immobilization; instead, apply Lighta, a partially composted organic mulch, after field establishment to conserve moisture and suppress weeds. Combining readily mineralizable organic inputs with post-planting Mulching will improve survival and growth in dryland systems. Future trials should determine optimal application rates, evaluate cost-effectiveness, and monitor long-term field performance for at least 24 months to guide large-scale baobab domestication programs in the Guinea-savanna zone.

References

Abbas, R. N. & Arshad, M. A. (2026). Weed Management for Sustainable Plant Nutrition and Soil Quality. *Sustainable Plant Nutrition and Soil Quality Management*, 139.

Adejumo, T. O., Musa, H. D., & Yakubu, A. (2020). Effects of organic amendments on soil fertility and seedling growth in degraded soils of northern Nigeria. *Journal of Forestry Research and Management,* 17(2), 45–56.

Asadu, C. (2026). Analytical Review of Research: Research on Yam for Increased and Sustainable Production. Analytical Review of Research on Yam for Increased and Sustainable Production.

Asghar, W., & Kataoka, R. (2022). Green manure incorporation accelerates enzyme activity, plant growth, and changes in the soil fungal community—*Archives of Microbiology*, *204*(1), 7.

Assogbadjo, A. E., Chadare, F. J., Kakaï, R. G., Fandohan, B., & Sinsin, B. (2012). Ecology and uses of *Adansonia digitata* L. in Benin. *African Journal of Ecology,* 50(1): 80–88.

Choudhary, V. K., Singh, S., & Deka, B. C. (2020). Green manuring for soil health and sustainable productivity: A review. *Agricultural Reviews*, 41(3), 229–238.

Demo, A. H., and Asefa Bogale, G. (2024). Enhancing crop yield and conserving soil moisture through mulching practices in dryland agriculture—*Frontiers in Agronomy*, *6*, 1361697.

Garba, A., Salami, K. D. & Akanbi, W. B. (2021). Assessment of Endangered Economic Tree Species and Conservation Techniques in Jigawa State, *FUDMA Journal of Agriculture and Agricultural Technology*, Vol. 7(2), 116-123

Gidado, H. A., Salami, K. D., Kareem, A. A., Jibo, A. U., Adam Fatima, O., D. O. (2023). Effect of frequencies of watering and water volumes on the growth performance of *Adansonia digitata* (Linn) Seedlings. *Australian Journal of Science and Technology* ISSN Number (2208–6404) Volume 7, Issue 1, March 2023 Australian

Hegde, R., Clara Manasa, P. A., & Salimath, S. K. (2025). Contemporary Silviculture. In *Textbook of Forest Science* (pp. 389–406). Singapore: Springer Nature Singapore.

Jibo, A. U., Salami, K., Lawal, A., & Muhammad, Y. (2022). Influence of Soil Amendments on the Growth Performance of *Eucalyptus camaldulensis* (Dehnh) Seedlings.

Jibo, A., Salami, K. D., & Mahmoud, I. (2023). Comparative Study of Parkia biglobosa (Jacq) R. Br. ex G. Don and *Azardirachta indica* A. Juss Root System Of The Planting Stocks Through Potting and Seedbed. *Ethiopian Journal of Environmental Studies & Management*, *16*(2), 142–150.

Kareem, I. A. (2022). Growth Rates of *Parkia biglobosa* Jacq. Seedlings (African Locust Bean Tree) As Influenced By Two Inorganic Manures. *International Journal of Agriculture, Environment and Bioresearch*, *7*(3).

Kumar, A., & Tripathi, A. (2019). Role of silviculture in sustainable forest management: A review. *International Journal of Forestry and Crop Improvement,* 10(1), 1–9.

Macdonald, R., & Everett, R. (2026). *Transition to peat-free horticulture in Scotland*. Royal Botanic Garden Edinburgh

Manono, B. O., & Mwami, B. (2026). Agroforestry and soil health: A review of impacts and potential for sustainable agriculture. *Earth*, *7*(1), 31.

Motbaynor, K., Alemu, A., & Gebremariam, Y. (2026). Effects of Soil Substrate on Germination and Seedling Growth of Adansonia digitata L. in Northwest Ethiopia. *Forest Science and Technology*, *22*(1), 109–118.

Musa, A. Y., Ibrahim, S. D., & Usman, M. (2021). Influence of fertilizer types on the growth of selected forest seedlings in savannah ecosystems. *Journal of Forestry and Environment,* 13(2), 25–33.

Nair, P. K. R., Visseren-Hamakers, I. J., & Groot, R. S. (2021). Agroforestry Systems and Sustainable Land Use. Springer Nature.

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., & Simons, A. (2009). Agroforestree Database: A Tree Reference and Selection Guide Version 4.0. World Agroforestry Centre.

Prem, M., Ranjan, P., Seth, N. & Patle, G. T. (2020). Mulching techniques to conserve the soil water and advance the crop production—A Review. *Curr. World Environ*, *15*, 10-30.

Prem, P., Singh, R., & Kumar, P. (2020). Role of silvicultural practices in enhancing forest productivity and soil quality. *International Journal of Forestry Research*, 14(2), 101–112.

Rashid, B., Malik, M. A., Padder, S. A., Parray, J. A., Bashir, Z., Sharma, A., & Ghazi, R. M. (2026). Bacterial consortium optimization for improved biological degradation of agricultural waste. *3 Biotech*, *16*(4), 11

Salami, K. D., and Lawal, A. A (2018). Tree Species Diversity and Composition in the Orchard of Federal University Dutse, Jigawa State. *Journal of Forestry Research and Managemen*t. ISSN 0189-8418, www.jfrm.org.ng,Vol 15(2):112-122

Salami, K. D., Bellu, Z., Jibo, A. U. and Nazil, A. (2026). Influence of Different Mulching Materials on Growth of *Adansonia Digitata* Linneous Seedlings. NL Journal of Agriculture and Biotechnology Volume 3 Issue 2 April 2026

Tobeskanian, L. A. Agro-Environmental Impacts of Climate Change in Mediterranean Coastal Agriculture: Salinization Processes and Food Security Challenges.

FISH SPECIES ABUNDANCE IN ACADJA SYSTEM OF FISH PRODUCTION USING PALM FRONDS AND BAMBOO CUTTINGS ON BADAGRY LAGOON, LAGOS STATE.

[*1,2]Theophilus Fasinu SUNNUVU, [1]Adams Ovie IYIOLA, and [1]Mabel Omowumi IPINMOROTI

[1]Department of Fisheries and Aquatic Resources Management
College of Agriculture and Renewable Natural Resources, Osun State University.
[2]Aquaculture and Fisheries Management, College of Agriculture, Lagos State University of Science and Technology, Lagos.
**Corresponding email: theomary2017@gmail.com*

Abstract

The Acadja system of fishing was conducted in Apa village, Badagry Lagoon, within the Badagry Local Government Area, to determine the abundance of fish species in the system. The study was conducted for 24 months, covering 2 rainy and 2 dry seasons. The experimental design comprises Treatments A – D, with each treatment having 3 replicates. Each treatment was harvested as follows: Treatment A replicates were harvested monthly; Treatment B replicates were harvested bi-monthly; Treatment C replicates were harvested tri-monthly; while Treatment D replicates were harvested Semi-annually. Identification of fish species in catches from the acadja systems revealed 26 species from 18 families during the rainy seasons and 18 species from 10 families during the dry seasons. The fish species caught in both rainy and dry seasons in this study were dominated by Chrysichthys nigrodigitatus, Chrysichthys auratus, Sicydium brevifile, Monodactylus sebae, and Oreochromis niloticus. The Simpson Index and Shannon-Weiner Index were used to analyze the data and compare species evenness and dominance. The results from the analyses clearly showed that harvesting frequency has a strong influence on fish community structure in acadja systems of fisheries which encourages ecological balance, this is because treatment A (monthly harvesting acadja) maintained the highest diversity and better species balance and best species diversities and stable ecosystem which suggests that frequent harvesting prevents any single species from dominating and allows continuous recruitment of different species and also gave room for species abundance. Treatments B and C showed moderate diversity but increasing dominance, especially by C. nigrodigitatus. As the harvesting interval increased, competition among species also increased, leading to reduced diversity. Treatment D recorded the lowest diversity and highest dominance. This indicates that longer harvesting intervals allow dominant species to take over, reducing biodiversity.

Introduction

Among the natural water resources given to humanity, fisheries resources have been identified as the most valuable due to their importance as a veritable source of protein and other minerals, which are important for the normal functioning of the body system (Ogunbadejo et al., 2012). Elezuo et al. (2020) maintained that fish protein is largely digestible and is very important in Nigerian diets; while fish provides more than 60% of the world's protein supply, especially in developing countries (Elezuo et al., 2024). Fish constitutes a major source of animal protein, especially in Africa, with

the most balanced amino acid profile, and its consumption cuts across cultural and religious barriers (Bolarinwa & Okeowo, 2017). Fish contributes significantly to the fight against hunger and healthy nutrition, providing a rich source of protein, healthy fats, and a variety of nutrients, including iodine, vitamin D, omega-3 fatty acids, and calcium (Elezuo et al., 2020). In addition to health benefits, it also provides a source of income for artisanal fishermen in the south-western Nigerian lagoons. Nigeria is the fourth largest importer of frozen fish in the world (Odioko & Becer, 2022; Ipinmoroti & Iyiola, 2022). According to FAO, (2024), the total fisheries and aquaculture production in 2021 reached a record of 218 million tonnes with Africa contributing only seven percent (7%), Nigeria (1.2%), in which capture fisheries contributed 91.2 million tonnes, fifty percent (50%) of the total production of aquatic animals, while the other fifty percent (50%) came from aquaculture (90.9 million tonnes).

One method of rehabilitating damaged resources in the aquatic environment is engineering (Olopade et al., 2008). One of the identified fisheries technique enhancements is the use of traditional sheltering techniques to improve fish habitat. Fish shelter is One of the techniques listed by Welcome and Batley (1998) for stock enhancement. This shelter fishing technique is not strange to Nigeria's fishers' cultural practices because Olopade et al. (2008) cited Fagade (1969) and Kusemiju (1973) describing the acadja fish shelter in Lagos Lagoon and Lekki Lagoon, respectively, while Adekoya (1997) reported the knowledge about shelter technique by Ogun state fishers through their indigenous knowledge systems. Ben et al. (2018) reported the acadja system as One of the shelter fishing techniques used by artisanal fishermen in the Benin Republic on the Port-Novo Lagoon. Yoboue et al. (2018) reported that the introduction of the acadjas system of fishing into the Ivorian lagoons was driven by the need to increase fishing productivity in those lagoons, which had lost productivity due to overfishing.

The Acadja compartment fishing system consists of branches of trees, shrubs or palm fronds tucked into the bottom of lagoons, lakes or rivers at a depth of 1 to 1.5m; with an outer ring of hardwood or bamboo poles (Olopade et al., 2008; Beverly et al., 2012; Gomna, 2015; Beverly et al., 2020). The Acadja system functions as protection or shelter, an escape route from predators, a breeding haven, a culture system, etc., for fish, preventing early harvest of small ones and gravid ones, and also provides surfaces for the growth of sessile organisms, thereby establishing a new food chain within the system (Olopade et al., 2008; Gomna, 2015; Ben et al., 2018). Badagry is a town located along the coast of Lagos State, Nigeria, stretching westward towards the border with the Republic of Benin (Osodein & Anetekhai, 2020). Many fishing villages within the Badagry Local Government are engaged in artisanal fishing using different types of fishing gears, crafts, and methods, including the Acadja system, shelters, and traps, on the Badagry Lagoon. Given the limited documented information on fish abundance in acadja systems in Badagry Lagoon, this study investigates fish species abundance using palm fronds and bamboo cuttings as acadja system installation materials. This study will therefore provide information that can help bridge the knowledge gap and identify necessary management measures in the Lagoon.

Materials and Methods

Study Area

Apa town, the study area, is One of the fishing villages along Badagry Lagoon in Badagry Local Government Area of Lagos state, Nigeria (Figure 1). The town comprises the Ogu (erroneously called Egun), Awori, and Ilaje people, who are predominantly artisanal fishers and farmers. Their

fishing activities involve the use of different types of fishing gears and crafts, such as traps, cast nets, seine nets, encircling nets, drag nets, hook and line, long lines, set nets, canoes, boats and other indigenous knowledge systems like Iken, acadja systems, brush parks, shrubs, etc. Badagry Lagoon is an open tidal estuary located in Lagos State, Nigeria, stretching westward towards the border with the Republic of Benin. Situated roughly between latitudes 6°22′–6°42′N and longitudes 2°42′–3°42′E, it forms part of the Lagos Lagoon complex, running parallel to the Atlantic Ocean coast and connected to Porto Alegre. The water depth ranges from 1m to 3m. It is characterized by estuarine and brackish water most of the year. The Lagoon experiences two broad seasons: the dry season (December – May) and the wetthe wet season (June — November) (Soyinka et al., 2010).

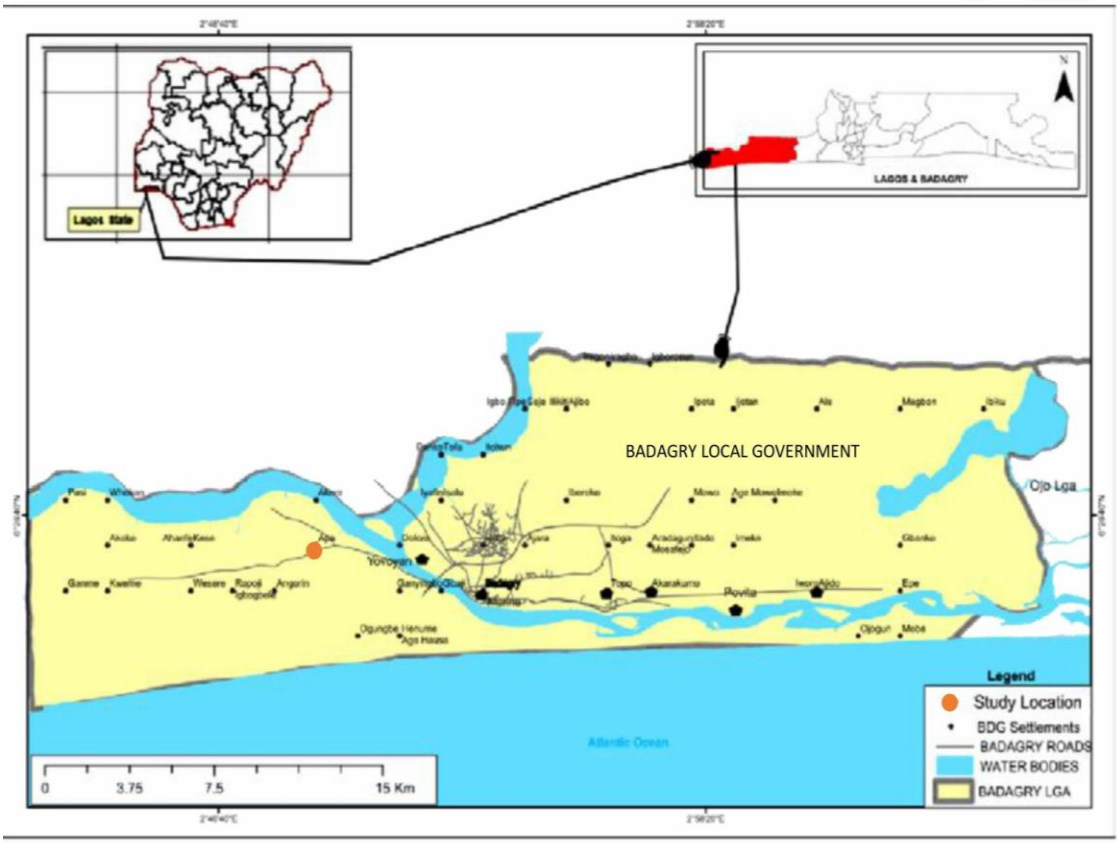


Figure 1: Badagry Local Government and study locations

Acadja system installation Designs

Four Treatments (A, B, C & D) of Acadja systems, with three replicates for each treatment (A1, A2 & A3; B1, B2 & B3; C1, C2 & C3; and D1, D2 & D3), were set up, as diagrammatically represented and described in Table 1. There were four sets of Acadja system compartments, with three replicates each, for a total of 12 compartments. Table 2 below shows the structural arrangements of the Acadja system compartment on water.

Table 1. Diagrammatic Representation of the Acadja setup.

Treatments	Acadja Duration	Replicates	Harvest Descriptions	Acadja Sizes

A	Monthly-based	A1, A2 & A3	Harvested monthly	$20m^2$ each
B	Bi-monthly based.	B1, B2 & B3	Harvested Bi-monthly	$20m^2$ each
C	Tri-monthly based.	C1, C2 & C3	Harvested Tri-monthly	$20m^2$ each
D	Semi-annually based	D1,D2 & D3	Harvested Semi-Annually	$20m^2$ each

Table 2: Arrangements of the acadja compartments on water by season.

Seasons	Acadja setups											
1st:Dry season (6 months)	A_1	B_1	C_1	D_1	B_2	C_2	D_2	A_2	C_3	D_3	A_3	B_3
1stRainy season (6 months)	B_1	C_1	D_1	A_1	C_2	D_2	A_2	B_2	D_3	A_3	B_3	C_3
2nd Dry season (6 months)	C_1	D_1	A_1	B_1	D_2	A_2	B_2	C_2	A_3	B_3	C_3	D_3
2nd:Rainy season (6 months)	D_1	A_1	B_1	C_1	A_2	B_2	C_2	D_2	B_3	C_3	D_3	A_3

Each of the six months represented a seasonal period (rainy and dry seasons) in Badagry, Lagos State, Nigeria.

Descriptions of the Acadja system installations (Construction) process

The construction as done by local fishermen and the sticks for acadja system installations were inserted vertically into the bottom soil sediment of about 1.5m. (Fig.2). Bamboo poles were erected at the four corners of each system and Bamboo poles were also used to fence the whole system to prevent intrusion of aquatic weeds and plants, fishing canoes or boats and transportation flying boats into the acadja compartment during the day or night. The system was installed in a straight line parallel to the shore (Fig 3). Each compartment was 5m by 4 m = 20 m2, with a 3m gap between each compartment. Palm fronds were used for all the compartments, and four sticks of palm fronds were installed per square metre for each system (80 sticks), forming rectangular shapes. Eight (8) bamboo cuttings were placed in each compartment, and none of the systems were stocked with fish seeds.



Figure 2: Materials used in construction



Figure 3: Series of Acadja systems

Harvesting and the fishing gears used for the process

Harvesting of these acadja systems was done as described in Table 1. An encircling net with 9mm mesh, a cast net, boats, a machete, a knife, and plastic containers were used. Harvest was completed early in the morning, as per the setup for each month. For sampling, the first step was to encircle the acadja system (Figure 4), and the installation materials (palm fronds) were then removed (Figure 7), thereby harvesting all fish species from the compartment.

Fish species identification

The harvested fish species were identified using the fish identification guides provided by Adesulu and Sydenham (2007) and Olaseobikan and Raji (2013) and sorted into their respective species groups.





Figure 4: Acadja system encircled **Figure 5; Installed materials removed**

Biological diversity

The following biological diversity indices were used: Shannon-Wiener Index (H′), Species Richness (S), Simpson's Index (D), and Evenness Index (E) (Robert, 1974; Madhuri et al., 2023).

Shannon–Wiener Index (H') = -Σ(pi ln pi).

Simpson's Index (D) = $\Sigma(pi^2)$.

Evenness (E) = H' / ln(S).

Where: N = total number of fish species
S = Species richness
Pi = Proportion of Each Species
pi = ni / N.

Results

Fish species identified

A total of twenty-six (26) fish species belonging to eighteen (18) families were identified during the rainy season harvest, as presented in Table 3. In comparison, a total of eighteen (18) fish species belonging to ten (10) families were identified during the dry season harvest, as presented in Table 4.

Table 3. Fish species harvested from the acadja system during the rainy seasons of installation

	Species names	**Genera**	**Families**	**Ogu local names (Badagry)**
1	*Chrysichthys nigroditatus*	Chrysichthys	Claroteidae	Oja
2	*C. auratus*	Chrysichthys	Claroteidae	Oja
3	*Synodontis nigrita*	Synodontis	Mochokidae	Sosogloso
4	*Synodontis melanopterus,*	Synodontis	Mochokidae	Sosogloso
5	*Synodontis batensoda*	Synodontis	Mochokidae	Sosogloso
6	*Schilbe uranoscopus,*	Schilbe	Schilbeidae	
7	*Brycinus nurse,*	Brycinus	Alestiidae	
8	*Brycinus leuciscus,*	Brycinus	Alestiidae	
9	*Alestes baremoze*	Alestes	Characidae	
10	*Machrobrachion machrobrachion*	Machrobrachion	Palaemonidae	Degon
11	*Machrobrachion rosenbergii,*	Machrobrachion	Palaemonidae	Degon
12	*Labeo parvus*	Labeo	Cyprinidae	Gonsha (ogonsha)
13	*Eleotris senegalensis*	Eleotris	Eleotridae	Mejoe

14	*M. sebae*	Monodactylus	Monodactylidae	Aklapa
15	*Mugil curema*	Mugil	Mugilidae	Wetin
16	*C. obscura*	Channa	Channidae	Hotun
17	*Parachanna obscura*	Parachanna	Channidae	Hotun
18	*Callinectes amnicola*	Callinectes	Portunidae	Agasa nowheme ton
19	*Sicydium brevifile*	Sicydium	Gobiidae	Alombo
20	*Nannocharax lineomaculatus*	Nannocharax	Distichodontidae	Agban
21	*Clarias gariepinus*	Clarias	Clariidae	Ason
22	*Clupea fimbrianta*	Clupea	Clupeidae	
23	*Hepsetus odoe*	Hepsetus	Hepsetidae	Kaka
24	*T. melanotheron,*	Tilapia	Cichlidae	Ohwe
25	*O.niloticus*	Oreochromis	Cichlidae	Ohwe
26	*Hyperopisus bebe*	Hyperopisus	Mormyridae	

Table 4: Fish species harvested from acadja system during the dry seasons of installation

No.	Species names	Genera	Families	Ogu local names (Badagry)
1	*C. nigroditatus*	Chrysichthys	Claroteidae	Oja
2	*C. auratus*	Chrysichthys	Claroteidae	Oja
3	*Neolabias powelli,*	Neolabias	Distichodontidae	
4	*T. guinesis,*	Tilapia	Cichlidae	Ohwe
5	*O.niloticus,*	Oreochromis	Cichlidae	Ohwe
6	*S.galileus,*	Sarotherodon	Cichlidae	Ohwe
7	*T.melanotheron,*	Tilapia	Cichlidae	Ohwe
8	*O.aureus*	Oreochromis	Cichlidae	Ohwe
9	*Sicydium brevifile*	Sicydium	Gobiidae	Alombo
10	*C. obscura*	Channa	Channidae	Hotun
11	*Callinetes amnicola*	Callinetes	Portunidae	Agasa nowheme ton
12	*Nannocharax fasciatus,*	Nannocharax	Distichodontidae	Agban
13	*M.sebae.*	Monodactylus	Monodactylidae	Aklapa
14	*Heterotis niloticus*	Heterotis	Osteoglossidae	Ohwa
15	*M.rosenbergii,*	Machrobrchion	Palaemonidae	Degon
16	*M. machrobrchion*	Machrobrchion	Palaemonidae	Degon
17	*Eleotris senegalensis*	Eleotris	Cyprinidae	Mejoe
18	*Clarias gariepinus*	Clarias	Clariidae	Ason

Biological diversity

The biological diversity indices for both rainy- and dry-season catches were calculated using the Shannon–Wiener Index (H′) and Simpson's Index (D), as shown above, and the results are presented in Table 5. Table 6 provides a comparison of treatments and their interpretations for each season. H-values had the highest diversity in raining values A1 (1.5698) and the least was in raining values B2 (0.6038). The D-value was highest in the rainy B2 value (0.7612). The highest

number of individuals was identified in rainy A2 values (288 individuals). The dry season indices are presented in Table 6.

Table 5: Results of calculations for rainy seasons' treatments (A, B, C, and D).

Formulas used	Rainy A1 Values	Rainy A2 Values	Rainy B1 Values	Rainy B2 Values	Rainy C1 Values	Rainy C2 Values	Rainy D1 Values	Rainy D2 Values
TOTAL(N)	219	288	153	162	63	107	32	24
Shannon (H')= −∑(pi*ln(pi))	1.5698	0.9659	1.1623	0.6038	1.1182	0.8289	1.6613	0.6238
Simpson (D)=∑ pi^2	0.3879	0.6326	0.4664	0.7612	0.4573	0.6541	0.2695	0.7049
Species Richness (S)	19	13	11	8	7	8	9	4
Evenness (E = H'/LN(S))	0.5331	0.3766	0.4847	0.2904	0.5746	0.3986	0.7561	0.450 0

Table 6: Results of calculations for dry seasons' treatments (A, B, C, and D).

Formulas used	Dry A1 Values	Dry A2 Values	Dry B1 Values	Dry B2 Values	Dry C1 Values	Dry C2 Values	Dry D1 Values	DryD2 Values
TOTAL(N)	53	153	21	**78**	**11**	97	4	**48**
Shannon (H')= −∑(pi*ln(pi))	1.618885	2.075642	1.1425	1.1663	2.0983	1.3275	0	0.8361
Simpson (D)=∑ pi^2	0.295835	0.169721	0.3605	0.4329	0.1405	0.3840	1	0.6363
Species Richness (S)	10	14	4	8	9	9	1	6
Evenness (E = H'/LN(S))	0.703073	0.786509	0.8241	0.5609	0.9550	0.6042	0	0.4667

Results from both seasons indicated that C. nigrodigitatus was the most dominant species across all treatments. The total number of individuals and species richness varied across treatments, with treatment generally recording higher values. Treatment A showed higher diversity and better species distribution, while Treatments B and C showed moderate diversity with increasing dominance. Treatment D recorded the lowest diversity and the highest dominance. From Table 6. In comparing the Treatments and their interpretations for the rainy seasons, the diversity indices showed

Discussion

The Nigerian coastal zone is home to 104 fish species from 50 families (Osodein & Anetekha, 2020). However, the Fish species composition of this study showed twenty-six (26) species from eighteen(18) families during the rainy season harvest, as presented in Table 3. In comparison,

eighteen (18) species from ten (10) families were recorded during the dry season harvest, as presented in Table 4, giving a total of 44 species from twenty-six families in all for both rainy and dry seasons. These contradict the values reported by Soyinka et al. (2010), who observed 37 fish species from 21 families in the Badagry Lagoon, while Bolarinwa and Okeowo (2017) recorded 64 species from 39 families in Badagry Coastal waters. Furthermore, results from both seasons indicated that C. nigrodigitatus was the most dominant and abundant species across all treatments.

The results clearly showed that harvesting frequency strongly influences fish community structure in acadja systems of fisheries, thereby promoting ecological balance. This is because Treatment A (monthly harvesting acadja) maintained the highest diversity and better species balance (Tables 5 & 6), suggesting that frequent harvesting prevents any single species from dominating and allows continuous recruitment of different species. Treatment A also showed the best species diversity and a stable ecosystem during the first and second rainy seasons, respectively (Table 5). During the dry seasons, Table 6 further showed that treatment A had a fairly productive balance and a highly diverse, stable species system during the first and second dry seasons, respectively. Treatments B and C showed moderate diversity (Tables 5 & 6) but increasing dominance, especially by C. nigrodigitatus. As the harvesting interval increased, competition among species also increased, leading to reduced diversity. Treatment D (semi-annual harvesting) showed the lowest diversity and the highest dominance, particularly during the second rainy season. This indicates that longer harvesting intervals allow dominant species to take over, reducing biodiversity (Tables 5 & 6). Reduced harvesting frequency in Treatments B, C, and D in the dry seasons also led to increasing dominance, especially by Chrysichthys nigrodigitatus, and reduced evenness (Table 6), as also confirmed by the same currency in treatment D during the rainy seasons

Seasonal differences were also observed, with some treatments showing lower diversity in the dry seasons (Tables 3 and 4). This might be due to environmental factors or prolonged competition within the system. In Table 3, which lists fish species harvested from the Acadja system during the first and second rainy seasons, there are 26 species from 18 families, compared with 18 species from 10 families harvested during the dry seasons (Table 4). This study found that the fish species associated with the acadja fishing system are those found in Badagry Lagoon, as confirmed by the works of Soyinka et al. (2010), Bolarinwa et al. (2016), Bolarinwa and Okeowo (2017), and Osodein and Anetekha (2020). The dominance exhibited was not by accident but due to the inclusion of Bamboo cuttings into the acadja system compartments, which served as hiding places and shelters for members of the Clariteidae family.

Conclusion

In Acadja system of fishing, different types that fish species are being caught as much as such fish species are found within Badagry Lagoon and as much such fish species are being caught by the local fishermen using other forms of fishing gears. This study showed that the monthly harvesting of acadja system that is of small size is the most effective method for maintaining both fish productivity and species diversity in acadja systems. The longer harvesting intervals of 2 months, 3 months or months tend to favor dominant species and reduce ecological balance as observed from this study. Proper management of harvesting frequency is therefore essential for sustainable fish production for acadja system in the lagoon environments.

Recommenations

To achieve an evenly distributed, highly diverse set of fish species associated with the acadja system of fishing, monthly harvesting of acadja fish from the Lagoon is recommended to sustain acadja-based fish production.

References

Adekoya, B.B. (1997): indigenous knowledge systems in fisheries. A paper presented at OGADEP's Annual PM-Season Training in Abeokuta, Nigeria.

Ben Sonneveld, Frejus Thoto & Donald Houessou.(2018). What does a fisherman want? Report on the survey among fishers around Lake Nokoué and Porto-Novo Lagoon in Benin, published by Amsterdam Centre for World Food Studies/Athena Institute, Vrije Universiteit.

Beverly, S., Griffiths, D. & Lee, R. (2012). Anchored fish aggregating devices for artisanal fisheries in South and Southeast Asia: benefits and risks. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand, RAP Publication 2012/20,65p.Cloi: 10.3176/eco. 2010.2.05.

Bolarinwa J.B. & Okeowo, T.O. (2017). The Species Composition and Diversity Of The Coastal Waters Of Badagry, Lagos State, Nigeria. Global Journal of Agricultural Research Vol.5, No.2, pp.26–31. Published by European Centre for Research Training and Development UK (www.eajournals.org). ISSN 2053-5805(Print), ISSN 2053-5813(Online).

Bolarinwa J.B., Okeowo, T., Fasakin E. & Fagbenro A. (2016).The Species Composition And Diversity Of The Coastal Waters Of Badagry, Lagos State, Nigeria. Global Journal of Agricultural Research Vol.4, No.2, pp.1–6. Published by European Centre for Research Training and Development UK (www.eajournals.org) ISSN 2053-5805(Print), ISSN 2053-5813(Online)

Durand, J.R. & Hem, S. (1996). The integration of extensive aquaculture (Acadja- enclose) into the lagoon village environment in Côte d'Ivoire. 33- 44 pp. In R.S.V. Pullin, J. Lazard, M. Lendre. ICLARM conf proc. 41, 575 p.m.

Adesulu, E.A and Sydeham, D.H.J. (2007).The freshwater fishes and Fisheries of Nigeria. Macmillan Nigeria Publishers Limited, Ilupeju Industrial Estate, P.O.Box 264, Yaba, Lagos. ISBN 978-978-018-362-2 (397).

Elezuo KO, Bello MU & Aladetohun NF (2024).Harnessing the fisheries sector of the blue economy for sustainable economic growth and development in Nigeria: Opportunities, challenges, and strategies. IJFAS 2024 ; 1 2(5) : 15 - 23 © 202 4 IJFAS.

Elezuo KO, Okeke EG, Olanrewaju VO, Quadri B (2020).Growth performance of Clarias gariepinus juveniles fed diets supplemented with garlic (Allium sativum) powder. J Aquat Sci. 2020;35(2):157-164.

FAO.(2024). In Brief: The State of World Fisheries and Aquaculture 2024. Blue Transformation in action. Rome. https://doi.org/10.4060/cd0690en

Gomna A (2015). A comparative study of the profitability of Brush parks in two states in Nigeria. International Journal of Fisheries and Aquaculture 7:160-166

Ipinmoroti, M. O. and Iyiola, A. O. (2022).Diversity, distribution and abundance of fish species in Lake Asejire, Oyo State, Nigeria. The Zoologist, 21: 49-56. http://dx.doi.org/10.4314/tzool.v21i1.8

Kouamé Parfait YOBOUE, Benié Rose Danielle ABOUA , Siaka BERTE1, Julien Kalpy COULIBALY , Nahoua Issa OUATTARA et Essetchi Paul KOUAMELAN (2018). Impacts des exploitations piscicoles en cages flottantes sur la structure des

macroinvertébrés benthiques de la lagune Ebrié (Côte d'Ivoire).In. J. Biol. Chem. Sci. 12(2): 769-780. ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

Laleye .P. (2000). p. 51- 52. In E.K. Abban, C.M.V Casal, T.M. Falk and R.S.V Pullin (eds) Biodiversity and sustainable use of fish in the coastal zone. ICLARM coni proc 63, 71p.

Madhuri Bhardwaj, Rashmi Tiwari, Ved Prakash Bhardwaj, Sourabh Bhardwaj (2023). A Short Review on Various Biodiversity Indices. International Journal of Advanced Research in Science, Communication and Technology (IJARSCT) International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal Volume 3, Issue 1 . Copyright to IJARSCT DOI: 10.48175/IJARSCT-13153 385 www.ijarsct.co.in

Odioko E & Becer Z.A (2022). The Economic Analysis of The Nigerian Fisheries Sector: A Review. Journal of Anatolian Environmental and Animal Sciences: 7, No: 2, 2022 (216-226:) DOI: https://doi.org/10.35229/jaes.1008836

Ogunbadejo Hussain, Aroriode Ojiyovwi Rebecca, Adedokun Wosilat (2012). Productivity and technical efficiency of fish farming in Lagos state. A Continental J. Fisheries and Aquatic Science 6 (2): 8–15, 2012 ISSN: 2141 – 4246 © Wilolud Journals, 2012 http://www.wiloludjournal.com Printed in Nigeria doi:10.5707/cjfas. 2012.6.2.8.15.

Olaosebikan, B. & Raji, A. (2013).Field Guide to Nigerian Freshwater Fishes Federal College of Freshwater Fisheries Technology, New Bussa, Nigeria (144p)

Olopade A O.. and Ajibade D. Aluko F.A (2008). Community-based fishery management: a case study of the Acadja method of fishing on the background creek, Ogun State, Nigeria. Journal of Agriculture and Social Research (JASR) vol. 8, No. 1, 2008.

Olufemi O. Soyinka, Minasu P. Kuton & Caroline I. Ayo-Olalusi (2010). Seasonal distribution and richness of fish species in the Badagry Lagoon, Southwest Nigeria Estonian Journal of Ecology, 2010, 59, 2, 147–157. Cloi: 10.3176/eco. 2010.2.05.

Oluwayemisi A. Osodein & Martins A. Anetekhai (2020). Fisheries of Ilaje Community, Badagry, Lagos, Nigeria. ISSN 2358-2731 https://doi.org/10.21472/bjbs(2020)071703 ISSN 2358-2731/BJBS-2020-0054/2020/7/17/3/261 Braz. J. Biol. Sci. http://revista.rebibio.net.

Robert K Peet (1974).The Measurement Of Species Diversity. Annu. Rev. Ecol. Syst. 1974.5:285-307. Downloaded from www.annualreviews.org. Access provided by Masaryk University on 10/15/20. For personal use only.Brazilian Journal of Biological Sciences, 2020, Vol. 7, No. 17, p. 261–282.

Solarin B.B and Udolisa R.E.K. (1993). An investigation of the Brush Park filling in Lagos Lagoon, Nigeria. Fisheries resource vol. 15, issue 4, January 1993 pp. 331- 337

Solarin, B. B. (1992). Aspects of the fishing industry and an overview of artificial reefs and fish aggregating devices for increasing fisheries output and variability in Nigeria. In: AnnualConf. Proc. - 10th Annual Conf. of FISON Abeokuta, 16th - 20th Nov. 1992, 242p. Southwest Nigeria Estonian Journal of Ecology, 2010, 59, 2, 147–157.

Uddin, K.B., Sanjib Basak, S., Mohammed Moniruzzannan, A.K.M. Impact of Brush Acadja Fisheries enhancement system in Benin; their productivity and environmental

Welcomme, R. L. (1972). An evaluation of the "acadja" methods of fishing practice in the coastal Lagoon of Dahomey (West Africa). Fish I3iology 4:39

WorldFish (2018). WorldFish Nigeria Strategy: 2018-2022. Penang, Malaysia: WorldFish.Strategy:2018-09.

SUB-THEME 6:
INFORMATION AND COMMUNICATION TECHNOLOGY: ARTIFICIAL INTELLIGENCE AND THEIR IMPACTS ON FOREST ECOSYSTEM

ISTF-NG2026

PREDICTING CLIMATE-DRIVEN HABITAT SHIFTS OF *Afzelia africana* Sm IN WEST AFRICA USING A MACHINE LEARNING APPROACH

***UGEGE Peter Edemewe[1]., UGEGE Bukola Hannah[2]., AGBENU David Ogbe[1]., AKOUN Mercy[1]., AIGBOKHAN John Oseyomon[1], BADEJO David Kolade[1] and OLASIEGBE Yetunde Faith[1]**

[1]Forestry Research Institute of Nigeria, Ibadan, Nigeria.
[2]Federal College of Forestry, Ibadan, Nigeria
**Corresponding Email: pugege@frin.gov.ng,/08057170045*

Abstract

Afzelia africana Sm. is an economically and ecologically important tropical tree species widely distributed across the savanna woodlands of West Africa. However, increasing anthropogenic pressure, habitat degradation, and climate change threaten the persistence and regeneration of this valuable timber species. Predicting potential shifts in species distribution under future climate scenarios is therefore essential for effective conservation planning. This study applied a machine learning approach to model the current and future habitat suitability of *Afzelia africana* across West Africa, with a focused assessment for Nigeria. Occurrence records (n = 178) obtained from biodiversity databases were cleaned to remove spatial errors and duplicates, and species distribution modelling was conducted using a Random Forest algorithm in Python with bioclimatic variables as environmental predictors. Model performance was evaluated using the Area Under the receiver operating characteristic (ROC) curve (AUC). The model showed excellent predictive performance (AUC = 0.956). Under current climatic conditions, approximately 71,685 grid cells across West Africa were predicted to be suitable for the species. Future projections indicate an expansion of suitable habitat, with 142,637 cells predicted for 2050 and 137,984 cells for 2070. Within Nigeria, suitable habitat is projected to increase from 7,345 cells under current conditions to 19,630 cells by 2050 and 18,515 cells by 2070. These findings indicate potential climate-driven shifts in the distribution of *Afzelia africana*, with important implications for biodiversity conservation, restoration planning, and climate-resilient forest management in West Africa.

Keywords: Species distribution modelling, Random Forest, climate change, habitat suitability, *Afzelia africana*, West Africa.

Introduction

Tropical forests and savanna woodlands support a large proportion of the world's terrestrial biodiversity and provide essential ecosystem services, including carbon sequestration, climate regulation, and livelihoods for rural communities (Intergovernmental Panel on Climate Change (IPCC), 2023). However, increasing deforestation, land-use change, and climate variability are altering the distribution and viability of many native tree species across tropical ecosystems (Sala *et al.*, 2000). *Afzelia africana* Sm. is an important multipurpose timber species widely distributed across the Sudanian and Guinean savanna zones of West Africa. The species is valued for its durable timber, medicinal properties, and ecological importance within savanna woodland ecosystems. Its wood is widely used for construction, furniture production, and boat building due to its strength and resistance to decay. Despite its economic and ecological value, natural populations of *A. africana* are declining due to overexploitation, habitat degradation, and limited

natural regeneration in disturbed landscapes (Tessi *et al*., 2024). Climate change is increasingly recognized as a major driver of species distribution shifts worldwide. Changes in temperature and precipitation regimes can alter ecological niches, potentially leading to habitat contraction, expansion, or shifts in geographic range (Parmesan, 2006). Understanding how future climatic conditions may influence habitat suitability is therefore essential for the conservation and sustainable management of long-lived tropical tree species such as *A. africana*.

Species Distribution Modelling (SDM) has emerged as an important tool for predicting species distributions using occurrence records and environmental variables (Elith & Leathwick, 2009). Recent advances in machine learning approaches, particularly the Random Forest algorithm, have improved the predictive accuracy of SDMs by effectively capturing nonlinear relationships and complex ecological interactions (Breiman, 2001; Cutler *et al.*, 2007). Despite the increasing application of SDMs globally, relatively few studies have focused on economically important indigenous tree species in West Africa. Nigeria represents a key part of the distribution range of *A. africana* and plays an important role in regional forest conservation. This study, therefore, applies a Random Forest species distribution modelling approach to predict the current and future habitat suitability of *Afzelia africana* across West Africa, with a focused assessment of habitat dynamics in Nigeria to support conservation and climate-adaptive forest management strategies.

Materials and Methods

Study Area

The study focused on a portion of West Africa extending approximately between latitudes 4°N and 20°N and longitudes 17°W and 15°E, covering five countries within the Guinea and Sudan savanna zones: Nigeria, Ghana, Benin, Togo, and Côte d'Ivoire. These countries form part of the West African region as defined by regional and international classifications (Nicholson, 2013). The Area spans diverse ecological zones ranging from humid tropical forests in the southern coastal regions to savanna ecosystems further inland. Climate across West Africa is strongly influenced by the West African monsoon system, resulting in marked gradients in rainfall and temperature (Nicholson, 2013; Intergovernmental Panel on Climate Change (IPCC), 2023). Annual rainfall varies from over 2,000 mm in coastal forest regions to less than 600 mm in the Sahel, while mean annual temperatures generally range between 24°C and 32°C (Fick & Hijmans, 2017). Nigeria was selected for detailed national-level analysis because it represents a significant portion of the natural distribution range of *Afzelia africana*. The country contains several ecological zones, including tropical rainforest, derived savanna, Guinea savanna, Sudan savanna, and Sahel savanna, which support a variety of economically important indigenous tree species.

Species Occurrence Data

Occurrence records for *Afzelia africana* were compiled from publicly available biodiversity databases, particularly the Global Biodiversity Information Facility (GBIF.org User, 2026), as well as relevant literature and herbarium records. Biodiversity occurrence databases provide important georeferenced records widely used in species distribution modelling studies (Ball-Damerow *et al*., 2019; Barbosa & Alves-Souza, 2025). Data cleaning procedures were applied to improve reliability, including the removal of duplicate records, records with missing or invalid coordinates, and points located outside the known distribution range of the species. Spatial filtering was also

performed to reduce sampling bias and spatial autocorrelation. After these procedures, 178 occurrence records were retained and used as presence data for model development.

Environmental Variables

Environmental predictors consisted primarily of bioclimatic variables derived from global climate datasets. Climate variables are key determinants of plant species distributions because temperature and precipitation strongly influence physiological processes and ecological interactions (Montoya-Jiménez *et al.*, 2022). Nineteen bioclimatic variables representing temperature and precipitation patterns were obtained from the WorldClim version 2 dataset, which provides high-resolution global climate surfaces based on long-term meteorological observations (Fick & Hijmans, 2017). Future climate projections were obtained for 2050 and 2070, representing mid-century and late-century conditions commonly used in climate impact assessments. All environmental layers were standardized to the same spatial resolution and geographic extent prior to modelling.

Species Distribution Modelling

Species distribution modelling was performed using the Random Forest (RF) algorithm. This machine learning technique constructs multiple decision trees and combines their predictions to improve model accuracy and reduce overfitting. Random Forest models are widely used in ecological studies because they effectively capture nonlinear relationships between environmental variables and species occurrences. Pseudo-absence points were generated to complement presence data, and environmental predictor values were extracted for both presence and pseudo-absence locations. The dataset was divided into training and testing subsets to enable independent model evaluation. The trained model was then used to produce continuous habitat-suitability predictions across the study region, with values ranging from 0 to 1.

Model Evaluation and Habitat Change Analysis

Model performance was assessed using the Area Under the Receiver Operating Characteristic Curve (AUC), a commonly used metric for evaluating species distribution models. AUC values range from 0.5 (random prediction) to 1.0 (perfect prediction). The model achieved an AUC value of 0.956, indicating excellent predictive performance (Lee *et al*., 2022). Continuous suitability predictions were converted into binary suitable and unsuitable habitats using a threshold value of 0.3. Habitat suitability maps were produced for current climate conditions and future projections for 2050 and 2070. Spatial overlay analysis was then used to identify areas of habitat gain, habitat loss, and stable habitat between current and future scenarios. This approach allowed the assessment of potential climate-driven distribution shifts across West Africa and within Nigeria.

Results

Model Performance

The Random Forest species distribution model for *Afzelia africana* showed excellent predictive performance. Model evaluation using the Area Under the Receiver Operating Characteristic Curve (AUC) produced a value of 0.956, indicating high accuracy in distinguishing between suitable and unsuitable habitats. This result suggests that the environmental predictors effectively captured the climatic conditions influencing the distribution of the species across West Africa.

Environmental Variable Importance

The Random Forest model also identified the relative importance of climatic variables influencing habitat suitability. Variable importance was assessed using the mean decrease in model accuracy. Precipitation seasonality (Bio15) was the most influential variable with an importance score of 0.242, followed by temperature seasonality (Bio4, 0.232). These results indicate that seasonal variability in rainfall and temperature strongly influences the ecological niche of *Afzelia africana*. Annual precipitation (Bio12, 0.223) also contributed significantly, highlighting the importance of rainfall availability. Other predictors, including annual mean temperature (Bio1) and precipitation of the warmest quarter (Bio18), showed lower but notable contributions. The relative importance of these environmental predictors is illustrated in Figure 1.

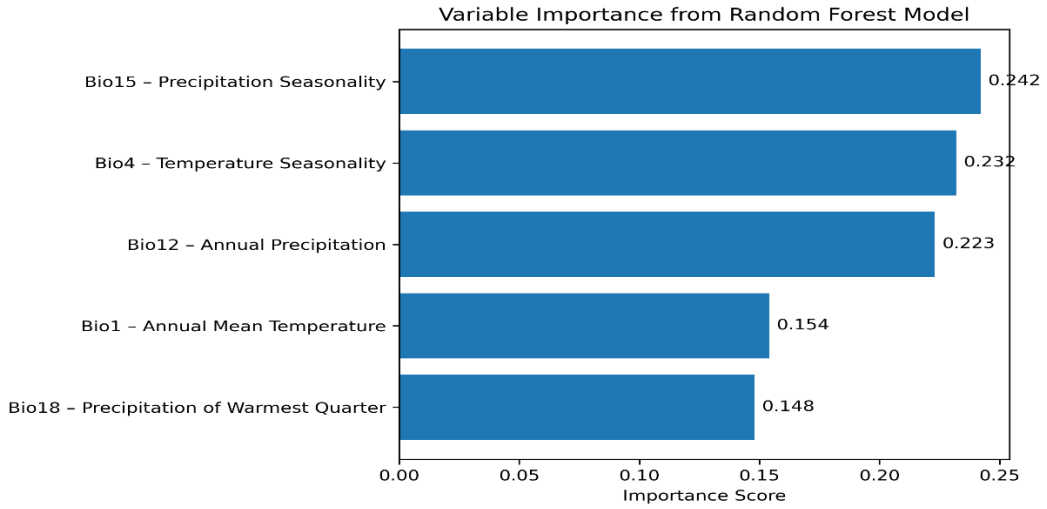


Figure 1. Relative importance of bioclimatic variables influencing the predicted distribution of *Afzelia africana* based on the Random Forest species distribution model.

Current Habitat Suitability

The predicted current habitat suitability map indicates that *Afzelia africana* is widely distributed across the savanna ecosystems of West Africa, particularly within the Guinea and Sudan savanna zones. The current suitability map (Figure 2A) shows that approximately 71,685 grid cells meet the suitability threshold (≥0.3). These areas occur mainly in regions characterized by moderate rainfall and warm temperatures typical of tropical savannas. In Nigeria, suitable habitats are concentrated mainly in the central and northern Guinea savanna regions, where environmental conditions support the species' persistence.

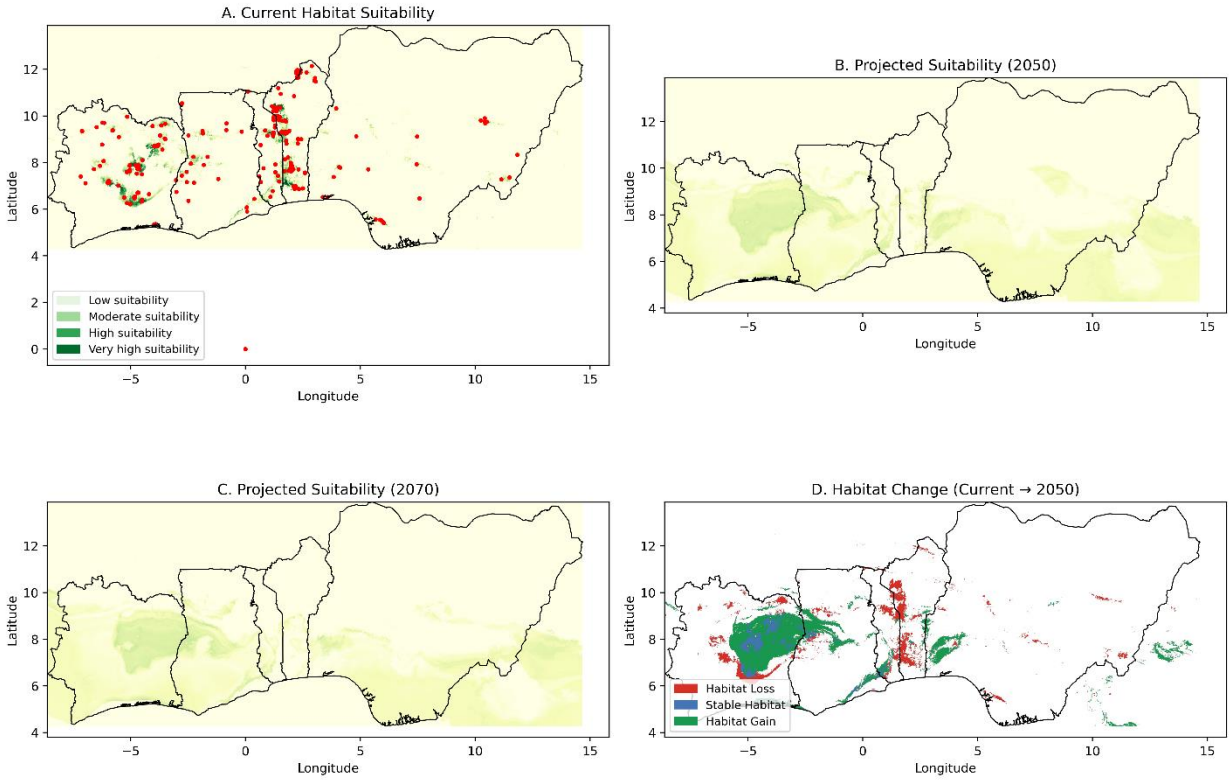


Figure 2. **Predicted habitat suitability and habitat change for *Afzelia africana* in West Africa: (A) current suitability, (B) 2050 projection, (C) 2070 projection, and (D) habitat gain and loss.3.4 Future Habitat Suitability Projections**

Future climate projections indicate a substantial expansion of suitable habitat for *Afzelia africana* across West Africa. Under the 2050 climate scenario, approximately 142,637 grid cells were predicted to be suitable (Figure 2B). Projections for 2070 indicate 137,984 suitable grid cells (Figure 2D), representing a slight decline from 2050 but still considerably higher than current levels. These results suggest that climate change may create new environmentally suitable areas for the species across parts of West Africa.

Table 1: Predicted Suitable Habitat Cells for *Afzelia africana* in West Africa

Climate Scenario	Suitable Cells
Current	71,685
2050	142,637
2070	137,984

Habitat Gain and Loss Across West Africa

Comparison of current and future suitability maps revealed notable shifts in habitat distribution. Habitat change analysis identified areas of habitat gain, habitat loss, and stable habitat. Approximately 123,055 grid cells represent habitat gain, while 52,103 grid cells represent habitat loss. Additionally, 19,582 grid cells remain stable under both current and future climatic conditions. The spatial distribution of these habitat changes across West Africa is shown in Figure 1D.

Table 2: Habitat Change Statistics for West Africa

Habitat Category	Number of Cells
Habitat Gain	123,055
Habitat Loss	52,103
Stable Habitat	19,582

Nigeria-Specific Habitat Dynamics

A national-level analysis was conducted to assess habitat changes within Nigeria. Under current climatic conditions, 7,345 grid cells were classified as suitable for *Afzelia africana*. Future projections indicate a significant increase, with 19,630 suitable cells predicted for 2050 and 18,515 cells for 2070. Habitat change analysis shows 19,313 grid cells with habitat gain, 7,028 with habitat loss, and 317 remaining stable. The spatial distribution of these changes within Nigeria is presented in Figure 3.

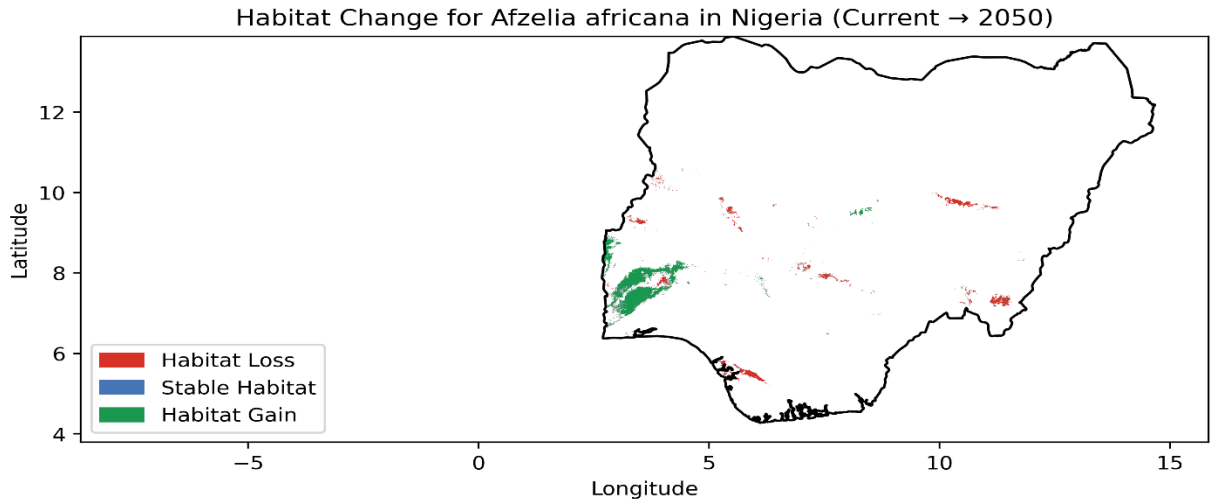


Figure 3. Spatial distribution of projected habitat gain, loss, and stable habitats for *Afzelia africana* in Nigeria under future climate conditions derived from the Random Forest species distribution model.

Table 3: Predicted Suitable Habitat Cells in Nigeria

Climate Scenario	Suitable Cells
Current	7,345
2050	19,630
2070	18,515

Discussion

Model Performance and Reliability

The Random Forest model developed in this study demonstrated excellent predictive performance, with an AUC of 0.956, indicating a strong ability to distinguish between suitable and unsuitable habitats for *Afzelia africana*. High AUC values are commonly reported in machine learning–based species distribution models and reflect strong predictive capability when modelling complex ecological relationships (Cutler *et al.*, 2007; Elith & Leathwick, 2009). Machine learning algorithms such as Random Forest are increasingly applied in ecological modelling because they effectively capture nonlinear relationships between environmental variables and species occurrence data. Compared with traditional statistical approaches, these methods often provide improved predictive accuracy for large-scale species distribution analyses (Breiman, 2001; Montoya-Jiménez *et al.*, 2022).

Influence of Climatic Variables on Species Distribution

The variable importance analysis identified precipitation seasonality (Bio15) and temperature seasonality (Bio4) as the most influential predictors of *Afzelia africana* distribution. This indicates that the species is strongly influenced by seasonal climatic variability rather than by average climatic conditions alone. West African savanna ecosystems are characterized by pronounced seasonal rainfall patterns driven by the West African monsoon system, which strongly influences vegetation structure and species composition (Nicholson, 2013). The importance of precipitation seasonality, therefore, reflects A. africana's ecological adaptation to environments with distinct wet and dry seasons. Annual precipitation (Bio12) was also a key predictor, consistent with studies showing that water availability strongly influences the distribution of tree species in tropical savannas (Lehmann *et al*., 2011).

Current Distribution Patterns

The predicted current habitat suitability patterns indicate that *Afzelia africana* is mainly associated with the Guinea and Sudan savanna zones of West Africa. These environments provide suitable climatic conditions, including moderate rainfall and seasonal climatic variability. The predicted distribution corresponds with previous ecological descriptions of the species as a characteristic component of savanna woodlands across tropical Africa (Tessi *et al*., 2024). In Nigeria, suitable habitats are concentrated within the Guinea savanna belt, as indicated by existing forestry records.

Climate Change and Habitat Shifts

The modelling results suggest a potential expansion of suitable habitat for *Afzelia africana* under future climate scenarios. Suitable areas are projected to increase substantially by 2050 and remain relatively high by 2070. Climate-driven redistribution of species is increasingly documented globally as organisms respond to changing temperature and precipitation regimes (Parmesan, 2006; Pecl *et al*., 2017). For drought-tolerant tropical tree species such as *A. africana*, changing climatic conditions may create new suitable habitats in regions that are currently marginal. However, expansion of climatically suitable areas does not necessarily guarantee species establishment, as dispersal limitations, land-use change, and habitat fragmentation may constrain colonization.

Habitat Dynamics and Conservation Implications

The habitat change analysis revealed substantial habitat gain alongside localized habitat loss across West Africa. While some areas may become unsuitable, the large number of predicted gain areas suggests potential range shifts under future climate conditions. Within Nigeria, the projected increase in suitable habitat may present opportunities for forest restoration and climate-resilient forestry programs. Identifying areas likely to remain suitable or become suitable in the future can support reforestation initiatives and sustainable timber management. Species distribution modelling provides valuable insights into biodiversity conservation under climate change by identifying potential habitat gains and losses, as well as stable refugia (Elith & Leathwick, 2009). Such information can guide conservation planning and restoration strategies for economically important species such as *Afzelia africana*.

Limitations of the Study

Several limitations should be considered when interpreting the results. First, the occurrence data used in this study were largely obtained from the Global Biodiversity Information Facility (GBIF), which may contain spatial sampling biases and uneven geographic coverage. Limited biodiversity data collection in parts of West Africa may therefore influence model accuracy. Second, the modelling framework relied primarily on climatic variables, whereas other environmental factors, such as soil properties, land-use patterns, and disturbance regimes, can also influence species distributions. Additionally, species distribution models predict climatic suitability rather than actual presence, so dispersal limitations and human pressures may restrict colonization of newly suitable areas. Finally, future projections are influenced by uncertainties associated with climate models and emission scenarios. Despite these limitations, the modelling framework provides valuable baseline insights into potential climate-driven distribution shifts of *Afzelia africana*. It highlights the need for improved biodiversity data collection and ecological monitoring in West Africa.

Conclusion and Recommendations

This study applied a Random Forest species distribution modelling approach to predict the current and future habitat suitability of *Afzelia africana* across West Africa, with a focused analysis for Nigeria. The model showed excellent predictive performance (AUC = 0.956), indicating strong reliability in identifying suitable habitats. Results suggest that under current climatic conditions,

about 71,685 grid cells across West Africa are suitable for the species. Future projections indicate a substantial expansion of suitable habitat, with 142,637 cells predicted for 2050 and 137,984 cells for 2070, although localized habitat loss may occur. In Nigeria, suitable habitat is projected to increase from 7,345 cells currently to 19,630 cells by 2050 and 18,515 cells by 2070, indicating potential opportunities for conservation and restoration. The variable importance analysis identified precipitation seasonality, temperature seasonality, and annual precipitation as key climatic drivers shaping the distribution of *Afzelia africana*. The occurrence data used in this study were primarily obtained from the Global Biodiversity Information Facility (GBIF), underscoring the importance of accessible biodiversity databases for ecological modelling. However, limited occurrence data for many African species underscores the need for greater investment in systematic biodiversity surveys and the development of national species occurrence repositories.

Conservation efforts should prioritize stable habitats and areas projected to gain habitat, particularly for restoration and climate-resilient forestry programs. Strengthening biodiversity data infrastructure and integrating modelling results into forestry and conservation policies will improve species monitoring and management. Overall, machine learning–based species distribution modelling provides valuable insights into climate-driven habitat shifts and can support evidence-based conservation and sustainable forest management in West Africa.

References

Ball-Damerow, J. E., Brenskelle, L., Barve, N., Soltis, P. S., Sierwald, P., Bieler, R., LaFrance, R., Ariño, A. H., & Guralnick, R. P. (2019). Research applications of primary biodiversity databases in the digital age. *PLOS One*, *14*(9), e0215794. https://doi.org/10.1371/journal.pone.0215794

Barbosa, W. L., & Alves-Souza, S. N. (2025). Data quality issues in data used in species distribution models: A systematic literature review. *Ecological Informatics*, *91*, 103378. https://doi.org/10.1016/j.ecoinf.2025.103378

Breiman, L. (2001). Random Forests. *Machine Learning*, *45*(1), 5–32. https://doi.org/10.1023/A:1010933404324

Cutler, D. R., Edwards, T. C., Beard, K. H., Cutler, A., Hess, K. T., Gibson, J., & Lawler, J. J. (2007). RANDOM FORESTS FOR CLASSIFICATION IN ECOLOGY. *Ecology*, *88*(11), 2783–2792. https://doi.org/10.1890/07-0539.1

Elith, J., & Leathwick, J. R. (2009). Species Distribution Models: Ecological Explanation and Prediction Across Space and Time. *Annual Review of Ecology, Evolution, and Systematics*, *40*(1), 677–697. https://doi.org/10.1146/annurev.ecolsys.110308.120159

Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, *37*(12), 4302–4315. https://doi.org/10.1002/joc.5086

GBIF.org User. (2026). *Occurrence Download* (p. 75085) [Text/tab-separated-values, application/zip]. The Global Biodiversity Information Facility. https://doi.org/10.15468/DL.WABWEF

Intergovernmental Panel On Climate Change (IPCC). (2023). *Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009325844

Lee, W.-H., Song, J.-W., Yoon, S.-H., & Jung, J.-M. (2022). Spatial Evaluation of Machine Learning-Based Species Distribution Models for Prediction of Invasive Ant Species Distribution. *Applied Sciences*, *12*(20), 10260. https://doi.org/10.3390/app122010260

Lehmann, C. E. R., Archibald, S. A., Hoffmann, W. A., & Bond, W. J. (2011). Deciphering the distribution of the savanna biome. *New Phytologist*, *191*(1), 197–209. https://doi.org/10.1111/j.1469-8137.2011.03689.x

Montoya-Jiménez, J., Valdez-Lazalde, J., Ángeles-Perez, G., De Los Santos-Posadas, H., & Cruz-Cárdenas, G. (2022). Predictive capacity of nine algorithms and an ensemble model to determine the geographic distribution of tree species. *iForest - Biogeosciences and Forestry*, *15*(5), 363–371. https://doi.org/10.3832/ifor4084-015

Nicholson, S. E. (2013). The West African Sahel: A Review of Recent Studies on the Rainfall Regime and Its Interannual Variability. *ISRN Meteorology*, *2013*, 1–32. https://doi.org/10.1155/2013/453521

Parmesan, C. (2006). Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of Ecology, Evolution, and Systematics*, *37*(1), 637–669. https://doi.org/10.1146/annurev.ecolsys.37.091305.110100

Pecl, G. T., Araújo, M. B., Bell, J. D., Blanchard, J., Bonebrake, T. C., Chen, I.-C., Clark, T. D., Colwell, R. K., Danielsen, F., Evengård, B., Falconi, L., Ferrier, S., Frusher, S., Garcia, R. A., Griffis, R. B., Hobday, A. J., Janion-Scheepers, C., Jarzyna, M. A., Jennings, S., … Williams, S. E. (2017). Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science*, *355*(6332), eaai9214. https://doi.org/10.1126/science.aai9214

Sala, O. E., Stuart Chapin, F., Iii, Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., H., L. F., J., R. B., K., A., L., R., Lodge, D. M., Mooney, H. A., Oesterheld, M., Poff, N. L., Sykes, M. T., Walker, B. H., Walker, M., & Wall, D. H. (2000). Global Biodiversity Scenarios for the Year 2100. *Science*, *287*(5459), 1770–1774. https://doi.org/10.1126/science.287.5459.1770

Tessi, D. R. Y., Kakpo, S. B., & Ganglo, J. (2024). Potential future distribution shifts for *Afzelia africana* Sm. Ex Pers. And *Pterocarpus erinaceus* Poir. In the context of climate change in Benin. *Forestry Studies*, *81*(1), 37–50. https://doi.org/10.2478/fsmu-2024-0012

DIGITAL FORESTS: INFORMATION AND COMMUNICATION TECHNOLOGY, ARTIFICIAL INTELLIGENCE AND THEIR IMPACTS ON FOREST ECOSYSTEMS

Emmanuel, I.B.[1*], Ogunbamowo, P. O.[1], Emmanuel, J.O.[2], Sowunmi, L.I.[1], Babalola, Y.O.[1], Oniya, E.A.[1], Aguda, O.[1], and Popoola, O.O.[1]

[1] *Biomedicinal Research Centre, Forestry Research Institute of Nigeria (FRIN), Ibadan*
[2] *Federal College of Forestry Mechanization, Afaka, Kaduna, Nigeria*
**Corresponding E-mail: emmanuel.ib@frin.gov.ng; +234-813-169-4728,*

Abstract

Forests cover approximately four billion hectares of the Earth's land surface and are vital to biodiversity conservation, climate regulation, and the livelihoods of billions of people. However, these ecosystems face unprecedented threats from deforestation, illegal logging, wildfire, and climate change. Information and Communication Technology (ICT) and Artificial Intelligence (AI) have emerged as transformative tools for addressing these threats through precision monitoring, predictive analytics, and evidence-based decision-making. This review synthesizes recent literature on the applications of ICT and AI in forest ecosystem management. Remote sensing, Unmanned Aerial Vehicles (UAVs), Internet of Things (IoT) sensor networks, machine learning (ML), and deep learning (DL) are examined, together with their demonstrated impacts on deforestation detection, forest health monitoring, wildfire prediction, carbon stock estimation, biodiversity conservation, and sustainable timber governance. Key findings show that deep learning models achieve up to 95.65% recall in wildfire detection, ML-powered satellite analysis attains 93% accuracy in Amazonian deforestation mapping, and AI-driven species identification systems reach 98.91% accuracy. Despite these gains, persistent challenges, including data scarcity, model transferability, infrastructure deficits in developing nations, and ethical concerns, remain. The review recommends integrated approaches, capacity building, and policy frameworks to maximize the benefits of ICT and AI for sustainable forest ecosystem management.

Keywords: artificial intelligence, deforestation, forest ecosystem, ICT, machine learning, remote sensing

Introduction

Forests are among the most ecologically valuable and functionally complex terrestrial systems on Earth. They harbour approximately 80% of the world's terrestrial biodiversity, store more than 650 gigatons of carbon, regulate hydrological cycles, and sustain the livelihoods of an estimated 1.6 billion people who depend directly on forest resources (FAO, 2020). Despite this importance, forests continue to face severe and accelerating threats. Global deforestation rates remain alarming, with approximately 10 million hectares of forest lost annually between 2015 and 2020, primarily in tropical regions (FAO, 2020). Adding to the pressure of land-use change are illegal logging, wildfire, invasive species, pests, diseases, and the escalating impacts of climate change. Traditional methods of forest monitoring, inventory, and management, while essential, are increasingly inadequate to address the scale, speed, and complexity of these challenges. Ground-based surveys are labour-intensive, costly, and limited in spatial coverage. Conventional remote sensing, though valuable, has historically required specialized expertise, expensive data acquisition, and lengthy

processing times. Against this background, Information and Communication Technology (ICT) and Artificial Intelligence (AI) have assumed growing significance in the forestry sector.

ICT comprises a broad range of digital tools, including satellite and airborne remote sensing, Unmanned Aerial Vehicles (UAVs or drones), Geographic Information Systems (GIS), the Internet of Things (IoT), cloud computing, and mobile applications. AI, on the other hand, is made up of machine learning (ML), deep learning (DL), computer vision, natural language processing, and expert systems, all of which enable computers to learn from data and make decisions with minimal human intervention (Perry *et a*l., 2022; Raihan, 2023). The convergence of ICT and AI is driving a paradigm shift in forest ecosystem management, moving from reactive, periodic assessments to proactive, continuous, and data-driven stewardship. The global AI industry was valued at 184 billion US dollars in 2024 and is projected to grow at a compound annual growth rate of 28.46%, reaching 826.7 billion US dollars by 2030 (Guma *et al*., 2025). Within forestry and wildlife management specifically, the AI market was valued at 1.7 billion US dollars in 2023 and is expected to reach 16.2 billion US dollars by 2032 (Factview Research, 2024). These figures highlight the scale of investment and the pace of technological integration in the sector. This review examines the current state of ICT and AI applications in forest ecosystem management. It evaluates their impacts on monitoring, conservation, and governance, identifies persistent challenges, and proposes pathways for maximizing the benefits of these technologies. The paper is organized under thematic sections covering remote sensing, UAV technology, IoT sensor networks, AI and ML applications, carbon and biomass estimation, biodiversity conservation, wildfire management, and governance considerations.

Overview of ICT Tools Applied in Forest Ecosystem Management

Information and Communication Technology provides the foundational data-acquisition infrastructure for AI applications. The primary ICT tools used in forest ecosystems include remote sensing platforms, UAVs, IoT sensor networks, GIS, and cloud computing. Table 1 summarizes the major tools and their forestry applications.

Table 1: Major ICT and AI tools applied in forest ecosystem management

ICT/AI Tool	Application in Forestry	Key References
Remote Sensing (Satellite)	Deforestation monitoring, land-use change, biomass estimation	Geoawesome (2024); Raihan (2023)
LiDAR (Airborne/UAV)	3D forest structure mapping, canopy height modelling, biomass	Xiang *et al*. (2024); Patel and Wong (2023)
Uncrewed Aerial Vehicles (UAVs)	Real-time forest patrol, illegal logging detection, and fire mapping	Buchelt *et al*. (2024); ICIMOD (2024)
IoT Sensor Networks	Real-time ecosystem monitoring, soil moisture, and microclimate data	Holzinger *et al*. (2022); Guma *et al*. (2025)

Machine Learning (RF, SVM, XGBoost)	Species identification, deforestation detection, and fire prediction	Geoawesome (2024); Raihan (2023)
Deep Learning (CNN, LSTM, GNN)	Image recognition, time-series analysis, illegal logging sound detection	Ramadan *et al*., (2024); Xu *et al*. (2024)
GIS & Google Earth Engine	Forest change detection, geospatial analysis, land-cover mapping	Solórzano *et al*. (2023); Rodrigues *et al*. (2024)
Blockchain Technology	Timber supply-chain traceability, carbon credit verification	Tan *et al*., (2019)

Remote Sensing and Satellite Imagery

Satellite remote sensing has long served as the cornerstone of large-scale forest monitoring. Modern platforms such as Landsat, Sentinel-1 and Sentinel-2, MODIS, and commercial very-high-resolution satellites provide multispectral, hyperspectral, Synthetic Aperture Radar (SAR), and thermal imagery at varying temporal and spatial resolutions. SAR sensors are particularly valued because they can penetrate cloud cover, enabling consistent monitoring of tropical forests where persistent cloudiness hampers optical sensors (Geoawesome, 2024). The global remote sensing market was valued at 17.1 billion US dollars in 2023 and is projected to exceed 37 billion US dollars by 2030, reflecting growing reliance on these technologies for environmental monitoring (Guma *et al*., 2025). Light Detection and Ranging (LiDAR) represents a major advancement in three-dimensional forest characterization. Airborne and mobile laser scanning systems generate dense point clouds from which tree height, canopy structure, stem diameter, and above-ground biomass can be estimated with high accuracy (Xiang *et al*., 2024). NASA's Global Ecosystem Dynamics Investigation (GEDI) full-waveform LiDAR sensor has been widely deployed for large-scale biomass and canopy structure analysis across tropical and temperate forests (Kulicki *et al*., 2024). The integration of satellite multispectral imagery with LiDAR data has substantially improved forest inventory accuracy and reduced field-survey costs.

Uncrewed Aerial Vehicles

UAVs have transformed forest monitoring by providing flexible, cost-effective, and high-resolution data acquisition at the stand and landscape scale. Equipped with RGB cameras, multispectral sensors, LiDAR, and thermal imagers, drones generate canopy height models, species maps, biomass estimates, and damage assessments with sub-metre accuracy (Buchelt *et al*., 2024). The combination of low-altitude flight, autonomous mission planning, and real-time data streaming makes UAVs particularly suited to detecting illegal logging, mapping post-fire damage, and monitoring hard-to-reach forest areas (ICIMOD, 2024). In 2023, UP42 and GLOBHE collaborated to deploy drone networks for community-based deforestation monitoring in tropical forests, coupling local knowledge with machine-learning-processed aerial imagery to provide detailed and contextually rich assessments of forest change (Geoawesome, 2024). Buchelt *et al*. (2024) reviewed the state of the art in drone-AI integration in forestry. They concluded that drones

benefit forest management in multiple ways, though sub-canopy flight and sensor fusion remain open research challenges.

Internet of Things and Sensor Networks

IoT sensor networks extend forest monitoring into continuous, ground-level observation. Low-cost wireless sensors deployed at strategic locations record microclimate variables, including temperature, humidity, soil moisture, and photosynthetically active radiation in real time. These data streams, transmitted via LoRaWAN or satellite uplinks to cloud servers, enable forest managers to track fine-scale environmental dynamics that satellite imagery cannot capture (Holzinger *et al*., 2022). IoT nodes with acoustic sensors have been used to detect chainsaw sounds in near-real time, triggering UAV dispatch to suspected illegal-logging sites (Ramadan *et al*., 2024).

Geographic Information Systems and Cloud Computing

GIS platforms, particularly the Google Earth Engine (GEE), have democratized access to petabyte-scale satellite archives and processing Power. GEE enables researchers and forest agencies to run ML algorithms on global datasets without requiring local high-performance computing infrastructure. The GEE-based random forest algorithm has been used to monitor forest conditions and detect illegal logging events in Indonesia using Sentinel-1 and Sentinel-2 time series (Ramadan *et al*., 2024). Cloud computing also underpins AI model training pipelines, enabling the development of large-scale deforestation-detection and species-distribution models that would be computationally intractable on local hardware.

Artificial Intelligence Applications in Forest Ecosystem Management

Deforestation and Land-Use Change Detection

Deforestation detection is One of the most mature applications of AI in forestry. ML algorithms, including random forests, support vector machines (SVMs), and gradient-boosted trees, are routinely applied to multispectral and SAR satellite imagery to classify land cover and detect forest cover loss. Deep learning models, particularly Convolutional Neural Networks (CNNs) and semantic segmentation architectures, have demonstrated superior performance in capturing the spatial patterns of deforestation across diverse forest types (Md Jelas *et al*., 2024). In the Amazon basin, random forest algorithms applied within GEE achieved up to 93% accuracy in identifying deforestation. In comparison, deep learning networks achieved accuracy rates of up to 97% across diverse forest landscapes (Geoawesome, 2024). Rodrigues *et al*. (2024) developed a dual-mode ML framework for classifying deforestation patterns in Brazilian Amazon native lands, achieving robust performance across varied ecological zones. The Radar for Detecting Deforestation (RADD) alert system, derived from dense Sentinel-1 time series, has proven effective in tracking selective logging in the Congo Basin (Ramadan *et al*., 2024). In October 2023, a collaboration between Google AI and the World Wide Fund for Nature (WWF) produced an AI-powered tool that detects deforestation with near-real-time precision using satellite imagery and ML (Factview Research, 2024).

Forest Health Monitoring and Disease Detection

Maintaining forest health is fundamental to the sustained provision of ecosystem services, including carbon sequestration, biodiversity support, and water regulation. AI enables the early detection of pest infestations, fungal diseases, and climate-induced stress by processing multispectral, hyperspectral, and thermal imagery. Wei *et al*. (2023) developed an ML-based spectral and spatial analysis system using hyper- and multispectral leaf images that achieved 92.4% accuracy in detecting Dutch elm disease and evaluating resistance screening. Thermal-imaging UAVs detect temperature anomalies associated with drought stress and root diseases before visible canopy symptoms appear. Hyperspectral sensors distinguish between healthy, stressed, and diseased foliage by capturing subtle reflectance differences across hundreds of narrow spectral bands (Guma *et al*., 2025). The integration of these data streams with deep learning architectures enables forest managers to implement targeted, spatially precise interventions, significantly reducing the spread of pests and the economic costs associated with widespread treatment.

Wildfire Prediction and Management

Wildfires represent One of the most destructive threats to forest ecosystems worldwide. The 2023 Canadian wildfire season alone burned approximately 18.5 million hectares, displacing 232,000 people and releasing approximately 647 teragrams of carbon into the atmosphere (Xu *et al*., 2024). In Africa, which accounts for approximately 70% of global burned area, wildfire prediction capabilities remain underdeveloped relative to the scale of the challenge (Xu *et al*., 2024). AI has significantly advanced wildfire prediction by enabling the integration of meteorological data, fuel characteristics, topography, historical fire records, and near-real-time satellite observations into predictive models. Deep learning models applied in recent studies achieved wildfire detection recall rates of 95.65%, representing a substantial improvement over traditional rule-based systems (Xu *et al*., 2024). Long Short-Term Memory (LSTM) networks have been applied to capture temporal dependencies in fire-weather variables, while spatiotemporal Graph Neural Networks (GNNs) have been used to model fire spread dynamics across landscapes (Shadrin *et al*., 2024; Rösch *et al*., 2025). The EU-funded SILVANUS project exemplifies an integrated AI-driven approach to wildfire management, combining satellite, UAV, and IoT data streams within a decision-support system that has been used successfully for wildfire combat and ecosystem restoration (Raihan, 2023). Di Giuseppe *et al*. (2025) developed a global data-driven fire activity prediction model using multi-source remote sensing and climate data, providing a significant step towards operationally reliable fire forecasting at global scales.

Carbon Stock and Above-Ground Biomass Estimation

Accurate quantification of forest carbon stocks is essential for climate change mitigation under frameworks such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation). ML algorithms have substantially improved the accuracy and cost-effectiveness of above-ground biomass (AGB) estimation by enabling the fusion of field inventory data with remote sensing covariates. Raihan (2023) reviewed multiple ML-based AGB estimation studies and found that gradient boosting methods, particularly XGBoost, outperformed conventional regression models, reducing biomass estimation error by approximately 18.3%. Random forests and linear regression models, combined with Landsat, Sentinel, and GEDI LiDAR data, are widely used for national-scale AGB mapping. Reiersen *et al*. (2022) used aerial imagery and deep learning to estimate tropical forest carbon stocks with high precision, providing a scalable approach for carbon

monitoring in data-sparse regions. Xu *et al*. (2024) demonstrated optimized carbon sequestration estimation in mangrove forests using AI-powered remote sensing, underscoring the particular value of these techniques for blue carbon ecosystems that are disproportionately important for climate regulation relative to their area. The ability to produce spatially explicit, frequently updated carbon maps is transforming the credibility and transparency of forest carbon markets.

Biodiversity Monitoring and Species Identification

The cost and difficulty of comprehensive field surveys have historically constrained forest biodiversity monitoring. AI is overcoming these limitations through automated species identification from images, acoustic recordings, and eDNA analyses. Computer vision models based on CNNs have been applied to camera-trap imagery, UAV photography, and herbarium specimens to identify plant and animal species with accuracy levels that rival or exceed expert taxonomists (Silvestro *et al*., 2022). Acoustic monitoring using IoT-deployed microphones combined with ML classifiers enables continuous, non-invasive passive surveillance of bird, bat, and insect communities across large forest areas (Crunchant *et al*., 2021). Song *et al*. (2023) developed a super-ensemble approach using ML to map land-cover types at high resolution across data-sparse African savanna landscapes, facilitating rapid biodiversity assessment. The UAV-based YOLOv7-KCC model deployed in the Brazilian Amazon achieves 98.91% species identification accuracy, enabling efficient and scalable inventory of forest biodiversity (Xu *et al*., 2024). Habitat suitability modelling using ML has become a standard tool for predicting the distribution of rare and endangered species under present and future climate scenarios. Silvestro *et al*. (2022) demonstrated that AI-powered biodiversity protection frameworks can significantly improve the strategic allocation of conservation resources by identifying priority areas for protection and restoration. The AI-driven analysis for the Google AI-WWF collaboration also provides near-real-time habitat-loss alerts, which are invaluable for rapid conservation responses (Factview Research, 2024).

Illegal Logging Detection and Forest Governance

Illegal logging causes an estimated 51–152 billion US dollars in economic losses annually and contributes significantly to tropical deforestation, biodiversity loss, and greenhouse gas emissions (Ramadan *et al*., 2024). Traditional detection through ground patrols and periodic satellite analysis is insufficient given the scale and covertness of illegal operations. AI-powered IoT and UAV systems are emerging as powerful deterrents and detection mechanisms. Ramadan *et al*. (2024) described a novel UAV-IoT system that deploys low-cost microphone-equipped nodes to detect chainsaw sounds via CNN models. Detected sounds trigger automated drone dispatch to affected areas, where AI analyzes live video for human presence, enabling a rapid, targeted law-enforcement response. The system's IoT nodes are designed for Power efficiency, enabling a battery life of at least 8 years, making the approach viable for long-term deployment in remote forests. Blockchain technology is increasingly applied to forest governance, particularly for timber supply-chain traceability and carbon credit verification. Tan *et al*. (2019) proposed blockchain-based frameworks for forest conservation and sustainable supply-chain governance, demonstrating how distributed ledger technology can eliminate the opacity that enables illegal timber trade. IBM and The Nature Conservancy jointly developed an ML-powered land management tool in 2023 that provides insights into forest health, tree growth patterns, and potential threats to guide evidence-based stewardship decisions (Factview Research, 2024).

Table 2: Selected performance benchmarks of AI models in forest ecosystem applications

Application	AI Technique	Performance	References
Wildfire detection	Deep CNN	95.65% recall	Xu *et al*. (2024)
Pest detection	ML classifiers	92.4% accuracy	Wei *et al*. (2023)
Species identification	YOLOv7-KCC (UAV)	98.91% accuracy	Xu *et al*. (2024)
Illegal logging detection	TLS/MLS + Sentinel-2	F1 score = 0.92	Xu *et al*. (2024)
Deforestation (Amazon)	Random Forest (GEE)	93% accuracy	Rodrigues *et al*. (2024)
AGB estimation	XGBoost + Remote sensing	18.3% error reduction	Raihan (2023)

ICT, AI and Climate-Smart Forestyr

Climate-Smart Forestry (CSF) is an emerging paradigm that integrates advanced technology with sustainable forest management to simultaneously enhance forest resilience, sequester carbon, and adapt to climate change (Nabuurs *et al*., 2017; Bowditch *et al*., 2020; Wang *et al*., 2025). CSF explicitly leverages informatization and AI as enabling pillars, positioning these technologies at the centre of next-generation forest management frameworks (Wang *et al*., 2025). To enhance ecosystem resilience, CSF decision-support systems leverage AI pipelines to process climate model outputs, phenological data, species distribution records, and real-time sensor observations, enabling the simulation of multiple management scenarios and the identification of optimal interventions. Deep learning models trained on historical climate and stand dynamics data project future forest states under different emission pathways, equipping managers with anticipatory planning tools (Wang *et al*., 2025). Lithuania's Forest 4.0 project exemplifies national-level CSF ambition, creating a centre of excellence for forest-related AI and IoT technologies involving academic institutions and technology companies to transform data collection, monitoring, and decision-making across the country's forests (Damaševičius *et al*., 2024; OECD, 2024). Similarly, AI action plans adopted by several European countries for 2023-2026 mandate the automation of forest data collection and the implementation of AI-driven monitoring systems, signalling a broad policy commitment to digital transformation in the forestry sector.

Challenges and Limitations

Despite the substantial demonstrated potential of ICT and AI in forest ecosystem management, significant challenges impede their widespread adoption, particularly in developing nations where forest management capacity is often most critically needed. Data scarcity and quality are

fundamental constraints. AI models require large volumes of high-quality labelled training data to generalize accurately across diverse forest types and geographic regions. In tropical Africa, Asia, and Latin America, historical remote sensing archives, field inventory data, and biodiversity occurrence records are often fragmentary, inconsistently collected, or inaccessible (Raihan, 2023). Models trained on well-documented temperate forests frequently underperform when transferred to structurally and spectrally distinct tropical ecosystems, a problem known as the domain shift or model transferability gap (Xu *et al*., 2024). Infrastructure deficits constitute another major barrier. Many tropical forest regions lack reliable internet connectivity, electricity, and the technical expertise necessary to deploy and maintain IoT networks, cloud-connected UAVs, and ML pipelines. The cost of sensors, drones, and high-performance computing remains prohibitive for many forest agencies and research institutions in low-income countries (Guma *et al*., 2025). This technological inequality risks deepening disparities in conservation outcomes between data-rich and data-poor regions.

Ethical and social concerns also merit serious attention. The deployment of surveillance technologies in forested landscapes raises questions about the privacy and rights of indigenous and local communities, many of whom depend on these forests for their livelihoods and cultural identities. Parris-Piper *et al*. (2023) cautioned that the "anti-politics" of smart technology in biodiversity conservation can marginalize local stakeholders and entrench technocratic governance paradigms at the expense of community agency and equity. Model interpretability presents a further challenge, particularly for high-stakes management decisions. The "black box" nature of deep learning models makes it difficult for forest managers and policymakers to understand and trust model outputs. The growing field of Explainable AI (XAI) is developing tools to address this, but their integration into operational forestry systems remains nascent (Holzinger *et al*., 2022).

Conclusion

Information and Communication Technology and Artificial Intelligence are fundamentally reshaping the global community's capacity to monitor, manage, and conserve forest ecosystems. Remote sensing, UAVs, IoT sensor networks, machine learning, and deep learning together provide an unprecedented toolkit for detecting deforestation in near-real time, predicting wildfires with high accuracy, estimating biomass and carbon stocks at the landscape scale, identifying species and detecting threats to biodiversity, and combating illegal logging through automated surveillance and blockchain-enabled governance. The technical performance of these systems, as documented in the recent literature, has reached levels of accuracy and reliability that make operational deployment increasingly feasible. However, equitable realization of these benefits requires sustained attention to data quality, infrastructure investment, model transferability, ethical governance, and capacity development, particularly in the tropical forest nations where the conservation stakes are highest. The convergence of ICT and AI with ecological science holds genuine transformative promise for sustainable forest ecosystem management, provided that technical innovation is matched by inclusive policy, equitable access, and deep community engagement.

Future Directions and Recommendations

Realizing the full potential of ICT and AI for forest ecosystems will require coordinated action across research, policy, technology development, and capacity building. Several priority directions

are identified. First, investment in open, standardized, multi-source forest data repositories is essential. Initiatives that aggregate satellite imagery, LiDAR point clouds, field inventory records, and acoustic monitoring data in accessible formats will substantially improve the training and transferability of AI models across diverse forest biomes. International frameworks such as REDD+ should include requirements for interoperable, open-data standards. Also, the development and validation of transferable, lightweight AI models that can operate on low-power edge computing devices will greatly expand the reach of smart forestry technologies to resource-constrained settings. Federated learning approaches, which train models across distributed data sources without centralizing raw data, offer a promising way to overcome both data-sharing barriers and infrastructure limitations. Then, multi-disciplinary integration is vital. The convergence of ecology, computer science, remote sensing, sociology, and policy analysis is necessary to ensure that AI-driven forest management is not only technically effective but also socially equitable and institutionally robust. Co-design approaches that involve forest-dependent communities in the development and governance of monitoring systems are essential for building trust and ensuring that the benefits of these technologies are broadly shared.

Furthermore, national and international policy frameworks must be updated to govern the ethical use of AI in forest ecosystems, address data sovereignty concerns, regulate UAV operations over sensitive habitats, and ensure that carbon monitoring AI systems meet robust transparency and verifiability standards for forest carbon markets. Lastly, sustained investment in digital capacity building in tropical forest nations is urgently needed. Training programmes in remote sensing, GIS, ML, and data management for forest agency staff, university researchers, and community forestry practitioners will be decisive in translating technological potential into on-the-ground conservation impact.

References

Bowditch, E., Santopuoli, G., Binder, F., del Río, M., La Porta, N., Kluvankova, T., Lesinski, J., Motta, R., Pach, M., Panzacchi, P., Pretzsch, H., Temperli, C., Tonon, G. and Seidl, R. (2020). What is climate-smart forestry? A definition from a multinational collaborative process focused on the mountain regions of Europe. Ecosystem Services. 43: 101113.

Buchelt, A., Adrowitzer, A., Kieseberg, P., Gollob, C., Nothdurft, A., Eresheim, S., Tschiatschek, S., Stampfer, K. and Holzinger, A. (2024). Exploring artificial intelligence for applications of drones in forest ecology and management. For. Ecol. Manag. 551: 121530. doi: 10.1016/j.foreco.2023.121530.

Crunchant, A.-S., Nakka, C. D., Isaacs, J. T. & Piel, A. K. (2021). Acoustic sensors. In: Conservation Technology. Oxford University Press, Oxford, UK, p. 53.

Damaševičius, R., Mozgeris, G., Kurti, A., & Maskeliūnas, R. (2024). Digital transformation of the future of forestry: An exploration of key concepts in the principles behind Forest 4.0. Frontiers in Forests and Global Change, 7, 1424327. https://doi.org/10.3389/ffgc.2024.1424327

Di Giuseppe, F., McNorton, J., Lombardi, A. & Wetterhall, F. (2025). Global data-driven prediction of fire activity. Nat. Commun. 16: 2918. doi: 10.1038/s41467-025-58097-7.

Factview Research (2024). Global Artificial Intelligence in Forestry and Wildlife Market – Size, Industry Growth and Sector Analysis by 2030. Factview Research.

https://factviewresearch.com/report/global-artificial-intelligence-in-forestry-and-wildlife-market. Retrieved March 2025.

FAO (2020). Global Forest Resources Assessment 2020: Main Report. Food and Agriculture Organization of the United Nations, Rome. 184pp.

Geoawesome (2024). How Drone Data Helps to Monitor and Reverse Deforestation While Empowering Local Communities. Geoawesome Blog. https://geoawesome.com/eo-hub/how-drone-data-helps-to-monitor-and-reverse-deforestation-while-empowering-local-communities/. Retrieved April 2025.

Guma, A., Mijwil, M., Adamopoulos, I., & Namuq, J. (2025). Leveraging the Internet of Things, Remote Sensing, and Artificial Intelligence for Sustainable Forest Management. Babylonian Journal of Internet of Things. 1-65. 10.58496/BJIoT/2025/001.

Holzinger, A., Saranti, A., Angerschmid, A., Retzlaff, C. O., Gronauer, A., Pejakovic, V., Medel, F., Krexner, T., Gollob, C. and Stampfer, K. (2022). Digital transformation in smart farm and forest operations needs human-centred AI: Challenges and future directions. Sensors 22: 3043. doi: 10.3390/s22083043.

ICIMOD (2024). Using Drones for Forest Monitoring. ICIMOD Blog. https://blog.icimod.org/resilient-economies-landscapes/using-drones-for-forest-monitoring/. Retrieved March 2025.

Kulicki, M., Cabo, C., Trzciński, T., Będkowski, J. and Stereńczak, K. (2024). Artificial intelligence and terrestrial point clouds for forest monitoring. Current Forestry Report. 11: 5. doi: 10.1007/s40725-024-00234-4.

Md Jelas, I., Zulkifley, M. A., Abdullah, M. and Spraggon, M. (2024). Deforestation detection using deep learning-based semantic segmentation techniques: a systematic review. Front. For. Glob. Change 7: 1300060. doi: 10.3389/ffgc. 2024.1300060.

Nabuurs, G. J., Verkerk, P. J., Schelhaas, M. J., González Olabarria, J. R., Trasobares, A. and Cienciala, E. (2017). Climate-smart forestry: mitigation impacts in three European regions. Eur. For. Inst. 9: 1–48. https://efi.int/sites/default/files/files/publication-bank/2018/efi_fstp_6_2018.pdf

Organization for Economic Co-operation and Development (2024). AI policy developments in Lithuania (2023–2026 Action Plan). Accessed online 5th of January, 2026 https://www.oecd.org/content/dam/oecd/en/publications/reports/2025/10/progress-in-implementing-the-european-union-coordinated-plan-on-artificial-intelligence-volume-1-country-notes_b0385317/lithuania_28a5cd52/295757f3-en.pdf

Parris-Piper, N., Dressler, W. H., Satizábal, P. & Fletcher, R. (2023). Automating violence? The anti-politics of 'smart technology' in biodiversity conservation. Biol. Conserv. 278: 109859. doi: 10.1016/j.biocon.2022.109859.

Patel, R. & Wong, M. (2023). Advances in drone-based LiDAR for forest structure analysis and environmental monitoring. Int. J. Remote Sens. 44(3): 512–531. doi: 10.1080/01431161.2023.2175648.

Perry, G. L. W., Seidl, R., Bellvé, A. M. & Rammer, W. (2022). An outlook for deep learning in ecosystem science. Ecosystems 25: 1700–1718. doi: 10.1007/s10021-022-00789-y.

Raihan, A. (2023). Artificial intelligence and machine learning applications in forest management and biodiversity conservation. Nat. Resour. Conserv. Res. 6: 3825. doi: 10.24294/nrcr.v6i2.3825.

Ramadan, M. N., Ali, M. A., Khoo, S. Y., & Alkhedher, M. (2024). AI-powered IoT and UAV systems for real-time detection and prevention of illegal logging. Results in Engineering, 24, 103277. https://doi.org/10.1016/j.rineng.2024.103277

Reiersen, G., Dao, D., Lütjens, B., Klemmer, K., Amara, K., Steinegger, A., Zhang, C. and Zhu, X. (2022). ReforesTree: a dataset for estimating tropical forest carbon stock with deep learning and aerial imagery. arXiv preprint arXiv:2201.11192. doi: 10.48550/arXiv.2201.11192.

Rodrigues, J., Dias, M. A., Negri, R., Hussain, S. M. & Casaca, W. (2024). A robust dual-mode machine learning framework for classifying deforestation patterns in Amazon native lands. Land 13: 1427. doi: 10.3390/land13091427.

Rösch, M., Nolde, M., Ullmann, T. and Riedlinger, T. (2025). Data-driven wildfire spread modelling of European wildfires using a spatiotemporal graph neural network. Forests 16(4): 704. doi: 10.3390/f16040704.

Shadrin, D., Illarionova, S., Gubanov, F., Evteeva, K., Mironenko, M., Levchunets, I., & Kalinchenko, L. (2024). Wildfire spreading prediction using multimodal data and a deep neural network approach. Sci. Rep. 14: 2606. doi: 10.1038/s41598-024-52821-x.

Silvestro, D., Goria, S., Sterner, T. & Antonelli, A. (2022). Improving biodiversity protection through artificial intelligence. Nat. Sustain. 5: 415–424. doi: 10.1038/s41893-022-00851-6.

Solórzano, J. V., Mas, J. F., Gallardo-Cruz, J. A., Gao, Y. and Oca, A. F. M. (2023). Deforestation detection using a spatio-temporal deep learning approach with synthetic aperture radar and multispectral images. ISPRS J. Photogramm. Remote Sens. 199: 87–101. doi: 10.1016/j.isprsjprs.2023.03.017.

Song, L., Estes, A. B., & Estes, L. D. (2023). A super-ensemble approach to map land cover types with high resolution over data-sparse African savanna landscapes. Int. J. Appl. Earth Obs. Geoinf. 116: 103152. doi: 10.1016/j.jag.2022.103152.

Tan, B. Q., Wang, F., Liu, J., Kang, K., & Costa, F. (2019). A Blockchain-Based Framework for Green Logistics in Supply Chains. *Sustainability*, *12*(11), 4656. https://doi.org/10.3390/su12114656

Wang, G.G., Lu, D., Gao, T., Zhang, J., Sun, Y., Teng, D., Yu, F., & Zhu, J. (2025). Climate-smart forestry: an AI-enabled sustainable forest management solution for climate change adaptation and mitigation. *Journal of Forestry Research,* 36, 7. https://doi.org/10.1007/s11676-024-01802-x

Wei, X., Zhang, J., Conrad, A. O., Flower, C. E., Pinchot, C. C., Hayes-Plazolles, N., Chen, Z., Song, Z., Fei, S., & Jin, J. (2023). Machine learning-based spectral and spatial analysis of hyper- and multispectral leaf images for Dutch Elm Disease detection and resistance screening. Artif. Intell. Agric. 10: 26–34. doi: 10.1016/j.aiia.2023.09.003.

Xiang, B., Wielgosz, M., Kontogianni, T., Peters, T., Puliti, S., Astrup, R., & Schindler, K. (2024). Automated forest inventory: Analysis of high-density airborne LiDAR point clouds with 3D deep learning. *Remote Sensing of Environment*, *305*, 114078. https://doi.org/10.1016/j.rse.2024.114078.

Xu, Z., & Jiang, D. (2024). AI-Powered Plant Science: Transforming Forestry Monitoring, Disease Prediction, and Climate Adaptation. Plants, 14(11), 1626. https://doi.org/10.3390/plants14111626

ISTF-NIG 2026

SUB-THEME 7:
NON-TIMBER FOREST PRODUCTS AND FOREST CONSERVATION

INFLUENCE OF DIFFERENT STORAGE MEDIA ON *CITRUS PARADISI* MACFAD (GRAPE FRUIT) PRESERVATION

Ojelabi, O.K, Ihediuche C.I, Ajiboye O.O., and Edet S.E

Department of Soil and Tree Nutrition, Forestry Research Institute of Nigeria, PMB 5054, Jericho, Ibadan, Oyo State, Nigeria
Corresponding Email: ty4ril2012@gmail.com

Abstract

The choice of storage medium plays a crucial role in maintaining fruit quality by influencing the physiological processes such as respiration, moisture loss, and microbial activity. Evaluating the effectiveness of different storage media is therefore essential for determining cost-effective and sustainable preservation strategies. This study investigates the impact of various storage media on the preservation of *Citrus Paradisi* (grapefruit) to determine their effects on shelf life, physical quality, and overall postharvest stability. The various media for grape fruit preservation include: Dry sawdust in a wooden box (T_1), Dry wood shavings in a wooden box (T_2), wet sawdust in a wooden box (T_3), wet wood shavings in a wooden box (T_4) and an open shelf (control) (T_5). The following criteria were used for grading: hard, relatively soft, soft, and very soft. The results of the study reveals that the effects of colour changes on the storage media on wet sawdust (T_3) retained its greenness for twenty-one (21) days when compared to open shelf (control) which retained greenness for only seven (7) days; the firmness of fruits in wet sawdust (T_3) was hard for twenty-one (21) days when compared with the open shelf (T_5) which was only hard for fourteen (14) days, relatively soft for two (2) days, soft for three (3) days, and very soft for two (2) days. Also, T_3 shows no pathological symptoms for 21days when compared with the rest of the storage media. There were significant differences in the weight and temperature of dry sawdust (T_1) when compared to open shelf (T_5). In conclusion, wet sawdust in a wooden box (T_3) delayed the ripening of grape fruits. It is therefore recommended that a storage structure composed of insulating materials should be considered when developing a storage structure for a more effective delay in grape fruit ripening.

Keywords: Grapefruit, Preservation, microbial activity, storage media, wood shavings.

Introduction

Grapefruit (*Citrus Paradisi*) is One of the oldest horticultural crops domesticated by man and belongs to the citrus genus, a taxon of flowering plants in the *Rutaceae* family, and is native to the West Indies, with a global distribution (Uysal *et al.,* 2011; More *et al.,* 2013). It is the second-largest citrus fruit produced worldwide, with an average annual production of more than 60 million. Worldwide, grapefruits are grown in every region that produces citrus and according to FAO (2019), China is the world's largest producer of grapefruit (4930000 tons), followed by Vietnam (818914 tons), the United States (511650 tons), and Mexico (488776 tons). Grape fruits are valued for their beneficial health effects and are a significant source of bioactive substances with strong antioxidant properties, including flavonoids and vitamin C; they are anti-inflammatory,

antimicrobial, and astringent, and are among the most potent neutral-central products (Strano *et al.,* 2022). As the tree ages, it can grow to a height of 4.5–6 meters. The leaves are dark green, big, ovate (egg-shaped), and bluntly pointed. The fruit has a spherical form. Between 30 and 50% of the total fruit production may be wasted after 30 to 60 days of storage due to postharvest losses, mostly caused by diseases (rots) and physiological abnormalities (Strano *et al.,* 2022).

Postharvest decay is mainly affected by harvest and handling. The different maturity stages have significant effects on the quality of fresh commodities. Harvested at horticultural maturity, non-climacteric fruit possesses all the qualitative characteristics (Siddiqui *et al.,* 2010; El-Beltagi *et al.,* 2022). The genetic progress of a species depends on safe conservation and efficient use of the native genetic variability. Many citrus species can be seen thriving in semi-wild or wild conditions in their natural habitat (Malik *et al.,* 2013). It is important to know the best storage method to preserve grape fruits, given poor handling after harvest, and to extend their longevity after maturity. Therefore, this study investigated the most effective storage condition for delaying over-ripening and the appropriate preservation of different storage media.

Materials and Methods

Study Area

This research was carried out in the laboratory of the Soil and Tree Nutrition Department of the Forestry Research Institute of Nigeria, Jericho, Ibadan, which lies between latitudes 07°23'N and 03°56'E. The study area receives 1400–1500 mm of rainfall annually, with mean maximum temperatures of 31.9 °C31.9 °C, minimum temperatures of 24.2 °C24.2 °C, and relative humidity of 74.6% (FRIN Annual Meteorological Report 2018).

Experimental Procedure

Freshly picked, physiologically mature, green grapefruits from a citrus plantation were acquired from the National Horticultural Research Institute along Idi-Ishin Road in Ibadan, Oyo State. To eliminate field heat, the grapefruits were pre-stored by putting them in a room at a temperature for an hour. It was then weighed using a weighing balance. The grapefruits were then put in various storage containers. Additionally, a thermometer was positioned in each medium to measure the temperature. Wood shavings and sawdust were acquired from a sawmill. Empty wooden boxes measuring 0.35 x 0.25 x 0.2 meters were built. The wooden boxes had apertures on the sides and tops measuring roughly 1.5 meters in diameter, allowing for ventilation. A moist storage medium was created by thoroughly moistening wood shavings and sawdust, and an adequate quantity of each was used in different boxes. When necessary, the wet storage conditions were subsequently moistened to maintain saturation throughout the experiment.

Data collection

The green grape's colour was noted and inspected once a day before storage, and an evaluation was conducted every day thereafter. Continuous colour assessment was conducted until each treatment reached the appropriate colour for marketing. The colour assessment was based on the horticultural colour chart (Abou Aziz *et al*., 1976). The colour grade ranges from green = 1, green with a trace of yellow = 2, more green than yellow = 3, more yellow than green = 4, tips of yellow

= 5, and completely yellow = 6. The experiment began with a firmness measurement. The senses of touch and sight were used to conduct and document subsequent observations for firmness. The following criteria were used for grading: hard, relatively soft, soft, and very soft. Fruits were visually categorized as having no pathological symptoms, mild pathological symptoms, heavy pathological symptoms, and very heavy pathological symptoms. Pathological symptoms, such as necrotic spots, browning, blackening, and skin rotting, were noted and documented. Fruits were classified as very neat (without patches), fairly neat (with little patches), or not neat (with patches) after their neatness was noted as the ripening process began. The grapefruits' initial weight was measured at the start of the experiment, and then daily thereafter. A sensitive scale was used, with a thermometer permanently inserted into each medium. The initial temperature under storage conditions was recorded at the start of the experiment, and daily measurements were taken thereafter. Pre- and post-storage analyses were performed on grapefruit for each treatment.

Data analysis

A completely randomized design was used for the experiment (CRD). Five (5) treatments were designed, with four (4) media storage units with an open shelf serving as the control. Each treatment was then replicated three (3) times, creating fifteen (15) experimental units. The weight and temperature data were analyzed descriptively, and the grape fruits were subjected to proximate analysis both before and after the experiment. The following proximate compositions were analyzed: dry matter, fat, crude protein, ash, crude fibre, sugar, moisture, and carbohydrate. Additionally, a physical assessment was conducted to evaluate colour, firmness, neatness, and pathological symptoms.

Treatments are as follows:

T_1 = *Dry sawdust in a wooden box (DS/WB)*

T_2 = *Dry wood shavings in a wooden box (DW/WB)*

T_3 = *Wet sawdust in a wooden box (WS/WB)*

T_4 = *Wet wood shavings in a wooden box (WW/WB)*

T_5 = *Open shelf (CONTROL*

Proximate Determination

The proximate composition (moisture, ash content, crude protein, fat content, crude fibre, and carbohydrate content) of grape fruits was determined using the standard AOAC (Association of Official Analytical Chemists) methods (AOAC 1990).

i. **Moisture content (%):** A fresh grapefruit sample of 2g was weighed and dried in an oven at 105 °C continuously until a constant weight was obtained. The ratio of the change in weight to the original weight in percentage gives the moisture content: (AOAC 1990)

$$\text{Moisture content} = \frac{W_o - W_{dry}(\%)}{W_o} \qquad \text{(i)}$$

ii. **Dry matter:** The dry matter was derived from the moisture content

$$\text{Dry matter (\%)} = 100 - \text{Moisture (\%)} \quad \text{(ii)}$$

iii. **Fat content:** The Soxhlet extraction apparatus with the thimble and siphon tube was used to extract the fat, which was oven-dried to constant weight. The weight of the thimble and its contents was measured using a weighing balance.

$$\text{Fat (\%)} = \frac{\text{weight of extracted fat}}{\text{sample weight}} \text{X } 100 \quad \text{(iii)}$$

iv. **Crude protein:** Protein content was determined using the modified Kjeldahl method described by AOAC (1990).

$$\%\text{N} = \frac{\text{instrument reading x slope x colour vol. x digest vol.}}{\text{weight of sample x aliquot taken x 10000}} \quad \text{(iv)}$$

$$\text{\% Crude Protein} = \text{\% Nitrogen x } 6.25 \quad \text{(v)}$$

v. **Ash content:** The dried sample was weighed and placed in a preheated muffle furnace for 1 hour, then placed in a desiccator to cool. The ash content was determined using the AOAC (2005) calculation.

$$\text{Ash} = 100\ \frac{W_{ash}(\%)}{W_o} \quad \text{(vi)}$$

W_{ash} = content weight after final drying, W_o = dried weight of the sample

vi. **Crude fibre:** The procedure followed the AOAC (2005) method of analysis.

$$\text{\% Crude fibre} = \frac{100\ (y\text{-}a)}{x} \quad \text{(vii)}$$

x = weight of sample (g), y = weight of insoluble matter (g), a = weight of Ash (g).

vii. **Sugar content:** The procedure was based on Lane and Eynon's (1923) method of Redox titration using Fehling's or Benedict'sBenedict's solution.

$$\text{Sugar (\%)} = \frac{\text{titre value x factor}}{\text{sample weight}} \text{ x } 100 \quad \text{(viii)}$$

viii. **Carbohydrate content:** The total carbohydrate content of the sample was determined by subtracting percentage moisture, crude protein, ash content, crude fat and fibre content from 100.

$$\text{Carbohydrate (\%)} = 100 - (\text{Moisture} + \text{Protein} + \text{Fat} + \text{Ash} + \text{Fibre}) \quad \text{(ix)}$$

Results and Discussion

The nutritional attributes of ripe and unripe grape fruits stored in various media are summarized in Table 1 below. Unripe grapes had a crude protein content of 1.90%, whereas mature grapes ranged from 0.87% to 1.83%. This indicates that crude protein decreased as the fruit ripened. Compared to the unripe grape fruit, which had a moisture content of 21.49%, the mature fruit had a higher moisture content, ranging from 24.49% to 39.95%. These results were consistent with those of Selcuk *et al.* (2011), who found that the moisture content of grape by-product was significantly higher, indicating that grape is a majora major constituent of water, which is essential for numerous chemical reactions during growth and processing across a variety of products.

Additionally, the sugar level of ripened grape fruit increased, ranging from 4.09% to 5.66%, greater than that of unripe grape fruit, which had a sugar content of 3.88%. The increases in moisture and sugar content as ripening progressed in the fruit were in line with Singh *et al.* (2015), who suggested that the build-up of glucose, fructose, and sucrose in fruits could be the cause of the sugar increase. Crude fibre content decreased as grape fruit ripened, as evidenced by the fact that unripe grape fruit had a crude fibre content of 1.57% and ripened grape fruit had a crude fibre content ranging from 0.48% to 1.32%.

Table 1: Proximate analysis for unripe and ripe grape fruits

Nutritional content	Unripe (%)	T_1(ripe) (%)	T_2(ripe) (%)	T_3(ripe) (%)	T_4(ripe) (%)	T_5(ripe) (%)
Crude protein	1.90	1.78	1.73	1.83	0.98	0.87
Crude fibre	1.57	1.24	1.32	0.99	0.86	0.48
Fats	0.55	0.29	0.18	0.31	0.25	0.12
Total ash	1.56	1.26	1.09	0.87	0.97	1.15
Carbohydrate	27.07	23.95	24.49	25.21	22.62	21.08
Dry matter	72.07	57.42	62.36	59.84	67.32	49.86
Sugar	3.88	5.08	5.32	4.09	5.03	5.66
Moisture content	21.49	34.09	31.05	24.49	33.25	39.95

Source: Nigeria Institute of Science Lab Tech (NISLT), 2016.

Table 2 reveals that the grape fruit stored in dry sawdust (T_1) remained dark green for nine (9) days before turning to Light green with an appearance of pale yellowish green on days ten (10) to twenty-one (21). In dry wood shavings (T_2), the grape fruit remained dark green for the first eight (8) days and then Light green with a hint of yellowish green for the next thirteen (13) days. Wet wood shavings (T_4) held their greenness for three (3) days, followed by four (4) days of trace of

yellowish green, four (4) days of more yellow than green, three (3) days of only the tips of green, and three (3) days of total yellow. Wet sawdust (T_3) retained its greenness for twenty-one (21) days. In contrast to the open shelf, which remained green for only seven (7) days, the results showed that wet sawdust (T_3) was the storage medium that prolonged the ripening of grape fruit for 21 days. As a result, T_3 is the best storage medium for preserving fresh grape fruits.

Table 2: Effects of storage media on colour change of grapefruit in 21 days of storage, length of storage per day

Treatment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
T_1 (DS/WB)	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
T_2 (DW/WB)	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2
T_3(WS/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T_4(WW/WB)	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
T_5(Control)	1	1	1	1	1	1	1	2	2	2	2	4	4	4	4	5	5	5	6	6	6

**NB: Green=1, Green with a trace of yellow = 2, More green than yellow = 3, More yellow than green=4, Only tips of yellow = 5, Completely yellow = 6.*

Table 3 revealed the grape fruit stored in dry sawdust (T_1) remained hard from the first (1) day of storage until the nineteenth (19) day and remained relatively soft for two (2) days; dry wood shavings (T_2) remained hard from the first (1) day of storage until the eighteenth (18) day of storage and remained relatively soft for three (3) days; wet sawdust (T_3) was hard for twenty-one (21) days; wet wood shavings (T_4) were hard for first fourteen (14) days and relatively soft for seven (7) days; and the open shelf (T_5) was hard for fourteen (14) days, relatively soft for two (2) days, soft for three (3) days, and very soft for two (2) days. The storage media that retain hardness for 21 days were T_3 (Wet sawdust in a wooden box (WS/WB). Thus, the best storage medium for keeping grape fruits fresh is wet sawdust (T_3). The capacity of wet sawdust to maintain high relative humidity, minimize moisture loss, and alter the microenvironment surrounding the fruit is responsible for the high level of grapefruit preservation. Similar to evaporative cooling methods, moist storage media, such as sawdust, reduce physiological degradation by lowering temperature and maintaining humidity through the retention of water in the medium (Ishaque et al., 2019; Strano et al., 2022).

Table 3: Firmness of grape fruit using different storage media, length of storage in days

Treatment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
T_1 (DS/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
T_2 (DW/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
T_3(WS/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T_4(WW/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2
T_5(Control)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	3	3	3	4	4

**NB: Hard = 1, relatively Soft = 2, Soft = 3, very Soft = 4.*

The grapefruit kept in dry sawdust (T_1) remained very clean for 16 days, slightly neat for 3 days, and not neat for 2 days, as shown in Table 4. The open shelf (T_5) was extremely neat for 17 days and slightly neat for 4 days, while the dry wood shavings (T_2) stayed very neat for 19 days and slightly neat for 2 days. The wet sawdust (T_3) stayed very neat for 21 days, and the wet wood shavings (T_4) remained very neat for 18 days and slightly neat for 3 days. According to the table below, wet sawdust (T_3) kept everything fresh for 21 days. Consequently, the best storage medium for extending the shelf life of grape fruits was (T_3).

Table 4: Neatness in appearance of grape fruit using different storage media, length of storage per day

Treatment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
T_1 (DS/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	3	3
T_2 (DW/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
T_3(WS/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T_4(WW/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
T_5(control)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2

**NB: Very Neat = 1, Slightly Neat = 2, Not Neat = 3.*

According to Table 5, grape fruit placed in dry sawdust (T_1) has no pathological symptoms for 20 days but mild symptoms for 1 day; dry wood shavings (T_2) has no pathological symptoms for 17 days and mild symptoms for 4 days; wet sawdust (T_3) has no pathological symptoms for 21 days; wet wood shavings (T_4) has no pathological symptoms for 18 days and mild symptoms for 3 days; and open shelf (T_5) has no pathological symptoms for 12 days, mild symptoms for 4 days, heavy symptoms for 4 days, and very heavy pathological symptoms for 1 day. According to the table, the storage medium with no pathological symptoms for 21 days is (T_3). Wet sawdust (T_3) is hence appropriate for grape fruit preservation.

Table 5: Pathological symptoms on grape fruits using different storage media, length of storage per day

Treatment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
T_1 (DS/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
T_2 (DW/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
T_3(WS/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T_4(WW/WB)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
T_5(control)	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	4

**NB: No pathological symptoms= 1, Slight pathological symptoms= 2, Heavy pathological symptoms = 3, Very heavy pathological symptoms= 4.*

Table 6 shows a large difference in the weight of dry sawdust (T1) and open shelf (T_5), as well as a substantial difference in their temperatures. There are significant differences in the weight of dry sawdust (T_1), wet wood shavings (T_4), and the open shelf control (T_5), indicating that Moisture loss during storage is the cause of the weight loss, and grapefruit loses weight as the temperature

rises (Imlak *et al.,* 2017). Lower temperatures temporarily delay fruit ripening, and a delay in the climacteric peak reduces the respiration rate (Fabi e*t al.,* 2010). The findings of this study indicate that temperatures between 20 °C and 23 °C affect grape fruit ripening and can be used to delay ripening.

Table 6: Weight and Temperature Change on Grape Fruit Using Different Storage Media

Treatments	Weight (G)	Temperature (°C)
T_1 (DS/WB)	822.61a	25.0b
T_2 (DW/WB)	619.59c	24.4b
T_3(WS/WB)	653.88b	23.5c
T_4(WW/WB)	647.21b	26.1a
T_5(open shelf)	603.01c	25.0b
GM	609.26	24.8
%CV	2.80	3.79

Conclusion and Recommendations

Unripe fruits contained higher crude protein and fibre, while ripe fruits showed increased moisture and sugar levels across storage media. The decline in protein and fibre with ripening reflects tissue softening and metabolic changes, whereas increased moisture and sugars enhance palatability but may reduce storage stability. Storage media influenced the extent of these nutritional changes. Wet sawdust in a wooden box works well for delaying the ripening of grape fruits, increasing storage and shelf life and ultimately lowering or managing the surplus of grape fruits available on the market. Therefore, it is recommended that a storage structure composed of insulating materials be created in order to store grapefruit. The insulating qualities of the materials used should be considered when developing storage structures; the more insulating the storage medium, the more effective it is for grape fruit.

References

Abou-Aziz, A. B., El-Nataway, S. M., Adel-Wahab, F. K., Kader, A. A. (1976). The effect of storage temperature on quality and decay percentage of 'Pairi' and 'Taimour' mango fruit. *Journal of American Society of Horticulture* 117(5) 5: 65–72.

AOAC. (1990). Official Methods of Analysis. 15th Edition, Association of Official Analytical Chemists, Washington DC. pp. 11–18.

AOAC. (2005). Official Methods of Analysis. 18th Edition, Association of Official Analytical Chemists, Washington DC.

El-Beltagi, H. S., Ullah, I., Sajid, M., Basit, A., Shehata, W. F., ALTURKI, S. M., ... & ALI, F. (2022). Influence of maturity stages on postharvest physico-chemical properties of grapefruit (Citrus paradisi var. 'Shamber Tarnab') under different storage durations. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *50*(1), 12620-12620.

Fabi, J. P., Peroni, F. H. G., & Gomez, M. L. P. A. (2010). Papaya, mango and guava fruit metabolism during ripening: postharvest changes affecting tropical fruit nutritional content and quality. *Fresh Produce*, *4*(1), 56–64.

FAO. (2019). The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction. Rome.

Forestry Research Institute of Nigeria Meteorological Report, 2018.

Imlak, M., Randhawa, M. A., Hassan, A., Ahmad, N., & Nadeem, M. (2017). Postharvest shelf-life extension and nutritional profile of Thompson seedless table grapes under calcium chloride and modified atmospheric storage.

Ishaque, F., Hossain, M. A., Sarker, M. A. R., Mia, M. Y., Dhrubo, A. S., Uddin, G. T., & Rahman, M. H. (2019). A study on low-cost postharvest storage techniques to extend the shelf life of citrus fruits and vegetables. *Journal of Engineering Research and Reports*, *9*(1), 1–17.

Lane, J.H. & Eynon, L. (1923). *J. Soc. Chem. Ind. Trans.* **42**, 32. Standard Analytical Methods of the Member Companies of the Corn Industries Research Foundation (1963).

Malik, S. K., Kumar, S., Singh, I. P., Dhariwal, O. P., & Chaudhury, R. (2013). Socio-economic importance, domestication trends and in situ conservation of wild Citrus species of Northeast India. *Genetic resources and crop evolution*, *60*, 1655–1671.

More, S., Sathe, S., Sonawane, A., Jadhav, A., & Kadam, V. (2013). Citrus paradisi: an overview. *Indo American Journal of Pharmaceutical Research*, *3*, 8070–8077.

Nigeria Institute of Science Laboratory Technology (NISLT), 2016.

Selcuk, A. R., Demiray, E., & Yilmaz, Y. (2011). Antioxidant Activity of Grape Seeds Obtained from Molasses (Pekmez) and Winery Production: *Academic Food Journal/Akademik GIDA*.

Siddiqui, M. W., & Dhua, R. S. (2010). Eating artificially ripened fruits is harmful. *Current ScienceScience*, 99(12), 1664–1668.

Singh, S. U. K. H. C. H. A. I. N., Aulakh, P. S., & Gill, P. P. S. (2015). Physicochemical changes during fruit development and maturation in grapefruit (Citrus paradisi Macf.) cv. Star Ruby. *The Ecoscan*, *9*(1&2), 17–20.

Strano, M. C., Altieri, G., Allegra, M., Di Renzo, G. C., Paterna, G., Matera, A., & Genovese, F. (2022). Postharvest technologies of fresh citrus fruit: Advances and recent developments for the loss reduction during handling and storage. *Horticulturae*, *8*(7), 612.

Uysal, B., Sozmen, F., Aktas, O., Oksal, B. S., & Kose, E. O. (2011). Essential oil composition and antibacterial activity of the grapefruit (Citrus Paradisi L) peel essential oils obtained by solvent-free microwave extraction: comparison with hydrodistillation. *International Journal of Food Science and Technology*, *46*(7), 1455–1461.

SURVEY OF NON-TIMBER FOREST PRODUCTS AND THEIR USES AMONG ENCLAVES IN ONIGAMBARI FOREST RESERVE, OYO STATE.

Haastrup, N.O., Bamigboye, A.O, Agboje, I, Agboola, I.S, Bamgboye, A.M, Ibikunle, K.Y, Abdulrahaman, M.A., Adenugba, J.G., and Abu, A.T

Forestry Research Institute of Nigeria, Jericho Hill, Ibadan
Corresponding Email: bobnath2013@gmail.com

ABSTRACT

Non-Timber Forest Products (NTFPs) are commonly used by indigenous and local communities. Sometimes, these products are either underutilized or not used at all. Hence, investigations into commonly utilized Non-Timber Forest Food Products, their purposes, and the purposes of use among communities in the Onigambari Forest Reserve, Oyo State. A multistage sampling technique was adopted, with the first stage involving random selection of information on the various NTFP sources and their uses. Twenty-eight Non-timber Forest species were identified as commonly consumed food sources. This study has shown that Non-timber Forest products are of great importance to rural dwellers, especially for their use as food and medicine.

Keywords: NTFPS, Utilized, Purpose of Use

Introduction

Resources derived from the forest, especially Non-Timber Forest Products, have received a favorable rating in various research reports, owing to the view that exploiting the forest for products other than timber can cause less harm (FAO, 2011). The role that Non-Timber Forest Products (NTFPs) play in rural people's livelihoods cannot be downplayed. It has been estimated that forests and trees contribute in several ways to the fundamental livelihoods of up to One billion people (Agrawal *et al.,* 2013). It is primarily a source of income for people in rural areas worldwide. Nigeria is not an exception, as Duong (2018) reported that about 17million jobs on a full-time basis are provided in the formal sector and 30 million in the informal sector through the trade of NTFPs, as well as a source of 13-35% of all rural non-farm employment. Nargawe *et al.* (2023) found that indigenous plants are widely used for ailments such as malaria, diabetes, tetanus, and pneumonia. Local knowledge ensures accessibility and affordability of remedies. Despite the expansion of modern healthcare, large populations in developing countries still rely on traditional remedies for physical and mental health. These plants are crucial for wellness and preventive care (Gogoi *et al.*, 2024).

The FAO (1997) reported that about 80% of the population in developing countries uses NTFPs to meet a number of their principal wellbeing and nutritional requirements. Nigeria is not an exception in the utilization of forest resources, and, if appropriately exploited, they cannot only address food security and health-related challenges but also improve household income (Adetunji & Akeredolu, 2019). However, there is a constant oversight of the contribution of forest food products, especially when it is crucial to improving diets. Several studies have shown that many of these forest resources are exploited solely for consumption, as seen in the Congo Basin, where 4.5 million tons of bush meat are killed each year, and in the extensive use of various wild fruits and vegetables in several parts of the world. (Sunderland, 2013 and Nasi *et al*, 2011). Hence, it is

imperative to consistently document the various Non-Timber Forest Products commonly used across different rural ecosystems and explore ways to harness this knowledge for the benefit of humanity and its environment. Data were collected on some non-timber forest food products commonly utilized by the enclaves surrounding Onigambari Forest Reserve in Ibadan, Oyo State, and the purposes for which each product is used.

Methodology

The study area is the Onigambari Forest Reserve, located in the Oluyole Local Government Area of Oyo State. It lies within latitude 7˚23′N and longitude 3˚33 ′ E, and covers an area of 11,618 hectares, between the river Ona on the West and the main road from Ibadan to Ijebu-Ode on the East. The Onigambari Forest Reserve, which the government of Oyo State owns, was established on the 4th September, 1899, and consolidated in 1948 (Chukwu & Bada, 2019).

Sampling method

A multistage sampling technique was used to select 6 villages within the forest reserve as the study area, which include Igbuso-gboro, Adebayo, Aba-Otun, Onipe, Alata, and Mamu. Purposive sampling was used to select respondents for the survey, individuals who were readily available to participate in the study. A total of 356 respondents were selected (Table 1). Interactive sessions with village heads or representatives were held to ease the administration of questionnaires to the community's respondents. The respondents were given questionnaires to assess their knowledge of non-timber forest products commonly used in the area, including a list of NTFPs. Furthermore, they were asked to list those not included in the questionnaires. The respondents were interviewed by a field assistant who used the local language (Yoruba) to obtain information.

Data Collection and Analysis

A total of 356 questionnaires were retrieved from the survey in the six sampled villages. Statistical analysis was conducted using descriptive methods. Also, a paired-samples t-test was conducted to compare the utilization of non-timber forest products (NTFPs) for food and medicinal purposes in the Onigambari Forest Reserve.

Results and Discussion

A total of 356 respondents were interviewed, and questionnaires were administered in the six villages, as shown in Table 1. Alata has the highest number of respondents (91), while Aba-Otun has the lowest (31).

Table 1: Surveyed Villages and Number of Respondents per Village

S/N	Village	No. of Respondents
1	Ibuso-gboro	52
2	Aba-Otun	31
3	Onipe	58
4	Adebayo	55
5	Alata	99
6	Mamu	61
	Total	**356**

The results showed that a total of 28 plant and animal species (Table 2) were consumed solely as food by all respondents. This revealed that many respondents rely on non-timber forest products, both plant and animal, as identified by Chukwu and Badas (2019).

Utilization of Forest Products in the Study Areas

As can be seen in Table 3, the frequency of utilization of species used as food and medicine with Honey, *Parkia biglobosa* and *Cucumis sativus* showing the highest utilization as both food (100%) and medicine (100%), followed by *Solanum aethiopicum* (food 298%, medicine 16.3%) and *Psidium guajava* (food 150%, medicine 57.9%), while *Garcinia kola, Vitellaria paradoxa* and *Ocimum gratissimum* were most used as medicine (99.7%) and less used as food. Table 4 showed that only five species of forest products are commonly consumed by respondents from the six villages around the Onigambari forest reserve for medicinal purposes. The results in tables 3 and 4 validates previous literatures by Nasi *et al*, 2011 and Gogoi *et al.* (2024) that identified the importance of traditional remedies made from indigenous plants as a crucial role player in the health of several people and the high prevalence (85%) of sub-Saharan Africans who routinely use these plants for primary health care (Abdullahi, 2011; Fadun ., *et al*, 2017).

Table 2: Frequency table for utilization of Non-Timber Forest Products as Food only among Enclaves of Onigambari Forest Reserve, Oyo State

S/N	NTFPs	Food	
		Frequency	**Percentage**
1.	*Carica papaya*	356	100
2.	*Thryonomys swinderianus*	356	100
3.	*Anacardium occidentale*	356	100
4.	*Agaricus bisporus*	356	100
5.	*Tetracarpidium conophorum*	356	100
6.	*Centrochelys sulcata*	356	100
7.	*Oryctolagus cuniculus*	356	100
8.	*Xerus erythropus*	356	100
9.	*Gonionotophis egbensis*	356	100
10.	*Adansonia digitata*	356	100
11.	*Coconut*	356	100
12.	*Ananas comosus*	356	100
13.	*Telfaria occidentales*	356	100
14.	*Musa paradisiaca*	356	100
15.	*Citrus sinensis*	356	100
16.	*Irvingia gabonensis*	356	100
17.	Monitor lizard	356	100
18.	Bats	356	100
19.	Monkey	356	100
20.	*Chrysophyllium albidium*	356	100
21.	*Dacryodes edulis*	356	100
22.	*Dioscorea alata*	356	100
23.	*Dialium guinense*	356	100

24.	*Porcupine*	356	100
25.	*Lime*	356	100
26.	*Threoboma cacao*	356	100
27.	*Abelmoschus esculentus*	356	100
28.	*Antelope*	356	100

Table 3: Frequency table for utilization of Forest Products as Food and Medicine among Enclaves of Onigambari Forest Reserve, Oyo State

S/N	NTFPs	Frequency (%)	
		Food	**Medicine**
1.	*Psidum guajava*	150(42.1)	106 (57.9)
2.	*Mangifera indica*	356(100)	52 (14.6)
3.	Honey	282(100)	74 (100)
4.	*Achatina maginata*	356(100)	22 (6.2)
5.	*Solanum aethiopicum*	298(83.7)	58 (16.3)
6.	*Vernonia amygdalina*	237(99.7)	119(0.3)
7.	*Vitellaria paradoxa*	1(0.3)	355(99.7)
8.	*Parkia bigloboas*	356 (100)	356 (100)
9.	*Ocimum gratissimum*	1(0.3)	355(99.7)
10.	*Cucumis sativus*	258 (100)	98(100)
11.	*Garcina kola*	1(0.3)	355(99.7)

Source: Field Survey 2019

Table 4: Frequency table for utilization of Forest Products as Medicine only among Enclaves of Onigambari Forest Reserve, Oyo State

S/N	NTFPs	Medicine	
		Frequency	**%**
1.	Azadirachta indica	356	100
2.	Mormordica Charantia	356	100
3.	Andrographis paniculata	356	100
4.	Cymbopogon citratus	356	100
5.	parquetina nigrescens	356	100

Source: Field Survey 2019

Results of a paired sample t-test

A paired-samples t-test was conducted to compare the utilization of non-timber forest products (NTFPs) for food and medicinal purposes in the Onigambari Forest Reserve. The result shows that there was no significant difference between the two utilization categories ($t = 0.178$, $df = 10$, $p = 0.863$). This indicates that the use of NTFPs for food does not differ significantly from their use for medicinal purposes among the identified species.

Conclusion

This study has shown that Non-timber Forest products are of great importance to rural dwellers, especially for their use as food and medicine. It has further reinforced the fact that NTFPS are

mostly means by which locals generate income by selling these products. Cultivation and improved environments can enable these non-timber forest species to thrive on a large scale and increase their availability in urban areas, thereby helping mitigate food insecurity and malnutrition.

References

Abdullahi, A. A. (2011). Trends and challenges of traditional medicine in Africa. *African Journal of Traditional, Complementary and Alternative Medicines*, 8(5S), 115–123. https://doi.org/10.4314/ajtcam.v8i5S.5 (doi.org in Bing)

Adetunji, S.A. and Akeredolu, O.A. (2019). Non-timber forest products and their benefits to rural livelihood: A case study of Saki agricultural zone of Oyo state, Nigeria *JMPS* 2019; 7(5): 146–149.

Agrawal, A., B. Cashore, R. Hardin, G. Shepherd, C. Benson and D. Miller. (2013). Economic contributions of forests. Background Paper 1, United Nations Forest on Forests (UNFF), 10th Session, Istanbul, Turkey. http://www.un.org/esa/forests/pdf/session_documents/unff10/ EcoContrForests.pdf.

Chukwu, V.E. and Bada, S.O. (2019). Assessment of Community Participation in Forestry in Onigambari Forest Reserve. *International Journal of Research and Innovation in Social Science (IJRISS)*. Vol. III, Issue III. ISSN 2455-6186. Pg 424.

Duong, N. (2008). The Role of Non-timber Forest Products in Livelihood Strategies and Household Economics in a Remote Upland Village in the Upper Ca River Basin, Nghe Tinh Phuong. *Journal of Science and Development*; 1:88-98.

Fadun, O.O., Soaga, J.A., Adedokun, M.O., & Oladoye, A.O. (2017). Ethno-medicinal values and diversity of understory plants in two forest plantations in Abeokuta, Ogun State, Nigeria. African Journal of Agriculture Technology and Environment Vol. 6(1): 53–66.

FAO (1997). Small-Scale Forest-Based Processing Enterprises. FAO Forestry paper No.79, Food and Agriculture Organization.

FAO (2011). *Medicinal plants and traditional medicine*. Food and Agriculture Organization of the United Nations

Gogoi, I., Dowara, M., & Chetia, P. (2024). *Traditional medicinal plants and their ethnomedicinal values*. In Traditional Resources and Tools for Modern Drug Discovery (pp. 377–399). Springer Nature. https://doi.org/10.1007/978-981-97-4600-2_14

Nasi, R., A. Taber, & N.V. Vliet. (2011). Empty Forests, Empty Stomachs? Bushmeat and Livelihoods in the Congo and Amazon Basins. *International Forestry Review* 13(3):355-68.

Nargawe, R., *et al.* (2023). *Ethnobotanical survey of indigenous medicinal plants and their role in traditional healthcare systems*. Plant Science Archives

Sunderland, T., Powell, B., Ickowitz, A., Foli, S., Pinedo-Vasquez, M., Nasi, R., & Padoch, C. (2013). *Food Security and Nutrition: The role of forests.* Bogor, Indonesia.: CIFOR. http://www.cifor.org/pen/

ANALYSIS OF PHYTOCHEMICALS IN *HOLARRHENA FLORIBUNDA (L)* PARTS FOR ORGANIC MANURE PRODUCTION

Abstract

The quest for sustainable agriculture has called for the use of plant based organic manure. This study examined the quality and quantity of phytochemicals components present in the leaf, stem-bark, and root of *Holarrhena floribunda*.

Fresh leaf, stem-bark, and root of Holarrhena floribunda were collected separately in zip lock bags and well labelled. The samples were authenticated, rinsed with water, air dried under shade, and pulverized using a laboratory mill. Regular phytochemical screening procedures were carried out for qualitative analysis, while spectrophotometric techniques were used for quantitative analysis. Extractions and phytochemical analysis of *H.floribunda* leaf, stem-bark, and root were done using standard laboratory procedures.

The results showed the presence of varied concentrations of, tannins, quinones, phenol, terpenoids, saponins, anthraquinone, coumarin, alkaloids, phytate, flavonoids and oxalate in all the plant parts been investigated. Abundant presence (+++) of alkaloids with a quantity of 0.205mg/g, demonstrating that the leaves are rich in nitrogen- containing secondary metabolites. Moderate concentration of tannins (10.000%), terpenoids (5.567%), quinones (1.820%), phytate (5.835%), phenol (2.555%), and oxalate (3.061%) were also recorded in the leaf of *H. floribunda*. The highest alkaloids concentration (0.245%) among the three plant parts, with strong qualitative presence (+++). This finding suggests that the root of *H. floribunda* serves as vital reservoir of bioactive alkaloids. This study concluded that the presence of phytochemicals both quantitatively and qualitatively in *H. Floribunda* is an indication that the plant parts can be processed for organic manual to enhance agricultural production.

Keywords:*Holarrhena floribunda*, phytochemicals, analysis, organic manual

Introduction

Holarrhana floribunda (G. Don) T. Dur and Schinz commonly known as False rubber tree is one of the family Apocynaceae due to its milky property that is secreted when the bark is wounded or cut, it is popularly called "Ako-ire" in Yoruba and "Gamon sauwa" in Hausa. *H. floribunda* a medium- sized tree of 4.5 to 17 meter high is widely distributed in West Africa, especially in Nigeria, it is characterized with shining ovate – acuminate leaves which length ranges between 5 and 18 cm long, it possesses white, scented flower with the inflorescence arranged like umbel. The fruits of *H. floribunda* which are always in pairs are long, slender, and are with pendulous pods of

about 30 to 60 cm long. Taxonomically, there are two varieties which are var. *floribuda* that produces glabrous leaves and var. *tomentalla* that produces densely pubescent leaves (Stephen, 2016).

The stem bark of is used as decoction to cure ailment like diarrhea, dysentery, stomach pain, and as antidote for snake bite. Also, the leaf of *H. floribunda* is good in the treatment of malaria, diabetes and indigestion (Bogne, *et al*., 2017). More importantly, *H. floribunda* being an indigenous forest tree could play a vital role in the enhancement of environmental services which is part of the uses of forests in Nigeria (Yusuff and Alamu, 2019). It has been identified that *H. floribunda* has pharmacological activities due to the presence of some bioactive compounds such as: holarrhesine, conessine, holaphylline, holaphyllamine, holamine and progesterone among others (Badmos *et.al,* 2016). The presence of different phytochemicals which play vital roles in organic matter decomposition, nutrient cycling, and soil microbial ecology have made *Holarrhana floribunda* parts suitable for production of organic manure which is an important component of sustainable agriculture. These phytochemicals include; tannins which help in reducing the rate of organic matter decomposition also dictates the release of nitrogen. This activity promotes long-term soil fertility and carbon balance and thereby enhancing soil matter perseverance. Quinones, otherwise known as redox-active compounds involve in microbial electron transport system, acting as electron carriage in the process of composting and decomposition, thereby promoting organic matter breakdown as well as microbial respiration. Antimicrobial qualities possess by quinones play important roles in destroying harmful microorganisms, resulting in the improvement of manure quality (Adamczyk, 2024). The role of phenolic compound such as simple phenolic acid is significant in the way they modulate microbial activity in soils through the inhibition and stimulation of microbial population and as well as humification process.

It is important to note that despite the vast application of *Holarrhena floribunda* in treating human diseases, its application for plant science has not been widely investigated to serve as literature in crop and environment protection expect the recent submission by Babalola and Alamu (2021) on the usage of *Holarrhena floribunda* as organic growth enhancer for cocoa seedlings in Nigeria which was found to be efficacious.

The main aim of this study therefore, is to determine the quality and quantity of phytochemical of *Holarrhena floribunda* parts for organic manure production.

Materials and Methods

Sample Source

Plant parts- leaf, stem-bark, and root of *Holarrhena floribunda* were sourced from Forestry Reserve Onigambari, Ibadan, Oyo State which is characterized by high humidity and moderate rainfall with Latitude7.43°N, longitude 3.85° E, and elevation 120m above sea level.

Sample Collection

Fresh leaf, stem-bark, and root of *Holarrhena floribunda* were collected separately in zip lock bags and well labelled. The samples were authenticated, rinsed with water, air dried under shade, and pulverized using a laboratory mill.

Qualitative Analysis of Phytochemicals

Qualitative analyses were carried out using the method of Trease and Evans (1989) and Harborne, (1993) to identify the different phytochemicals in the leaf, stem-bark, and root of H. floribunda before quantitative analyses were done.

Quantitative Analysis

Alkaloids Determination

Five gram (5g) each of leaf, stem-bark, and root of *H. floribunda* was weighed into 250ml beaker and 200ml acetic acid in ethanol was added to each sample, covered and allowed to stand for 4 hours at 25°c. These were filtered using filter paper No. 42 and the filtrates were concentrated using water bath (Memmert) to one quarter each of original volume. Concentrated ammonium hydroxide was added drop wise to each extract until the precipitate were complete. The whole solutions were allowed to settle and the precipitate were collected and washed with dilute NH_4OH (1% ammonia solution). They were then filtered with pre-weighed filter papers. The residue on the filter papers were alkaloid, this was then oven dried, calculated and expressed as percentage of weight of the samples analyzed (Odeyemi *et al*., 2023).

Flavonoids Determination

The plant sample (10g) was extracted repeatedly with 100ml of 80% aqueous methanol at room temperature. The whole solution was filtered through whatman filter paper No 42 (1255mm). The filtrate was later transferred into a crucible and evaporated into dryness over a water bath and weighed to a constant weight.

Determination of Saponin

Exactly 5g each of the sample (*H. floribunda*) leaf, stem-bark, and root were put into 20% acetic acid in ethanol and allowed to stand in a water bath at 50^0c for 24 hours. These were filtered and the extracts were concentrated using a water bath to one-quarter of the original volume. Concentrated NH_4OH was added drop-wise to the extracts until the precipitates were complete. The whole solutions were allowed to settle and the precipitates were collected by filtration and weighed. The saponin contents were weighed and calculated in percentage (Odeyemi *et al*., 2023)

Tannin Determination

Percentage Tannin in leaf, stem-bark, and root of *H. floribunda* done by adding 20 g each of the samples to petroleum ether and were covered for 24 hours. The samples were filtered and allowed to stand for 15 minute in order for the petroleum ether to evaporate. They were then re-extracted by soaking in 100 ml of 10% acetic acid in ethanol for 4 hours. The samples were then filtered and the filtrates collected. NH_4OH (25 ml) was added to each filtrate to precipitate the alkaloids. The alkaloids were heated with electric hot plate to remove some of the NH_4OH still in solutions. The remaining volume were measured to be 33 ml. Five milliliter (5 ml) each of these were taken and 20 ml of ethanol was added to them. They were titrated with 0.1 M

N_a OH using phenolphthalyne as indicator until a pink end point is reached. Tannin content in each extract was then calculated in percentage.

Determination of Phytate

Phytate contents were determined by weighing 0.2 g each of the samples (*H. floribunda* leaf, stem-bark, and root) into 250 ml conical flask differently, the samples were soaked in 100 ml of 2% concentrated HCL for 3hr, the samples were then filtered. Fifty milliliter (50 ml) of the filtrates were laced in 250 ml beakers and 100 ml distilled water was added to each sample. Ten milliliter

(10 ml) of 0.3% ammonium thiocynate solution was added as indicator and titrated with standard iron chloride solution which contained 0.00195 g iron per 1 ml (Odeyemi *et al*., 2023).

Phenol Determination

The quantity of phenol in each sample (leaf, stem-bark, and root of *H. floribunda* was determined using spectrophotometer method. The samples were boiled in 50 ml of $(CH_3CH_2)_2O$ for 15 minutes. Five milliliter (5 ml) each of the boiled samples was pipetted into 50 ml flasks separately, and 10 mil of distilled water was added to each mixture, the samples were made up to the marks and left or 39 min to react for colour development and measured at 505nm wavelength using spectrophotometer.

Determination of Anthraquinone

Magnesium Acetate solution was added each to tree, stem-bark, and root of *H. floribunda* samples solution, the development of pink colour indicates the presence of Anthraquinones.

RESULTS

The qualitative phytochemical analysis of the *H. floribunda* leaf, stem-bark, and root

The qualitative phytochemical analysis of *H. floribunda* leaf, stem-bark, and root showed the presence of oxalate, phytate, saponin, alkaloids, flavonoids, tannin, phenol, terpenoids, anthraquinone, quinones, coumarin, and fat & oil at varying levels. Tables 1,2, and 3 showed the results of analysis.

Table 1: Qualitative analysis of Phytochemicals in *Holarrhena floribunda* leaf

S/N	PHYTOCHEMICALS	QUALITY	QUANTITY
1	Alkaloids	+++	**0.205mg/g**
2	Flavonoids	+	**0.094%**
3	Tannins	++	**10.000%**
4	Quinones	++	**1.820%**
5	Phenol	+	**2.555%**

6	Saponin	**-**	**0.151%**
7	Anthraquinone	+	**0.420%**
8	Phytate	+	**5.835%**
9	Oxalate	+	**3.061%**
10	Terpenoids	++	**5.567%**
11	Coumarin	**-**	**0.31%**
12	Fat & Oil	**-**	**2.840%**

Table 2: Qualitative analysis of Phytochemicals in *Holarrhena floribunda* stem-bark

S/N	PHYTOCHEMICALS	QUALITY	QUANTITY
1	Alkaloids	++	**0.189%**
2	Flavonoids	+	**0.134%**
3	Tannin	++	**16.500%**
4	Quinines	++	**3.470%**
5	Phenol	+	**15.916%**
6	Saponin	**-**	**0.186 %**
7	Anthraquinone	+	**0.860%**
8	Phytate	+	**20.044%**
9	Oxalate	+	**4.592mg/g**
10	Terpenoids	++	**5.808%**
11	Coumarin	**-**	**0.68%**
12	Fat & Oil	**-**	**1.960%**

Table 3: Qualitative analysis of Phytochemicals in *Holarrhena floribunda* root

S/N	PHYTOCHEMICALS	QUALITY	QUANTITY
1	Alkaloids	+++	**0.245%**
2	Flavonoids	+	**0.024%**
3	Tannins	++	**11.400%**

ISTF-NIG 2026

4	Quinones	++	**2.140%**
5	Phenol	+	**8.711%**
6	Saponin	-	**0.283%**
7	Anthraquinone	+	**1.210%**
8	Phytate	+	**10.446%**
9	Oxalate	+	**0.720mg/g**
10	Terpenoids	++	**5.607%**
11	Coumarin	-	**0.94%**
12	Fat & Oil	-	**1.43%**

Key: +++(Abundance); ++(High); +(Moderate); - (Low)

Discussion

The result of this study revealed the quality and quantity of phytochemical in the leaf, stem-bark, and root of *H. floribunda* with varying values.

Table 1 shows an abundant presence of oxalate, phytate, saponin, alkaloids, flavonoids, tannin, phenol, terpenoids, anthraquinone, quinones, coumarin, fat and oil in varying concentrations. These phytochemicals are known to be significantly medicinal, serving as antioxidant, antibacterial, antimicrobial agent. They also have organic manure properties for plants growth generally (Mukavi, *et al.*, 2026).

Table 1 above showed the phytochemical constituents of *H. floribunda* leaf. The result showed the abundant presence (+++) of alkaloids with a quantity of 0.205mg/g, demonstrating that the leaves are rich in nitrogen- containing secondary metabolites. Alkaloids are significant bioactive compounds linked with pesticides and antimicrobial activities, which may increase the disease suppressive potential of organic manure produced from the plant materials. This abundant presence of alkaloids corroborates the findings that species of *Holarrhena* are rich source of steroidal alkaloids with important which possess high pharmacological properties (Badmus *et al*., 2019).

The result showed that moderate concentration of tannins (10.000%), terpenoids (5.567%), quinones (1.820%), phytate (5.835%), phenol (2.555%), and oxalate (3.061%) were also recorded in the leaf of *H. floribunda*. Research findings have revealed that tannins and phenol contribute

significantly to antioxidant and antimicrobial properties of plants and animals, therefore, making these compounds enhance soil microbial activities and lower the activities of harmful pathogens especially when added to organic manure components (Omowumi *et al*., 2026).

The presence of flavonoids (0.094%) and anthraquinones (0.420%) also indicates antioxidant and biological activity abilities of *H. floribunda* leaf which is in line with the findings of Badmus *et al*., (2016) which revealed that the presence of flavonoids are responsible for the antioxidant activity of the plant leaves and that this forms the scientific basis for its traditional usage. Saponin, coumarin, and fat and oil were present in low concentration which indicates that these phytochemicals are less abundant in the leaf of *H. floribunda*. Nevertheless, their presence may still add to nutrient mineralization and microbial stimulation during the organic manure production in relation to the findings of Adejoro *et al*., (2025) which said that organic nutrient sources significantly increased soil microbial activity and enhanced decomposition processes in cultivated soil.

The results as showed from Table 2 above revealed that the stem-bark of *H. floribunda* contains relatively higher concentrations of many phytochemicals than the leaf and root. Tannins (16.500%), phenols (15.916%), and phytate (20.044%) were specifically abundant in the stem-bark. These high contents of tannin and phenol indicate antioxidant and antimicrobial properties, which may contribute to conservation of organic matter and suppression of detrimental microbial activities in the process of organic manure production. The stem-bark of *H. floribunda* as well contained reasonable amounts of quinones (3.470%), terpenoids (5.808%), and oxalate (4.592mg/g), this shows that the stem-bark may contain strong bioactive strength. Quinones are known for antimicrobial and redox properties, while terpenoids add to biological resistance mechanisms in plants. The relatively low alkaloids concentration (0.189%) also established the phytochemical abundance of *H. floribunda* stem-bark. Anthraquinone (0.860%), flavonoids (0.134%), coumarin (0.68%), and fat & oil (1.960%) occurred in fairly lower concentrations. Though saponin was quantitatively absent, a trace quantity (0.186%) was identified quantitatively, this suggests slight accumulation in the stem-bark tissues. The presence of these phytochemicals indicates the defensive activities and metabolites storage exhibits by stem-bark tissue. This work agrees with the finding of Odusina and Ibrahim (2018) which said that the presence of

phytochemicals in *H. floribunda* contribute greatly to antimicrobial activities and bioactive properties of the plant

The results of Table 3 shows the quality and quantity of phytochemicals in the root of *H. floribunda*. The highest alkaloids concentration (0.245%) among the three plant parts, with strong qualitative presence (+++). This finding suggests that the root of *H. floribunda* serves as vital reservoir of bioactive alkaloids. Appreciable quantities of tannins (11.400%), phytate (10.446%), phenol (8.711%), and terpenoids (5.607%) recorded in the root of *H. floribunda*, the presence of these phytochemical indicates the roles of antioxidant action, nutrient cycling, and microbial regulation in soil. Also, the reasonable concentration of quinones (2.140%) and anthraquinones (1.210%) shows that the root of *H. floribunda* has antimicrobial and biological activities which are indicators for organic manure production. The flavonoids quantity (0.024%) of the root of *H. floribunda* was lowest in relation to those of leaf and stem-bark, this indicates low flavonoid biosynthesis or buildup in root tissues. The content of oxalate (0.720mg/g) was lesser that those of the leaf and stem-bark which revealed low anti-nutritional effect in the root of *H. floribunda.* Coumarin quantity (0.94%) was moderately higher in the root than in the leaf and stem-bark of *H. floribunda*, this indicates buildup of aromatic compounds in underground tissues. The presence of these phytochemical is in line with the report of LeBlanc *et al* (2024) which reported that the green waste compost greatly impacts the functionality of microbes and also lead to the reduction of the activity of pathogen in an infected soil.

Generally, the results showed that all parts of *H. floribunda* possess appreciable quality and quantity phytochemicals across the three parts. The stem- bark has the highest quantities of tannins, phenol, phytate, quinones, and terpenoids, while the root contains the highest alkaloids and anthraquinone. Meanwhile, the leaf contained the reasonable quantities of most phytochemicals which may play vital roles in bioactive compounds. The differences recorded in the qualities of phytochemical in *H. floribunda* parts may be as a result of physiological activities, metabolite storage, and mechanism of defense displayed by different plant parts.

Conclusion

From the results of the analysis of phytochemical quality and quantity of *H. floribunda* leaf, stem-bark, and root, it is concluded that these parts possess high potential for organic manure production, thereby enhancing sustainable agricultural practices. It is therefore recommended that all stakeholders should begin to focus on the inclusion of H. floribunda parts in the production of organic manual to enhance environmental friendly agriculture.

References

Adamczyk, B. (2024). Tannin and Climate Change: Are Tannins able to Stabilize Carbon in the Soil. *Journal of Agricultural and Food Chemistry*, 72(16), 8928-8932.

Adejoro, S.A, Olusola, O.J., Alade, O.d. (2025). Organic and Inorganic Nutrient Sources Effects on Soil Microbial Activity in Cultivated Soil. *Journal of Trends in Applied Science Research 20(1): 48-55.*

Antwi, S., Oduro-Mensah, D., Obiri, D.D., Osafo, N., Antwi, A.O., Anssh, H.O., Ocloo, A., & Okine, L.K.N. (2022). Hydro-Ethanol Extract of *Holarrhena floribunda* Stem bark Exhibits Anti- Anaphylactic and Anti- Oedematogenic Effects in Murine Models of Acute Inflammation. *BioMed Central Complementary Medicine and Therapies*, 22: 80.

Babalola, E. A. and Alamu, L.O. (2021).Assessment of Aqueous Leaf Extract of False Rubber Tree (*Holarrhena floribunda*) on Vegetative Growth of Three Varieties of Cocoa Seedlings. *Journal of Pure and Applied Agriculture*, 6(2); 17-24.

Badmus, J. A., Ekpo, O.E., Hussein, A.A., Meyer, M., and Hiss, D.C. (2019). Cytotoxic and Cell Cycle Arrest Properties of Steroidal Alkaloids Isolated from *Holarrhena floribunda* Leave. *BioMedical Central* Complementary *Medicine and Therapies*, 19: 112.

Badmus, J. A., Ekpo, O. E., Rautenbach, F., Marnewick, J., Hussein, A.A., & Hiss, D.C. (2016). Isolation and Antioxidant Activity of Flavonoids from *Holarrhena floribunda* (G. Don.) Leaves. *Journal of Acta Biochimica Polonica,* 63(2): 853-861.

Bogne, K. P., Penlap, B. V., Lontsi, D. and Etoa, E. F. (2017). Anti -bacteria Activities of the Extracts and Conessine from *Holarrhena floribunda* G. Don. (Apocynaceae), *AfricanJournal of traditional Complementary and Alternative Medicines*, 4(3):352-356.

Harbrne, J. B. (1993). Phytochemical Methods. Chapman and Hall Ltd., London, United Kingdom. 49-188.

LeBlanc, N.R. and Harrigian, F. C. (2024). Green Waste Compost Impacts Microbial Functions Related to Carbohydrate use and Active Dispersal in Plant Pathogen- Infected Soil. *Journal of Microbial Ecology*, 87:44.

Mukavi, J. W., Cal, M., Kaiser, M., Maser, P., Kimani, N. J., Omasa, L. K. and Schmidt, O. T. (2026). Identification of Steroidal Alkaloids with in Vitro Antiprotozal Activity from Holarrhena pubescence Wall. Ex G. Don. *Journal of Molecules*, 31(4), 733-741.

Odeyemi, O., Onochie, A. U., Odeyemi, S. O. and Oshim, I. O. (2023). Evaluation of Qualitative and Quantitative Phytochemical Constituents of *Napoleonaimperialis* Stem Bark. *Journal of GSC Biological and Pharmaceutical Science*, 24(01), 202-208.

Odusina, B.O and Ibrahim, S. A. (2018). Phytochemical Screening, Antimicrobial Activities and Quantity Estimates of Bioactive Compounds in Extracts of *Holarrhenafloribunda*. Journal of Chemical Society of Nigeria, 43(3): 114

Omowumi, T.A., Odunayo, O. V., Timothy, S.K., and Akingbolabo, O. D. (2026). Phytochemical Composition and Antimicrobial Efficacy of Nigeria Polyherbal Formulations against Antibiotic Resistant Micro-organisms. Scientific Reports.

Stephen, A. (2016): Evaluation of the Anti-inflammatory Effects of the Hydroethanolic Extract of *H. floribunda* in Marine Models of Inflammation: A thesis submitted in partial fulfillment of the requirement for the degree of Master of Philosophy.

Trease, G. E. and Evans, W. C. (1989). Pharmacognosy. 11th Edition. Macmillan Publishers, London, United Kingdom.

Yusuff Z.O. and Alamu L.O. (2019).Effectiveness of Forest Management as Affected by the Land Use Act in Onigambari Forest Reserve, Oluyole Local Government area, Ibadan, Nigeria. Advance in Social Sciences Research Journal, 6(12): 16-23.

GROWTH PERFORMANCE OF *Shorea roxburghii* G. Don SEEDLINGS UNDER DIFFERENT WATER REGIMES AND SOIL TEXTURAL CLASSES.

RUFAI Samsideen Olabiyi[1], SOWUNMI Linda ifeanyichukwu[1], OGUNBAMOWO Paul O[1]., OYEYINKA Barnabas Oluwatomide[1], *ADEBISI Oladapo Akeem[2], BALOGUN Lateefat Adewumi[2], ONIFADE Akeem Olakunle[1], BELLO Aliyu Oladotun[1], and EMMANUEL Ileri-Oluwa Busayo

[1]Forestry Research Institute of Nigeria
[2]Federal College of forestry, Ibadan
Corresponding Author: adebisioladapo4@gmail.com; +23408147222750

Abstract

Nigeria's forests contain economically valuable timber species, but over-exploitation has caused the decline of several, including *Shorea roxburghii*. Poor natural regeneration of this species has been linked to environmental constraints, particularly soil texture and water availability. This study therefore evaluated the growth response of *S. roxburghii* seedlings under different soil textural classes and watering regimes to determine optimal nursery conditions for regeneration. A total of 120 uniform seedlings were transplanted into polythene pots and arranged in a two-factor factorial in a Completely Randomized Design with six replications. Treatments comprised five soil textural classes: sand, loamy sand, sandy loam, loam, and clay, and three watering regimes: daily, every other day, and once weekly. Plant height, collar diameter, and leaf number were measured for twelve weeks. Soil texture significantly influenced seedling growth. Loamy sand produced the highest mean of plant height of 16.1 cm, while sandy loam resulted in the greatest collar diameter of 2.21 mm. Leaf production was not significantly affected by soil type. Watering regime significantly affected plant height and leaf number but had no significant effect on collar diameter. Seedlings watered daily attained greater height, whereas watering every other day produced the highest leaf number. These findings indicate that well-drained soils, particularly loamy sand and sandy loam, combined with consistent watering, enhance early growth performance of *S. roxburghii* seedlings. The study recommends adopting these soil types and watering schedules in nursery practices to promote effective regeneration and sustainable afforestation programmes in Nigeria.

Keywords: *Shorea roxburghii,* seedling growth performance, soil textural classes, watering regimes, nursery management, forest regeneration.

Introduction

Forests are important natural resources that are central to human life (Addas *et al*., 2023 Stenlund *et al*., 2025). They fuel the continuous socio-economic development of many developing and developed countries (Aziz *et al*., 2020; Kainyande *et al*., 2022; Imbrenda *et al*., 2023). Forest cover spans about one-third of global land area, but worryingly, only about 25% are naturally intact (Grassi *et al*., 2018; Wang *et al*., 2025). Climate change-related conditions limit the regenerative ability of tree species, and it is important to note that successful plantation and afforestation initiatives, require sufficient nutrient relations knowledge of tree seedling species

(Rajasugunasekar *et al*., 2023; Liu *et al*, 2025; Tandalla *et al*., 2025). Forest biosphere sustainability through rewilding measures has become a germane, resilient, nature-based mitigation against biodiversity depletion by encouraging tree and underground diversity (Hua *et al*., 2022; Palli *et al*., 2023; Svenning *et al.*, 2024). Notably, terrestrial ecosystem protection, restoration, and sustainable utility, is a key component of the Sustainable Development Goals (SDGs) (Katila *et al*., 2024). Water deficiency impedes plant growth and physiological mechanisms, thereby resulting in leaf size decline and cell shrinkage as a result of turgor pressure suppression (AbdelSalam *et al*., 2018; Kaaria *et al*., 2021). The root system in plants is highly sensitive to soil conditions, water and nutrient uptake (Chen *et al*., 2020). Soil texture has significant impact on soil aeration, nitrogen leaching regulation, and soil fertility (Xiao *et al*., 2021; Wang *et al*., 2022; Bhatt *et al*., 2025; Franzluebbers *et al*., 2025). It is the proportion of clay, silt and sand particles, with each of the soil particulate size contributing to water dynamics in the form of drainage enablement, water holding capacity and an intermediate of these properties (Mishra and Singh, 2025). For agricultural productivity and sustainability, the synergy between soil texture and water retention remains key (Mishra and Singh, 2025). Similarly, soil texture interestingly lays the foundation for the interaction of water with soil matrix, generally influencing nutrient cycling, root penetration and ecological resilience (Mishra and Singh, 2025).

Shorea roxburghii G. Don is a tropical timber tree member of the Dipterocarpaceae family. It is a critically endangered, according to the IUCN Red List (Mun, 2018). It is semi-evergreen and fast growing, with adult individuals reaching up to over 25m in height, producing beautifully lustrous and textured wood (Mun, 2018; Nguyen, 2020). The medicinal and industrial value of *S. roxburghii* make it important to improve its cultivation, conservation, multiplication and production of healthy seedlings for afforestation and reforestation, in the face of the teething challenge of contemporary forest resource depletion. This study evaluated the growth response of *S. roxburghii* seedlings under different soil textural classes and watering regimes to determine optimal nursery conditions for regeneration efforts.

Materials and Methods

Study area

The study was carried out at the Central Nursery Green house of the Forestry Research Institute of Nigeria (FRIN), Jericho Hill, Ibadan Nigeria, located at longitude (7°23'18"N – 7°23'43"N) and latitude (3°51'20"E – 3°51'43"E). The Mean annual rainfall is about 1548.9 mm, distributed over approximately 90 days. The mean maximum temperature is 31.9°C, minimum 24.2°C while the mean daily relative humidity is about 71.9% (FRIN, 2016).
The seeds of *S. roxburghii* were obtained from the seed section, in FRIN and tested for viability prior to sowing. Two hundred seeds were sown directly on a prepared bed and adequately watered daily. First emergence was observed at the fifth day after sowing and germination was monitored for 12 weeks. The emerged seedlings with 2-3 true leaves were transplanted into the polythene pots having a dimension of $12 \times 14 \times 16\ cm$ (Height x Width x Depth) containing the different textural classes and allowed to acclimate for before starting growth measurements.

Experimental Design

The experimental design used for the study was 3×5 factorial experiment in a completely randomized design (CRD). Factor A: 3 watering regimes (daily, every other day, and once weekly) and Factor B: 5 textural classes (sand, loamy sand, sandy loam, loam, and clay). Each combination of soil textural class and watering regime was replicated eight times.

Experimental Procedure

The five soil textural classes (sand, loamy sand, sandy loam, loam, and clay) were prepared using the soil textural triangle method (Kareem *et al*., 2021) (Table 1). A total of one hundred and twenty seedlings of 2-3 leaves with good vigour and relatively uniform growth were purposively selected and transplanted into polythene pot ($12 \times 14 \times 16\ cm$) filled with 1.5 kg of the prepared soils. These were exposed to different watering according to the treatments, each soil textural class was replicated 8 times under each watering. Growth parameters, including plant height, collar diameter, and leaf count, were measured weekly for 12 weeks, commencing from two weeks after transplanting.

Table 1: Compositions of different textural classes of soil.

Textural Class	Composition	Percentage
Sand	Sand	90
	Silt	10
	Clay	10
Loamy sand	Sand	80
	Silt	10
	Clay	10
Sandy loam	Sand	65
	Silt	20
	Clay	15
Loam	Sand	50
	Silt	28
	Clay	22
Clay	Sand	20
	Silt	10
	Clay	70

Data Analysis

The collected data were subjected to analysis of variance (ANOVA) using SPSS version 21 and significant differences among treatment means were determined using Duncan's Multiple Range Test (DMRT) at a 5% probability level.

Results and Discussion

Effect of watering regime and soil textural classes on the mean plant height of *S. roxburghii* Seedlings

Results presented in Table 1 indicate that there was no significant interaction between watering regime and soil textural class on the plant height of Shorea roxburghii seedlings ($p = 0.062$). However, both watering regime ($p = 0.003$) and soil textural class ($p < 0.001$) had significant main effects on seedling height. Among the watering regimes, seedlings watered every other day achieved the highest mean height (13.5 cm), which did not differ significantly from daily watering (13.3 cm). Seedlings watered once weekly exhibited the lowest mean height (11.5 cm). Regarding soil textural classes, the tallest seedlings were recorded in loamy sand (16.1 cm), while the shortest were observed in loam (11.2 cm), although this was not significantly different from other soil types. These results indicate that S. roxburghii seedlings grow best in well-drained soils, particularly loamy sand, and benefit from regular watering, either daily or every other day, to maximize early height development.

Table1: **Effect of water regime and soil textural classes on the mean plant height of *S. roxburghii* seedlings**.

Watering Regime	Textural Class	Wk 2	Wk 4	Wk 6	Wk 8	Wk 10	Wk 12
Everyday	Sand	10.9	11.3	11.7	12.3	13.0	13.8
	Loam sand	10.7	11.0	11.4	11.6	14.3	18.1
	Sandy loam	8.5	8.9	9.3	9.5	10.1	12.3
	Loam	9.0	9.4	9.8	10.2	11.0	11.7
	Clay	8.6	9.2	9.6	9.6	10.2	10.9
	Mean	**9.5**	**10.0**	**10.3**	**10.6^{ab}**	**11.7^{b}**	**13.3^{b}**
Every other day	Sand	9.7	10.2	10.9	11.3	12.3	13.2
	Loam sand	10.0	10.3	10.6	11.4	13.2	18.0
	Sandy loam	10.1	10.9	11.8	12.4	12.9	13.1
	Loam	9.4	9.6	9.8	10.2	10.7	10.9
	Clay	8.9	9.7	10.5	10.6	11.5	12.4
	Mean	**9.6**	**10.2**	**10.7**	**11.1^{c}**	**12.1^{b}**	**13.5^{b}**
Once a week	Sand	8.3	8.7	9.1	9.5	10.2	11.0
	Loam sand	7.3	8.1	8.8	9.0	10.0	12.4
	Sandy loam	9.3	9.8	10.3	10.5	11.2	12.0
	Loam	8.2	8.5	8.8	9.2	9.9	11.1
	Clay	8.4	8.9	9.4	9.8	10.5	11.0
	Mean	**8.3**	**8.8**	**9.3**	**9.6^{a}**	**10.4^{a}**	**11.5^{a}**
Mean Textural Class	Sand	9.6	10.1	10.6	11.0	11.8	12.7^{a}
	Loam sand	9.4	9.8	10.3	10.6	12.5	16.1^{b}
	Sandy loam	9.3	9.9	10.4	10.8	11.4	12.4^{a}

	Loam	8.8	9.2	9.5	9.8	10.5	11.2[a]
	Clay	8.6	9.3	9.8	10.0	107	11.4[a]
					p-value		
Watering Regime		0.115	0.093	0.078	0.047	0.026	0.003
Textural Class		0.811	0.786	0.681	0.541	0.131	0.000
Interaction Effect		0.722	0.722	0.695	0.501	0.264	0.062

Means of watering regime (bold) with same alphabets in superscript in the same column are not significantly different (p>0.05);
Means of textural class (Not bold) with same alphabets in superscript in the same column are not significantly different (p>0.05).

Effect of watering regime and soil textural classes on the mean collar diameter of *S. roxburghii* Seedlings

Results presented in Table 2 showed that there was no significant interaction between watering regime and soil textural class on the collar diameter of *S. roxburghii* seedlings at the end of the study period (p = 0.381). Similarly, watering regime had no significant effect on collar diameter (p = 0.525). However, soil textural class significantly influenced collar diameter (p = 0.029). The highest mean collar diameter was recorded in sandy loam (2.21 mm), which did not differ significantly from sand (2.20 mm), loamy sand (2.05 mm), and loam (1.89 mm). The lowest mean collar diameter was observed in clay (1.82 mm), which was significantly lower than those of other soil textural classes except loam. These results indicate that soil texture plays a more important role than watering regime in influencing collar diameter development of *S. roxburghii* seedlings, with sandy loam providing the most favourable conditions for stem growth.

Table 2: Effect of water regime and soil textural classes on the mean collar diameter of *S. roxburghii* seedlings.

Watering Regime	Textural Class	Wk 2	Wk 4	Wk 6	Wk 8	Wk 10	Wk 12
Everyday	Sand	1.17	1.30	1.61	1.74	2.13	2.24
	Loam sand	1.13	1.32	1.42	1.61	1.90	2.08
	Sandy loam	1.15	1.35	1.38	1.59	1.82	2.03
	Loam	1.29	1.38	1.51	1.61	1.84	1.94
	Clay	1.22	1.33	1.35	1.46	1.59	1.65
	Mean	**1.19[b]**	**1.34[a]**	**1.45**	**1.60**	**1.85**	**1.97**
Every other day	Sand	1.34	1.52	1.68	1.86	2.18	2.29
	Loam sand	1.32	1.43	1.59	1.71	2.00	2.12
	Sandy loam	1.00	1.16	1.39	1.55	1.94	2.10
	Loam	1.30	1.34	1.41	1.46	1.57	1.61
	Clay	1.14	1.31	1.50	1.62	1.85	1.90
	Mean	**1.22[b]**	**1.35[b]**	**1.51**	**1.64**	**1.91**	**2.00**
Once a week	Sand	0.78	1.02	1.29	1.53	1.88	2.09
	Loam sand	0.78	0.93	1.28	1.39	1.83	1.95
	Sandy loam	0.93	1.07	1.58	1.72	2.37	2.50
	Loam	0.94	1.09	1.37	1.52	1.95	2.10
	Clay	0.86	0.93	1.27	1.37	1.81	1.91
	Mean	**0.86[a]**	**1.01[a]**	**1.36**	**1.51**	**1.97**	**2.11**
Mean Textural Class	Sand	1.09	1.28	1.52	1.71	2.06[c]	2.20[b]
	Loam sand	1.08	1.22	1.43	1.57	1.91[abc]	2.05[b]

	Sandy loam	1.03	1.19	1.45	1.62	2.04^{bc}	2.21^{b}
	Loam	1.18	1.27	1.43	1.53	1.79^{ab}	1.89^{ab}
	Clay	1.07	1.19	1.37	1.48	1.75^{a}	1.82^{a}
					p-value		
Watering Regime		0.000	0.000	0.051	0.103	0.521	0.525
Textural Class		0.745	0.811	0.053	0.061	0.047	0.029
Interaction Effect		0.775	0.673	0.119	0.158	0.128	0.381

Effect of watering regime and soil textural classes on the mean number leaves of *S. roxburghii* Seedlings.

Results presented in Table 3 showed that there was no significant interaction between watering regime and soil textural class on the leaf production of *S. roxburghii* seedlings ($p = 0.216$). Similarly, soil textural class had no significant effect on leaf production ($p = 0.665$). However, watering regime significantly influenced leaf production ($p < 0.001$). The highest mean number of leaves was recorded under the daily watering regime (5.7), which did not differ significantly from watering every other day (5.5). The lowest mean number of leaves was observed under the once-weekly watering regime (4.2), which was significantly lower than those recorded under the other watering treatments. These results suggest that frequent watering promotes leaf development in *S. roxburghii* seedlings, while reduced watering frequency limits leaf production.

Table 3: **Effect of water regime and soil textural classes on the mean number of leaves of *S. roxburghii* seedlings.**

Watering Regime	Textural Class	Wk 2	Wk 4	Wk 6	Wk 8	Wk 10	Wk 12
Everyday	Sand	3.5	4.7	4.8	5.2	5.3	5.8
	Loam sand	3.2	4.5	4.5	5.0	5.3	6.2
	Sandy loam	2.7	4.2	4.5	4.8	5.2	6.3
	Loam	2.3	3.5	4.2	4.5	5.0	5.5
	Clay	2.7	3.2	3.8	4.2	4.5	4.8
	Mean	**2.9^{b}**	**4.0^{b}**	**4.4^{b}**	**4.7^{b}**	**5.1^{b}**	**5.7^{b}**
Every other day	Sand	2.8	4.8	5.2	5.3	5.3	6.0
	Loam sand	2.3	4.2	4.3	4.8	4.8	5.8
	Sandy loam	2.2	3.7	4.3	4.5	4.5	5.2
	Loam	2.0	3.2	3.5	4.0	4.2	4.7
	Clay	2.3	4.2	4.3	4.8	5.2	5.8
	Mean	**2.3^{a}**	**4.0^{b}**	**4.3^{b}**	**4.7^{b}**	**4.8^{b}**	**5.5^{b}**
Once a week	Sand	2.3	2.8	3.3	3.8	3.8	4.0
	Loam sand	2.5	3.5	3.7	4.0	4.0	4.3
	Sandy loam	2.3	3.2	3.3	3.8	3.8	3.8
	Loam	2.3	3.0	3.3	4.3	4.3	4.5
	Clay	2.5	3.5	4.0	4.3	4.5	4.5
	Mean	**2.4^{a}**	**3.2^{a}**	**3.5^{a}**	**4.1^{a}**	**4.1^{a}**	**4.2^{a}**
Mean Textural Class	Sand	2.9^{c}	4.1^{b}	4.4	4.8	4.8	5.3
	Loam sand	2.7^{bc}	4.1^{b}	4.2	4.6	4.7	5.4

	Sandy loam	2.4[ab]	3.7[ab]	4.1	4.4	4.5	5.1
	Loam	2.2[a]	3.2[a]	3.7	4.3	4.5	4.90
	Clay	2.5[abc]	3.6[ab]	4.1	4.4	4.7	5.1
				p-value			
Watering Regime		0.001	0.002	0.005	0.022	0.003	0.000
Textural Class		0.008	0.050	0.326	0.621	0.846	0.665
Interaction Effect		0.333	0.147	0.542	0.442	0.472	0.216

DISCUSSION

Water is essential for optimal plant growth, and different tree species exhibit varying water requirements. Soil texture also plays an important role in determining water infiltration, which influences water availability, nutrient uptake, and several physiological processes in plants (Rufai *et al*., 2021). Therefore, evaluating plant growth under different soil textural classes and watering regimes is necessary to determine the conditions that support optimal growth and development (Iroko *et al*., 2020). The variation in growth parameters observed during the early developmental stage of *S. roxburghii* in this study highlights the important role of water availability and soil texture in plant growth and development. This observation is consistent with previous studies by Rufai *et al*., (2021) and Kareem *et al*., (2021), who emphasized the importance of adequate watering and suitable soil texture in promoting seedling growth. The results further showed that *S. roxburghii* seedlings grew successfully in all soil textural classes tested. However, the highest growth parameters were recorded in loamy sand and sandy loam soils. Specifically, the highest plant height and leaf production were observed in loamy sand, while the greatest collar diameter was recorded in sandy loam. This may be attributed to the better drainage and aeration properties of these soils, which enhance root development and nutrient uptake (Tisdale *et al*., 2003; Kareem *et al*., 2021). These findings agree with earlier reports by Kareem *et al*., (2019) and Ogunwande, (2014), who indicated that the species can grow in a wide range of soils, from loam to lateritic soils with moderate fertility.

Conversely, loam and clay soils produced relatively lower growth parameters in terms of plant height, collar diameter, and leaf production. The relatively poor performance of seedlings in clay soil may be associated with its high acidity and poor aeration, which can limit root growth and nutrient availability (Ritu *et al*., 2010; Iroko *et al*., 2020). This observation also supports the findings of Sah *et al*. (2003), who reported that high clay content in soil can inhibit plant growth.
The results also revealed that watering regime had no significant effect on the collar diameter of *S. roxburghii* seedlings. This observation is consistent with the findings of El Amin *et al*. (2013), who reported that irrigation frequency did not significantly influence the height or collar diameter of several tropical tree species including *Acacia tortilis*, *Acacia ehrenbergiana*, *Azadirachta indica*, and *Eucalyptus microtheca* under nursery conditions. However, this result differs from the findings of Olajide *et al*., (2014), who reported that watering regime significantly influenced collar diameter in *Dialium guineense* seedlings. Furthermore, watering regime significantly affected plant height and leaf production in *S. roxburghii* seedlings. This agrees with the findings of Mohammed *et al*., (2013), who reported that watering regime significantly influenced seedling height and leaf number in several tropical tree species. However, the present findings differ from those of Iroko *et al*., (2020) and Bolanle-Ojo *et al*., (2018), who observed that watering regime and watering quantity had no significant effect on the height and leaf production of *Entandrophragma angolense* and *Artocarpus heterophyllus* seedlings.

The highest growth parameters were observed under the daily and every-other-day watering regimes. This may be attributed to the adequate soil moisture conditions provided by these treatments, which are essential for seedling survival and growth (Akinyele, 2007). These findings are consistent with Rufai *et al*., (2021), who reported that *Senna alata* seedlings watered daily with 200 mL of water produced the highest growth parameters. In contrast, the lowest growth parameters were recorded under the once-weekly watering regime, which likely subjected the seedlings to water stress. Water stress is known to adversely affect physiological processes such as photosynthesis, nutrient transport, and cell expansion, thereby reducing plant growth (Vandoorne *et al*., 2012; Sale, 2015). Overall, *S. roxburghii* seedlings demonstrated adaptability to the various soil textural classes and watering regimes tested, as no mortality or transplant shock was observed throughout the study period.

Conclusion and Recommendation

Watering regime and soil texture are important factors influencing plant growth and development, particularly during the early seedling stage. This study evaluated the effects of different watering regimes and soil textural classes on the growth performance of *Shorea roxburghii* seedlings. The results showed that soil texture significantly influenced seedling growth. Loamy sand produced the highest plant height and leaf production, while sandy loam resulted in the greatest collar diameter. However, soil texture had no significant effect on leaf production. Watering regime significantly influenced plant height and leaf number, with daily and every-other-day watering regimes producing better growth performance compared to once-weekly watering. Based on these findings, the use of well-drained soils such as loamy sand and sandy loam, combined with regular watering regimes (daily or every other day), is recommended for nursery production of *S. roxburghii* seedlings. Adopting these practices will enhance the production of vigorous and healthy seedlings for afforestation and reforestation programmes.

Acknowledgements

The authors gratefully acknowledge the assistance of Mrs Ruth Etura Ayang and Mr Jubril, technical staff of the Forestry Research Institute of Nigeria Herbal Garden, for their technical support and guidance during the fieldwork and plant handling processes involved in this study.

References

Abdelsalem, E., Alatar, A. and El-Sheikh, M.A. (2018). Inoculation with arbuscular mycorrhizal fungi alleviates harmful effects of drought stress on damask rose. *Saudi Journal of Biological Sciences*. 25:1772-1780.

Addas, A. (2023). Impact of forestry on environment and human health: an evidence-based investigation. *Frontiers in Public Health*. 11:1-15.

Akinyele, A.O. (2007). *Silvicultural requirement of seedlings of Buchholzia coriacea Engler.* Unpublished PhD Thesis, Department of Forest Resources Management, University of Ibadan, Nigeria. pp 20-34.

Aziz, N., Sharif, A. and Rong, K. (2020). Revisiting the role of forestry, agriculture, and renewable energy in testing environment Kuznets curve in Pakistan: evidence from Quartile ARDL approach. *Environmental Science*. 27:1-14.

Bhatt, R., Kunal, Garg, A.K., Majumder, D., Verma, K.K. and Wagner de Oliveira, M. (2025). Soil texture: Unlocking fertility and productivity for better crops. *Agriculture Association of Textile Chemical and Critical Reviews Journal*. 13:396-408.

Bolanle-Ojo, O.T., Akinyele, A.O. and Aduradola, A.M. (2018). Morphological and physiological response of *Artocarpus heterophyllus* (Jackfruit) seedlings to selected environmental factors. *Journal of Agricultural Science and Food Research*. 9:1-7.

Chen, Y., Palta, J., Vara Prasad, P.V. and Siddique, K.H.M. (2020). Phenotypic variability in bread wheat root systems at the early vegetative stage. *BMC Plant Biology*. 20:1-16.

El Amin, E.E., Blal, M.E. and Mahmoud, A.E. (2013). Gum Arabic (*Acacia Senegal* (L.) Willd) viscosity in relation to rainfall and soil metal ions. *Journal of Forest Products and Industries*. 2:34-37.

Forestry Research Institute of Nigeria (FRIN) (2016). *Forestry Research Institute of Nigeria, Annual Meteorological Report*.

Franzluebbers, A.J., Farmaha, B.S., Zentella, R. and Kafle, A. (2025). Soil-profile fertility is altered by soil texture and land use across physiographic regions in the south-eastern United States. *Agronomy Journal*. 117:1-21.

Grassi, G., House, J., Kurz, W.A., Cescatti, A., Houghton, R.A., Peters, G.P., Sanz, M.J., Vinas, R.A., Alkama, R., Arneth, A., Bondeu, A., Dentener, F., Fader, M., Federic, S., Friedlingstein, P., Jain, A.K., Kato, E., Koven, C.D., Lee, D., Nabel, J.E.M.S., Nassikas, A.A., Perugini, L., Rossi, S., Sitch, S., Viovy, N., Wiltshire, A. and Zaehle, S. (2018). Reconciling global model estimates and country reporting of anthropogenic forest CO_2 sinks. *Nature*. 8:914-920.

Hua, F., Bruijnzeel, L.A., Meli, P., Martin, P.A., Zhang, J., Nakagawa, S., Miao, X., Wang, W., Mcevoy, C., Pena-Arancicbia, J.L., Brancalion, P.H.S., Smith, P., Edwards, D.P. and Balmford, A. (2022). The biodiversity and ecosystem service contributions and trade-offs of forest restoration approaches. *Forest Ecology*. 376:839-844.

Imbrenda, V., Coluzzi, R., Mariani, F., Nosova, B., Cudlinova, E., salvia, R., Quaranta, G., Salvati, L. and Lanfredi, M. (2023). Working in (Slow) progress: Socio-environmental and Economic dynamics in the Forestry sector and the contribution to sustainable development in Europe. *Sustainability*. 15:1-21.

Iroko, O.A., Amadi, J.O., Rufai, S.O. and Wahab, W.T. (2020). Comparative effect of different potting media on the early growth of *Entandrophragmaangolense*(Welw.). *Journal of Applied Sciences, Information, and Computing*. 1:67-70.

Kaaria, K.G., Gweyi-Onyango, J.P. and Muui, C.W. (2021). Influence of water regimes on growth, yield and nutrient uptake of Sorghum. *African Journal of Horticultural Science*. 18:1-20.

Kainyande, A., Auch, E.F. and Okoni-Williams, A.D. (2022). The Socio-economic contributions of large-scale plantation forests: perceptions of adjacent rural communities in the Northern province of Sierra Leone. *Trees, Forests, and People*. 10:1-14.

Kareem, A.A., Aduradola, A.M. and Oladoye, A.O. (2019). Effect of different textural classes of soil and light intensity on *Mansoniaaltissima* A Chev. Seedlings. *Journal of sustainable Environmental Management*. 11:23-29.

Kareem, A.A., Akinyemi, G.O., Sulaimon, O.N. and Adebayo, A.G. (2021). Effects of different textural classes of soil and light intensity on *Daniella oliveri* Hutch and Dalz seedlings. *Journal of Forestry Research and Management*. 18:37-146.

Katila, P., Pierce Colfer, C.J., de Jong, W., Galloway, G., Pacheco, P. and Winkel, G. (2024). *Introduction: Restoring forests and trees for sustainable development.* In: Restoring forests and trees for Sustainable Development. Pp 1-22.

Liu, J. (2025). Progress in research on the effects of environmental factors on natural forest regeneration. *Frontiers in Forests and Global Change*. 8:1-15.

Mishra, R. and Singh, D. (2025). Role of soil texture and structure in water retention and crop productivity. *International Journal of Creative Research Thought*.13:d328-d335.

Mohammed, A.E., Khalid, A.I. and Talaat, D.A. (2013). Effect of different watering regimes on growth performance of five tropical trees in the nursery. *Jonares*. 1:14-18.

Mun, H.W., Azam, F.A., Kassim, A.S. and Hoe, A.L. (2018). Assessment of growth and biomass of *Shorea roxburghii* G. Don in selected areas of Peninsular Malaysia. *International Journal of Agriculture, Forestry and Plantation*. 7:41-45.

Nguyen, T.T. (2020). Individual tree diameter increment and mortality models for medium and rich forest in Dong Nai Culture and Nature Reserve. *Vietnam Journal of Forest Science*. 3:73-86.

Ogunwande, O.A. (2014). *Silvicultural requirements of seedlings of Andrographis paniculata Burms.* A PhD Thesis submitted to Department of Forest Resources Management, University of Ibadan, Nigeria. pp178.

Olajide, O., Oyedeji, A.A., Tom, G.S. and Kayode, J. (2014). Seed germination and effects of three watering regimes on the growth of *Dialiumguineense*(Wild) Seedlings. *American Journal of Plant Sciences*. 5:3049-3059.

Palli, J., Balvia, M., Biondi, F., Calcagnile, L., Cerbino, D., D'Elia, M., Muleo, R., Schettino, A., Quarta, G., Sassone, N., Solano, F., Zienna, P. and Piovescan, G. (2023). The longevity of fruit trees in Basilicata (Southern Italy): Implications for Agricultural Biodiversity Conservation. *Land*. 12:1-17.

Rajasugunasekar, D., Chandra, A. and Kolar, A.B. (2023). Effect of climate change on the regeneration potential of native tree species. *European Chemical Bulletin*. 12:7708-7723.

Ritu, V. (2010). Effect of different sand and soil ratios on the growth of *Terminalia arjuna* W. & A. *New York Science Journal*. 3: 22-26.

Rufai, S.O., Olaniyi, M.B., Lawal, I.O., Iroko, O.A. and Olaniyi, A.A. (2021). Growth response of *Eryhthrophleum suaveolens* (GILL AND PERR.) BRENAN as influenced by different organic manures. *Journal of Forestry Research and Management*. 18:60-70.

Sah, S.P., Upadhyay, S.K., Pandit, P. and Lilles, J.B. (2003). Effects of soil on sissoo (*Dalbergia sissoo,* Roxb.) growth in a plantation forest of Nepal. *Indian Forester*. 129:1059-1068.

Sale, F.A. (2015). Evaluation of watering regimes and different pot sizes in the growth of *Parkia biglobosa* (Jacq) Benth seedlings under nursery condition. *European Scientific Journal*. 11:313-325.

Stenlund, S., Theberge, D., Aastrup, M.L., Cominelli, S., Mac Donald, H., Nadeau, S., Zhao, J. and Sponarski, C.C. (2025). The well-being of *Homo sapiens* in forests: A scoping review of frameworks and indicators. *Trees, Forests and People*. 21:1-12.

Svenning, J.C., Mc Geoch, M.A., Normad, S., Ordonez, A. and Riede, F. (2024). Navigating ecological novelty towards planetary stewardship: challenges and opportunities in biodiversity dynamics in a transforming biosphere. *Philosophical Transactions B*. 379:1-11.

Tandalla, D.C., Homeier, J. and Batary, P. (2025). Resources of tropical tree seedlings to nutrient addition: A meta-analysis to understand future changes in Tropical forest dynamics. *Current Forestry Reports*. 11:1-15.

Tisdale, S.L., Nelson, W.L., Beaton, J.D. and Haulin, J.L. (2003). Soil fertility and fertilizer. 5th Edn, Prentice-Hall, New Delhi.

Vandoorne, B., Mathieu, A.S., Van den Ende, W., Vergauwen, R., Perilleux, C., Javaux, M. and Lutts, S. (2012). Water stress drastically reduces root growth and inulin yield in *Cichorium intybus* (var. *sativum*) independently of photosynthesis. *Journal of Experimental Botany*. 63:4359-4373.

Wang, L., He, Z., Zhao, W., Wang, C. and Ma, D. (2022). Fine soil texture is conducive to crop productivity and nitrogen retention in irrigated cropland in a desert-oasis ecotone, North west China. *Agronomy*. 12:1-15.

Wang, L., Wei, F., Tagesson, T., Zhongxiang, F. and Svenning, J. (2025). Transforming forest management through rewilding: Enhancing biodiversity, resilience, and biosphere sustainability under global change. *One Earth*. 8:1-15.

Xiao, Q., Dong, Z., Han, Y., Hu, L., Hu, D. and Zhu, B. (2021). Impact of soil thickness on productivity and nitrate leaching from sloping cropland in the upper Yangtzee River Basin. *Agriculture, Ecosystems and Environment*. 311:107266.

ISTF-NIG 2026

THREATS TO HONEYBEES: HONEYBEES AND BEEKEEPING PRACTICES IN MANGU LOCAL GOVERNMENT AREA, PLATEAU STATE, NIGERIA

ERHABOR T. A., ATSEN E. O. and UKANYIRIOHA C. J.

Department of Forestry Technology, Federal College of Forestry, Jos, Nigeria,
Corresponding Email: erhabort@gmail.com/ 07035010430

Abstract

Beekeeping primarily produces honey, an apiary product of great importance for health and nutrition. Beyond their importance in nutrition and as a valuable raw material in industries, bees are among the most essential components of the ecosystem, given their immense contribution to plant pollination and the resulting increase in agricultural productivity. Threats to honeybees and beekeeping practices affect bee populations, the ease of beekeeping, and the profitability of honey production. In Mangu Local Government Area, 50 active beekeepers were purposively selected to identify threats to honeybees and beekeeping practices using a semi-structured questionnaire. To ascertain the extent of perceived threats, a 5-point Likert scale was used. Threats from anthropogenic activities were the highest in the study area, with mean scores ranging from 3.72 to 3.46. Biological threats from Ants (3.72), Honey badger termites (3.56), birds (3.52), Beetles (3.48), and Lizards (3.46) as well as threats from management and government policies, poor extension services (3.72), lack of business support services (3.72), absence of policies on beekeeping (3.56), inadequate beekeeping skills (3.56), crude beekeeping materials (3.52), poor storage facilities (3.48), and use of chemicals (3.46), were high in the study area. Environmental (climatic) conditions were not considered as major threats to beekeeping practice in the study area. Despite threats facing the beekeeping subsector, there are still numerous significant opportunities to boost honey production in the district.

Keeping biological threats, honey, and pollination

Introduction

Honeybees (*Apis mellifera* and its subspecies) are vital pollinators in both natural and agricultural ecosystems. They contribute significantly to crop production, biodiversity, and food security in Nigeria (Gebremedhn *et al*., 2025). In Nigerian agriculture, honeybees support the reproduction of many food crops and provide valuable economic products such as honey, bee venom and beeswax, which support rural livelihoods and economic development (Ejikeme & Ugwu, 2023). Despite these benefits, there is growing concern about declining bee populations and the sustainability of beekeeping (apiary) activities nationwide (Oladimeji & Ajao, 2023). Studies across various states in Nigeria highlight the multi-faceted challenges facing honeybees, apiaries and beekeepers (Akinmulewo *et al.*, 2017; Oladimeji *et al*., 2019; Kashumba, 2025). For example, predators (ants and lizards) and anthropogenic activities such as the unethical use of pesticides and theft have been identified as major constraints to beekeeping in Nigeria (Lawal *et al*., 2019). Additionally, socio-economic and management constraints, such as poor apiary management and inadequate technical knowledge, have been shown to exacerbate stress on hive colonization, thereby reducing the potential for honey yields and pollination efficiency among Nigerian bee farms (Oladimeji & Ajao, 2023). Changes in local climate are also perceived to affect honey production and bee behavior in

Nigeria (Ijigbade, 2017; Nwaiwu *et al*., 2025). In Southeastern Nigeria, ate change and associated shifts in crop flowering patterns are reported to have impacted honey production and colony workload (Nwaiwu *et al*., 2025). This underscores the complex interplay among environmental, biological, and human-induced factors affecting apiculture in Nigeria.

Compounding these local stressors are broader concerns about food security and the integrity of the ecosystem. Declining bee populations could undermine crop productivity and rural incomes, especially in Nigeria, where reliance on insect pollination is high for many staple and high-value crops (Abah *et al*., 2025). Moreover, genetic studies in Nigeria indicate the importance of understanding and conserving honeybee diversity to maintain resilient bee populations in both rural and urban environments (Adejuwon *et al*., 2023). Given this backdrop, it is important to identify and analyze locally specific threats to honeybees and beekeeping practices to develop evidence-based policies, improve beekeeping practices, and strengthen the overall sustainability of Nigeria's apicultural sector.

Methodology

Study Area

The research was conducted in the Mangu Local Government Area (LGA) of Plateau State, Nigeria. The area lies between latitudes 8°55′28″ and 9°45′05″ North of the Equator and longitudes 9°00′29″ and 9°17′38″ East of the Greenwich Meridian. Mangu shares boundaries with Bauchi State to the northeast and consists of eleven districts, covering approximately 3,619 km². According to the 2006 National Population Census (projected at 2.4% annual population growth), the LGA has a population of 473,925 people. Agriculture constitutes the primary economic activity, engaging over 75% of the population, with beekeeping serving as an important complementary livelihood.

Sampling Procedure and Data Collection

A purposive sampling technique was employed to select respondents actively involved in beekeeping within the study area. Fifty (50) beekeepers were selected to ensure representation across different scales of operation, including small-scale producers. This approach ensured the inclusion of diverse management capacities and production levels. Primary data were collected using semi-structured questionnaires administered directly to respondents. Additional information was obtained through field observations and key informant interviews, which provided contextual understanding of beekeeping practices and constraints in the area.

Data Analysis

Data were analyzed using percentages and presented in tables and charts. A 5-point Likert scale was used to analyze responses obtained. The mean score of respondents below 2.60 (1.0–2.60) was considered as low threat, the score variable of the respondents within the range of (2.61–3.40) was considered as moderate threat, and the mean score of respondents above 3.40 (3.40–5.0) was considered as high threat in this study.

Result and Discussion

All 50 respondents in this study reported experiencing threats in beekeeping practices (Table 1). These threats are diverse and include pests and predators, adverse environmental conditions, anthropogenic activities, management, and government policies.

Biological Threats to Honeybees and Beekeeping Practices

Pest infestations are a major threat to honeybees and beekeeping practices. The findings thus reveal that the pests posing the greatest threat to honeybees and beekeeping practices are ants, with a mean of 3.72; other pests, in order of mean, include honey badger 3.56, birds 3.52, small hive beetles 3.48, and wax moth 1.08 (Table 2). Others include beetles, spiders, wasps, praying mantises, and monkeys, with a mean of 1 each.

Table 1: Respondents' views on experiencing threats in beekeeping practices

Experiencing threats	Frequency	Percentage
Yes	50	100
No	0	0

Table 2: Biological threats to honeybees and beekeeping practices on a 5-point Likert scale

Factors	Variables						
	5	4	3	2	1	Total	Mean
Ants	0	45	0	1	4	186	3.72
Wax month	0	0	0	4	46	54	1.08
Beelike	0	0	0	0	50	50	1
Bettles	15	20	0	4	11	174	3.48
Spiders	0	0	0	0	50	50	1
Wasps	0	0	0	0	50	50	1
Praying mantis	0	0	0	0	50	50	1
Lizards	14	19	3	4	10	17.3	3.46
Birds	12	23	1	3	10	176	3.52
Hamagot/helmet mat	0	0	0	0	50	50	1
Monkeys	0	0	0	0	50	50	1
Snake	0	0	0	0	50	50	1
Honey badger termite	14	23	0	3	10	178	3.56

Key 5: Strongly agree, 4: Agree, 3: Undecided, 2: Decided, 1: Strongly decided.

These findings therefore reveal that bee pests and predators are major constraints on the honey sub-sector (Gidey *et al*., 2012). That ant, honey badger (*Mellivora capensis*), bee-eater birds, small hive beetle (*Aethina tumida*), and lizard are the most serious pest problems in the beekeeping sector (Tesfaye *et al*., 2017; Ayele *et al*., 2020). The prominence of these pests and predators suggests that effective pest management strategies are essential for improving

honey production. Their impact can lead to colony destruction, reduced hive productivity, and increased economic losses for beekeepers.

Environmental Factors as Threat to Honeybees and Beekeeping Practices

Uncertainty about environmental factors was identified as a major hindrance to beekeeping activities. Environmental threats to honeybees and beekeeping practices include rainfall (2.96), shortage of bee forage (2.96), wind (2.94), excessive sunshine (2.92), and drought (2.86) (Table 3). Although the results show that respondents could not determine whether environmental threats to honeybees and beekeeping practices are high or low, several authors have reported otherwise, stating that environmental factors pose major threats to honey production. It has been recognized that global climate change is highly detrimental to bee populations and biodiversity (Ojija *et al.,* 2025). Because climatic factors (rainfall, sunshine, wind, drought, etc.) are not independent, their interactions have a major impact on bee populations. It has also been recognized that habitat/forage loss (degradation, destruction, and fragmentation) is a major causal factor in the decline of bee population and diversity (Wagner *et al.,* 2021; Belsky & Joshi, 2019)

Anthropogenic Activities as a Threat to Honeybees and Beekeeping Practices

The results of anthropogenic activities as threats to honeybees and beekeeping practices reveal that the main threats are herdsmen (3.72) and thieves (3.72), followed by deforestation and vegetation clearing (3.56) and bush burning (3.56) (Table 4).

Table 3: Environmental factors as a threat to honeybees and beekeeping practices on a 5-point Likert scale

Factors	Variables						
	5	4	3	2	1	Total	Mean
Drought	0	0	45	3	2	143	2.86
Rainfall	0	0	49	0	1	14.8	2.96
Sunshine	0	0	47	2	1	14.6	2.92
Wind	0	0	48	1	1	147	2.94
Bee forage	0	0	49	0	1	148	2.96

Key 5: Strongly agree, 4: Agree, 3: Undecided, 2: Decided, 1: Strongly decided.

Table 4: Anthropogenic activities as a threat to honeybees and beekeeping practices on a 5-point Likert scale

Factors	Variables						
	5	4	3	2	1	Total	Mean
Herdsmen	0	45	0	1	4	186	3.72
Fire/bush burning	14	19	3	4	10	173	3.46
Deforestation	14	23	0	3	10	178	3.56
Vegetation clearing	14	23	0	3	10	178	3.56
Thieves	0	45	0	1	4	186	3.76

Key 5: Strongly agree, 4: Agree, 3: Undecided, 2: Decided, 1: Strongly decided.

Threats from herders and thieves are security issues. They could affect the distribution of hives, but deforestation and vegetation clearing reduce the availability of range and ting sites for s, thereby reducing ey production (Belsky & Joshi, 201The threatreat posed by herders and theft discourages beekeepers from placing hives in optimal locations, especially in forested or remote areas where forage is abundant. This limits effective hive distribution and reduces productivity. The result shows that anthropogenic threats to honeybees and beekeeping practices are high due to urbanization and its impacts on the landscape, leading to pollination shortages and bee population decline (Dar *et al.,* 2017). The destruction of natural vegetation not only affects bees but also disrupts broader ecosystem balance. Bees lose nesting sites and shelter, leading to colony stress and migration. Abah et al. (2025) reported that habitat degradation in Nigeria contributes to declining pollinator populations and reduced ecosystem services.

Management Concepts and Government Policies as Threats to Honeybee and Beekeeping Practices

Poor extension services (3.72), lack of business support (3.72), lack of policies in apiculture, lack of training and skills of beekeeper (3.56), inadequate beekeeping equipment (3.52), storage facility and post-harvesting (3.48), chemical application (3.46), and high cost of beehives production (3.06) possess high threats to the honeybees as well as beekeeping practices in the study area (Table 5). Other factors that are threats according to their means include swarming (2.06), absconding (1.08), and marketing (1.06). The result reveals that management and government policies are major threats to honeybees and beekeeping and that the major constraints of beekeeping are a lack of beekeeping knowledge, shortage of trained workforce, shortage of beekeeping equipment, pest and predators, as well as inadequate research and extension services to support the apiculture development program (Tesfaye *et al*., 2017; Tarekegn, 2023). Most local beekeepers lack basic tools such as veils, gloves, smokers, and other equipment required for beekeeping (Ejigu *et al*., 2009).

Table 5: Management concepts as a threat to honeybee and beekeeping practices on a 5-point Likert scale

Factors	Variables						
	5	**4**	**3**	**2**	**1**	**Total**	**Mean**
Absence of policies in apiculture	14	23	0	3	10	178	3.56
Poor extension service	0	45	0	1	4	186	3.72
Lack of training/skill of the beekeeper	14	23	0	3	10	178	3.56
High cost of beehives	2	0	47	1	0	153	3.06
Lack of business support service	0	45	0	1	4	186	3.72
Marketing	0	0	1	1	48	53	1.06
Beekeeping materials/ equipment	13	23	1	3	10	176	3.52
Chemical application	14	19	3	4	10	173	3.46
Absconding	0	0	1	2	47	54	1.08

Swarming	0	0	4	45	0	103	2.06
Storage facility/post-harvest handling	15	20	0	4	11	174	3.48

Keys 5: Strongly agree, 4: Agree, 3: Undecided, 2: Decided, 1: Strongly decided.

The absence of an apiculture policy and poor extension services pose significant threats to honeybees and beekeeping practices in the study area (Table 5). The absence of clear, supportive policies impedes the structured development of the apiculture value chain, including production, processing, and marketing. This thus aligns with Tadesse *et al*. (2021), who argue that weak institutional frameworks hinder the commercialization and expansion of beekeeping enterprises. The findings, therefore, reinforce the notion that apiculture is often neglected in national agricultural planning. According to the Federal Ministry of Agriculture and Rural Development (FMARD, 2018)**,** policy focus in Nigeria has historically been skewed toward crop production, with limited emphasis on apiculture despite its economic and ecological importance. Therefore, to improve and sustain the culture, we should pay close attention to policy formulation. Findings indicate that beekeeping in Mangu Local Government Area is confronted with multiple and interrelated challenges, particularly from anthropogenic activities, biological pests and predators, and weak institutional support structures. While environmental factors were perceived as moderate constraints, threats arising from insecurity, habitat destruction, poor extension services, absence of supportive policies, and inadequate technical skills were considered significant.

Despite these challenges, the beekeeping subsector in the district holds considerable potential for growth and improvement. The presence of active beekeepers and favorable agricultural engagement suggests opportunities to enhance honey production, quality, and market value. Strengthening extension services, developing clear apiculture policies, improving access to training and modern equipment, and implementing effective pest and predator control strategies are critical steps toward sustainable development of the sector. With coordinated support from government agencies, research institutions, and private stakeholders, beekeeping in Mangu LGA can transition from largely traditional practices to a more resilient and commercially viable enterprise, contributing meaningfully to rural livelihoods, food security, and ecosystem sustainability.

References

Abah, M.A., Oladosu, M.A., Julius, S.O., Tatah, S.V., Onyeoche, A.S. (2025). Pollination Efficiency of Indigenous Insects on Major Nigerian Crops: A Case Study of Cocoa, Cashew, and Oil Palm Farms. *Trends in Biological Sciences*, 1(2), 110-120

Adejuwon, S. F., Yusuf, O. S., Bello, L. B., & Oduola, A. O. (2023). Genetic Diversity of West African Honey Bee (*Apis mellifera adansonii*) from Rural and Urban Areas of Kwara State, Nigeria. *The Iraqi Journal of Veterinary Medicine*, 47(2), 110–116.

Akinmulewo, B.O., Oladimeji, Y.U. and Damisa, M.A.(2017). Assessment of the Technical Efficiency of Improved Apiculture on the Poverty Status of Bee Farmers in Abuja, Nigeria. *Ethiopian Journal of Environmental Studies & Management* 10(6): 781 – 794

Ayele B., Jenberie A., Haylemelekot M. & Ayalew W. (2020). Beekeeping diseases and pests in the TT and WestWest Gojjam zones of the Amhara Region, Ethiopia. *Journal of Entomology and Zoology Studies*, 8(6): 32-45

Belsky J. & Joshi N. K. (2019). Impact of Biotic and Abiotic Stressors on Managed and Feral Bees. Insects. 10(8):233. doi: 10.3390/insects10080233

Dar S. A., Mir G. M., Parry M. A., Yaqob M., & Nisar M. (2017). Threats of Anthropogenic Pressure on Insect Pollinators. *Int J Plant Res* 2017;30:469

Ejigu K., Gebey T. and Preston T. R. (2009). Constraints and prospects for apiculture research and development in the Amhara region, Ethiopia. *Livestock Research for Rural Development. 21(172).* Retrieved February 28, 2025, from http://www.lrrd.org/lrrd21/10/ejig21172.htm

Ejikeme J. N. U. & Ugwu C. V. (2023). HoneybeeHoneybee Production Practices As A Sustainable Livelihood Among The Igbo Of Southeastern Nigeria. *International Journal of Social Sciences and Management Review.* 6(2): 8-25

Gebremedhn, H., Lefebre, R. & de Graaf, D.C. (2025). Living in harmony with nature: the key to resilience of honeybees (*Apis mellifera*) in Africa. *Apidologie* **56**, 67. doi:/10.1007/s13592-025-01193-w

Gidey A. Mulugeta S. & Fromsa A (2012). Prevalence of bee lice Braulacoeca (Diptera: Braulidae) and other perceived constraints to honey bee production in Wukro Woreda, Tigray Region, Ethiopia—Global Vet;8:631-635.

Ijigbade, J.O. (2017). Effect of Climate Variability on Honey Production in Ondo State, Nigeria *Journal of Multidisciplinary Engineering Science Studies* 3(10): 2189-2195

Kashumba F. M. (2025). Determinants of the intervened beekeeping technological adoption in Sub-Saharan Africa: a systematic review. *Cogent Food & AgriCulture* 11(1) : 1 – 16

Lawal, A. A., Mustapha, S., & Oyerinde, A. A. (2019). Incidence of predators and anthropogenic activities affecting beekeeping in Nigeria. *Journal of Advanced Research in Food, Agriculture and Environmental Science*.

Nwaiwu, J. C., Chukwu, A. O., & Egwuonwu, H. A. (2025). Perceived Effects of Climate Change on Honey Production in Southeast Nigeria. *GPH-International Journal of Agriculture and Research*.

Ojija F, Mng'ong'o M., Aloo B. N., Mayengo G. & Helikumi M. (2025). Effect of global climate change on insect populations, distribution, and their dynamics. *Journal of Asia-Pacific Entomology*, 28(3) doi. 10.1016/j.aspen.2025.102442.

Oladimeji, Y. U., and Ajao, A. M. (2023). Prevalence of honey bee stressors and socio-economic factors influencing honey bee stressors and coping strategies in bee farms in Kwara State, Nigeria. *FUDMA Journal of Sciences*.

Oladimeji, Y. U., Hassan, A. A., Egwuma, H., Sani, A. A., Galadima, S. A., & Ajao, A. M. (2019). Analysis of Risks in Honeybee Production Farms in Nigeria: A Boost to Food Security. *Egypt. Acad. J. Biolog. Sci. (A. Entomology)* 12(1): 163- 176

Tarekegn A. (2023). Determinants of modern box hive technology adoption in Benishangul Gumuz Regional State, western Ethiopia. *Journal of Science and Development*, 11(1) : 49 – 61

Tesfaye B., Dadi G. & Gelgelu T. (2017). Assessment of honeybee enemies (pests and predators) in the Bale Zone, southeastern Ethiopia. *Journal of Agricultural Extension and Rural Development*, 9(4): 53-61

Wagner D. L., Grames E. M., Forister M. L., Berenbaum M. R. & Stopak D. (2021). Insect decline in the Anthropocene: Death by a thousand cuts. *Proc. Natl. Acad. Sci.*118, e2023989118. doi:10.1073/pnas. 2023989118

Federal Ministry of Agriculture and Rural Development (FMARD) (2020). *National Livestock Transformation Plan* (2019 – 2028). Implementation Guidelines for FGN and State. Pp. 80

Tadesse B., Tilahun Y., Woyamo W., Bayu M. & Adimasu Z. (2021). Factors influencing organic honey production level and marketing: evidence from southwest Ethiopia. *Heliyon* 7. doi: 10.1016/j.heliyon.2021.e07975

ISTF-NIG 2026

SOURCES AND USES OF BITTER KOLA AMONG DWELLERS IN EKITI STATE, NIGERIA

***[1]OLOWOYO Felix Babatunde.[2]AZEEZ Ismail Olabisi. and [2]FASORO Oyinlola Abiodun.**

Abstract

This study assessed the sources and uses of *Garcinia kola* (bitter kola) among stakeholders in Ekiti State, Nigeria. Using multistage random sampling, 198 bitter kola stakeholders (producers, processors, wholesalers, retailers, and consumers) were sampled. The sources of *Garcinia kola* were analyzed among processors, wholesalers, retailers, and consumers. The uses were analyzed from consumers of *Garcinia kola*. The study's data were collected using structured questionnaires and analyzed descriptively. Findings showed that the majority of respondents were married adults, predominantly engaged in farming, with household sizes ranging from six to nine members. Processors primarily sourced *Garcinia kola* from farms (55.6%) and plantations (38.9%), while wholesalers and retailers largely obtain the product directly from farm gates (76.2%) and larger market actors (73.8%). Consumers acquired the product mainly from retailers (50.0%). Traditional medicinal uses for treatments of lung function (88.10%), cold relief (76.19%), infectious diseases (19.05%), and immunity enhancement (16.67%) were the prominent reported benefits. Cultural and social applications, including traditional worship (59.52%), weddings (42.86%), and naming ceremonies (33.33%), were also significantly associated with *G. kola*. Findings underscore the socio-economic and cultural importance of *G. kola* in rural livelihoods and highlight the imperative of managing and implementing sustainable production practices for this non-timber forest product in local economies.

Keywords: *Garcinia kola*, value chain, Ekiti State, socio-economic uses, non-timber forest products

Introduction

Bitter kola (*Garcinia kola*) is a widely valued non-timber forest product (NTFP) in Nigeria and across West Africa. It is recognized for its medicinal, cultural, and economic benefits. Numerous studies have documented its broad pharmacological and therapeutic properties, including antimicrobial, anti-inflammatory, and detoxifying effects, which contribute to its prominence in traditional medicine and modern phytotherapy (Adewumi & Olatunji, 2018; Eze & Mohammed, 2020; Okereke *et al*, 2021). In many communities, particularly among the Yoruba, bitter kola also holds significant cultural relevance, playing key roles in ceremonies, social interactions, and indigenous belief systems (Karim & Ogunlade, 2019; Banjo & Aderinto, 2020). As demand for bitter kola continues to grow, its stakeholders have expanded to include traders, wholesalers, and end users. These stakeholders form part of the broader NTFP sector, which contributes substantially to rural livelihoods, income diversification, and community resilience in Nigeria (Danladi & Yusuf, 2019; Mensah, 2019; Ibrahim & Aluko, 2022). However, the sourcing, distribution, and utilization of bitter kola are influenced by ecological factors, local market structures, and rural trade patterns, all of which vary across regions in Southwest Nigeria (Ajani *et al*., 2021; Chukwu & Ekong, 2021; Adeosun & Kehinde, 2022).

Ekiti State, with its diverse forest vegetation and active participation in NTFP trade, provides a strategic environment for examining the sources and uses of bitter kola (Oladoyin & Salawu, 2023). Understanding how bitter kola is sourced, processed, distributed, and utilized in Ekiti State can therefore provide valuable insights for promoting rural economic development and supporting sustainable forest management (Fasakin & Ojo, 2019; Sanni & Olorunfemi, 2021; Taiwo & Ibrahim, 2021; Yusuf & Edosa, 2023). This study thus seeks to assess the sources and uses of bitter kola among dwellers in Ekiti State, Nigeria. Through detailed examination of sources, utilization, market interactions, and consumption patterns, the research aims to improve utilization and the discovery of new sources.

Methodology

The research was conducted in Ekiti State, Nigeria (Figure 1), a predominantly rural region where subsistence farming underpins the local economy. Agriculture is central to the state's socio-economic fabric. Ekiti State experiences a bimodal rainfall pattern, with annual precipitation ranging from 1,200 to 1,500 mm and daily temperatures ranging from 20°C to 35°C. The fertile soils further enhance agricultural productivity. Geographically, the state lies between longitudes 4°51' and 5°45' East and latitudes 7°15' and 8°05' North. It shares borders with Kwara, Kogi, Osun, Edo, and Ondo States. Culturally, the state exhibits linguistic and social homogeneity, with the majority of residents speaking the Ekiti dialect of Yoruba. According to population data, Ekiti State had approximately 2.7 million inhabitants in 2006, which increased to an estimated 3.6 million by 2022.

ISTF-NIG 2026

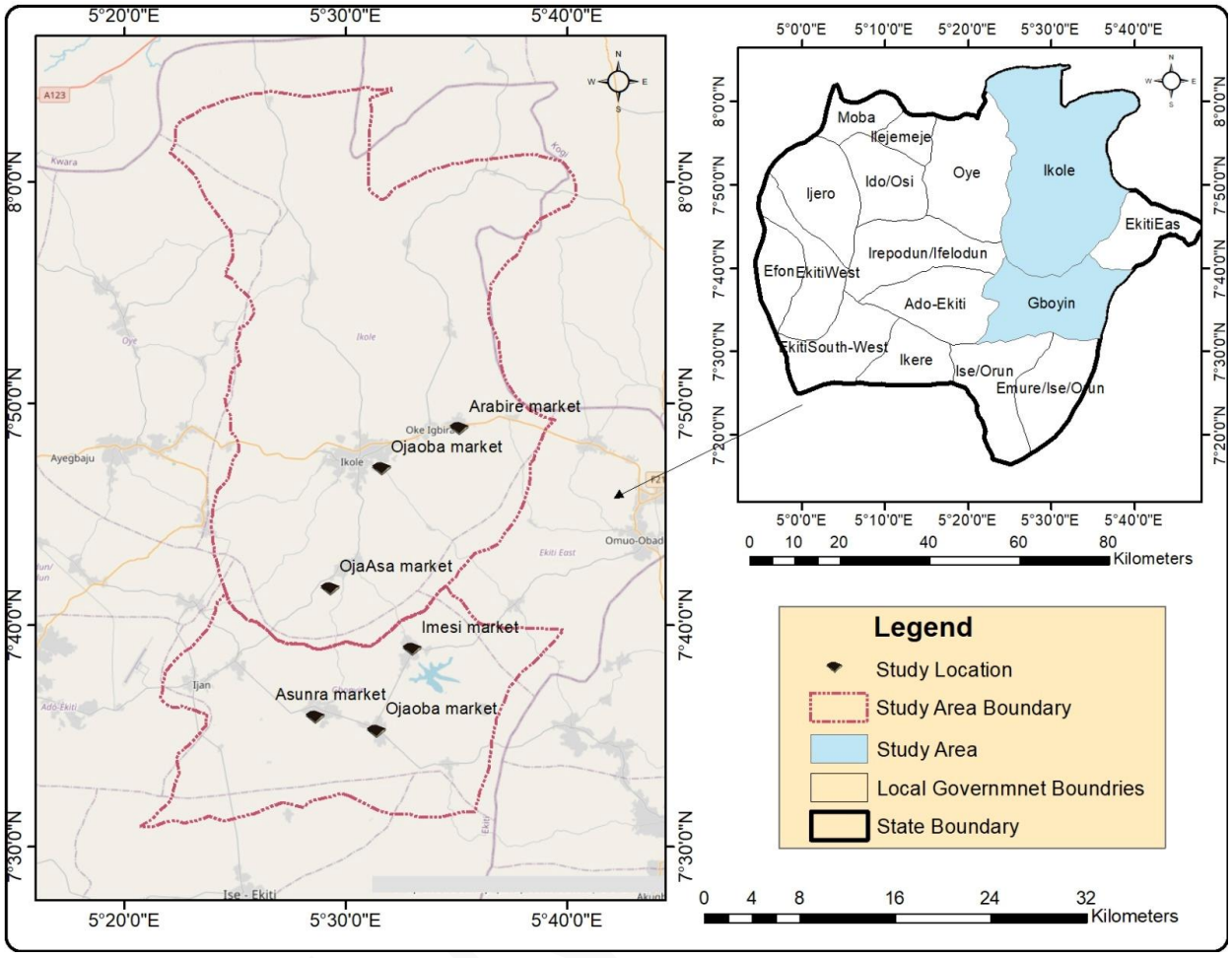


Figure 1: Map of the study area

Sampling Technique

A multistage sampling technique was adopted to select respondents across the two purposively selected Local Government Areas. In the first stage, two senatorial districts were purposively identified and chosen in the state (Ekiti South and Ekiti North), while One Local Government Area (LGA) was purposively selected in each of the chosen senatorial districts in the second stage to make a total of two local government areas, namely: Gbonyin and Ikole in Ekiti State (Table 1). In the third stage, three villages were selected in each LGA, making a total of six (6) villages. Each of these villages was considered a marketing unit or location. In stage four, snowball sampling was used to select respondents, i.e., producers (4), processors (4), wholesalers (8), retailers (8) and consumers (9) from the study area in Ekiti state (Table 2).

Table 1: Study Area Locations

S/N	States	Senatorial District	LGAs	Villages	Markets	Latitude (N)	Longitude (E)	Market Days
1	**Ekiti**	Ekiti South	Gbonyin	Aisegba Ekiti	Asunra market	7.4323	5.4821	EVERY 5 DAYS

		Agbado Ekiti	Ojaoba market	7.5885	5.5229
		Imesi Ekiti	Imesi market	7.6500	5.5500
Ekiti North	Ikole	OdoAyedun Ekiti	Arabire market	7.8163	5.5854
		Ikole Ekiti	Ojaoba market	7.6224	5.2206
		Ijesaisu Ekiti	OjaAsa market	7.6958	5.4883
				7.1010	4.1167

Table 2: Sampling Distribution

S/N	Senatorial District	LGAs	Villages	Markets	Producer	Processor	Wholesaler	Retailer	Consumer
1	Ekiti South	Gbonyin	Aisegba	Asunra	4	4	8	8	9
			Agbado	Ojaoba	4	4	8	8	9
			Imesi	Imesi	4	4	8	8	9
	Ekiti North	Ikole	Odo Ayedun	Arabire	4	4	8	8	9
			Ikole	Ojaoba	4	4	8	8	9
			Ijesaisu	OjaAsa	4	4	8	8	9
	Total				24	24	48	48	54
	Total Retrieved				18	18	42	42	42

Results and Discussions

Socio–economic characteristics of *Garcinia Kola* actors

The socio-economic characteristics of participants in the *Garcinia kola* value chain in Ekiti State (Table 3) revealed a demographic structure that aligns with broader patterns identified in studies of non-timber forest product (NTFP) sectors across Nigeria. The distribution showed a marked male dominance among producers and an equal gender distribution among processors, with higher female participation among wholesalers, retailers, and consumers. Women constitute over 90% of actors in several categories, reflecting earlier findings that NTFP marketing and retailing are female-dominated activities in Southwest Nigeria (Adeosun & Kehinde, 2022; Chukwu & Ekong, 2021). Producers, however, showed a more balanced gender distribution, consistent with research noting that men often engage more in forest gathering and primary harvesting (Ajani *et al*, 2021). The age distribution indicated that most value-chain actors, especially wholesalers and retailers,

were over 40 years old, suggesting that older adults possess the market networks, cultural knowledge, and harvesting experience necessary for meaningful involvement in the bitter kola trade. The trend, as echoed by Adewumi and Olatunji (2018) and Karim and Ogunlade (2019), highlighted the role of age-based knowledge transmission in the use of culturally significant forest products.

The data also showed that nearly all participants, except a small proportion of consumers, are married, which aligns with the observation that household responsibilities and livelihood pressures often drive adults into NTFP-related economic activities (Danladi & Yusuf, 2019; Ibrahim & Aluko, 2022). Christianity dominated religious affiliation across categories, reflecting regional demographic patterns in Ekiti State. Household sizes remained moderate, mostly between 1 and 10 persons, suggesting that involvement in the bitter kola chain may help support households of this size. This link is supported by studies demonstrating the crucial role of NTFPs in sustaining rural dwellers (Mensah, 2019; Yusuf & Edosa, 2023). Farming stands out as the predominant occupation across all groups, particularly wholesalers and retailers, consistent with findings that many rural actors combine NTFP trade with agriculture as a livelihood diversification strategy (Ogunlola & Adedeji, 2017; Ogunbiyi & Falade, 2022).

Educational levels vary, with most participants having secondary Education, though a significant proportion of wholesalers and retailers have only primary or no formal Education. This mirrors earlier observations that NTFP commerce attracts individuals across educational levels, including those with limited formal schooling, due to low entry barriers to participation (Bamidele & Akinyemi, 2020; Taiwo & Ibrahim, 2021). The result revealed experience levels in the trade are relatively high, with many wholesalers having over 20 years of engagement, reinforcing the argument by Fasakin and Ojo (2019) that long-term experience enhances efficiency, bargaining Power, and product knowledge within NTFP value chains. Monthly income distributions indicate that a large majority across all categories earned above ₦50,000, indicating that bitter kola is a financially rewarding enterprise, consistent with previous research that emphasized the significant income-generating potential of NTFPs in rural Nigeria (Olawale & Oginni, 2022; Oladoyin & Salawu, 2023). Furthermore, many participants belonged to trade associations, e.g., Egbe Agbelere, Egbe Olobi, and Egbe Olorogbo, especially wholesalers and retailers, which aligns with findings that group membership enhances market coordination, access to information, and collective bargaining (Sanni & Olorunfemi, 2021; Ogunbiyi & Falade, 2022). Overall, the table reinforces earlier scholarly claims about the socio-economic relevance of bitter kola and its strong integration into rural livelihoods and local trade structures in the Southwest.

Table 3: Frequency Distribution of Socio-economic Characteristics of Garcinia kola in Ekiti State

Variables	Producers		Processors		Wholesalers		Retailers		Consumers	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Sex										
Female	8	44.4	9	50.0	40	95.2	41	97.6	33	78.6
Male	10	55.6	9	50.0	2	4.8	1	2.4	9	21.4
Age										
<20 years	1	5.6	0	0.0	-	-	-	-	-	-
20-30 yrs	1	5.6	0	0.0	-	-	-	-	1	2.4
30-40 yrs	2	11.1	2	11.1	4	9.5	5	11.9	12	28.6
40-50 yrs	6	33.3	8	44.4	18	42.9	14	33.3	12	28.6
>50 yrs	8	44.4	8	44.4	20	47.6	23	54.8	17	40.5
Marital status										
Single	0	0.0	0	0.0	0	0.0	0	0.0	4	9.5
Married	18	100.0	18	100.0	42	100.0	42	100.0	38	90.5
Religion										
Christianity	17	94.4	17	94.4	34	81.0	35	83.3	39	92.9
Islam	1	5.6	1	5.6	8	19.0	7	16.7	2	4.8
Traditional	0	0.0							1	2.4
Household size										
1–10	15	83.3	17	94.4	36	85.7	39	92.9	40	95.2
11–20	3	16.7	1	5.6	6	14.3	3	7.1	2	4.8
21–30	0	0.0	0	0.0	0	0.0				
Mean household size	9		8		8		7		6.26	
Main occupation										
Farming	9	50.0	9	50.0	39	92.9	39	92.9	36	85.7
Otherwise	9	50.0	9	50.0	3	7.1	3	7.1	6	14.3
Education										
No formal	2	11.1	1	5.6	9	21.4	13	31.0	6	14.3
Primary	1	5.6	8	44.4	14	33.3	11	26.2	10	23.8
Secondary	11	61.1	5	27.8	17	40.5	17	40.5	17	40.5

ISTF-NG 2026

OND/HND/NCE	1	5.6	2	11.1	1	2.4	1	2.4	7	16.7
University	3	16.7	2	11.1	1	2.4			2	4.8
Experience (yrs)										
1–10	6	33.3	4	22.2	5	11.9				
11–20	6	33.3	8	44.4	15	35.7				
21–30	4	22.2	4	22.2	16	38.1				
31–40	1	5.6	2	11.1	2	4.8				
41–50	1	5.6	0	0.0	4	9.5				
Mean experience	19.56		21.06		23.57					
Monthly income										
>10,000–≤20,000		0	0.0	1	5.6	1	2.4	3	7.1	1	2.4
>20,000–≤30,000		0	0.0	1	5.6	1	2.4	1	2.4	2	4.8
>30,000–≤40,000		0	0.0	0	0.0	1	2.4	3	7.1	3	7.1
>40,000–≤50,000		1	5.6	2	11.1	4	9.5	4	9.5	4	9.5
>50,000		17	94.4	15	83.3	30	71.4	30	71.4	25	59.5
Association										
Yes		11	61.1		35	83/3		39	92.9		
No		7	38.9		7	16.7		3	7.1		

ISTF-NIG 2026

Sources of *Garcinia Kola* in Ekiti State

The result of *Garcinia kola* in Ekiti State (Table 4) showed a structured but multi-layered supply chain, reflecting the complexity typical of NTFP distribution systems in Southern Nigeria. Among processors, farms constituted the primary source of bitter kola (55.6%), followed by dedicated *G. kola* plantations (38.9%), while very few obtained their supply directly from forests. This pattern suggests a gradual shift from wild harvesting toward semi-cultivated or cultivated systems. Wholesalers relied predominantly on direct farmgate purchases (76.2%), a sourcing strategy that allows them to secure bulk quantities at relatively lower costs and maintain consistent quality. This agrees with Adeosun and Kehinde (2022), who observed that farmgate transactions dominate NTFP wholesale markets in Southwest Nigeria due to better price negotiation and reduced intermediary costs. Retailers, unlike wholesalers, obtained most of their supplies from wholesalers (73.8%), indicating a clear vertical flow in the value chain, with wholesalers serving as the central distribution hub. Only a small proportion of retailers sourced from larger retailers or neighbouring states, highlighting both the localized nature of the bitter kola supply chain and the dependence of smaller traders on established actors who control product aggregation (Chukwu & Ekong, 2021). Consumers obtained bitter kola mainly from retailers (50.0%) and, to a lesser extent, directly from farm gates (26.2%) or wholesalers (21.4%), reflecting a typical end-market structure in which proximity, convenience, and trust guide purchasing behaviour. Similar consumption patterns were reported by Unaeze *et a*l. (l 2013) and Karim and Ogunlade (2019), who emphasized the role of informal retail markets as the primary access point for culturally important botanical products.

Overall, the table demonstrates a supply chain that begins mostly at farms and farm gates, funnels through wholesalers as aggregation points, and terminates primarily at retailers before reaching end users. This hierarchical, centralized supply chain reflects broader national patterns in NTFP marketing, in which increased domestication, strong wholesale networks, and limited direct consumer access to producers shape product movement (Bamidele & Akinyemi, 2020).

Table 4: Sources of *G. kola* in Ekiti State

Variables	Frequency	Percentages	Mode
Processors			
Forest	1	5.6	Farm
Free areas	0	0.0	
Farm	10	55.6	
G. kola plantation	7	38.9	
Total	**18**	**100.0**	
Wholesalers			
Directly at the farm gate	32	76.2	Farm Gate
Gate middlemen	8	19.0	
Bigger Wholesaler	2	4.8	
Total	42	100.0	

Retailers			
Directly at the farm gate	0	0.0	Wholesalers
Farmgate middlemen	1	2.4	
Wholesaler	31	73.8	
Bigger retailers	10	14.3	
Neighbouring State	4	9.5	
Total	42	100.0	
Consumers			
Directly at the farm gate	11	26.2	Retailers
Farmgate middlemen	1	2.4	
Wholesaler	9	21.4	
Retailers	21	50.0	
Bigger retailers	0	0.0	
Total	42	100.0	

Uses of *Garcinia Kola* in Ekiti State

The uses of *Garcinia kola* in Ekiti State, as captured in Table 5, highlighted its multifaceted significance across both traditional medicinal and socio-cultural contexts. Medicinally, a large proportion of respondents relied on *G. kola* to support lung function (88.1%) and to relieve cold symptoms (76.19%), which aligns with findings by Ojo and Owolabi (2020), who noted the plant's strong respiratory and anti-inflammatory properties widely recognized across Southwestern Nigeria. Its use in addressing infectious diseases (19.05%), boosting immunity (16.67%), and managing conditions such as arthritis, back pain, and eye pressure further reflects its broad therapeutic profile. The observation is consistent with reports from Okereke et al. (2021) and Eze and Mohammed (2020), who stated that it has antimicrobial and detoxifying effects. Although less frequently mentioned, its application in managing malaria, typhoid, and food poisoning showed the continued reliance on traditional pharmacotherapy for common ailments in rural communities, echoing insights from Adewumi and Olatunji (2018).

Beyond health-related issues, this study found that *G. kola* maintained deep cultural and social relevance in Ekiti society. Its significant role in traditional worship (59.52%), weddings (42.86%), naming ceremonies (33.33%), and oath-taking rituals reflected a long-standing symbolic association between the plant and communal identity, spirituality, and social cohesion. Adekunle and Bamidele (2021) similarly observed that bitter kola is integral to ritual communication, purification rites, and conflict mediation in Yoruba communities. It also explained its strong presence in activities such as divination, hospitality, offerings, and dispute settlement. The substantial reliance on bitter kola for traditional health care (47.62%) further illustrated the overlap between medicinal and cultural domains, reinforcing earlier claims by Banjo and Aderinto (2020) that the plant functions as both a social currency and a therapeutic resource.

Table 5: Uses of *G. kola* in Ekiti state

Variables	*Frequency	Percentage	Mode
Traditional uses			
Lung function	37	88.10	Lung Function
Eye pressure	4	9.52	
Arthritis	3	7.14	
Infectious diseases	8	19.05	
Cold remedy	32	76.19	
Immunity	7	16.67	
Weight loss	1	2.38	
Malaria infections	2	4.76	
Food poisoning	1	2.38	
Back pain	2	4.76	
Typhoid fever	2	4.76	
Chronic rheumatism	1	2.38	
Cultural/social uses			
Naming ceremony	14	33.33	Traditional Worship
Wedding	18	42.86	
Hospitality	12	28.57	
Divination	7	16.67	
Traditional worship	25	59.52	
Oath taking	10	23.81	
Dispute settlement	6	14.29	
Traditional health care	20	47.62	

Multiple responses recorded

Conclusion

Assessment of the sources and uses of bitter kola among stakeholders in Ekiti State, Nigeria, highlighted the plant's enduring relevance as both an economic commodity and a culturally embedded resource. The study revealed domination by mature, experienced, and predominantly female actors, especially at processing, retailing, and consumption stages, reflecting broader patterns in the NTFP sector where women play central roles in distribution and trade. The sourcing structure showed that bitter kola was sourced mainly from farms and plantations rather than forests, indicating a gradual transition toward more controlled, sustainable production systems. The study revealed that wholesalers remain the pivotal link between producers and the wider market, serving as aggregation points that drive the overall flow of the commodity.

The observed uses of bitter kola were equally diverse and significant. Medicinally, it was valued for its effectiveness in improving lung function, relieving cold symptoms, managing infections, boosting immunity, and alleviating various pains and inflammatory conditions. All of which aligned with documented ethnomedicinal properties of *Garcinia kola*. Culturally, its role in traditional worship, ceremonies, hospitality, oath-taking, divination, and community health practices confirmed its symbolic depth and its integration into social identity and cultural

continuity within Yoruba communities. The findings collectively affirmed that bitter kola remains a critical component of rural livelihoods, traditional health systems, and cultural heritage in Ekiti State.

Recommendations

To strengthen bitter kola stakeholders in Ekiti State, efforts should focus on promoting sustainable cultivation by providing high-quality seedlings, conducting agroforestry training, and supporting plantation development. Given the wide-ranging medicinal and cultural uses of bitter kola, there is a need to document and preserve traditional knowledge associated with the plant while also supporting scientific validation of its therapeutic strengths. Public awareness initiatives should promote safe and informed consumption, particularly as reliance on traditional remedies continues to grow. Access to finance remains essential for smallholder participants, and microcredit schemes tailored to NTFP enterprises that would empower producers, processors, and traders to expand their operations. Finally, strengthening cross-state market linkages and improving rural infrastructure would enhance the profitability and reach of the bitter kola trade, securing its role as a vital livelihood resource in Ekiti State.

References

Adekunle, R. A, & Bamidele, J. F. (2021). Socio-cultural symbolism of forest products in Yoruba communities. *African Journal of Cultural Ecology, 9(2) 77-93*

Adeosun, M. B., & Kehinde, J. A. (2022). Market dynamics and rural trade patterns of non-timber forest products in Southwest Nigeria. *African Journal of Agricultural Markets, 7*(2), 88–102.

Adewumi, T. A., & Olatunji, F. K. (2018). Medicinal relevance of *Garcinia kola* in West Africa. *Journal of Ethnobotanical Studies, 12*(3), 44–55.

Ajani, O. T., Olabode, A., & Fadare, S. (2021). Agro-ecological determinants of NTFP distribution in southern Nigeria. *Journal of Forestry and Rural Livelihoods, 9*(1), 15–27.

Bamidele, O. S., & Akinyemi, A. M. (2020). Challenges in NTFP marketing and value addition in Nigeria. *International Review of Rural Development, 3*(4), 122–134.

Banjo, S. A., & Aderinto, A. R. (2020). Cultural uses of bitter kola among Yoruba communities. *Nigerian Journal of Cultural Studies, 5*(2), 60–73.

Chukwu, V. C., & Ekong, F. U. (2021). Informal market structures in the Nigerian NTFP sector. *West African Journal of Rural Trade, 11*(2), 99–113.

Danladi, M. L., & Yusuf, A. T. (2019). Socio-economic potentials of forest-based livelihoods in Nigeria. *Journal of Environmental Economics, 6*(3), 71–82.

Eze, O. P., & Mohammed, K. S. (2020). Phytomedical applications of *Garcinia kola*: A review. *Nigerian Journal of Herbal Medicine, 14*(1), 30–42.

Fasakin, A. A., & Ojo, B. A. (2019). Actor interactions in the NTFP trade chain in Osun State. *Journal of Agricultural Value Chains, 8*(1), 50–63.

Ibrahim, R. O., & Aluko, M. T. (2022). Livelihood contributions of NTFPs to rural households in Nigeria. *Sustainable Livelihoods Review, 4*(2), 110–124.

Karim, M. L., & Ogunlade, J. T. (2019). Traditional uses and market value of bitter kola in rural communities. *Journal of Indigenous Knowledge Systems, 10*(1), 22–34.

Mensah, K. (2019). Non-timber forest products and community well-being in West Africa. *West African Eco-Research Review, 8*(3), 55–70.

Ogunbiyi, F. S., & Falade, O. M. (2022). Production and distribution trends of NTFPs in Nigeria. *Nigeria Journal of Agricultural Economics, 14*(2), 77–95.

Ogunlola, M. B., & Adedeji, S. O. (2017). Economic importance of bitter kola to smallholder farmers. *Journal of Rural Agro-Economics, 5*(4), 101–115.

Ojo, O. M., & Owolabi, S. D. (2020). Ethnomedicinal relevance of indigenous plant species in Southwestern Nigeria. *Journal of Herbal Pharmacology, 5*(1), 55–70.

Okereke, P. U., Nwachukwu, J. C., & Bello, L. R. (2021). Therapeutic properties of bitter kola: An updated review. *African Journal of Medicinal Plants, 13*(2), 18–29.

Oladoyin, T. A., & Salawu, O. K. (2023). Forest vegetation and NTFP availability in Southwestern Nigeria. *Journal of Environmental and Forest Sciences, 12*(1), 39–52.

Olawale, Y. A., & Oginni, P. M. (2022). Policy implications for sustainable NTFP value chain development in Nigeria. *Development Policy Journal, 9*(2), 66–80.

Sanni, K. O., and Olorunfemi, E. T. (2021). Enhancing value chain efficiency for rural economic development. *Journal of Rural Policy and Planning, 6*(3), 140–153.

Taiwo, K. F., & Ibrahim, A. M. (2021). Local variations in the utilization of non-timber forest products in Nigeria. *African Journal of Resource Management, 7*(1), 82–96.

Unaeze H.C, Oladele A.T., and Agu L.O (2013). Collection and Marketing of Bitter kola (Garcina kola) in Nkwerre Local Government Area, Imo State, Nigeria, in the *Egyptian Journal of Biology*, Vol. 15, pp. 37 – 43 http/dx. doi ors/10.4314/gb v15i: 5. Egyptian British Biological Society (EBB Soc).

Yusuf, Z. A., & Edosa, A. B. (2023). Sustainable management of forest resources for rural livelihoods in Nigeria. *Forestry and Community Development Review,* 11(2), 95-108.

ISTF-NIGERIA 2026

NON-TIMBER FOREST PRODUCTS AS PATHWAYS FOR FOREST ECOSYSTEM CONSERVATION AND RESILIENT ECONOMIES

***AMAECHI Deborah Chiamaka[1], AGWU Onyebuchi Patrick[2], OYEYINKA Barnabas Oluwatomide[3], FARINLOYE Olaitan Ayomide[4]**

[1]Department of Forest Production and Products, University of Ibadan
[2]Department of Forest Resources Management, Osun State University
[3]Biomedicinal Research Centre, Forestry Research Institute of Nigeria
[4]Federal College of Forestry, Forestry Research Institute of Nigeria
Corresponding Author: damaechi254868@stu.ui.edu.ng/ +2347039483912

Abstract

Nigerian forests, which make up around 12.8% of the nation's landmass and are home to approximately 4,715 vascular plant species, 864 bird species, and 285 animal species, are among the most species-rich in Africa (Global Forest Watch, 2024). However, Nigeria is experiencing a deforestation emergency, with an estimated 350,000 to 400,000 hectares of forest lost each year to agricultural expansion, illegal logging and urbanization (Climate Scorecard, 2024). Non-timber forest products (NTFPs), including medicinal plants, wild foods (shea and ogbono), resins, fibers, honey, and bushmeat, are an important but underutilized tool for sustainable forest management in Nigeria at the nexus of rural livelihoods and forest conservation. This systematic review of peer-reviewed literature from 2020 to 2025 assesses the collective role of NTFPs in strengthening livelihoods and protecting biodiversity across Nigeria's varied ecosystems. Employing a PRISMA-driven approach, 87 articles were analyzed across five key themes: biodiversity impacts, carbon storage and ecosystem services, economic benefits, governance and sustainability challenges. The findings reveal that sustainable NTFP systems in Nigeria support forest structure, diversity and processes. NTFP livelihoods account for 20-60% of household income in forest-fringe areas, providing vital livelihoods for rural Nigerians, especially women and marginalized communities (Nguuma et al., 2025; Adaaja et al., 2024). Nigeria's shea industry alone generates substantial export revenue, exporting more than 17,000 tonnes of shea products in 2023 (Shea Nigeria, 2023). However, sustainability is constrained by over-harvesting, insecure rights, ineffective markets, and climate change. The National REDD+ Strategy (2021) and the revised National Forest Policy (2020) provide the governance structures in which NTFPs can be positioned as key tools to achieve conservation and development objectives. NTFPs, supported by suitable institutions, secure property rights and efficient markets, provide a strategy for ecologically sound Nigerian forests and inclusive rural development.

Keywords: Non-timber forest products, Nigeria, biodiversity conservation, ecosystem services, rural livelihoods, sustainable forest management, REDD+, conservation policy

Introduction

Nigeria is One of Africa's most biologically rich countries, with its forests, savannas, and wetlands home to thousands of plant and animal species, many found only in Nigeria (Federal Ministry of Environment, 2022). From the rainforests of the South (Niger Delta, Cross River State) to the Guinea savanna woodlands of the Middle Belt and the Sahel scrublands of the north, Nigeria is

home to a remarkable diversity of plants and animals in its nine agroecological zones, including the critically endangered Cross River gorilla, the white-throated guenon, and many medicinal plants (Afeonkhai & Ayoola, 2025). However, this biodiversity is in danger. Between 2001 and 2022, Nigeria was home to One of the world's highest deforestation rates, losing 163,000 hectares per year, or more than 1.25 million hectares of forest (Global Forest Watch, 2024). Land clearing for agriculture, illegal logging, fuelwood extraction, and urbanization are the major causes, with the lack of enforcement of environmental policies exacerbating the problem (Owen & Husaini, 2024).

Nigeria's forests are vital to the rural economy. Forests support the livelihoods of around 80% of the Nigerian rural population and contribute about 2.5% to the national GDP, with more than 5 million people employed in the sector (UNEP Grid, 2022). Non-timber forest products (NTFPs) - defined by the FAO (1999) as non-wood biological items obtained from forests and other wooded lands - play a significant and complex role. Nigerian NTFPs include medicinal products (such as neem (Azadirachta indica), moringa (Moringa oleifera), and bitter leaf (Vernonia amygdalina)); wild food products (such as shea (Vitellaria paradoxa), ogbono (Irvingia gabonensis), African locust bean (Parkia biglobosa) and bush mango); resins and gums; raffia, bamboo, and rattan; and wildlife products (such as honey, beeswax and bushmeat).

NTFPs, unlike timber, can be sustainably harvested without altering the structure and function of forests. This makes NTFPs a potential means of balancing conservation and livelihoods for Nigeria's forest-dependent communities (Adaaja et al., 2024). Nigeria's new National Forest Policy (2020) and National REDD+ Strategy (2021) provide policy support for scaling up NTFP-based forest management. More recently, the Kunming-Montreal Global Biodiversity Framework (GBF) was adopted in 2022, which emphasizes the sustainable use of wild species, including NTFPs, in the fight to conserve biodiversity (CBD, 2022). Nigeria is One of the countries that will update its National Biodiversity Strategies and Action Plans (NBSAPs) to align with the GBF targets. Despite increasing awareness of the role and importance of NTFPs, knowledge and policy evidence remain limited. The conditions under which NTFP systems in Nigeria deliver conservation outcomes alongside resource extraction remain poorly understood. Key issues such as ecological thresholds, governance, markets, and security of tenure are often treated separately, without a clear understanding of their interactions and impacts on forest sustainability (Opute et al., 2025).

This review fills these gaps by integrating evidence from ecology, economics and governance with a focus on Nigeria. It seeks to: (i) evaluate the ecological values of NTFPs for conservation and ecosystem services in Nigeria; (ii) assess their economic importance in supporting rural livelihoods and national economies; (iii) explore governance arrangements that impact sustainability; and (iv) offer evidence-based insights for incorporating NTFPs into Nigeria's conservation and development agenda.

Methodology

Review Design and Search Strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria are used in this study's systematic review methodology (Page et al., 2021). Because the available literature varied in study designs, outcome variables, and reporting formats, a narrative synthesis

was used rather than a quantitative meta-analysis. Studies carried out in Nigeria or directly related to Nigerian and West African forest systems were given special attention.

Three significant scholarly databases, Scopus, Web of Science, and Google Scholar, were thoroughly searched between August 2024 and March 2025. Key terms related to Nigeria, conservation results, and non-timber forest products were combined using Boolean operators. To identify additional pertinent research missed by the first database searches, we also used a snowballing approach to the reference lists of all qualifying publications. Peer-reviewed research published between 2020 and 2025 was given priority, with additional information from reputable organizations, including the Forestry Research Institute of Nigeria (FRIN), the Nigerian Federal Ministry of Environment, the FAO, CIFOR, and IUCN.

Inclusion and Exclusion Criteria

Studies were included if they met the following criteria: (i) published between 2020 and 2025 in peer-reviewed journals or by recognized international or national organizations such as FAO, CIFOR, IUCN, and Nigeria's Federal Ministry of Environment; (ii) addressed ecological, economic, or governance dimensions of NTFPs within Nigerian or comparable West African forest ecosystems; and (iii) presented original empirical data, systematic synthesis, or substantive policy analysis. Studies were excluded if they: (i) focused exclusively on timber or plantation forestry without reference to NTFPs; (ii) examined urban green spaces not linked to broader forest ecosystems; or (iii) were conference abstracts, opinion pieces, or non-peer-reviewed articles lacking sufficient methodological rigour. Pre-2020 foundational studies were included where they provided indispensable methodological or conceptual grounding explicitly referenced by more recent Nigerian literature.

Screening, Selection, and Synthesis

A two-phase screening procedure was employed. All retrieved records' titles and abstracts were first examined for relevance. The pre-established inclusion and exclusion criteria were then applied to the full texts of potentially eligible studies. The screening was conducted independently by two reviewers, and disagreements were resolved by consensus and debate. The study site, forest type or ecological zone, NTFP category, outcome variables, important findings, and methodological approach were all noted on a standardized data extraction form. Tote story synthesis: We organized the retrieved data into thematic themes.

Table 1: PRISMA Flow Summary of Literature Search and Selection

Stage	Action	Records
Initial identification	Records retrieved from Scopus, Web of Science, and Google Scholar	312
Title/Abstract screening	Records retained after relevance screening	154
Full-text assessment	Complete texts were acquired, and their appropriateness was evaluated.	112
Excluded (full text)	Excluded because of methodology, language, or scope	25
Final inclusion	Studies included in the systematic review	87

Results

Scope and Diversity of NTFPs Reviewed

This review, which analyzed 87 studies, represents a cross-section of NTFPs from Nigeria's tropical, sub-tropical and savanna ecosystems. Medicinal plants/phytomedicines (n = 34) were the most common category, reflecting Nigeria's ethnobotanical diversity and the pivotal role of phytomedicines in local health care. Plants such as *Azadirachta indica* (neem), *Parkia biglobosa* (African locust bean) and *Khaya senegalensis* (African mahogany) were commonly mentioned for their medicinal uses (Bello et al., 2022). The second most studied category was wild food (n = 28), including fruits, nuts, seeds, and mushrooms, particularly shea (Vitellaria paradoxa) and ogbono (Irvingia gabonensis and I. wombolu) for their economic and nutritional value (Owoeye & Zaman, 2024). Other categories included fibres and craft materials (such as bamboo and rattan; n = 11), gums and resins (n = 12), and wildlife products (such as honey and bushmeat; n = 9). Geographically, studies from the Southwest and South-South zones of Nigeria, which fall within the tropical rainforest zone (from Ogun and Ondo States to Edo and Cross River States), accounted for 38% of the total studies. The North-Central savanna (including Kwara, Kogi and Benue States) accounted for 27%, and the North-West and North-East (including Kano, Adamawa and Sokoto States) for 22%. The South-East and the Niger Delta region accounted for 13%. This pattern is consistent with the distribution of forest resources and forest-based livelihoods across Nigeria's ecological zones, as well as the concentration of research efforts in the southern rainforest belt.

Table 2: Major NTFP Categories in Nigeria, Ecological Functions, and Economic Roles

NTFP Category	Nigerian Examples	Key Ecological Function	Primary Economic Role in Nigeria
Medicinal plants	Neem, Moringa, African locust bean *(Parkia biglobosa*), Bitter leaf (*Vernonia amygdalina*)	Habitat provisioning, pollinator support	Traditional healthcare, pharmaceutical supply
Wild foods	Shea (*Vitellaria paradoxa*), Ogbono (*Irvingia gabonensis*), Bush mango, Mushrooms	Seed dispersal, forest regeneration	Food security; export commodity markets
Resins & gums	Gum arabic, Irvingia wombolu exudates	Supports soil biota and trophic webs	Cosmetics, food industry, trade
Fibres & crafts	Raffia palm, Bamboo, Rattan	Structural habitat; carbon storage	Furniture, construction, handicrafts
Wildlife products	Honey, Beeswax, Bush meat, Giant African snails	Pollination: ecological keystone roles	Domestic food and protein supply

Biodiversity Conservation Outcomes

The studies reviewed here show that, where sustainable practices drive community-based NTFP harvesting in Nigeria, it is generally compatible with the structure, composition and biodiversity of forests. One of the most extensive studies of sacred groves in southwestern Nigeria (Idanre Hills, Igbo-Olodumare, Ogun-Onire, and Osun-Osogbo) by Onyekwelu et al. (2024) showed that community-managed forest remnants had Shannon-Wiener diversity indices of 2.63-3.55 and tree species richness of 41-85 per grove, which were higher than spatially proximate degraded forests. These groves currently serve as repositories of indigenous tree species of profound social, religious, and ecological importance, with abundant seedlings and saplings that reflect strong regeneration potential. A study from the forests of Cross River National Park and Okwangwo Division found that households dependent on NTFP were less likely to convert forest to agriculture than non-NTFP dependent households, as the non-agricultural income derived from NTFPs reduced the incentives to convert forest to farmland (Adaaja et al., 2024).

This is consistent with research in Adamawa State, where Nguuma et al. (2025) found that rural communities in the Kwabaktina Forest Reserve maintained a diverse portfolio of NTFPs (Borassus fruits, honey, moringa and bushmeat), while engaging in active forest management through customary tenure regimes and temporal harvesting patterns. Likewise, Opute et al. (2025) in Edo State observed that NTFP abundance and socioeconomic usefulness were significantly higher in communities with well-developed informal systems of regulating NTFP harvesting. The influence of NTFPs on faunal biodiversity in Nigeria is evident through their roles in pollination and seed dispersal. Shea (Vitellaria paradoxa), a major economic NTFP in Nigeria, is pollinated by a variety of bee species and dispersed by mammals (Adaaja et al., 2024). Nigeria is responsible for 45% of the world's shea production, with shea trees grown in 21 states in the Guinea and Sudan savannas (Shea Nigeria, 2023). Thus, shea tree populations depend on the integrity of both pollinators and savanna woodlands. Governance also has significant impacts on biodiversity: indigenous conservation practices in Yoruba, Igbo, Efik, and Hausa culture groups (such as taboos against harvesting certain species, setting aside sacred groves and harvest restrictions) have been linked to greater abundance of plant species and less ecosystem instability in Nigeria's forest belts (Owen & Husaini, 2024).

Carbon Sequestration and Ecosystem Services

Nigerian forest ecosystems, particularly the tropical rainforests of the South and the savanna woodlands of the Middle Belt and North, provide substantial carbon storage and a range of ecosystem services that are closely linked to NTFP systems. Onyekwelu et al. (2024) measured biomass stocks of 87.8 to 231.85 tonnes per hectare and carbon stocks of 43.9 to 115.9 tonnes of carbon per hectare in four sacred groves in southwestern Nigeria, demonstrating the significant climate-mitigation potential of community-protected forest areas. A complementary study in the Ise-Ekiti Forest Reserve, southwestern Nigeria, found that undisturbed plots had a total biomass of 102.6 Mg ha-1 and a carbon stock of 51.3 Mg C ha-1, compared to 70.8 Mg ha-1 and 35.4 Mg C ha-1, respectively, in disturbed plots (Carbon Research, 2024). The significance of forest conservation, particularly NTFP-based management as a motivator for communities to oppose conversion and preserve above- and below-ground carbon deposits, is highlighted by this contrast.

Nigeria's National REDD+ Strategy (2021), which was created in accordance with the United Nations Framework Convention on Climate Change (UNFCCC), specifically acknowledges the

importance of sustainable NTFP use and community forest management as elements of Nigeria's strategy to lower emissions from deforestation and forest degradation (Federal Ministry of Environment, 2021). A key element of alternative livelihood programs, which are anticipated to lessen the financial incentive for forest destruction, is NTFP-based livelihoods, according to the strategy. As part of participatory forest monitoring, Nigeria's community-based REDD+ pilot programs, such as those in Cross River State, have formed forest management committees that apply NTFP governance regulations. (Owen & Husaini, 2024).

Beyond carbon, NTFP landscapes provide a wide array of ecosystem services across Nigeria. These include pollination services critical to agricultural productivity, watershed protection in headwater areas of the Niger, Benue, and Cross rivers, soil stabilization and microclimate regulation in savanna agroforestry systems, and provisioning services such as food and medicine. Nigeria's medicinal plant heritage is particularly significant: an estimated 25% of pharmaceutical medications globally are derived from or inspired by plant-based compounds (Newman & Cragg, 2020), and Nigeria's biodiversity supports a substantial portion of the country's traditional healthcare system, with over 60% of the rural population relying primarily on plant-based medicine (UNEP Grid, 2022). The bark and fruit of Prunus africana (African cherry) and Khaya senegalensis (African mahogany), both found in Nigerian forests, have documented pharmaceutical applications and contribute to both local healthcare provision and international trade.

Economic Valuation and Contributions

The economic significance of NTFPs to Nigerian rural households is substantial and well-documented in recent literature. A systematic review by Adaaja et al. (2024), published in the FUDMA Journal of Sciences, found that NTFPs are critically important to the livelihoods of forest-adjacent communities across Nigeria's ecological zones, serving as both a primary source of income and a safety net during agricultural lean seasons. In communities proximate to forest reserves in northern Nigeria, NTFP income accounts for 20–60% of total household income (Nguuma et al., 2025). In the rainforest communities of the Southwest and South-South regions, the contribution can exceed 60% for households primarily dependent on wild food collection and medicinal plant harvesting (Opute et al., 2025). Ganiyu et al. (2023) found in Kwara State that NTFPs such as locust bean, fruits and vegetables, and fish were among the most economically utilized products, with a significant market gap between high demand and insufficient supply, indicating unrealized commercial potential.

Nigeria's shea sector illustrates the scale of NTFP economic potential at the national level. With 21 states in the shea belt, Nigeria is the world's largest producer of shea, accounting for 45% of worldwide shea production and 53% of global shea butter output (Shea Nigeria, 2023). Over 17,000 metric tons of shea products, valued at about ₦20 billion ($14.5 million), were exported from Nigeria in 2023 (Shea Nigeria, 2023). (Shea Nigeria, 2023). The Nigerian Export Promotion Council (NEPC) and the Center for the Promotion of Imports from Developing Countries (CBI) are working together on the Shea Nigeria Project (2022–2025), which aims to strategically shift Nigeria's shea industry from raw nut exports to higher-value processed shea butter. The project is expected to result in significantly higher export earnings. In the forest areas of Edo, Delta, Cross River, and Imo States, many rural Nigerians, mostly women, depend on the ogbono (Irvingia gabonensis) business for their livelihood. (Owoeye & Zaman, 2024).

NTFP value chains in Nigeria are often characterized by inefficiencies that limit manufacturers' market share, despite their economic significance. Due to unequal market Power, restricted market access, inadequate post-harvest handling infrastructure, and a lack of quality assurance systems, producers at the collection and processing stages usually receive a disproportionately small share of retail prices (Adaaja et al., 2024). Women are the primary collectors and processors of several NTFPs, including shea, ogbono, and African locust beans. However, they encounter obstacles to market access, credit, and land rights due to gender inequities. (Ganiyu et al., 2023; Owen & Husaini, 2024).

Governance Frameworks and Policy Landscapes

The governance structure of forests and NTFPs in Nigeria has undergone significant evolution during the review period. The new National Forest Policy (2020) provides a general framework for sustainable forest management and forest governance in Nigeria in response to emerging issues, namely climate change, population pressure, and illegal logging (Federal Ministry of Environment, 2020). The National REDD + Strategy (2021), which was created as part of Nigeria's climate pledges as part of the Paris Agreement, offers a 30-year implementation strategy (2021-2050) that connects the NTFP-based enterprise development to community forest management, carbon finance, and reduced deforestation (Federal Ministry of Environment, 2021). The Nigerian National Wildlife and Forest Crime Strategy (20222026) also highlights the government's desire to protect biodiversity and enforce legal frameworks governing the management of forest resources (UNODC, 2022). A consistently important factor of sustainable NTFP management in Nigerian studies is tenure security. With a legally recognized or de facto right to forest resources, communities are much more likely to invest in sustainable harvesting, resource regeneration, and proactive forest protection (Owen & Husaini, 2024). Customary land tenure systems, which control tenure to forest resources in most rural societies in Nigeria, are often not legally registered, a situation that creates tenure insecurity and discourages long-term forest management.

The 2025 National Initiative to Support Communities on Protected Land Stewardship (NISCOPS), which formed 49 community forest management committees, is a promising tool for formalizing community rights and incorporating indigenous governance systems into national forest management. CBNRM projects have recorded positive results in various states in Nigeria. The Joint Forest Management model, piloted in Cross River and Ondo States, has yielded better conservation outcomes when communities are given significant co-management rights and participatory monitoring roles (Owen & Husaini, 2024). The KunmingMontreal Global Biodiversity Framework (GBF), which was adopted in 2022, establishes a new momentum to scale these approaches with Targets 9 (sustainable use of wild species) and 22 (indigenous and community governance), which are highly applicable to NTFP systems in Nigeria (CBD, 2022; Cooke et al., 2023). Nigeria is projected to update its NBSAP to meet these targets, with a chance to entrench NTFP-based conservation directly into national biodiversity planning.

Threats and Sustainability Challenges

NTFP systems in Nigeria face a multifaceted network of interrelated sustainability issues. Overharvesting is the most urgent threat, driven by a combination of population growth (Nigeria has approximately 233 million people and an annual rate of growth of 2.1%; Grokipedia, 2024) and the growing pressure of commercialization in the absence of corresponding management

systems. Medicinal plant species, including Prunus africana and Khaya senegalensis, are reported to be declining due to unsustainable bark extraction across the Nigerian rainforest belt, with investigations in Adamawa State recording declines of up to 40% resulting from bark stripping (Ekwueme & Onyeke, 2022). Overexploitation by removing natural formations is also contributing to the loss of biodiversity and to the decline in the quality of the ecosystem services it provides. Climate change is a progressively serious systemic danger to Nigerian NTFP systems. Research in the Sahel and Guinea savanna regions of Nigeria has reported failures in traditional harvest cycles due to phenological variations, unpredictable precipitation, and extended dry seasons (Afeonkhai & Ayoola, 2025). Such climatic changes have direct impacts on the productivity of economically important NTFPs, such as shea, whose fruiting period is sensitive to temperature changes, and honey, whose production depends on seasonal flowering patterns.

The average temperature of Nigeria has increased by about 1.1°C over the twentieth century, and rainfall has also decreased by 81mm over the same period. Climate projections indicate that temperatures in Nigeria will continue to rise, and rainfall is also projected to decline in the coming years (Grokipedia, 2024). This agricultural expansion, urban encroachment, and oil and gas infrastructure-driven land-use change remain the most dominant structural drivers of NTFP decline in Nigeria. Over 20,000 kilometres of oil and gas pipelines in the Niger Delta region have directly deforested large areas and bisected mangrove and lowland forest ecosystems, disrupting ecological processes that are fundamental to the production of fish, honey, and bushmeat (Grokipedia, 2024). Constraints associated with markets are also very limiting to the realization of NTFP value. Price volatility of shea and ogbono, the perishability of many forest food products, the lack of well-developed cold storage and processing infrastructure, and weak bargaining positions in value chains create persistent income instability for NTFP-dependent households across Nigeria (Adaaja et al., 2024; Ganiyu et al., 2023).

Conclusion

To demonstrate that non-timber forest products (NTFPs) play a crucial role at the intersection of forest conservation and rural economic resilience in Nigeria, this systematic analysis synthesizes evidence across ecological, economic, and governance dimensions. Well-managed NTFP systems have shown the ability to concurrently support biodiversity conservation, carbon retention, and the livelihoods of Nigerians who depend on forests, from the sacred groves of southwest Nigeria to the shea parklands of the Guinea savanna, the ogbono forests of the Niger Delta, and the medicinal plant communities of the Middle Belt. According to the reviewed literature, a consistent set of enabling conditions—secure community tenure over forest resources, sustainable harvesting practices integrated into functional governance systems, effective market infrastructure that permits producers to receive fair compensation, supportive legal and policy frameworks, and proactive climate change adaptation- is necessary to achieve these outcomes in the Nigerian context. NTFP systems in Nigeria risk becoming poverty traps rather than avenues for resilience in the absence of these favorable circumstances, and they also contribute to the very ecological degradation they are meant to prevent.

A historically significant policy window for repositioning NTFPs as key tools of Nigeria's conservation and development strategy is created by the combination of the country's updated National Forest Policy (2020), National REDD+ Strategy (2021), National Wildlife and Forest Crime Strategy (2022–2026), and its obligations under the Kunming–Montreal Global Biodiversity Framework. NTFPs provide a workable, ecologically sound, and culturally grounded solution for forests that are both productive and conserved, as well as for inclusive and resilient rural economies, as Nigeria faces the intertwined crises of accelerating deforestation, rural poverty, and climate vulnerability.

Recommendation

The following suggestions are put forth for Nigerian policymakers, conservationists, and development finance organizations based on the synthesized data with particular reference to Nigeria's forest governance setting:

Integrate NTFPs into Nigeria's Revised NBSAP:

To achieve Targets 9 and 22, Nigeria's National Biodiversity Strategies and Action Plans, currently being revised under the Kunming–Montreal GBF, should specifically incorporate NTFPs. NTFPs provide quantifiable and economical means of promoting the sustainable use of wild species and inclusive biodiversity governance in Nigeria's forest communities.

Scale NTFP Enterprises under Nigeria's REDD+ Strategy:

NTFP-based enterprise growth should be given top priority in Nigeria's National REDD+ Strategy (2021) as a key element of alternative livelihood initiatives. Climate finance vehicles, such as the Green Climate Fund and the Nigeria Sovereign Green Bond program, should scale up NTFP-driven forest management models within Nigeria's mitigation and adaptation portfolios, based on results from trial programs in Cross River and Ondo States.

Formalise Community Tenure over Forest Resources:

The Federal and State Governments should accelerate the legal recognition of customary and community land rights in NTFP-producing forest landscapes. The NISCOPS programme should be given full legal standing and scaled nationally. Development finance institutions should integrate enforceable tenure conditions into forest sector investments, recognizing tenure security as a foundational determinant of long-term NTFP sustainability.

Invest in NTFP Value Chain Infrastructure:

For important Nigerian NTFPs such as shea, ogbono, locust beans, and honey, targeted government and private-sector investment is required in post-harvest handling, processing technologies, cold storage, rural transportation infrastructure, digital market access platforms, and quality assurance frameworks. Other high-potential NTFPs should follow the Shea Nigeria Project (2022–2025) model of transitioning from raw exports to value-added goods, with specific provisions for women's economic development.

Institutionalise Adaptive Management and Monitoring:

The systematic tracking of NTFP species abundance, population dynamics, and harvest intensity across ecological zones should be added to Nigeria's National Forest Monitoring System. Resources should be allocated to the Forestry Research Institute of Nigeria (FRIN) to develop frameworks for participatory monitoring that account for local ecological knowledge, and to

establish evidence-based harvest thresholds for key species such as Prunus africana, Khaya senegalensis, and Irvingia gabonensis.

Mainstream Climate Resilience into NTFP Programming:

Climate risk assessments for key species and production systems across Nigeria's agroecological zones should be incorporated into NTFP programs. The integration of NTFP agriculture into agroforestry systems, species diversity, assisted regeneration of climate-sensitive species, and social protection measures for extremely susceptible producer groups in Nigeria's Sahel and Guinea savanna zones are all recommended adaptation options.

References

Adaaja, B.O., Akemien, N.N., Alawiye, M.A., Zaman, E.Y., Yahaya, U., & Khidir, H.Y. (2024). Economic and ecological sustainability of non-timber forest products (NTFPs) in Nigeria: A review. *FUDMA Journal of Sciences,* 8(6), 196–204. https://doi.org/10.33003/fjs-2024-0806-2909

Afeonkhai, E., & Ayoola, O.J. (2025). Deforestation in Akoko Edo Local Government Area, Edo State, Nigeria: Impact, drivers, and mitigation strategies. *International Journal of Innovative Science and Research Technology,* 10(4), 1732–1737. https://doi.org/10.38124/ijisrt/25apr1070

Bello, A., Yusuf, R., & Tanko, L. (2022). Ethnobotanical survey of medicinal plants in Adamawa State, Nigeria. *African Journal of Traditional Medicine*, 19(1), 78–92.

CBD [Convention on Biological Diversity]. (2022). Kunming–Montreal Global Biodiversity Framework. CBD/COP/DEC/15/4. United Nations, Montreal.

Climate Scorecard. (2024). Assessing forest cover and composition in Nigeria. Retrieved from https://www.climatescorecard.org/2024/11/assessing-forest-cover-and-composition-in-nigeria/

Cooke, S.J., Harrison, I., Thieme, M.L., Landsman, S.J., Birnie-Gauvin, K., Raghavan, R., & Hanna, D.E. (2023). Is it a new day for freshwater biodiversity? Reflections on outcomes of the Kunming–Montreal Global Biodiversity Framework. *PLOS Sustainability and Transformation*, 2(5), e0000065.

Ekwueme, C., & Onyeke, S. (2022). Declining medicinal plant species due to bark stripping in Adamawa State, Nigeria. *Journal of Ethnopharmacology and Forest Biology,* 14(2), 45–57.

FAO. (1999). Towards a harmonized definition of non-wood forest products. *Unasylva,* 50(198), 63–64.

FAO. (2020). Global Forest Resources Assessment 2020: Main Report. Food and Agriculture Organization, Rome.

Federal Ministry of Environment, Nigeria. (2020). National Forest Policy (Revised). Federal Ministry of Environment, Abuja.

Federal Ministry of Environment, Nigeria. (2021). National REDD+ Strategy 2021–2050. Federal Ministry of Environment, Abuja.

Federal Ministry of Environment, Nigeria. (2022). National Strategy to Combat Wildlife and Forest Crime in Nigeria 2022–2026. UNODC/Federal Ministry of Environment, Abuja.

Ganiyu, A., Adekunle, V.A.J., & Afolabi, O.O. (2023). Users' attitude towards the utilization of non-timber forest products in Kwara State, Nigeria. *Nigerian Journal of Forestry and Environmental Research*, 5(1), 112–125.

Global Forest Watch. (2024). Nigeria's deforestation rates and statistics. Retrieved from https://www.globalforestwatch.org/dashboards/country/NGA/

Grokipedia. (2024). Deforestation in Nigeria. Retrieved from https://grokipedia.com/page/Deforestation_in_Nigeria

Newman, D.J., & Cragg, G.M. (2020). Natural products as sources of new drugs over the nearly four decades from 01/1981 to 09/2019. *Journal of Natural Products,* 83(3), 770–803.

Nguuma, S.L., Ngunan, V.P., Alumun, A.M., & Vahya, P. (2025). Assessment of non-timber forest products utilization in Kwabaktina Forest Reserve, Adamawa State, Nigeria. *Journal of Forests*, 12(1), 1–16. https://doi.org/10.18488/jof.v12i1.4077

Nwosu, P.C., Okechukwu, A., & Okafor, J. (2020). Deforestation and biodiversity loss in Nigeria. *Journal of Ecology and Environment*, 15(2), 78–95.

Onyekwelu, J.C., Agbelade, A.D., Stimm, B., & Mosandl, R. (2024). Role of sacred groves in southwestern Nigeria in biodiversity conservation, biomass and carbon storage. *Environmental Monitoring and Assessment,* 196(3), 269. https://doi.org/10.1007/s10661-024-12407-6

Opute, O.H., Jimoh, S.O., Idumah, F.O., et al. (2025). Analysis of prevalence and prioritization *of non-timber forest products used as means of livelihoods in Edo State, Nigeria. Agroforestry Systems,* 99, 160. https://doi.org/10.1007/s10457-025-01252-2

Owen, O., & Husaini, S. (2024). Political economy of forest policy in Nigeria. The Policy Practice Working Paper 3. Retrieved from https://thepolicypractice.com

Owoeye, A., & Zaman, E.Y. (2024). Exploitation of *Irvingia wombolu* (Ogbono) by rural women in Etsako Central Local Government Area of Edo State. *FUDMA Journal of Sciences*, 8(6), 205–213.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *The BMJ,* 372, n71.

Shea Nigeria. (2023). Nigeria: A global leader in shea butter production. Retrieved from https://sheanigeria.com/nigeria-a-global-leader-in-shea-butter-production/

UNEP Grid. (2022). Forest/Nigeria – Interactive country fiches. United Nations Environment Programme. Retrieved from https://dicf.unepgrid.ch/nigeria/forest

UNODC. (2022). National strategy to combat wildlife and forest crime in Nigeria 2022–2026—United Nations Office on Drugs and Crime, Vienna.

World Bank. (2022). Forests for development: Policy, practice, and a changing context. World Bank Publications, Washington DC.

LAND USE AND LAND COVER CHANGE: IMPACT ON URBAN FOREST LANDSCAPE

***OBADIMU Olusegun Olusola[1] and Odeyale Olajumoke Celinah[2]**

[1]Forestry Research Institute of Nigeria, PMB 5054, Jericho Hill, Ibadan, Nigeria
[2]Federal College of Forestry, Ibadan, PMB 5087, Jericho Hill, Ibadan, Nigeria
**Corresponding Email: obadolusola@gmail.com ; 08034309571*

Abstract

Urbanization has emerged as One of the most significant drivers of land use and land cover change (LULCC) globally, fundamentally altering urban forest landscapes and their associated ecosystem services. This article examines the multifaceted impacts of LULCC on urban forest ecosystems, which include fragmentation, biodiversity loss, microclimate modification, and hydrological disruption. This review shows how rapid urban expansion and infrastructural development are reshaping urban forests, diminishing their carbon storage capacity through tree loss and degradation, while inadequate coordination in land-use planning further accelerates forest decline. The analysis shows that when urban forests are fragmented, thinned, or degraded, they no longer function as they used to, and their ability to provide essential services to the city is weakened. However, although these factors are under serious pressure from land conversion, thoughtful planning and well-designed green infrastructure can help reconnect them, protect their function, and support more sustainable urban living. This review concludes with recommendations for integrated land-use planning that prioritize urban forest conservation amid rapid urban transformation. Urban planning must evolve to treat forests as essential infrastructure rather than optional amenities, embedding conservation objectives within developmental processes. This necessitates policy innovation, sustained investment in green space protection, and meaningful community engagement to ensure equitable distribution of urban forest benefits.

***Keywords**: land use change, urban forestry, ecosystem services, landscape fragmentation, urbanization, green infrastructure*

Introduction

The global transition towards urban living represents One of the most profound demographic shifts in human history. By 2050, approximately 68% of the world's population is projected to reside in urban areas (United Nations, 2018), driving unprecedented demand for land conversion and infrastructure development. This transformation fundamentally alters land use and land cover patterns, with particularly significant implications for urban forest landscapes, here as the mosaic of trees, woodlands, and associated vegetation within urban and peri-urban environments (Nowak *et al.*, 2018). Urban forests constitute critical green infrastructure, providing ecosystem services including air quality regulation, urban heat island mitigation, stormwater management, carbon sequestration, and psychological well-being (Roy *et al*., 2012; Livesley *et al*., 2016). However, these ecological assets face mounting pressures from residential expansion, commercial development, transportation networks, and industrial activities that fragment habitats, reduce canopy cover, and degrade ecological functionality (Seto *et al*., 2011). Understanding the mechanisms through which LULCC impacts urban forest landscapes is essential for developing sustainable urban planning strategies.

This article provides a comprehensive review of the relationship between LULCC and urban forest dynamics, examining spatial patterns, ecological consequences, and management implications. The analysis integrates perspectives from landscape ecology, urban planning, and environmental science to offer a multidimensional understanding of these complex interactions.

Drivers of Land Use and Land Cover Change in Urban Contexts

Urban Expansion Patterns

Urban growth manifests through multiple spatial patterns: sprawl, inner-city development, and peri-urban expansion, exerting distinct pressures on forest landscapes. Sprawl-type development, characterized by low-density residential expansion into peripheral areas, typically results in the direct conversion of forested lands and agricultural areas into built environments (Irwin & Bockstael, 2007). Angel *et al*. (2011) documented the fact that this pattern predominates in North American and Australian cities, where automobile-dependent development models facilitate rapid land consumption. In contrast, compact development strategies, increasingly favoured in European and Asian contexts, generate different LULCC dynamics. Haase *et al*. (2018) observed that although high-density development reduces overall land consumption, it often increases pressure on remaining green spaces within the urban matrix, leading to forest degradation rather than outright elimination. The infill development process may eliminate remnant forest patches that persisted through earlier development phases, reducing habitat connectivity and ecological functionality.

Economic and Policy Drivers

Economic forces fundamentally shape LULCC trajectories. Land value gradients drive conversion of lower-value forested lands to higher-value commercial and residential uses, particularly in rapidly growing metropolitan regions (Brueckner, 2000). The speculative nature of land markets often results in premature conversion, in which forest lands are cleared in anticipation of future development that may not materialize for decades, creating "leapfrog" development patterns that fragment landscapes (Robinson *et al*., 2005). Policy frameworks significantly mediate these market forces. Zoning regulations, urban growth boundaries, and protected area designations can constrain or channel development pressure (McDonald *et al*., 2008). However, governance fragmentation across municipal boundaries often undermines coordinated land use planning, resulting in forest loss at jurisdictional edges where regulatory oversight is weakest (Carrion-Flores & Irwin, 2004).

Spatial Impacts on Urban Forest Landscapes

Fragmentation and Patch Dynamics

LULCC fundamentally reconfigures the spatial structure of urban forests through fragmentation processes. As development proceeds, continuous forest cover is subdivided into progressively smaller, isolated patches with altered edge-to-area ratios (McGarigal & Cushman, 2002). This fragmentation reduces core habitat area, increases exposure to edge effects, including invasive species colonization and altered microclimatic conditions, and impedes species movement across the landscape (Fahrig, 2003). Empirical studies demonstrate consistent patterns of forest patch reduction and isolation. In the Beijing metropolitan region, rapid urban expansion between 1992

and 2015 reduced the number of forest patches while increasing mean patch size, indicating the consolidation of remaining forests into fewer reserves surrounded by development (Zhang *et al*., 2019). Conversely, studies of European cities reveal more complex dynamics, in which agricultural abandonment in peri-urban zones can drive forest regeneration even as urban core forests decline (Haase & Nuissl, 2007).

Canopy Cover Reduction and Configuration Changes

Beyond simple area metrics, LULCC alters the spatial configuration and quality of urban forest cover. Impervious surface expansion directly eliminates tree cover, while infrastructure development severs root systems and compacts soils, degrading remaining forest patches (Scalenghe & Marsan, 2009). The pattern of tree cover that emerges is often uneven across the city, with wealthier neighbourhoods usually having more trees than poorer communities, raising concerns about environmental fairness (Heynen *et al*., 2006). Remote sensing studies showed that urban forest cover is constantly changing over time. For example, a long-term study of 25 U.S. cities found that tree canopy declined by about 0.33% each year between 2009 and 2014, with faster losses occurring in places experiencing rapid population growth and more intense development (Nowak & Greenfield, 2018). These losses are frequently irreversible; once converted to built uses, land rarely returns to forest cover within relevant planning timeframes.

Ecological Consequences of Urban Forest Transformation

Biodiversity Impacts

LULCC-induced forest modification profoundly affects urban biodiversity. Habitat area reduction following land conversion elevates extinction risk for forest-dependent species, while fragmentation impedes dispersal and gene flow among remaining populations (Hanski, 2011). According to Aronson *et al*. (2014), urban forests are usually less diverse than forests that experience little human disturbance. They tend to have fewer species, indicating lower biodiversity. The mix of plants and animals changes over time, and cities become dominated by species that can survive almost anywhere. The spatial configuration of remaining forests critically mediates biodiversity outcomes. The study conducted by Gilbert-Norton *et al*. (2010) revealed that keeping forest areas connected helps species survive much better than when the same forest area is broken into separate, isolated patches. However, urban infrastructure, roads, buildings, and impervious surfaces create barriers that limit functional connectivity even where physical forest patches remain proximate (Benítez-López *et al*., 2010).

Ecosystem Service Degradation

The transformation of urban forests through LULCC diminishes their capacity to provide regulating and cultural ecosystem services. Canopy cover reduction directly compromises urban heat island mitigation; empirical studies documented temperature increase of 2–8°C in deforested areas compared to forested reference sites (Ziter *et al.,* 2019). Cities get hotter than they should be, and people end up using more energy, like running fans and air conditioners more often. The extra heat makes it easier for vulnerable people to fall sick or even die from heat-related illnesses. Living in such an environment becomes uncomfortable, making daily life stressful and exhausting for city residents. Hydrological services are similarly compromised. Forest removal and soil

sealing reduce evapotranspiration and infiltration, increasing stormwater runoff volumes and velocities (Booth *et al*., 2002). The loss of urban forests has been associated with increased flooding frequency, stream channel degradation, and reduced groundwater recharge (Walsh *et al.*, 2005). These hydrological impacts cascade through aquatic ecosystems, elevating pollutant loads and altering habitat conditions for aquatic biota. Carbon storage and sequestration capacities are reduced as forest biomass is eliminated or degraded. Nowak *et al.* (2013) estimated that urban tree cover in the United States stores approximately 643 million tons of carbon, with annual sequestration of 25.6 million tons. Land conversion that directly reduces canopy cover diminishes these climate-regulation services, potentially undermining municipal climate-mitigation objectives.

Socio-Ecological Dimensions

The distribution of LULCC impacts exhibits significant socioeconomic patterning, and, according to the submission by Gerrish and Watkins (2018), marginalized communities often experience disproportionate urban forest loss due to development pressure, limited political influence over land-use decisions, and historical patterns of disinvestment. This inequitable distribution of green infrastructure results in disproportionate exposure to environmental risks, including heat stress, air pollution, and flooding (Jesdale *et al.,* 2013). Conversely, urban greening initiatives may inadvertently drive gentrification, in which environmental improvements increase property values and displace existing residents (Anguelovski *et al*., 2019). This "green gentrification" paradox highlights the need for integrative planning approaches that simultaneously address environmental quality and housing affordability.

Cultural and Aesthetic Values

Urban forests provide substantial cultural ecosystem services, including recreation, aesthetic enjoyment, and place attachment. LULCC that eliminates or degrades these landscapes diminishes quality of life and severs connections to natural heritage (Kendal *et al*., 2015). The loss of iconic urban forests, such as the Atlantic Forest fragments in São Paulo or the oak woodlands of California cities, represents not merely ecological degradation but cultural impoverishment.

Management and Policy Responses

Green Infrastructure Planning

Strategic green infrastructure planning provides a framework for accommodating urban development while maintaining the functionality of forest landscapes. Green infrastructure approaches prioritize the conservation of connected networks of natural and semi-natural areas, integrating urban forests with other green spaces to maintain ecological processes (Benedict & McMahon, 2006). Implementation mechanisms include conservation easements, transfer of development rights, and greenbelt designations that channel development away from critical forest areas. Furthermore, the concept of "nature-based solutions" has gained acceptability as a means of addressing urban challenges through ecosystem restoration and management. Urban forest expansion and enhancement are central to this approach, offering cost-effective alternatives to gray infrastructure for stormwater management, heat mitigation, and air quality improvement (Eggermont *et al.,* 2015).

Adaptive Management and Restoration

Given the inevitability of urban growth, adaptive management strategies that enhance the resilience of remaining urban forests are essential. This includes managing forest composition to favour stress-tolerant species, restoring degraded patches to improve connectivity, and implementing soil protection measures during development to preserve root systems (Ordoñez & Duinker, 2013). Urban forest restoration presents opportunities to reverse LULCC impacts in appropriate contexts. Reforestation of vacant lands, brownfield remediation with tree planting, and stream buffer restoration can incrementally rebuild forest cover and ecological functionality (Pataki *et al.,* 2011). However, restoration success requires sustained commitment to maintenance and protection from future development pressure.

Future Directions and Research Needs

Several critical research frontiers warrant attention. First, the development of high-resolution remote sensing and machine learning techniques enables increasingly sophisticated monitoring of urban forest dynamics, facilitating rapid response to canopy cover changes (Myeong *et al*., 2001). Integration of these technologies with planning workflows could enhance adaptive management capacity. Second, longitudinal studies tracking biodiversity and ecosystem service outcomes across different LULCC scenarios are needed to strengthen the evidence base for planning decisions. Most studies examine different places at a single point in time, rather than tracking how a single place changes over time. However, tracking these changes over time would give us a much better understanding of how urban ecosystems grow, adapt, and when they might reach critical points. It is equally important to pay more attention to balancing people's needs with the health of nature when planning our city forests. Participatory mapping, citizen science, and community-based forest management offer pathways to democratize green space governance and ensure that urban forest conservation serves diverse social needs (Connolly *et al*., 2014).

Conclusion

Land use and land cover change represent the primary driver of urban forest landscape transformation, with far-reaching consequences for biodiversity, ecosystem services, and human well-being. The spatial reconfiguration of urban forests through fragmentation, reduced canopy cover, and degradation fundamentally alters ecological function and diminishes their capacity to provide critical urban services. Addressing these challenges requires integrated approaches that transcend traditional disciplinary and administrative boundaries. Urban planning must evolve to treat forests as essential infrastructure rather than optional amenities, embedding conservation objectives within development processes. This necessitates policy innovation, sustained investment in green space protection, and meaningful community engagement to ensure equitable distribution of urban forest benefits. As urbanization accelerates globally, the choices made regarding urban forest conservation will profoundly shape the sustainability and livability of cities for generations. The evidence reviewed here demonstrates both the vulnerability of urban forests to LULCC and the potential for strategic interventions to maintain these vital ecological assets amidst urban transformation.

References

Angel, S., Parent, J., Civco, D. L., & Blei, A. M. (2011). Making room for a planet of cities. Lincoln Institute of Land Policy. hppt://www.linclponinst.edu/publications/working-papers/making-room-planet-cities

Anguelovski, I., Connolly, J. J., Pearsall, H., Shokry, G., Checker, M., Maantay, J., & Sporn, S. R. (2019). Why green "climate gentrification" threatens poor and vulnerable populations. *Proceedings of the National Academy of Sciences*, 116(52): 26139–26143. https://doi.org/10.1073/pnas.1920490117

Aronson, M. F., La Sorte, F. A., Nilon, C. H., Katti, M., Goddard, M. A., Lepczyk, C. A. and Winter, M. (2014). A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. *Proceedings of the Royal Society B: Biological Sciences*, 281(1780): 20133330. https://doi.org/10.1098/rspb.2013.3330

Benedict, M. A., & McMahon, E. T. (2006). Green infrastructure: Linking landscapes and communities. Island Press. 320pp.

Benítez-López, A., Alkemade, R., and Verweij, P. A. (2010). The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis. *Biological Conservation*, 143(6): 1307-1316. https://doi.org/10.1016/j.biocon.2010.02.009

Booth, D. B., Hartley, D. & Jackson, R. (2002). Forest cover, impervious-surface area, and the mitigation of stormwater impacts. *Journal of the American Water Resources Association*, 38(3): 835–845. https://doi.org/10.1111/j.1752-1688.2002.tb05532.x

Brueckner, J. K. (2000). Urban sprawl: Diagnosis and remedies. *International Regional Science Review*, 23(2): 160–171. https://doi.org/10.1177/016001700761012710

Carrion-Flores, C. & Irwin, E. G. (2004). Determinants of residential land-use conversion and sprawl at the rural-urban fringe. *American Journal of Agricultural Economics*, 86(4): 889–904. https://doi.org/10.1111/j.0002-9092.2004.00641.x

Connolly, J. J., Svendsen, E. S., Fisher, D. R., & Campbell, L. K. (2014). Networked governance and the management of ecosystem services: The case of urban environmental stewardship in New York City. Ecosystem Services, 10: 187–194. https://doi.org/10.1016/j.ecoser.2014.08.005

Eggermont, H., Balian, E., Azevedo, J. M., Beumer, V., Brodin, T., Claudet, J. & Le Roux, X. (2015). Nature-based solutions: New influence for environmental management and research in Europe. *GAIA-Ecological Perspectives for Science and Society*, 24(4): 243–248. https://doi.org/10.14512/gaia.24.4.9

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. Annual Review of Ecology, *Evolution, and Systematics*, 34: 487-515. https://doi.org/10.1146/annurev.ecolsys.34.011802.132419

Gerrish, E. & Watkins, S. L. (2018). The relationship between urban forests and income: A meta-analysis. *Landscape and Urban Planning*, 170: 293–308. https://doi.org/10.1016/j.landurbplan.2017.09.005

Gilbert-Norton, L., Wilson, R., Stevens, J. R. & Beard, K. H. (2010). A meta-analytic review of corridor effectiveness. *Conservation Biology*, 24(3): 660–668. https://doi.org/10.1111/j.1523-1739.2010.01450.x

Haase, D. & Nuissl, H. (2007). Does urban sprawl drive changes in the water balance and policy? The case of Leipzig (Germany) 1870–2003. *Landscape and Urban Planning*, 80(1-2): 1–13. https://doi.org/10.1016/j.landurbplan.2006.06.008

Haase, D., Kabisch, S., Haase, A., Andersson, E., Banzhaf, E., Baró, F. and Wolff, M. (2018). Greening cities–To be socially inclusive? About the alleged paradox of society and ecology in cities. *Habitat International*, 79: 18-27. https://doi.org/10.1016/j.habitatint.2017.04.005

Hanski, I. (2011). Habitat loss, the dynamics of biodiversity, and a perspective on conservation. Ambio, 40(3): 248-255. https://doi.org/10.1007/s13280-011-0147-3

Heynen, N., Perkins, H. A. & Roy, P. (2006). The political ecology of uneven urban green space: The impact of political economy on race and ethnicity in producing environmental inequality in Milwaukee. *Urban Affairs Review*, 42(1): 3–25. https://doi.org/10.1177/1078087406290729

Irwin, E. G. & Bockstael, N. E. (2007). The evolution of urban sprawl: Evidence of spatial heterogeneity and increasing land fragmentation. **Proceedings of the National Academy of Sciences**, 104(52): 20672–20677. https://doi.org/10.1073/pnas.0705527105

Jesdale, B. M., Morello-Frosch, R., & Cushing, L. (2013). The racial/ethnic distribution of heat risk–related land cover in relation to residential segregation. *Environmental Health Perspectives*, 121(7): 811–817. https://doi.org/10.1289/ehp.1205919

Kendal, D., Williams, N. S. & Williams, K. J. (2015). A cultivated environment: Exploring the global distribution of future urban croplands. *Global Environmental Change*, 37: 51–59. https://doi.org/10.1016/j.gloenvcha.2015.08.013

Livesley, S. J., McPherson, G. M. & Calfapietra, C. (2016). The urban forest and ecosystem services: Impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. *Journal of Environmental Quality*, 45(1): 119–124. https://doi.org/10.2134/jeq2015.11.0567

McDonald, R. I., Kareiva, P. & Forman, R. T. (2008). The implications of current and future urbanization for global protected areas and biodiversity conservation. *Biological Conservation,* 141(6): 1695-1703. https://doi.org/10.1016/j.biocon.2008.04.025

McGarigal, K. & Cushman, S. A. (2002). Comparative evaluation of experimental approaches to the study of habitat fragmentation effects. *Ecological Applications*, 12(2): 335–345. https://doi.org/10.1890/1051-0761(2002)012[0335:CEOEAT]2.0.CO;2

Myeong, S., Nowak, D. J. & Duggin, M. J. (2001). A temporal analysis of urban forest carbon storage using remote sensing. *Remote Sensing of Environment*, 101(2): 277–282. https://doi.org/10.1016/j.rse.2005.12.001

Nowak, D. J. & Greenfield, E. J. (2018). Declining urban and community tree cover in the United States. *Urban Forestry & Urban Greening*, 32: 32–55. https://doi.org/10.1016/j.ufug.2018.03.006

Nowak, D. J., Greenfield, E. J., Hoehn, R. E., & Lapoint, E. (2013). Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution*, 116: 381–389. https://doi.org/10.1016/S0269-7491(02)00214-7

Nowak, D.J., Hirabayashi, S., Bodine, A. & Greenfield, E. (2018). Effects of trees and forests on air quality and human health in the United States. *Environmental Pollution*, 193: 119 - 129

Nowak, D. J., Hirabayashi, S., Bodine, A., & Greenfield, E. (2014). Effects of trees and forests on air quality and human health in the United States. *Environmental Pollution*, 193: 119–129. https://doi.org/10.1016/j.envpol.2014.05.028

Ordoñez, C. and Duinker, P. N. (2013). An analysis of urban forest management plans in Canada: Implications for urban forest management. *Landscape and Urban Planning,* 116: 36-47. https://doi.org/10.1016/j.landurbplan.2013.04.006

Pataki, D. E., Carreiro, M. M., Cherrier, J., Grulke, N. E., Jennings, V., Pincetl, S., & Zipperer, W. C. (2011). Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the Environment*, 9(1): 27–36. https://doi.org/10.1890/090220

Robinson, L., Newell, J. P. & Marzluff, J. M. (2005). Twenty-five years of sprawl in the Seattle region: Growth management responses and implications for conservation. *Landscape and Urban Planning,* 71(1): 51–72. https://doi.org/10.1016/j.landurbplan.2003.10.002

Roy, S., Byrne, J., & Pickering, C. (2012). A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. *Urban Forestry & Urban Greening*, 11(4): 351–363. https://doi.org/10.1016/j.ufug.2012.06.006

Scalenghe, R. and Marsan, F. A. (2009). The anthropogenic sealing of soils in urban areas. *Landscape and Urban Planning*, 90(1-2): 1-10. https://doi.org/10.1016/j.landurbplan.2008.10.011

Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. *PLoS One,* 6(8): e23777. https://doi.org/10.1371/journal.pone.0023777

Walsh, C. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., Groffman, P. M., & Morgan, R. P. (2005). The urban stream syndrome: Current knowledge and the search for a cure. *Journal of the North American Benthological Society*, 24(3): 706–723. https://doi.org/10.1899/0887-3593(2005)024[0706:TUSSCK]2.0.CO;2

Ziter, C. D., Pedersen, E. J., Kucharik, C. J., & Turner, M. G. (2019). Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer. *Proceedings of the National Academy of Sciences,* 116(15): 7575–7580. https://doi.org/10.1073/pnas.1817561116

ISTF-NIGERIA 2026

SPROUTING AND ROOTING ABILITY OF *Irvingia wombolu* (VERMOESEN) LEAFY STEM CUTTINGS AS INFLUENCED BY GROWTH MEDIA

ADEBUSUYI, G.A.*, OYEDEJI, O.F., ALAJE V.I., AMADI, J.O., and NOLA, M.O.

Forestry Research Institute of Nigeria, P.M.B. 5054, Jericho Forest Hill, Ibadan, Nigeria.
***Corresponding Author:** goldenscopes@yahoo.com; +234 803 827 6947*

Abstract

Irvingia wombolu is one of the indigenous tree species found in Nigeria and it is of multipurpose use and of socio-economic importance to the life of the entire populace. The study investigated the effect of growth media (Riversand, Sawdust and Riversand/Sawdust {1:1}) on the sprouting and rooting ability of *Irvingia wombolu*.

One hundred and twenty (120) single node stem cuttings were collected from a mother tree (plus tree) and replicated four times. The cuttings were placed in a non-mist propagator at the Physiology and Tree breeding Section's Nursery of the Forestry Research Institute of Nigeria, Jericho, Ibadan, Oyo State, Nigeria. Data on number of leaves, shoot length (cm), callus formation, rooted cuttings, number of roots and length of roots (cm) were collected and analyzed using Analysis of Variance (ANOVA) and significant means were separated using Duncan Multiple range Test (DMRT) at 5% probability level.

For the number of roots, rooted cuttings, root length, number of shoots and shoot length, riversand/sawdust has the highest figures of 14.25, 5.25, 11.30, 13.50 and 9.90 respectively. For dead cuttings, sawdust recorded the highest number of dead cuttings (6.75), followed by riversand (5.00), the least was observed in riversand/sawdust (2.75).

Based on the findings of this study, it is therefore, concluded that *Irvingia wombolu* cuttings has the potential for regeneration by vegetative means and the best growth mediun is a 1:1 mixture of riversand and sawdust.

Keywords; *Irvingia wombolu,* growth media, riversand/sawdust

Introduction

The tropical rainforest of West Africa is endowed with trees of high value with multipurpose uses. Many rural households of these regions depend heavily on these resources for their food, medicinal and construction needs (Jepkemboi, 2023, Odeyale *et al.,* 2025). Chiefly among these is *Irvingia wombolu* which has enormous potential, both in economic terms and as species for sustainable production (Odeyale *et al.,* 2025). The species is a valuable source of income for West and Central African farmers through the sales of kernels which fetch a price higher than the fruits (Derebe *et al.,* 2023; Ebanga *et al.,* 2026). Despite the high value of the species to farmers, the long gestation period of seed sown trees, poor germination capacity, variability of fruits, kernel characteristics and tree size and limited knowledge base (Gélinas, 2025), and other factors, indicate the need for improvement of the species for domestication. While vegetative propagation may greatly facilitate

the process of domestication of fruit trees by enabling the rapid multiplication of selected genotypes and the production of superior planting stock and shortening fruiting time for farmers (Tang *et al.,* 2024; Niella *et al.,* 2025).

The vegetative propagation of *Irvingia wombolu* (African bush mango) through cuttings presents several challenges, particularly concerning the selection and composition of the growth medium. Successful rooting is crucial for the domestication and sustainable production of this economically important tree species (Gboazo *et al.,* 2026).

Irvingia wombolu is known to be recalcitrant to rooting from cuttings, especially from mature plant material (Mbakwe, and Nzekwe, 2008). This inherent difficulty necessitates careful optimization of environmental factors, with the growth medium being a primary determinant of success.

The growth medium for *Irvingia wombolu* cuttings must therefore, provide a delicate balance of moisture retention, aeration, and structural support, while also potentially supplying essential nutrients or facilitating hormonal action. Problems arise when the medium fails to meet these specific requirements (Mangezi *et al.,* 2026).

This study therefore, aims at examining the effect of different growth media on the sprouting and rooting potential of *Irvingia wombolu* stem cuttings.

Materials and Methods

Study area

The experiment was carried out for 8 weeks at the nursery of Physiology and Tree Breeding Section, Forestry Research Institute of Nigeria, Ibadan. It is located between Latitude 7°23'18"N and 7°23'43"N and Longitude 3°51'20"E and 3°51'43"E. The climate of the area is Tropical Savanna vegetation. Rainfall in the region is unimodal starting from May to September, and a dry season starting from October through April. The average annual temperature is 26.5° C and about 1311mm of precipitation falls annually. (FRIN, 2019; https://en.climate-data.org/location/529/)

Propagator setup

A non-mist propagation unit was established at the Physiology and Tree Breeding Section's Nursery, Department of Sustainable Forest Management for the experiment. The propagator consisted of a wooden frame enclosed in a clear polythene to maintain high humidity around the cuttings and allow the penetration of light into the propagation unit with a water-tight block work base (Leakey *et al.,* 1990). The base of the propagator was covered by a thin layer of sand (10 cm depth) to prevent the polythene from being punctured by the granite and then successive layers of small to medium size granite (0.5–5 cm, to a depth of 25 cm) and then was filled with water (Leakey *et al.,* 1990).

Preparation of growth media

The river sand used was collected from a stream close to ornamental nursery of Forestry Research Institute of Nigeria (FRIN) while sawdust was collected from the Forest Product Development and

Utilisation (FPD&U) Department of FRIN. The growth media was thoroughly washed and sterilized using an autoclave.

Collection of leaf cuttings

Leafy stem cuttings of *Irvingia wombolu* were obtained from a mother tree (plus tree) within Forestry Research Institute of Nigeria. The mother tree was sprayed with systemic fungicides and insecticides (Imidacloprid 10%+Metalaxyl 10%+Carbendazim 10% WS) prior to severance. The cuttings were further cut into equal lengths of 5cm; each cutting had a single node with a leaf. These cuttings were dipped into water immediately after severance and kept in a shady area in the nursery to prevent dehydration.

Experimental setup

A total number of one hundred and twenty (120) single node stem cuttings were collected from a mother tree (plus tree). 10 cuttings each were randomly assigned to the 3 treatments namely riversand, sawdust and riversand/sawdust (1:1), replicated four times and set in the propagator using Completely Randomized Design (Plate 1).



Plate 1: Setting-up of Cuttings in the Non-Mist Propagator

Morphometric parameters/Growth variables

The following parameters were assessed after sixty days; percentage cutting mortality (Equation I), percentage sprouted cuttings (Equation II), presence and number of roots (≥ 2 mm in length), root length (mm), number of new shoots, length of shoot (mm), and callus formation.

- Percentage cutting mortality was calculated as:

  %C.M. = X/Y * 100----------Equation I

Where X= number of dead cuttings

Y= number of cuttings set

- Percentage sprouted cuttings were calculated as

  %S.C. = A/B * 100----------Equation II

Where A= number of sprouted cuttings

B= number of cuttings set

the presence and number of roots were assessed by physical count, root length was assessed by the use of meter rule (mm), number of new shoots were assessed by physical count, length of shoot was assessed by the use of meter rule (mm) and Callus formations were assessed by physical count

Statistical analysis

Data collected on the presence and number of roots (≥ 2 mm in length), root length (mm), number of new shoots, length of shoot (mm), and callus formation was subjected to analysis of variance (ANOVA) and significant means were separated with the use of Duncan Multiple Range Test (DMRT) at 5% level of probability using RStudio statistical package.

Results

The analysis of variance revealed highly significant differences ($p<0.05$) among the treatments. For the number of rooted cuttings, the mixture of riversand and sawdust has the highest number of rooted cuttings of 5.25, followed by riversand (1.75) and the least was observed in sawdust (1.25) (Table 1).

For the number of roots, the mixture of riversand and sawdust also has the highest with 14.25, it was followed by riversand (4.75) and the least was recorded in sawdust (3.75) (Table 1).

Table 1: Mean Separation (Duncan) for the Effect of Growth Media on the Parameters Assessed on *Irvingia wombolu* Cuttings.

Growth Media	Rooted Cuttings	Callused Cuttings	Dead Cuttings	Number of Roots	Root Length	Number of Shoots	Shoot Length
River Sand	1.75[b]	2.00[a]	5.00[b]	4.75[b]	10.60[a]	10.75[ab]	7.90[b]
Sawdust	1.25[b]	2.00[a]	6.75[a]	3.75[b]	10.85[a]	7.00[b]	7.95[b]
Riversand/Sawdust	5.25[a]	3.25[a]	2.75[c]	14.25[a]	11.30[a]	13.50[a]	9.90[a]

Means with the same alphabet are not significantly different from each other

ISTF-NIG 2026

For root length, the mixture of riversand and sawdust recorded the highest figure of 11.30, it was followed by sawdust (10.85) and the least was recorded in Riversand (10.60). The same trend was observed in shoot length, with the mixture of riversand and sawdust having the highest figure of 9.90 and was followed by sawdust (7.95) and the least was recorded in Riversand (7.90). Number of shoots followed a different trend, the highest was also recorded in Riversand/sawdust (13.50), but was followed by riversand (10.75) and the least was recorded in sawdust (7.00) (Table 1).

For dead cuttings, sawdust recorded the highest number of dead cuttings (6.75), followed by riversand (5.00), the least was observed in riversand/sawdust (2.75) (Table 1).

Table 2: Analysis for Effects of Growth Media on the Sprouting and Rooting of *Irvingia wombolu* Cuttings

Source	DF	SS	MS	F-value	P-value
Rooted Cuttings					
Growth Media	2	38.000	19.000	40.235	0.000*
Error	9	4.250	0.472		
Total	11	42.250			
Callused Cuttings					
Growth Media	2	4.167	2.083	3.947	0.059ns
Error	9	4.750	0.528		
Total	11	8.917			
Dead Cuttings					
Growth Media	2	32.167	16.083	26.318	0.000*
Error	9	5.500	0.611		
Total	11	37.667			
Number of Roots					
Growth Media	2	268.667	134.333	27.322	0.000*
Error	9	44.250	4.917		
Total	11	312.917			
Root Length					
Growth Media	2	1.007	0.503	0. 802	0.478ns
Error	9	5.650	0.628		
Total	11	6.657			
Number of Shoots					
Growth Media	2	85.167	42.583	7.130	0.014*
Error	9	53.750	5.972		
Total	11	138.917			
Shoot Length					
Growth Media	2	10.407	5.203	6.058	0.022*
Error	9	7.730	0.859		
Total	11	18.137			
Percentage Mortality					
Growth Media	2	3216.667	1608.333	26.318	0.000*
Error	9	550.000	61.111		
Total	11	3766.667			
Percentage Sprouted					
Growth Media	2	3216.667	1608.333	26.318	0.000*
Error	9	550.000	61.111		
Total	11	3766.667			

***** = Significant (α=0.05), ns= Not Significant (α=0.05)

ISTF-NIG 2026



Plate 2: *Irvingia wombolu* Cuttings with new Leaves and Sprouts after Four (4) Weeks in the Propagator

ISTF-NIG



Plate 3: *Irvingia wombolu* Cuttings with Leaves and Roots at the End of the Experiment



Plate 4: *Irvingia wombolu* Cuttings with Leaves, Callus and Tiny Roots at the End of the Experiment



Plate 5: *Irvingia wombolu* Cuttings with Callus formation at the End of the Experiment

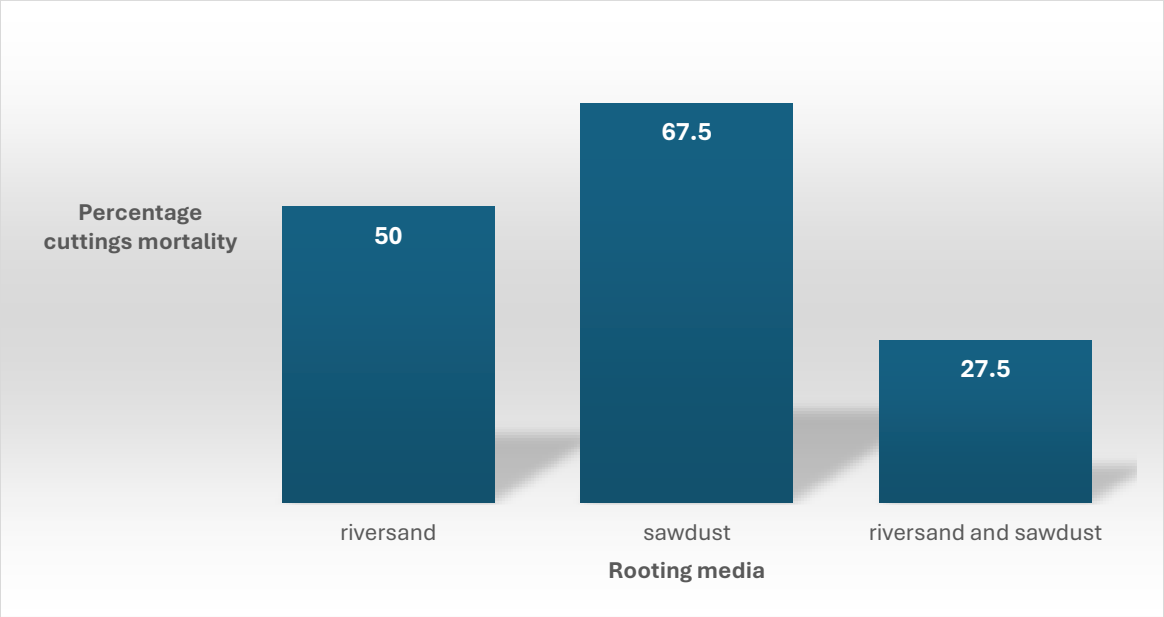


Figure 1: Effect of Rooting Media on Percentage Cutting Mortality

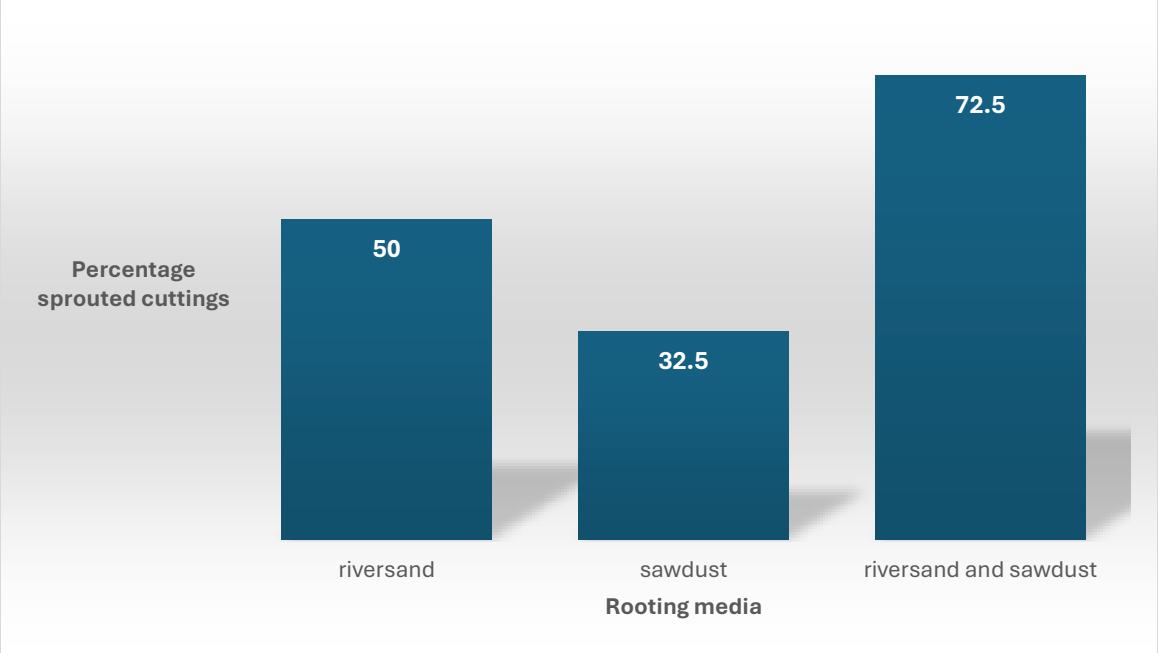


Figure 2: Effect of Rooting Media on Percentage Sprouted Cuttings

Discussion

The ability of stem cuttings to produce new shoots is a crucial factor in the success of vegetative propagation in woody plants, although this capacity differs among species (Memon *et al*., 2013). The success of stem cuttings is influenced by several internal and external factors, including the

age of the parent plant (ortet) (Ambebe *et al*., 2017), the type of growth medium used (Ashiono *et al*., 2017), the nature of the cutting (Washa, 2014), plant hormones (Bhardwaj *et al*., 2017), plant species, the health status of the source plant, size of the cutting, and environmental conditions (Kramer and Kozlowski, 2014).

Significant differences ($p<0.05$) were observed among the growth media tested. The combination of river sand and sawdust produced the highest number of rooted cuttings, as well as superior root number, root length, and shoot length. This was followed by river sand alone, while sawdust recorded the lowest values. However, the number of shoots showed a slightly different pattern: although the highest was still observed in the sand–sawdust mixture, it was followed by river sand, with sawdust again producing the least. In terms of mortality, sawdust resulted in the highest number of dead cuttings, followed by river sand, whereas the sand–sawdust mixture recorded the lowest mortality. These findings differ from those of Amadi *et al*. (2022), who reported that topsoil produced the highest percentage of rooted cuttings in *Piper guineense*, followed by sawdust, while river sand gave the lowest results. They also noted that the rooting medium did not significantly influence rooting ability in *P. guineense*. Nonetheless, the use of an appropriate rooting medium is essential for successful propagation. Similarly, Alaje *et al*. (2022) found that potting media significantly affected root number, root length, and leaf production.

The present findings support Khayyat *et al*. (2007), who emphasized the importance of soil medium in determining the quality of rooted cuttings. However, several studies have reported negative effects of sawdust on plant growth parameters, including reduced sprouting in *Massularia acuminata* (Usman and Akinyele, 2015), decreased leaf length in *Ficus binnendijkii* (Shah *et al*., 2006), reduced leaf area in *Irvingia wombolu* (Dolor, 2011), shorter plant height in *Helianthus annuus* (Yerima *et al*., 2015), and lower diameter and biomass in *Eucalyptus saligna* (Ashiono *et al*., 2017), as well as poor rooting in *Ricinodendron heudelotii* (Tchinda *et al*., 2013). Conversely, positive effects of sand, either alone or mixed with sawdust, have been reported for sprouting in *Warburgia ugandensis* (Akwatulira *et al*., 2011) and *M. acuminata* (Usman and Akinyele, 2015), as well as improved foliage development and leaf production in *G. latifolia* (Ofodile *et al*., 2013) and enhanced stem length and leaf number in *Ficus hawaii* (Hassanein, 2013), which aligns with findings for *C. africana*.

Differences in performance among growth media are likely due to variations in their physical properties (Khayyat *et al*., 2007), particularly those affecting water and air availability to plants (Baiyeri, 2005). Excess water can restrict oxygen diffusion, leading to oxygen deficiency (anoxia) at the base of cuttings. Sawdust required less frequent irrigation than sand or the sand–sawdust mixture, indicating its high-water retention capacity. However, excessive water retention can negatively impact plant growth and survival, as reported by Ofodile *et al*. (2013) and Caspa *et al*. (2014).

On the other hand, sand—either used alone or in combination with other materials—appears to provide favorable conditions for plant growth. Its properties likely include adequate pore space for gas exchange and a suitable oxygen diffusion rate, which supports root respiration and nutrient uptake (Fonteno and Nelson, 1990). High aeration within the growth medium is particularly important for stimulating metabolic processes and promoting root initiation (Yeboah and Amoah, 2009), consistent with the findings of Waziri *et al*. (2015).

Conclusion

This study successfully demonstrates that *Irvingia wombolu* is amenable to vegetative propagation. The 1:1 mixture of riversand and sawdust is the most effective medium for sprouting and rooting, offering the best balance of physical properties for cutting survival and growth. Also, the use of locally available materials (riversand and sawdust) in a non-mist propagator makes this technology accessible to smallholder farmers and local nurseries.

References

Akwatulira, F., Samson, G., John, B.L.O., Paul, S., Susan, B.T., John, R.M. and Alice, M. (2011): Influence of Rooting Media and Indole-3-butyric Acid (IBA) Concentration on Rooting and Shoot Formation of *Warburgia ugandensis* Stem Cuttings. *African Journal of Plant Science* 5: 424-428.

Amadi, J. O., Alaje, V. I., Oyedeji, O. F**.**, Appah, O. R. and Ogunwande, O. A. (2022): Effect of Growth Hormones and Potting Media on Rooting Potentials of African Black Pepper (*Piper guineense*). *Journal of Forestry, Environment and Sustainable Development* (JOFESD), 8(1): 52 – 61. https://www.eruditescholars.net ISSN No:- 2449-1845. www.uniuyo.edu.ng

Ambebe, T.F., Akenji, M.J. and Njoya, M.T.M. (2017): Growth Responses of Branch Cuttings of *Cordia africana* to Physiological Age. *Journal of Horticulture and Forestry* 9: 91-97.

Ashiono, F.A. Wangechi, H.K. and Kinyanjui, M.J. (2017): Effects of Sawdust, Forest Soil and Cow Dung Mixtures on Growth Characteristics of Blue Gum (*Eucalyptus saligna*) Seedlings in South Kinangop Forest, Nyandarua, Kenya. *Open Journal of Forestry* 7: 373-387.

Baiyeri K.P. (2005): Response of *Musa Species* to Macro Propagation: II: The Effects of Genotype, Initiation and Weaning Media on Sucker Growth and Quality in the Nursery. *Afr. J. Biotechnol*. 4(3): 229–234.

Bhardwaj, D.R., Singh, R., Lal, H., Nath, V. and Singh A.K. (2017): Effect of Node Number and Auxin Concentration on Propagation of Ivy Gourd (*Coccinia cordifolia Cogn*) Through Stem Cuttings. *Vegetos* 30:1.

Caspa, R.G., Biloso, A., Akalakou, C., Mafolo, J., Tsobeng, A., Kouodiekong, L. and Tchoundjeu, Z. (2014): Nursery Substrates and Provenances Influence Rooting Performance of Juvenile, Single-node Vine Cutting of *Gnetum africanum* Welw. (Gnetaceae). *AFRIKA FOCUS* 27: 7-21.

Derebe, B., Alemu, A., and Asfaw, Z. (2023): Contribution of Nontimber Forest Products Earn to Livelihood in Rural Households and the Type of Use: A Systematic Review. *International Journal of Forestry Research*, 2023, 9643290. https://doi.org/10.1155/2023/9643290

Dolor, D. (2011): Effect of Propagation Media on the Germination and Seedling Performance of *Irvingia wombolu* (Vermoesen). *American Journal of Biotechnology and Molecular Sciences* 1: 51-56.

ISTF-NIG 2026

Ebanga, A. P., Zekeng, J. C., Chimi, C. D., Fobane, J. L., Menyene, L. F. E., Syampungani, S., and Mbolo, M. M. (2026): Exploring Household Forest Dependency: Socio-Economic Drivers, Resource Utilisation, and Conservation Challenges in Eastern Cameroon. *World Development Sustainability*, 8, 100275. https://www.sciencedirect.com/science/article/pii/S2772655X2600008X

Fonteno, W.C., Nelson, P.V. (1990). Physical Properties of Plant Responses to Rockwool Amended Media. *Journal of the American Society for Horticultural Science*115: 375-381.

FRIN (2019): Forestry Research Institute of Nigeria Annual Report 2019.

Gboazo, Y. M., Siendou, C., Traoré-Ouattara, K., Soro, M., and Abdoulaye, D. (2026): Impact of Compost-Amended Substrates on the Rooting of *Irvingia gabonensis* Cuttings in a Nursery on the Outskirts of Taï National Park, Ivory Coast. *Journal of Experimental Agriculture International*, 48(2), 619-626. https://journaljeai.com/index.php/JEAI/article/view/4092

Gélinas Bélanger, J. (2025): Taming the Wild: Domesticating Untapped Northern Fruit Tree and Shrub Resources in the Era of High-Throughput Technologies. *AoB PLANTS*, 17(1), plae074. https://academic.oup.com/aobpla/article/17/1/plae074/7942640

Hassanein, A.M.A. (2013): Factors Influencing Plant Propagation Efficiency via Stem Cuttings. *Journal of Horticultural Science and Ornamental Plants* 5(3): 171-176

Jepkemboi, S. (2023): Genetic Diversity and Population Structure of *Irvingia gabonensis* and *Irvingia wombolu* in West and Central Africa. *Molecular Ecology*, 32(1), 1-15. https://www.tandfonline.com/doi/abs/10.1080/14728028.2022.2160380

Khayyat, M., Nazari, F. and Salehi, H. (2007): Effect of Different Pot Mixtures on pothos (*Epipremnum aureum* L. And Andre 'Golden Pothos') Growth and Development. *American-Eurasian Journal of Agricultural and Environmental Sciences* 2:341 348.

Kramer, P.J., Kozlowski, T.T. (2014): Physiology of Woody Plants. *Academic Press*, San Diego, California.

Leaky R.R.B., Mesen J.F., Tchoundjeu Z., Longman K.A., Dick J.McP., Newton A., Matin A., Grace J., Murno R.C. and Muthoka P.N. (1990): Lowkey Techniques for Vegetative Propagation of Tropical Trees. *Commonwealth Forestry Review.* 69:237-257.

Mangezi, S., Manjeru, P., Makuvaro, V., Chaibva, P., Mutetwa, M., and Muziri, T. (2026): Cattle Manure Amended Soil Influences Germination and Early Seedling Development of Marula (*Sclerocarya birrea* (A. Rich) Hochst.). *Frontiers in Food Science and Technology*, 5, 1734009.https://www.frontiersin.org/journals/food-science-and technology/articles/10.3389/frfst.2025.1734009/full

Mbakwe, R., and Nzekwe, U. (2008): Rooting of the Mature and Juvenile Stem Cuttings of *Irvingia wombolu* (Vemeosen). *Journal of Agriculture and Food Sciences*, 2(1), 7-12. https://www.ajol.info/index.php/jafs/article/view/41606

Memon N-un-nisa, Ali N., Baloch M.A. and Chachar Q. (2013): Influence of Naphthalene Acetic Acid (NAA) on Sprouting and Rooting Potential of Stem Cuttings of *Bougainvillea. Sci. int.* (Lahore), 25(2), 299-304.

Niella, F., Rocha, P., Bustamante, K., and Thalmayr, P. (2025): Vegetative propagation: A Tool for the Participatory Domestication and Conservation of Native Fruit Trees in the Paranaense Forest. *Agrociencia Uruguay*, 29(NE3), e1540. https://www.researchgate.net/publication/396603065_Vegetative_propagation_A_tool_for_the_participatory_domestication_and_conservation_of_native_fruit_trees_in_the_Paranaense_forest

Odeyale, O., Jayeoba, F. M., Aluko, A. K., and Bankole, J. F. (2025): Ethno-Botanical Survey of *Irvingia gabonensis* and *Irvingia wombolu* in Selected Markets in Akinyele Local Government Area, Oyo State, Nigeria. *FUDMA Journal of Sciences*, *9*(11), 48-54. https://fjs.fudutsinma.edu.ng/index.php/fjs/article/view/3945.

Ofodile, E.A.U., Chima, U.D. and Udo, E.F. (2013): Effect of Different Growth Media on Foliage Production and Root Growth in *Gongronema latifolia* Benth Stem Cuttings. *Greener Journal of Agricultural Sciences* 3: 215-221.

Shah, M., Khattak, A.M. and ul Amin, N. (2006): Effect of Different Growing Media on the Rooting of *Ficus ninnendijkii* 'amstelqueen' Cuttings. *Journal of Agricultural and Biological Science* 1(3): 15-17.

Tang, L., Amin, A., Syed, S., Oza, A., Rahman, A., and Brohi, S. A. (2024): Intelligent Rapid Asexual Propagation Technology—A Novel Aeroponics Propagation Approach. *Agronomy*, 14(10), 2289. https://www.mdpi.com/2073-4395/14/10/2289

Tchinda, N.D., Messi, H.J.C.M., Fotso, Nzweundji, G., Tsabang, N., Dongmo, B., Oumar, D., Tarkang, P.A., Caver, A. and Ndoumou, D.O. (2013): Improving Propagation Methods of *Ricinodendron heudelotti* Baill. from Cuttings. *South African Journal of Botany* 88: 3-9.

Usman, I.A.,Akinyele, A.O. (2015): Effects of Growth Media and Hormones on the Sprouting and Rooting Ability of *Massularia acuminata* (G. Don) Bullock ex Hoyl. *Journal of Research in Forestry, Wildlife and Environment* 7:137-146.

V. I. Alaje, J. O. Amadi, A. O. Williams, O. F. Oyedeji, O. A. Geply, and G. A. Adebusuyi (2022): Vegetative Propagation of African Black Pepper (*Piper guineense*): The Role of Growth Hormones and Rooting Media. *Australian Journal of Science and Technology*. ISSN 2208-6404, Volume 6; Issue 2; (71 – 77).

Washa, B.W. (2014): Effective Cutting Type in the Rooting of *Dalbergia melanoxylon* in Tanzania. *International Journal of Agri Science* 4: 256-259.

Waziri, M.S., Kyari, B.A., Ibrahim, M., Apagu, B., Yunana, B., Askira, M.N. and Benisheikh, B.A. (2015): Effect of Different Soil Media on the Rooting and Growth of *Delonix regia* Stem Cuttings in Maiduguri. *International Journal of Innovative Agriculture & Biology Research* 3:6-11.

Yeboah, J.S.T.L.and Amoah, F.M. (2009): The Rooting Performance of Shea Tree (*Vitellaria paradoxa* C.F. Gaertn) Cuttings Leached in Water and Application of Rooting Hormone in Different Media. *Journal of Plant Sciences* 4: 10-14.

Yerima, B.P.K., Tiamgne, Y.A., Fokou, L., Tziemi, T.C.M.A. and Van Ranst, E. (2015): Effect of Substrates on Germination and Seedling Emergence of Sunflower (*Helianthus annuus* L.)

at the Yongka Western Highlands Research/Garden Park, Bamenda – Cameroon. *TROPICULTURA* 33: 91-100.

ISTF-NIG 2026

ASSESSMENT OF FRUIT QUALITY, SEED GERMINATION AND SEEDLING GROWTH OF *Parkia biglobosa* (Jacq.) R.Br. ex G.Don AND *Tamarindus indica* L. FROM THREE PROVENANCES IN THE SAVANNAH ECO-REGION OF NIGERIA

***Addra M. E., Oyun M. B., Isha G. Y., Dakuru I. E., Kyari O. S.**

Department of Horticulture and Landscape Technology, College of Agriculture Science and Technology, Lafia, Nasarawa State.
Department of Forestry and Wildlife Management, Nasarawa State University, Keffi, Shabu-lafia Campus.
Corresponding author: emmanuelsmigleaddra@coastlafia.edu.ng;+234-9036231647

Abstract

The selection of appropriate seed sources is essential for successful tree establishment and sustainable utilization of indigenous fruit trees in the savannah eco-region of Nigeria. This study assessed fruit quality, seed germination, and early seedling growth of *Parkia biglobosa* (Jacq.) R.Br. ex G.Don and *Tamarindus indica* L. collected from three provenances (Morro, Funtua, and Nguru). A factorial experiment (2 species × 3 provenances) was conducted under uniform nursery conditions using a Randomized Complete Block Design. Fruit quality parameters evaluated include: pod length, pod width, pod weight, and number of seeds per pod. Germination percentage and germination time were recorded, while seedling growth parameters, including plant height, stem girth, number of leaves, and number of branches, were measured at 4, 8, and 12 weeks after transplanting (WAT). Data were analyzed using a two-way analysis of variance (ANOVA), and means were separated using the Least Significant Difference (LSD) at the 5% significance level. Significant differences ($p \leq 0.05$) were observed among species and provenances for most fruit and growth parameters. Morro provenance produced the highest fruit length (24.67±0.29 cm for *P. biglobosa* and 14.91±0.15 cm for *T. indica*), fruit width (3.45±0.27 cm for *P. biglobosa* and 3.20 cm for *T. indica*). Germination percentage was highest in Nguru 97.20±1.74% for *P. biglobosa* and 92.80±4.41% for *T. indica*). At 12 WAT, seedlings from Morro provenance recorded superior plant height (12.76±0.37 cm) and leaf production in *P. biglobosa*. Growth trends showed progressive increases in vegetative parameters from 4 to 12 WAT. The observed variations among provenances suggest genetic and environmental influences on fruit traits, germination performance, and early seedling growth. Morro and Funtua provenances demonstrated better overall seedling performance, indicating their potential for domestication, conservation, and large-scale propagation in the Nigerian savannah.

Keywords: *Parkia biglobosa*, *Tamarindus indica*, provenance, seed germination, savannah, Nigeria

Introduction

Forest resources are renewable natural resources and Nigeria as a nation is copiously gifted with these resources (Ijeomah *et al.,* 2010), of all the forest resources, trees have been categorized as the major produce based on the high economic values generated from them, there are several uses of trees to man, early humans depended on natural woodlands for foods such as fruit and nuts (Carol *et al., 2005*). A greater number of tree species increases the number of ecological niches

occupied by species (Wunderle, 1997; Kanowski *et al.,* 2003). Moreover, trees provide many ecosystem services, such as species conservation, soil erosion prevention, and habitat preservation for plants and animals (Armenteras *et al.,* 2013). Ecologically, trees can be further classified into indigenous and exotic taxa. A tree species is regarded as native and indigenous to a given region or ecosystem if its presence in that region is the result of natural processes with no human intervention. Every natural organism has its own natural range of distribution in which it is regarded as native and indigenous. Tree species play a crucial role in the ecological stability and socio-economic well-being of communities in the Savannah eco-region of Nigeria. Among these species, *Parkia biglobosa* (Jacq.) R. Br. ex G. Don (African locust bean) and *Tamarindus indica* L. (Tamarind) are particularly valued for their nutritional, medicinal, and economic significance. *P. biglobosa* provides seeds that are processed into a protein-rich condiment. At the same time, *T. indica* is widely used for its fruit pulp, which serves as a food ingredient, herbal medicine, and industrial raw material.

The Savannah eco-region of Nigeria has a long history of assessing the survival, growth, and productivity of exotic species for the establishment of commercial plantations. More specifically, species introduction, provenance, and progeny trials are found in most countries, although the levels of investment in trial management vary from region to region. As stated by Emtage (2004), the established supply chain and the rapid growth rates of exotic species have led to them being favored for plantation use rather than the indigenous species, hence indigenous tree species like *P.* and *T. indica* are perpetually being neglected while the exotic species are encouraged, due to the promotion of exotic trees for plantation purposes, the indigenous are being threatened in the natural forests (Mohammed_*et al.,* 2013). Despite their importance, these species face challenges such as declining population, poor seed germination, and inadequate conservation efforts, necessitating research into their fruit quality, seed viability, and seedling establishment across different provenances, to conserve the threatened indigenous tree species in the savannah Eco-region of Nigeria, it is expedient that the fruit quality, Seed germination and early seedling growth of *P. biglobosa* and *T. indica* is studied.

The selection of appropriate seed sources is a fundamental consideration in forest management, particularly when planning reforestation programmes to achieve successful plantation establishment. Identifying suitable seed sources can be facilitated by using seed zoning and seed transfer guidelines, which rely on understanding variations in fruit morphological traits, germination behaviour, and early seedling growth among different populations of the same species (Shu *et al.,* 2012). Furthermore studies have shown that fruit quality, seed germination and early growth performance can vary significantly among provenances due to genetic and environmental factors (Moles_*et al.,* 2005), provenance trials have been used globally to assess species adaptability and growth potential in different ecological zones, ultimately aiding in species selection for agroforestry, afforestation and reforestation programs (Leakey_*et al.,* 2012), identifying the best performing provenances of *P. biglobosa* and *T. indica* in the savannah eco region of Nigeria can enhance reforestation success rates and ensure the establishment of resilient forest ecosystems (Odebiyi_*et al.,* 2004). By assessing the fruit quality, germination and early growth performance of *P. biglobosa* and *T. indica* from different provenances, this research provided practical recommendations for forest regeneration, ecological restoration, and sustainable land management in Nigeria's savannah region, despite the ecological and economic significance of *P. biglobosa* and *T. indica* in the savannah. Studies have explored fruit quality, seed

germination and growth of *P. biglobosa* and *T. indica*. There is limited research on how different provenances influence these processes in the savannah. This study will fill this knowledge gap and provide data-driven recommendations for conservationists, government, policymakers, and forest managers to enhance afforestation, reforestation, and sustainable forest management initiatives in Nigeria. Thus, the general objective of the study was to assess the variability in fruit quality, seed germination, and early seedling growth of *P. biglobosa* and *T. indica* across three provenances in the savannah eco-region of Nigeria. The specific objectives are to: assess the fruit morphological characteristics of *P.* and *T. indica* collected from three provenances in the savannah eco-region of Nigeria, determine the rate and percentage seed germination of the test species from three provenances in the savannah eco-region of Nigeria and assess early growth performance of seedlings from seeds of the test species collected from three provenances in the savannah eco-region of Nigeria.

Materials and Methods

The Study Area

The study area spans three distinct agro-ecological zones (Provenances) representing distinct savannah zones in Nigeria to capture environmental variability: Moro, Kwara State (8°41' N, 4°28' E) represents the Southern Guinea Savanna with a bimodal rainfall pattern of approximately 1,200 mm (Adio_*et al.,* 2022); Funtua, Katsina State (11°32' N, 7°19' E) is situated within the Sudan Savanna on the High Plains of Hausaland (Abaje_*et al.,* 2024) and Nguru, Yobe State (12°52' N, 10°27' E) represents the Sahel Savanna within the Hadejia-Nguru Wetlands, characterized by erratic rainfall typically below 400 mm (Ringim_*et al.,* 2015) these locations were selected based on the natural distribution and ecological adaptability of *P. biglobosa* and *T. indica* within the savannah eco-regions.

Experimental Site/location

The study was conducted at the Department of Forestry and Wildlife Management's nursery site at Nasarawa State University, Keffi and located at Shabu-Lafia, the State capital. Lafia is located between (08033°N and 08032°E), north central, Nigeria. Rainfall in Lafia typically occurs from March to October, with average monthly rainfall ranging from 40 mm to 350 mm. July and August are usually months of heavy rainfall. The daily maximum temperature ranges from 20.0 °C to 38.5 °C, and the daily minimum temperature ranges from 18.7 °C to 28.2 °C. The months of February to early April have the highest maximum temperatures, while the lowest maximum temperatures are recorded in December and January because of the prevailing cold harmattan wind from the northern part of the country at this time. The relative humidity rises from April to a maximum of about 75- 90 percent in July (NIMET Lafia, 2010)—the soil type in the study area is highly leached ultisols with low base saturation. The soil is strongly acidic, with a high content of iron and Aluminium oxides, hence reddish-brown in colour, with very low organic matter content and low total nitrogen and available phosphate. The dominant clay type is Kaolinite. (Ajayi_*et al.* 2017). Vegetation of the study area is that of the southern Guinea Savannah with interspersion of thicket, grassland, trees, fringing woodlands or gallery forest along the streams. The natural vegetation of the area consists of grasses and scattered wild and economic trees, such as *Vitellaria paradoxa* (Shea butter tree) and *Parkia spp*. (locust bean tree), *Gmelina arborea* (Gmelina trees), and *Anacadium spp.* (Cashew trees) *Tamarindus indica* (tamarind tree)*, Mangifera indica* (Mango). To

mitigate the effects of seasonal water scarcity and high evapotranspiration during the extended dry period, these deciduous species typically undergo leaf senescence and abscission as a critical survival mechanism (Somanin *et al.,* 2023; Oyedeji *et al.,* 2021).

Experimental Design

The experiment followed a Randomized Complete Block Design (RCBD) with two species (*P. biglobosa* and *T. indica*) and three (3) provenances (treatments) which are (Moro, Funtua, and Nguru), each with five (5) replicates, consisted of a batch of fruits, seeds and seedlings subjected to laboratory analysis and same nursery conditions, watering was done daily after germination, seedling performance was monitored in a controlled setting.

Fruit Sampling Method and Processing

Mature ripe fruit pods of *P. biglobosa* and *T. indica* were manually harvested from three distinct provenances: Nguru (Yobe State), Funtua (Katsina State), and Moro (Kwara State). For each species per provenance, 250–300 fully ripened, healthy fruits were collected from multiple trees and bulked to form a composite sample. Fruit quality parameters were assessed separately for each species. Pod length and width were measured with a tape measure, and pod weight was recorded with a digital scale. The number of seeds per pod was manually counted following the methodology of Adedire and Ajayi (1996). To ensure contemporary accuracy in morphological characterization, these physical parameters align with recent descriptor standards for indigenous fruit trees (Dawit *et al.,* 2023; Saeed *et al.,* 2023).

Seed Germination Experiment

Seeds of *P. biglobosa* and *T. indica* were carefully extracted, pulp removed, and air-dried. Scarification was used for better germination. Seeds of both species were subjected to pre-germination treatment methods to overcome seed dormancy. For *P. biglobosa*, seeds they werewere immersed in hot water at 80°C for 5 minutes, following the procedure of Olamiju *et al.* (2013), while *T. indica* seeds were treated with hot water and scarified manually where necessary, as described by Yakubu *et al.* (2018). Similar thermal scarification methods have been validated in recent studies for optimizing germination of savannah leguminous seeds (Ahmed *et al.,* 2024; Malik *et al.,* 2024). Fifty seeds were used per Block, and the experiment was replicated five times, making a total of 250 seeds per species per provenance. This was used for reliability, treated seeds was sown separately in nursery bags containing a topsoil and sand mixture (2:1), The nursery bags were placed under the shaded canopy of *Senna siamea* trees and watering was carried out daily using watering cans to maintain uniform temperature and moisture, germination percentage, mean germination time, and germination speed index was calculated according to (Adebisi_*et al.,* 2017). Data on germination was recorded once a week for a period of six (6) weeks from the date of sowing. Data was collected on the following:

1. **Germination percentage (GP) =** $\left(\frac{\text{Total number of germinated seeds}}{\text{Total seeds sown}}\right) \times 100\%$ …….Eqn1.
2. **Mean germination time (MGT)** $= \Sigma \left(\frac{\text{Days} \times \text{No.of newly germinated seeds}}{\text{Total germinated seeds}}\right)$……..Eqn2.

3. **Germination speed index (GSI)** = $\Sigma \left(\frac{\text{No.of germinated seeds}}{\text{,Days after sowing}}\right)$…….Eqn3.

Early Seedling Growth Experiment

Prior to transplanting, a medium sized black polyethene bags was filled with topsoil and fully watered to maintain the moisture content of the soil, top soil was sieved in order to remove coarse properties properly bulked to enhance its homogeneity, following germination seedlings was then transplanted into polybags, a total number of five hundred (500) seedlings each of *P. biglobosa* and *T. indica* seedlings was used for the experiment, Early seedling growth was assessed separately for both species over a period of 8–12 weeks, seedling height was measured using a measuring tape, stem diameter at the collar region was measured using a Vernier caliper. The number of leaves per seedling was counted manually following Falemara *et al.* (2014). Mean height, stem diameter, Mean leaf count, and mean number of branches per species and provenance were recorded throughout the experimental period.

Statistical analysis of data

Data analysis involved both descriptive and inferential statistics to compare variation among the provenances (Morro, Funtua, and Nguru). Data was analyzed using descriptive statistics, including means and standard errors. Analysis of Variance (ANOVA) was employed to assess significant differences among species and provenances for fruit quality, germination, and early seedling growth parameters. Where differences were significant, mean separations were conducted using the Least Significant Difference test at the 5% level of significance. SPSS, Minitab and STAR statistical software were used for all statistical analyses.

Results

Table 1: Morphological Characteristics of *P. biglobosa* and *T. indica* fruit

Species	Provenance	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	No. of seeds
Parkia biglobosa	Funtua	20.75±0.18^{b}	3.38±0.21^{ab}	17.57±0.74^{b}	9.00±0.23^{b}
Parkia biglobosa	Morro	24.67±0.29^{a}	3.45±0.27^{a}	22.16±1.23^{a}	12.14±1.24^{a}
Parkia biglobosa	Nguru	14.89±0.24^{c}	2.52±0.27^{b}	11.61±0.59^{c}	7.39±0.33^{c}
LSD		0.6484	0.7080	2.3291	2.6037
P-value		0.001	0.04	0.000	0.0274
Tamarindus indica	Funtua	12.89±0.19^{b}	2.39±0.21^{b}	9.86±0.16^{b}	6.56±0.57^{a}
Tamarindus indica	Morro	14.91±0.15^{a}	3.20±0.19^{a}	11.68±0.45^{a}	5.19±0.35^{b}

ISTF-NIG 2026

Tamarindus indica	Nguru	10.84±0.17^{c}	2.49±0.25^{b}	8.45±0.48^{c}	3.87±0.19^{c}
LSD		0.6216		0.0009	1.3340
P-value		0.001	0.0589	1.2093	0.0053

Means with the same superscript within a column are not significantly different at $p \leq 0.05$ using the LSD test. Values are expressed as mean ± standard error (SE), n = 5.

Table 2: Germination experiment for *P. biglobosa* and *T. indica*

Species	Provenance	Germination (%)	Mean Germination Time(Days)	Germination Speed Index
Parkia biglobosa	Funtua	83.20±1.20^{b}	19.22±0.47^{b}	3.02±0.08^{a}
Parkia biglobosa	Morro	92.00±1.67^{a}	20.89±0.49^{ab}	3.00±0.07^{a}
Parkia biglobosa	Nguru	97.20±1.74^{a}	21.62±0.38^{a}	3.06±0.08^{a}
LSD		5.9063	1.7137	
P-value		0.0019	0.0314	0.8684
Tamarindus indica	Funtua	85.60±0.98^{ab}	20.77±0.97^{a}	2.82±0.14^{a}
Tamarindus indica	Morro	80.00±1.15^{b}	20.92±0.92^{a}	2.67±0.13^{a}
Tamarindus indica	Nguru	92.80±4.41^{a}	19.52±0.83^{b}	3.18±0.07^{b}
LSD		9.0924		
P-value		0.0343	0.5087	0.0686

Means with the same superscript within a column are not significantly different at $p \leq 0.05$ using the LSD test. Values are expressed as mean ± standard error (SE), n = 5.

Table 3: Early growth at 4WAT

Species	Provenance	Plant height (cm)	Girth	Number of leaves	Number of branches
Parkia biglobosa	Funtua	9.32±0.30^{b}	0.29±0.02^{b}	17.11±0.45^{ab}	3.24±0.18^{a}
Parkia biglobosa	Morro	10.00±0.17^{a}	0.35±0.02^{a}	18.49±0.55^{a}	3.63±0.19^{a}
Parkia biglobosa	Nguru	9.00±0.32^{b}	0.30±0.01^{ab}	16.17±0.51^{b}	2.72±0.24^{a}
LSD		0.663	0.0543	1.5502	
P-value		0.022	0.0459	0.0253	0.0741
Tamarindus indica	Funtua	9.89±0.12^{b}	0.26±0.02^{b}	17.88±0.54^{ab}	3.63±0.23^{a}

ISTF-NIG 2026

Tamarindus indica	Morro	10.76±0.21[a]	0.32±0.01[a]	19.01±0.31[a]	3.96±0.15[a]
Tamarindus indica	Nguru	9.40±0.16[b]	0.25±0.02[b]	16.96±0.52[b]	2.82±0.18[b]
LSD		0.507	0.0516	1.2875	0.4795
P-value		0.001	0.0482	0.0188	0.0016

Means with the same superscript within a column are not significantly different at $p \leq 0.05$ using the LSD test. Values are expressed as mean ± standard error (SE), n = 5.

Table 4: Early growth at 8WAT

Species	Provenance	Plant height (cm)	Girth	Number of leaves	Number of branches
Parkia biglobosa	Funtua	10.27±0.22[b]	0.39±0.02[a]	18.53±0.42[b]	4.05±0.19[b]
Parkia biglobosa	Morro	11.21±0.25[a]	0.38±0.02[a]	20.20±0.26[a]	4.74±0.19[a]
Parkia biglobosa	Nguru	9.09±0.22[c]	0.41±0.01[a]	18.02±0.20[b]	4.74±0.27[a]
LSD		0.7292		0.9558	0.5632
P-value		0.0005	0.4459	0.0019	0.0330
Tamarindus indica	Funtua	12.64±0.38[b]	0.34±0.02[a]	19.36±0.31[b]	4.56±0.24[ab]
Tamarindus indica	Morro	14.19±0.29[a]	0.37±0.02[a]	20.57±0.47[a]	5.16±0.16 [a]
Tamarindus indica	Nguru	12.01±0.11[c]	0.35±0.02[a]	17.82±0.21[c]	4.11±0.24[b]
LSD		0.5271		1.0952	
P-value		0.0000	0.6264	0.0014	0.0519

Means with the same superscript within a column are not significantly different at $p \leq 0.05$ using the LSD test. Values are expressed as mean ± standard error (SE), n = 5.

Table 5: Early growth at 12WAT

Species	Provenance	Plant height (cm)	Girth	Number of leaves	Number of branches
Parkia biglobosa	Funtua	11.87±0.32[a]	0.47±0.01[b]	18.44±0.48[b]	5.19±0.18[a]
Parkia biglobosa	Morro	12.76±0.37[a]	0.50±0.01[a]	20.47±0.21[a]	5.32±0.16[a]
Parkia biglobosa	Nguru	11.46±0.24[b]	0.43±0.01[c]	19.02±0.19[b]	5.25±0.16[a]
LSD			0.0232	1.1341	
P-value		0.0839	0.0007	0.0087	0.8861

ISTF-NIG 2026

Tamarindus indica	Funtua	13.67±0.31[b]	0.46±0.01[a]	20.37±0.39 [a]	4.99±0.13[a]
Tamarindus indica	Morro	15.08±0.22[a]	0.48±0.02[a]	21.01±0.13 [a]	5.10±0.35[a]
Tamarindus indica	Nguru	13.33±0.19[b]	0.45±0.01[a]	20.43±0.15 [a]	5.17±0.29[a]
LSD		0.4187			
P-value		0.0000	0.3813	0.1249	0.8368

Means with the same superscript within a column are not significantly different at $p \leq 0.05$ using the LSD test. Values are expressed as mean ± standard error (SE), n = 5

Discussion

Effects of species and provenance on fruit morphology

For *P. biglobosa*, Morro provenance had the highest mean values for fruit length, width, weight, and number of seeds, while Nguru had the lowest. This suggests that the Morro population may possess superior genetic potential for reproductive traits. Variations in fruit size and seed number among provenances have been reported in *P. biglobosa* across West Africa. For instance, studies have shown significant differences in pod length, weight, and seed number due to environmental and genetic factors (Sacandé & Clethero, 2007; Gbegbelegbe *et al.,* 2011). According to Leakey (2014), fruit size in indigenous tree species is often influenced by climatic factors such as rainfall, soil fertility, and temperature, which affect assimilate allocation during fruit development. The lower fruit size and seed number recorded in Nguru may be associated with the relatively drier conditions typical of northern savanna zones. Water stress has been shown to reduce fruit development and seed formation in tropical trees (Taiz *et al.,* 2015). Environmental stress conditions often result in smaller fruits due to reduced photosynthetic activity and carbohydrate availability. According to Dida *et al.* (2016), *T. indica* fruit traits vary significantly among provenances due to climatic and edaphic differences, which influence resource allocation during pod development. Similarly, Akinnifesi *et al.* (2008) observed substantial variability in fruit morphology among African agroforestry trees, highlighting the roles of genetic and site effects in shaping fruit characteristics. The high degree of variability in *T. indica* fruit length observed in this study agrees with findings by Gebauer *et al.* (2002), who reported similar ecological influences on pod size across semi-arid zones. Hence, Morro provenance may be more suitable for domestication and improvement programs aimed at enhancing fruit size and productivity. Across both species, provenance exerted a highly significant effect on fruit length, with Morro consistently producing longer fruits than Funtua and Nguru. This pattern underscores the strong influence of both genetic and environmental factors on fruit morphology in savannah tree species. The consistency of results across *P. biglobosa* and *T. indica* suggests a shared ecological response pattern, in which provenances from wetter, more fertile zones exhibit superior fruit traits. These findings align with earlier studies by Teklehaimanot (2004) and Ouedraogo *et al.* (2012), which emphasized that both *P. biglobosa* and *T. indica* exhibit marked geographic variation in fruit characteristics due to environmental adaptation. Morro provenance, therefore, represents a promising genetic resource for selection and domestication to improve fruit size and overall yield potential in the savannah eco-region of Nigeria.

Germination response across provenances

The higher Germination Percentage in Nguru seeds suggests superior seed quality and better physiological adaptation to the environmental conditions of the Sahelian zone. Such enhanced germination capacity may be attributed to the exposure of the parent trees to arid conditions, which can induce the production of more resilient seeds with improved desiccation tolerance and dormancy-breaking ability (Oni *et al.,* 2020). The relatively lower germination observed in the Funtua provenance may reflect suboptimal seed development or differences in seed coat hardness that delay water uptake and germination (Adebisi *et al.,* 2017). Similar provenance effects have been reported by Yakubu *et al.* (2018), who found that germination performance in *P. biglobosa* varied with seed source, reflecting genetic variability and environmental adaptation across the savannah eco-regions of Nigeria. For *T. indica*, the mean germination percentage also varied significantly among provenances. The analysis of variance (ANOVA) for Mean Germination Time (MGT) among the three provenances showed no significant difference ($p > 0.05$). The F-value (0.74) and corresponding probability value of 0.51 indicate that provenance did not significantly influence mean germination time. Similarly, the replication effect was also not significant ($F = 0.87$; $p = 0.52$). Although differences were not statistically significant, Funtua exhibited the longest mean germination time, while Nguru recorded the shortest. The Least Significant Difference (LSD) test at the 5% level showed that there were no significant differences among the provenances, although slight variations were observed. The mean germination times were 19.22 days for Funtua, 20.90 days for Morro, and 21.62 days for Nguru. Based on the grouping, Funtua (b) was statistically different from Nguru (a), while Morro (ab) was intermediate and not significantly different from either of the two. This indicates that Nguru seeds exhibited slightly longer Mean Germination Times than Funtua seeds, with Morro showing intermediate performance. The observed variation in Mean Germination Time (MGT) among the provenances suggests that genetic or environmental factors at the seed source locations may have influenced seed dormancy and germination behavior.

Early Growth of *Parkia biglobosa* and *Tamarindus indica* at 4WAT

For *Parkia biglobosa*, Morro provenance recorded the highest plant height (10.00 cm), girth (0.35 cm), and number of leaves (18.49), while Nguru generally recorded the lowest values. Funtua showed intermediate performance. The superior performance of Morro provenance suggests greater vigor and possibly better adaptation of that population to nursery conditions. According to Leakey (2014), early seedling vigor in indigenous fruit trees is often linked to the genetic quality of the seed source and maternal environmental effects. The reduced growth performance observed in Nguru provenance may reflect adaptation to harsher climatic conditions in its native environment. Trees from drier zones often exhibit conservative growth strategies, allocating more resources to stress tolerance than to rapid early biomass accumulation (Taiz *et al.,* 2015).

Similarly, *Tamarindus indica* seedlings from Morro provenance recorded the highest plant height (10.76 cm), girth (0.32 cm), number of leaves (19.01), and number of branches (3.96), while Nguru consistently recorded the lowest growth values. These findings are consistent with previous reports that *T. indica* exhibits significant variability in early growth performance across ecological zones (El-Siddig *et al.,* 2006). Early growth differences among provenances are often attributed to inherent genetic variability and adaptive differentiation shaped by long-term environmental

pressures (White *et al.,* 2007). The higher number of branches recorded in Morro provenance is particularly important, as branching influences canopy architecture and future productivity. According to Lambers *et al.* (2008), early vegetative growth patterns can determine long-term competitive ability and biomass accumulation.

Both species exhibited a similar trend, with Morro provenance performing best, followed by Funtua, while Nguru showed comparatively lower growth performance. This consistent pattern across species strengthens the argument that provenance origin significantly influences early developmental traits. The results support the concept that populations from more favorable ecological zones tend to express higher growth potential under nursery conditions. However, it is important to note that slower-growing provenances may possess adaptive traits such as drought tolerance, which could be advantageous under field conditions.

Early Growth of *P. biglobosa* and *T. indica* at 8 WAT

The results at 8 weeks after transplanting revealed significant ($p \leq 0.05$) differences among provenances for plant height, stem girth, number of leaves, and number of branches in both *P. biglobosa* and *T. indica*. This indicates that provenance influence on early growth persisted beyond the initial establishment phase. Provenance-based variation in seedling growth traits is widely recognized in forest genetics and is primarily attributed to genetic differentiation, local adaptation, and genotype–environment interactions (Zobel & Talbert, 1984; White *et al.,* 2007).

Conclusion

Based on the findings of this study, it can be concluded that both genetic factors (species), provenance-related variation reflecting genetic differentiation and environmental adaptation significantly influence fruit quality, seed germination, and early growth performance of *P. biglobosa* and *T. indica* in the savannah eco-region of Nigeria. Morro provenance consistently demonstrated superior performance across fruit and growth traits, indicating high reproductive and vegetative potential. Nguru provenance, although less productive in fruit and early growth traits, may harbor important drought-adaptive traits. The observed species × provenance interactions highlight the importance of considering species-specific responses in tree improvement programs. Provenance selection is therefore critical for tree domestication, seed source selection in nursery production, tree improvement programmes, agroforestry development, and sustainable management of indigenous fruit trees in the Nigerian savannah.

References

Abaje, I. B., Tukura, B.A., & Isma'il, M. (2024). Location Analysis of Public Water Facilities in Funtua Town, Katsina State, Nigeria*. Sokoto Journal of the Social Sciences*, 14(1).

Adebisi, M. A., Olasunkanmi, O. J., & Ajala, M. O. (2017). Influence of seed coat characteristics on water uptake and germination of some tropical forest tree seeds. *Journal of Agricultural Science and Environment,* 17(1), 1–12.

Adedire, C. O., & Ajayi, T. S. (1996). Assessment of the insecticidal properties of some plant extracts as grain protectants against the maize weevil *Sitophilus zeamais Motschulsky*. *Nigerian Journal of Entomology*, 13, 56–64.

Adio, A. A., Salisu, A O., Akanbi-Gada, M.A., & Najeemdeen, B. A. (2022). Effects of Charcoal Production on Soil Physicochemical Properties in Moro Local Government Area of Kwara State, Nigeria. *Journal of Environmental Protection*, 13(2), 221–236.

Ahmed, M., Gungula, D. T., & Tame, V. T. (2024). Assessment of pre-sowing treatments on germination and early growth of tamarind (*Tamarindus indica* L.) in Kano State, Nigeria. *Journal of Agricultural Science and Practice,* 9(1), 12–20.

Ajayi F. A., Egbewole Z. T., Haruna, I. M., Jayeoba, O. J., Bala, L. W., Solomon, S. M. & Rotowa, O. J. (2017). Susceptibility of Some Servicing Wood Species to Subterranean Termites in Lafia, Nasarawa State, Nigeria. *International Journal of Applied Research and Technology*. 6(8): 126 – 135.

Akinnifesi, F. K., Leakey, R. R. B., Ajayi, O. C., Sileshi, G., Tchoundjeu, Z., Matakala, P., & Kwesiga, F. R. (Eds.). (2008). *Indigenous Fruit Trees in the Tropics*: Domestication, Utilization and Commercialization. World Agroforestry Centre (ICRAF) and CAB International Publishing.

Armenteras, D., Cabrera, E., Rodríguez, N., and Retana, J. (2013). National and regional determinants of tropical deforestation in Colombia. Regional Environmental Change, 13(6), 1181e1193.

Carol, U., Colin, R. & John, W.(2005). Trees. Dorling Kindersley Limited, London. 360p.

Dawit, M., Neupane, C., Pereira, M., Koirala, A., & Walsh, K. B. (2023). Fruit sizing in orchards: A review from caliper to machine vision with deep learning. *Horticulturae*, 9(5), 571.

Dida, M. M., Thagana, W. M., & Kahiu, N. G. (2016). Fruit traits variation among provenances of *Tamarindus indica* L. in Kenya. *International Journal of Agronomy and Agricultural Research,* 8(3), 110–121.

El-Siddig, K., Gunasena, H. P. M., Prasad, B. A., Pushpakumara, D. K. N. P., Ramana, K. V. R., Vijayanand, P., & Williams, J. T. (2006). Tamarind, *Tamarindus indica* L. Southampton Centre for Underutilised Crops, Southampton, UK

Entage, B. (2004).Seed source variation and its importance in plantation forestry. *Forest Ecology and Management,* 197(1–3), 15–23.

Falemara, B. C., Nwadike, C., and Obashola, E. O.(2014). Pre-germination and dormancy response of *Adesonia digitata* L. seeds to pre-treatment techniques and growth media. *European Journal of Agriculture and Forestry Research,* 2(1), 31-41.

Gbegbelegbe, S., Wanjiku, J., Gelan, A., Karugia, J., & Massawe, S. (2011). Challenges and prospects of tracking informal cross-border trade in the COMESA region. Paper presented at Tropentag 2011: Development on the Margin, Bonn, Germany.

Gebauer, J., El-Siddig, K., Salih, A. A., & Ebert, G. (2002). *Tamarindus indica* L. fruit length variation: Evidence for domestication in Sudan? Proceedings of the Deutscher Tropentag, Kassel, Germany.

Ijeomah H M, Aiyeloja AA (2010). Ecotourism: An instrument for combating the Degradation of renewable natural resources.Degradation H M, Aiyeloja A A (eds) Practical Issues in Forest and Wildlife Resources Management. Green canopy consultants, Choba, Porthacourt, Nigeria, 625 p

Kanowski, J., Catterall, C.P., Wardell-Johnson, G.W., Proctor, H. & Reis, T. (2003). Development of forest structure on cleared rainforest land in eastern Australia under different reforestation methods. *Forest Ecology and Management* 183: 265–280.

Lambers, H., Chapin, F. S., III, and Pons, T. L. (2008). *Plant Physiological Ecology* (2nd ed.). Springer-Verlag.

Leakey, R. R., Tchoundjeu, Z., Smith, R. I., Munjuga, M., & Kalinganire, A. (2012). Agroforestry tree domestication. Tropical Forestry Handbook, 339–367.

Malik, A., Muhammad, T., Muhammad, M., & Faisal, M. (2024). Analysis of interrelationships between pod length and seed yield traits in leguminous tree species—Frontiers in Plant Science, 15, 1361771.

Mohammed, A., Ayanwale, A. B., & Olayode, O. O. (2013).Economic importance and conservation challenges of indigenous tree species in the savannah region of Nigeria. *Journal of Agricultural Science,* 5(4), 45–52.

Moles, A. T., Warton, D. I., & Westoby, M. (2005). Seed size and plant strategy across the whole life cycle. Oikos, 110(1), 91–105.

NIMET, 2010. Nigerian Meteorological Agency, Lafia Station. Report.

Odebiyi, J. A., Bada, S. O., and Alao, J. S. (2004). Germination, growth, and biomass production of *Parkia biglobosa* (Jacq.) R.Br. ex G.Don*. Nigerian Journal of Forestry,* 34(1), 20-27.

Olamiju, O., Adewusi, H. G., & Omidiran, B. A. (2013). Effect of pre-sowing treatments on the germination and early growth of *Parkia biglobosa* (Jacq.) R.Br. ex G.Don. *Journal of Research in Forestry, Wildlife and Environment,* 5(2), 22–33.

Omi, S. K., Oladele, O. N., & Adegeye, A. O. (2020). Seed quality and physiological adaptation of *Parkia biglobosa* (Jacq.) R.Br. ex G.Don across different ecological zones in Nigeria—*International Journal of Forestry Research*, 2020.

Ouedraogo, A., & Thiombiano, A.(2012). Regeneration patterns of four threatened tree species in the Sudanian savannas of Burkina Faso. Agroforestry Systems, 86(1), 35–48.

Oyedeji, S., Somanin, O.J., & Odiwe, A.I. (2021). Eco-evaluation of the nutrient dynamics of dry season litterfall in Guinea Savannah, North-Central Nigeria. *Nigerian Journal of Basic and Applied Sciences,* 29(1), 12–24.

Ringim, A. S., Zungum, I. U., Ibrahim, S., & Ahmed, B. (2015). Characteristics and Socio-Economic Activities of Local Communities Living Along the Nguru Wetlands, Yobe State, Nigeria. *Journal of Applied Sciences and Environmental Management,* 19(2).

Sacandé, M., & Clethero, C. (2007). *Parkia biglobosa* (Jacq.) R.Br. ex G.Don Seed Leaflet No. 124—Forest and Landscape Denmark.

Saeed, M., Ahmad, S., & Ghafoor, A. (2023). Integrated characterization and physical properties of *Tamarindus indica* L. fruit using digital measurement tools. Foods, 14(14), 2521.

Shu X, Yang X, Yang Z (2012). Variation in Seed and Seedling Traits among Fifteen Chinese Provenances of *Magnolia officinalis*. Not. Bot. Hortic. Agrobot. 40(2):274–283.

Somanin, O.J. Oyedeji, S., & Odiwe, A.I. (2023). Nutrient dynamics of dry-season litter flux from dominant tree cover in a tropical savannah ecosystem. *Journal of Applied Science and Environmental Management,* 27(4), 685–693.

Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. (2015). Plant Physiology and Development (6th ed.). Sinauer Associates, Inc.

Teklehaimanot, Z. (2004). Exploiting the potential of agroforestry trees: *Parkia biglobosa* (Jacq.) R.Br. ex G.Don and *Vitellaria paradoxa* in Sub-Saharan Africa. Agroforestry Systems, 61(1), 207–220.

White, T. L., Adams, W. T., & Neale, D. B. (2007). Forest Genetics. CABI Publishing. [Source: SCIRPReference](https://www.scirp.org/reference/referencespapers?referenceid=3274287)

Wunderle, J.M.J. (1997). The role of animal seed dispersal in accelerating native forest regeneration on degraded tropical lands. *Forest Ecology and Management* 99: 223–235.

Yakubu, F. B., Oboho, E. G., & Aghimien, E. V. (2018). Provenance variation in seed germination and seedling growth of *Parkia biglobosa* (Jacq.) R.Br. ex G.Don. *Journal of Forestry Research and Management*, 15(2), 143–155.

Zobel, B. J., & Talbert, J.T. (1984). *Applied Forest Tree Improvement*. John Wiley and Sons.

ISTF-NIG 2026

NON-TIMBER FOREST PRODUCTS IN NORTHERN NIGERIA: AN ASSESSMENT OF ABUNDANCE IN TOFA LOCAL GOVERNMENT AREA, KANO STATE, NIGERIA

[1]Abdulrashid Inuwa, [1]Ridwanu Mukhtar Bunza, [2]Halliru Bilyaminu [1]Adamu Abubakar, [1]Bello Rufa'i Wali, [1]Jibril O Abannikanda, [1]Mohammad Umar, [1]Mahmud Sarki, [1]Abubakar Sa'id Usman, [1]Barira Harazimi and [1]Yusuf Ibrahim Maigora

[1]Department of Forestry and Wildlife Management, Bayero University, Kano. Nigeria
[2]Department of Forestry and Wildlife Management, ADUSTECH, Wudil
Corresponding author: inuwaabdulrashid@gmail.com, +2348141961957

Abstract

Non-timber forest products (NTFPs) constitute critical ecological and socioeconomic resources that sustain rural livelihoods across the semi-arid landscapes of northern Nigeria. This study assessed the socio-demographic characteristics of resource users, patterns of NTFPs utilization, and the diversity of commonly harvested species in the Tofa Local Government Area of Kano State. Data were collected from 120 respondents using structured questionnaires, and descriptive statistics were used for analysis. The demographic profile revealed that the majority of respondents were in the economically active, knowledge-intensive age groups, with individuals aged 46–55 years accounting for 43.4% and those aged 36–45 years accounting for 28.3%. Male respondents dominated the sample (86.7%). Educational attainment was generally low, with 58.3% possessing primary Education. Farming emerged as the principal occupation (45.8%). The findings indicate a high level of familiarity with NTFPs among respondents (68.3%), although a notable proportion (20.9%) reported limited awareness. NTFPs harvesting was largely periodic, with weekly (35.0%) and monthly (34.2%) collection being the most common practices. Woodland ecosystems constituted the primary harvesting zones (61.7%). Seasonal availability was strongly associated with rainfall patterns, with 75.8% of respondents identifying the rainy season as the period of peak NTFPs abundance. Food provision represented the dominant utilization pathway (74.2%), followed by medicinal uses (21.7%). The study documented a diverse assemblage of economically and nutritionally valuable species, including *Adansonia digitata*, *Parkia biglobosa*, *Faidherbia albida*, *Vitellaria paradoxa*, *Moringa oleifera*, and *Tamarindus indica*, as well as other fruit-bearing and multipurpose species. These findings highlight the central role of indigenous tree resources in supporting food security, traditional healthcare systems, and livelihood resilience in semi-arid agroecosystems. Strengthening sustainable management and conservation of these species is therefore essential for maintaining ecosystem services and sustainable rural livelihoods.

Keywords: Non-timber, Forest, Products, Abundance

Introduction

Non-timber forest products (NTFPs) are widely recognized as critical to rural livelihoods and food security, especially in sub-Saharan Africa. In Nigeria, households derive substantial income from NTFPs (Jimoh *et al.*, 2013), and protected-area studies show 68% of Kano communities earn 20–60% of their income from NTFPs. Ideally, understanding the abundance of NTFPs would enable sustainable management and livelihood support. In an optimal scenario, local resource managers and policymakers would have detailed inventories of key NTFP species and their availability, supporting conservation and community development. In reality, Tofa's NTFP resources are virtually undocumented. Surveys in adjacent areas (such as Falgore Game Reserve) reveal a heavy

reliance on firewood, fruit, nuts, and medicinal herbs, but those contexts have more forest. For Tofa's landscape of farmlands and woodlots, the NTFP baseline is unknown. The lack of data means potential over-exploitation could go unnoticed, and opportunities (for instance, non-fuelwood uses of Vitellaria or Parkia) remain unquantified. As the FAO (2012) notes, the lack of systematic NTFP data is a major barrier to recognizing these resources' role in livelihoods. Consequently, there is a risk that NTFPs are overlooked in local development planning, despite their proven importance elsewhere.

Previous studies in northern Nigeria have documented the use of NTFPs and their socioeconomic importance, but they have not measured abundance in farmed savanna areas. Suleiman *et al*. (2017) conducted a rigorous household survey near Kano's Falgore Reserve and confirmed high NTFP dependency (NTFP income = 20–60% for 68% of households). Fajobi and Fingesi (2018) reported that NTFPs were "abundant" and collected year-round in nearby Niger State communities, with *Vitellaria paradoxa* and *Parkia biglobosa* being the most lucrative species. These studies, however, focus on forest-adjacent or more vegetated zones. No published work has assessed which NTFP species occur in a deforested, predominantly agricultural LGA like Tofa, nor their population densities. Mokwa and Kano data highlight that NTFPs play year-round roles in rural diets and incomes, yet Tofa's status remains unknown. While the importance of NTFPs is well documented (FAO, 2012; Suleiman *et al.*, 2017), actual surveys of NTFPs' abundance in northern Nigerian farmland are lacking. This study will fill that gap by inventorying NTFP species and quantifying their abundance in the fields and fallows of Tofa LGA. Hence, the study aims to provide baseline data for resource management and to inform local development strategies that integrate NTFP utilization.

Methodology

Description of Study Area

Tofa is a Local Government Area (LGA) in Kano State, Nigeria. It has an area of 202 km^2 and a population of 97,734 according to the 2006 census. The LGA's headquarters are in the town of Tofa, located at 12.05°N 8.27°E. The postal code of the area is 701. The LGA comprises several towns and villages, such as Dokadawa, Langel, Yanoko, Lambu, Kadawa, Doka, Ginsawa, and Kazardawa. The LGA is predominantly occupied by members of the Hausa/Fulani ethnic group, who speak the Hausa language and practice Islam. Some notable landmarks in Tofa LGA include Gerawa Primary School and the Kofar Ruwa Iron Rod MarketRod (KNSG, 2022).

Sampling Techniques

A purposive sampling technique was used to select a community within the Tofa Local Government Area for the study. A stratified random sampling technique was used to select participants for interviews and surveys. Stratification was based on demographic factors, such as age, gender, occupation, and residence duration in Tofa LGA, to ensure a diverse representation of the community. A total of 120 respondents were included in the sample, and a structured questionnaire was administered.

Data Collection

A structured questionnaire was administered to each respondent through individual and focus group discussions. An interview with the respondent was conducted to supplement the

questionnaire data. The primary data were collected using a structured questionnaire. The questionnaire was designed to collect the following types of information: demographic information; identification and Utilization of NTFPs; abundance and Distribution of NTFPs; socioeconomic importance of NTFPs; and Management and Conservation of NTFPs.

Data Analysis

Simple descriptive statistics, such as percentages, frequency distribution tables, and mode, were used to achieve the objectives using IBM SPSS V16 x 86V.

Results and Discussions

Table 1 presents the demographic characteristics of the respondents involved in the study. A total of 120 respondents participated in the survey. The age distribution shows that the majority of respondents were in the middle- to older-adult age groups. Specifically, respondents aged 46–55 years constituted the largest proportion (43.4%), followed by those aged 36–45 years (28.3%)**.** Younger respondents were relatively fewer, with 15.0% in the 26–35 years age group and 13.3% in the 18–25 years age group. This distribution suggests that most respondents were mature individuals with likely considerable experience and knowledge of local resources and livelihood activities.

Table 2 presents the respondents' knowledge, collection patterns, sources, seasonal availability, and uses of non-timber forest products (NTFPs) in the study area. The results indicate that a large proportion of respondents possess considerable familiarity with NTFPs. Specifically, 68.3% of respondents reported being very familiar with NTFPs, while 10.8% reported being somewhat familiar. However, 20.9% of the respondents stated that they were not familiar with NTFPs at all, suggesting that although awareness is generally high, a notable proportion of the population still has limited knowledge of these resources.

ISTF-NG 2026

Table 1: Demographic Characteristics of the Respondents

Variable	Frequency	Percentages
Age		
18-25	16	13.3
26-35	18	15.0
36-45	34	28.3
46-55	52	43.4
Gender		
Male	104	86.7
Female	16	13.3
Education		
Primary	70	58.3
Secondary	36	30.0
Tertiary	14	11.7
Marital Status		
Single	87	72.5
Married	33	27.5
Household size		
1-5	28	23.4
6-10	42	35.0
11-15	50	41.6
Total	120	100.0
Languages		
Hausa	120	100.0
Primary occupation		
Farmer	55	45.8
Trader	33	27.5
Artisan/craftsperson	14	11.7
Government employee	15	12.5
Student	3	2.5

Source: Field Survey (2023)

Table 2: Identification and Utilization of NTFPs

Variable	Frequency	Percentages
Familiarity with NTFPs		
Very familiar	82	68.3
Somewhat familiar	13	10.8
Not familiar at all	25	20.9
Frequency of collecting or using NTFPs		
Daily	10	8.3

IST-NIG 2026

Table 2: Identification and Utilization of NTFPs

Variable	Frequency	Percentages
Weekly	42	35.0
Monthly	41	34.2
Rarely	27	22.5
Areas of the forest where NTFPs were collected from		
Woodland areas	74	61.7
Riverbanks	27	22.5
Specific tree types	19	15.8
Seasonal abundance of NTFPs		
Rainy season	91	75.8
Dry season	15	12.5
No specific season	14	11.7
Primary purposes for using NTFPs		
Medicinal purposes	26	21.7
Food consumption	89	74.2
Craft-making	5	4.1
Total	120	100.0

Sources: Field Survey (2023)

Table 3 below presents the various non-timber forest products (NTFPs) commonly used or collected in the forests of Tofa Local Government Area, highlighting their botanical names, common names, local Hausa names, and the specific plant parts used. The results reveal a wide range of plant species that contribute significantly to local livelihoods, nutrition, and traditional practices in the area.

Table 3: NTFPs Commonly Used or Collected From Tofa Forests

Botanical Name	Common Name	Local Name	Part Use
Adansonia digitata	Baobab	Kuka	Leaves
Pakia biglobossa	Locus Bean	Daruwa	Seeds
Faidherbia albida	Ana tree	Gawo	Fruits and Leaves
Tamarindus indica	Tamarind	Tsamiya	Leaves and seeds
Acacia nilotica	Acacia	Bagaruwa	Fruits, Gum, leaves

ISTF-NIG 2026

Diospyros misipiliformis	Ebony	Kanya	Fruits
Honey	Honey	Zuma	Bye, product of the bee
Vitellaria paradoxa	Shea butter	Kadanya	Shea butter
Mangifera indica	Mango	Mangoro	Fruits
Moringa oleifera	Moringa	Zogale	Leaves, seeds and oil
Ziziphus mauritiana	Indian Jujube	Magariya	Fruits
Citrus sinensis	Orange	Lemu	Fruits and Leaves
Phoenix dactylifera	Date	Debino	Fruits
Piliostigma reticulatum	Camel foot	Kargo	Fruits and Leaves

Source: Field Survey (2023)

Discussion

Demographic characteristics of the respondents

The demographic profile of respondents in this study provides important insights into the socioeconomic context that shapes the utilization and management of natural resources in the Tofa Local Government Area. The predominance of respondents in the 36–55-year age range suggests that middle-aged and older adults are the primary custodians of knowledge about local environmental resources and livelihood practices. This finding aligns with earlier studies across West African rural landscapes, which indicate that ecological knowledge, particularly regarding forest resources and non-timber forest products (NTFPs), is often concentrated among older members of the community due to their longer engagement with farming and traditional land-use systems (Shackleton & Shackleton, 2004; Suleiman *et al.,* 2017). Younger individuals were relatively underrepresented in the survey, which may reflect increasing rural–urban migration among youth in northern Nigeria in search of Education and employment opportunities. Such demographic shifts have been widely documented and are often associated with the gradual erosion of traditional ecological knowledge systems (Nkem *et al.*, 2010).

The male dominance observed among respondents is also consistent with findings reported in several studies on forest resource utilization in northern Nigeria and other parts of sub-Saharan Africa. Men often occupy more visible roles in activities such as farming, woodland management, and resource harvesting, which frequently position them as primary respondents in resource-based surveys (Boffa, 1999; Arnold & Pérez, 2001). However, the relatively low participation of women in this study contrasts with research suggesting that women play critical roles in the collection, processing, and marketing of many NTFPs, particularly those related to household nutrition and traditional medicine (Shackleton *et al*., 2011). The limited representation of women may therefore reflect sociocultural norms that restrict women's participation in formal surveys or public decision-making processes rather than their actual level of involvement in resource use. The educational profile of respondents shows that most participants had only primary or secondary Education, with relatively few having tertiary qualifications. This pattern is characteristic of many rural

communities in developing countries where educational infrastructure and economic resources limit access to higher Education (FAO, 2014). Similar educational patterns have been documented in studies of rural livelihoods and agroforestry systems in northern Nigeria (Suleiman *et al.,* 2017). While basic literacy may support knowledge exchange and adoption of improved land management practices, low levels of advanced Education can constrain access to technical information, extension services, and modern resource management strategies.

The household structure observed in this study further reflects the traditional socioeconomic organization of rural communities. The predominance of large household sizes, particularly those with 11–15 members, mirrors patterns reported in other agrarian societies in West Africa where extended family systems remain common (Nkem *et al.,* 2010). Large households often provide labor for farming, resource collection, and other livelihood activities, thereby strengthening household resilience in resource-dependent economies. However, such demographic pressure can also increase demand for land and forest resources, potentially contributing to overexploitation if sustainable management practices are not maintained. The finding that all respondents identified Hausa as their primary language underscores the cultural homogeneity of the study area and reflects Hausa's dominance as the lingua franca across northern Nigeria. In many rural communities, indigenous knowledge of plant species, seasonal cycles, and resource-harvesting techniques is transmitted orally through a shared language and cultural framework (Shackleton & Shackleton, 2004).

Identification and Utilization of NTFPs

The findings of this study reveal a relatively high level of familiarity with non-timber forest products (NTFPs) among respondents, with more than two-thirds reporting being very familiar with these resources. This pattern reflects the central role that NTFPs play in rural livelihoods across much of sub-Saharan Africa, where communities have historically relied on forest-derived products for food, medicine, and income. Similar levels of awareness have been reported in studies conducted in other parts of West Africa, where indigenous knowledge systems enable local populations to identify, harvest, and utilize a wide range of plant and animal resources (Shackleton *et al.,* 2011; Suleiman *et al.*, 2017). The relatively high familiarity observed in this study, therefore, reinforces the argument that NTFPs remain embedded in traditional livelihood systems. However, the presence of a notable minority of respondents who reported little or no familiarity with NTFPs suggests possible shifts in livelihood patterns or generational differences in ecological knowledge. Increasing rural–urban migration, changes in dietary preferences and reduced reliance on forest-based livelihoods may contribute to declining knowledge of NTFPs among some segments of the population.

The frequency of NTFP collection reported by respondents further underscores the importance of these resources and reflects patterns of sustainable or opportunistic harvesting. The predominance of weekly and monthly collection suggests that NTFPs are generally harvested as complementary resources rather than as primary daily subsistence products. This finding aligns with research by Angelsen *et al.* (2014), who observed that forest products often serve as supplementary livelihood resources that households access periodically depending on need, availability, and seasonal conditions. The relatively small proportion of respondents engaging in daily collection may indicate that most NTFPs in the study area are not staple commodities requiring constant

harvesting, but rather seasonal or opportunistic resources integrated into broader livelihood strategies. The identification of woodland areas as the principal source of NTFPs is also consistent with ecological patterns documented in savanna landscapes of northern Nigeria and the wider Sahel region. Woodlands often harbor a diverse array of multipurpose tree species that provide edible fruits, leaves, seeds, gums, and medicinal materials (Boffa, 1999). The lower reliance on riverbanks and specific tree stands may reflect the spatial distribution of vegetation in the semi-arid environment, where woodland patches often represent the most productive ecological zones for NTFPs availability. Similar findings have been reported across the Sudan savanna, where woodland ecosystems serve as critical reservoirs of biodiversity and livelihood resources (FAO, 2014).

Seasonality also emerged as a key factor influencing NTFP availability, with the majority of respondents indicating that resources are most abundant during the rainy season. This pattern is ecologically plausible, as increased rainfall promotes vegetative growth, flowering, and fruiting in many savanna tree species. Previous studies have similarly documented strong seasonal variation in NTFPs production, particularly for edible fruits and leafy vegetables that become widely available during periods of higher rainfall (Shackleton & Shackleton, 2004). Nevertheless, the small proportion of respondents reporting dry-season availability highlights the presence of certain species capable of producing harvestable products year-round, suggesting an important buffering role for NTFPs during periods of food scarcity. The predominance of food consumption as the primary use of NTFPs in this study reinforces the widely recognized role of forest resources in enhancing rural food security. Edible fruits, leaves, and seeds from wild or semi-domesticated species often provide essential micronutrients and dietary diversity in rural households (FAO, 2014). The substantial proportion of respondents who use NTFPs for medicinal purposes further underscores the continued reliance on traditional healthcare systems, particularly in rural areas where access to formal medical facilities may be limited. In contrast, the relatively low use of NTFPs for craft-making suggests that their economic utilization in artisanal industries may be less developed in the study area compared with other regions.

NTFPs Commonly Used or Collected From Tofa Forests

The diversity of non-timber forest products (NTFPs) identified in this study reflects the ecological and socioeconomic importance of indigenous tree species within rural landscapes of northern Nigeria. The prominence of species such as *Adansonia digitata*, *Parkia biglobosa*, *Faidherbia albida*, and *Tamarindus indica* highlights the enduring role of multipurpose savanna trees in supporting household nutrition, traditional medicine, and local livelihoods. These findings are consistent with earlier studies across the West African savanna, which emphasize the centrality of indigenous tree species in traditional agroforestry and parkland systems (Boffa, 1999; Bayala *et al.*, 2014). In particular, *Parkia biglobosa* and *Adansonia digitata* have been widely documented as key food resources, providing protein-rich seeds and nutrient-dense leaves that contribute significantly to rural diets (Lovett & Haq, 2000; Teklehaimanot, 2004). The continued reliance on these species in the present study therefore reinforces their ecological resilience and cultural importance in local food systems.

The presence of multipurpose species such as *Acacia nilotica*, *Diospyros mespiliformis*, and *Piliostigma reticulatum* further reflects the multifunctional nature of NTFP species in savanna ecosystems. These trees provide a range of products, including edible fruits, gums, fodder, and medicinal materials, thereby enhancing their value to rural communities. Similar patterns have been reported in studies of agroforestry parklands in the Sahel and Sudan savanna zones, where farmers intentionally conserve or protect valuable tree species within cultivated landscapes (Boffa, 1999; Bayala *et al.,* 2014). Such management practices contribute to the persistence of biodiversity within agricultural systems while simultaneously supporting rural livelihoods. The identification of honey as an important NTFP also underscores the ecological linkages between forest vegetation and apiculture. Forest trees provide nectar, pollen, and nesting sites that are essential to bee populations, which in turn support honey production. Previous research has similarly emphasized the importance of forest ecosystems for sustaining apiculture-based livelihoods in rural Africa (FAO, 2014). The inclusion of honey on the list of commonly used NTFPs suggests that forest conservation may indirectly support income generation through beekeeping.

Several economically significant species identified in the study, including *Vitellaria paradoxa* and *Moringa oleifera*, further illustrate the nutritional and commercial potential of NTFPs. *Vitellaria paradoxa* (shea tree) is widely recognized for producing shea butter, which serves as both a household food product and an internationally traded commodity (Lovett & Haq, 2000). Similarly, *Moringa oleifera* has gained global attention for its high nutritional value and medicinal properties. The presence of these species in the study area suggests opportunities to expand local value chains and improve rural incomes through sustainable NTFP commercialization. Fruit-bearing species such as *Mangifera indica*, *Ziziphus mauritiana*, *Citrus sinensis*, and *Phoenix dactylifera* also contribute significantly to dietary diversity and seasonal food availability. Their inclusion reflects the integration of both indigenous and introduced species within local resource-use systems. This finding is consistent with research indicating that rural communities often manage mixed assemblages of native and cultivated species to diversify livelihood resources and enhance resilience to environmental variability (Teklehaimanot, 2004).

Conclusion

Overall, the demographic profile indicates that the respondents were predominantly middle-aged male farmers with primary Education, relatively large households, and a shared Hausa cultural background, characteristics typical of rural communities in northern Nigeria. These demographic features are important for understanding local knowledge, resource-use patterns, and the socioeconomic context of non-timber forest product utilization in the study area. Most respondents are familiar with these resources and use them periodically, primarily sourcing them from woodland areas. A diverse range of plant species contributes to the availability of NTFPs in Tofa's forests. Most of these species produce edible fruits, leaves, seeds, gums, or oils that play crucial roles in food security, traditional medicine, and local economic activities. This diversity highlights the ecological and socioeconomic importance of forest resources in sustaining rural livelihoods within the study area.

Recommendations

Sustainable harvesting practices need to be implemented to ensure the long-term availability of NTFPs. This includes promoting regeneration and minimizing overexploitation.NTFP products and markets need to diversify to reduce dependence on specific products and mitigate the impact of fluctuating market demand.

References

Angelsen, A., Jagger, P., Babigumira, R. (2014). Environmental income and rural livelihoods: A global-comparative analysis. *World Development*, 64, S12–S28.

Arnold, J. E. M., & Pérez, M. R. (2001). Can non-timber forest products match tropical forest conservation and development objectives? *Ecological Economics*, 39(3), 437–447.

Bayala, J., Sanou, J., Teklehaimanot, Z., Ouedraogo, S., &Kalinganire, A. (2014). Parklands for buffering climate risk and sustaining agricultural production in the Sahel of West Africa. *Current Opinion in Environmental Sustainability*, 6, 28–34.

Boffa, J. M. (1999). *Agroforestry parklands in sub-Saharan Africa*. FAO Conservation Guide 34. Food and Agriculture Organization of the United Nations

Fajobi, E. A., &Fingesi, U. I. (2018). Contribution of non-timber forest products (NTFPs) to the livelihood of people in Mokwa Local Government Area, Niger State, Nigeria. World News of Natural Sciences, 21, 77–89.

FAO (2012). The State of the World's Forests 2012 Food and Agriculture Organization of the United Nations, Rome.

FAO. (2014). *State of the World's Forests: Enhancing the socioeconomic benefits from forests*. Food and Agriculture Organization of the United Nations, Rome.

Jimoh, S., Amusa, T., & Azeez, I. (2013). Population distribution and threats to sustainable management of selected non-timber forest products in tropical lowland rainforests of Southwestern Nigeria. *Journal of Forest Research*, 24(1), 75 – 82. doi:10.1007/s11676-013-0327-z

Lovett, P. N., & Haq, N. (2000). Evidence for anthropic selection of the shea nut tree (*Vitellaria paradoxa*). *Agroforestry Systems*, 48, 273–288.

Nkem, J., Santoso, H., Murdiyarso, D., Brockhaus, M., &Kanninen, M. (2010). Using tropical forest ecosystem goods and services to plan climate change adaptation, with implications for food security and poverty reduction. *SAT eJournal*, 4(1), 1–23.

Shackleton, C. M., & Shackleton, S. E. (2004). The importance of non-timber forest products in rural livelihood security and as safety nets: A review of Evidence from South Africa. *South African Journal of Science*, 100(11–12), 658–664.

Shackleton, S., Delang, C., & Angelsen, A. (2011). From subsistence to safety nets and cash income: exploring the diverse values of non-timber forest products for livelihoods and poverty alleviation. In S. Shackleton, C. Shackleton, & P. Shanley (Eds.), *Non-timber forest products in the global context* (pp. 55–81). Springer.

Suleiman, M. S., Wasonga, V. O., Mbau, J. S., Suleiman, A., & Elhadi, Y. A. (2017). Non-timber forest products and their contribution to households' income around Falgore Game Reserve in Kano, Nigeria. *Ecological Processes*, 6(1), 1–14.

Teklehaimanot, Z. (2004). Exploiting the potential of indigenous agroforestry trees: *Parkia biglobosa* and *Vitellaria paradoxa* in sub-Saharan Africa. *Agroforestry Systems*, 61–62, 207–220.

ISTF NG 2026

WILD-HARVESTED NTFPS AS GENETIC RESERVOIRS: A SYSTEMATIC REVIEW OF IRVINGIA SPECIES AND THEIR ROLE IN CLIMATE RESILIENCE

JAYEOBA, Feyiropo Morenike; AGBO-ADEDIRAN, Adewale Opeyemi, OKON-AKAN, Omolabake Abiodun and LAWAL, Ibraheem Oduola

Federal College of Forestry, Ibadan.
Corresponding e-mail: Jayeoba78@gmail.com.

Abstract

Non-timber forest products (NTFPs) sustain rural livelihoods, support biodiversity, and contribute to food security; many are obtained from wild plant populations that harbor significant genetic diversity, making them valuable reservoirs for species improvement and climate resilience. *Irvingia* species, commonly known as African bush mango, are wild-harvested NTFPs valued for their edible fruits and kernels. These species play important roles in local diets, income generation and traditional agroforestry systems. However, commercialization, deforestation, and unsustainable harvesting threaten wild populations and genetic resources. This review examines *Irvingia* species as wild-harvested NTFP reservoirs of genetic diversity. A systematic review of the literature (2015-2025) was conducted across Google Scholar, Scopus, Web of Science, and other scientific databases, following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. A total of 86 studies were included, covering genetic analyses, phytochemical and pharmacological studies, ethnobotanical surveys, and conservation assessments. Molecular marker studies reveal moderate genetic diversity (e.g., Nei's gene diversity ≈0.117) and significant population structuring across West and Central Africa, with diversity hotspots in southern Nigeria and Cameroon, highlighting the importance of conserving wild germplasm. Phenotypic variation in fruit and kernel characteristics further underscores the potential of these species for tree improvement.
Additionally, phytochemical and pharmacological studies have identified bioactive compounds responsible for antimicrobial, antioxidant, anti-inflammatory, and anti-diabetic activities, reinforcing the medicinal significance of these species. However, increasing demand for bush mango kernels has intensified harvesting pressure, contributing to habitat degradation and potential genetic erosion. Integrating agroforestry and community-based management with genomic research could enhance conservation and sustainable utilization of *Irvingia* genetic resources for climate-resilient agriculture.
Keywords: Non-Timber Forest Products; Genetic Diversity; Climate-Resilience; *Irvingia* Species; Agroforestry; Germplasm Conservation

Introduction

Non-timber forest products (NTFPs), including fruits, seeds, and resins, provide vital nutrition, income, and medicine across tropical Africa. Beyond these provisioning roles, wild-harvested NTFPs serve as genetic reservoirs, harbouring high allelic diversity and wild germplasm essential for future crop domestication (Acquaah, 2015). By preserving critical phenotypic traits such as

increased fruit mass, high pulp-to-seed ratios, and precocity, these reservoirs provide the genetic toolkit needed to develop climate-resilient varieties, ensuring sustainable food security and ecosystem resilience (Alaje *et al*., 2025; Alowanou-Kélé *et al*., 2025). As climatic regimes shift, this wild genetic diversity becomes a strategic asset for plant resilience and for identifying chemical diversity that can lead to pharmacological discovery (Salgotra & Chauhan, 2023; Zhang & Batley, 2020). The genus *Irvingia* (Irvingiaceae) (particularly *Irvingia gabonensis* and *Irvingia wombolu*) is widely used across West Africa. The kernels, locally known as "ogbono" or "dika nut," are major culinary products in Nigeria, and various plant parts are used in traditional medicine. Wild and semi-domesticated trees coexist in agroforestry landscapes and remnant forests, making *Irvingia* a valuable model for examining how wild NTFP stands function as genetic reservoirs. Phenotypic surveys (Anegbeh *et al*., 2003) and genetic studies (Lowe *et al*., 2000; Jepskemboi, 2022) indicate substantial variation in fruit and kernel traits and measurable population structure, which gives evidence that wild provenances harbour allelic variation useful for breeding and possibly chemotypic diversity relevant to pharmacology. (Anegbeh *et al*., 2003; Alaje *et al*., 2025). This review synthesizes genetic, phytochemical, pharmacological, ecological and socioeconomic evidence to address four questions: What is the genetic diversity and population structure of wild *Irvingia* populations in Nigeria and neighbouring regions? How does phytochemical variation map onto genetic variation across populations? How do harvesting practices and market chains affect the conservation status of these genetic reservoirs? What priorities and interventions are needed to conserve wild NTFP genetic resources for climate resilience and pharmacological potential?

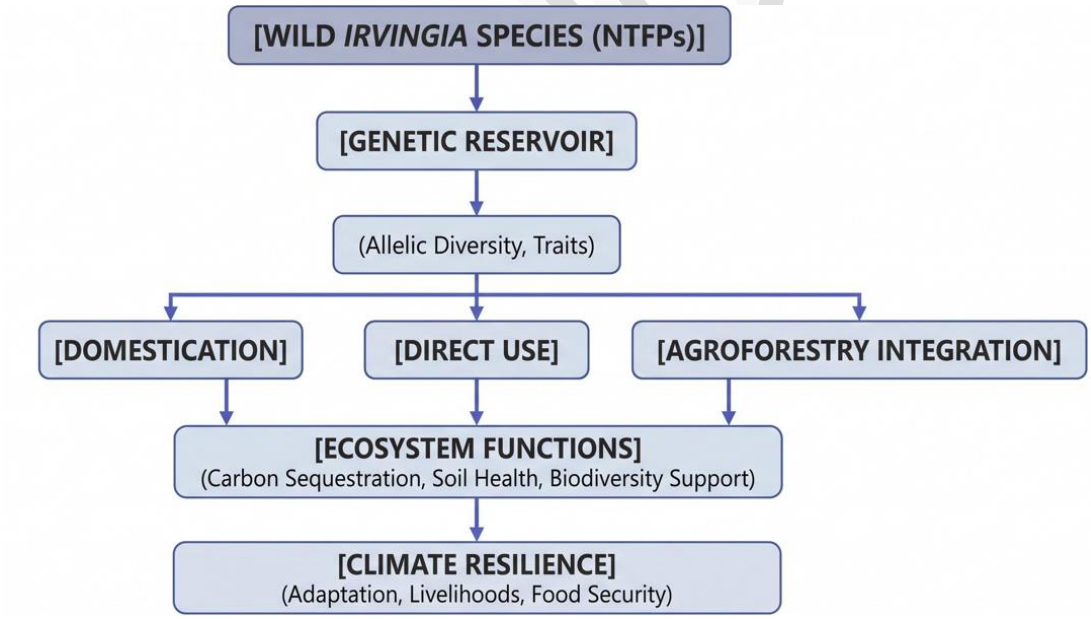


Figure 1: **Conceptual framework illustrating the role of wild Irvingia species as genetic reservoirs underpinning domestication, direct use, and agroforestry integration pathways, and their contributions to ecosystem functions and climate resilience. Adapted from Zimmerer et al. (2019) and FAO (2019)**

Materials and Methods

Data Extraction

A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) - aligned systematic search (Page *et al*., 2021) was conducted across multiple databases with relevant scientific studies, including PubMed/MEDLINE, Scopus, Web of Science, CAB Abstracts, African Journals Online (AJOL), Google Scholar, CIFOR-ICRAF repository, IITA repository, and GBIF for occurrence. The keywords used in the web search engines were, "Irvingia", "*Irvingia gabonensis", "Irvingia wombolu*", "bush mango", "ogbono", "genetic diversity", "population structure", "genomics", "phenotypic variation" "AFLP", "SSR", "DArTseq", "SNP", phytochem, metabolom, flavonoid, "tannin", "fatty acid", "pharmacolog", "antioxidant", "anti-inflammatory", wild-harvested NTFPs, "genetic reservoirs", "plant diversity conservation", "climate resilience", "conservation strategies", "sustainable utilization", "agroforestry", "domestication". Nonetheless, other phrases reflecting subjects of interest were used.

During the search process, the keywords were used in a variety of combinations, including synonyms, alternative terminologies, alternative spellings, related terms, and variations in Word endings. Boolean operators, viz., "AND", "OR", "-", "NOT", and "+", were used to combine and exclude terms when searching in Google and Google Scholar. Wildcard operators, viz., (*), (?), (~) and (!) were used when searching the databases. Topics explored include empirical genetic, phytochemical, pharmacological, ethnobotanical, or conservation studies involving *Irvingia* or NTFPs as genetic resources, among others; Nigerian data were prioritized; peer-reviewed articles, theses, and quality institutional reports. The search was conducted over a month and included references published up until December, 2025. Study quality was assessed based on sampling design, marker resolution, geographic coverage, and methodological transparency. Two independent reviewers screened all publications resulting from these searches; disagreements were resolved by consensus, duplicates were removed, and pertinent records were collated using Mendeley, a web-based bibliography database manager.

Inclusion criteria for this review included: (1) English-language documents, (2) published primary and secondary literature, (3) published student theses, (4) peer-reviewed articles and (5) technical and institutional reports. Studies were excluded if they:(1) consisted of non-empirical commentary, opinion pieces, or marketing materials lacking methodological detail, (2) were duplicates without new data, (3) lacked essential metadata such as sample origin or locality and (4) fell outside the thematic scope of *Irvingia* biology, chemistry, or conservation. We retrieved and evaluated all documents that met the review's inclusion criteria; however, this does not exclude the possibility of oversight of materials such as unpublished student theses, conference proceedings, or review literature.

Table 1: **Summary of the data extraction process**

Category	Details
Databases Searched	PubMed/MEDLINE, Scopus, Web of Science, CAB Abstracts, AJOL, Google Scholar, CIFOR-ICRAF repository, IITA repository, GBIF
Keywords Used	"Irvingia", "Irvingia gabonensis", "Irvingia wombolu", "bush mango", "ogbono", "genetic diversity", "population structure", "genomics", "phenotypic variation", "AFLP", "SSR", "DArTseq", "SNP", "phytochem", "metabolom", "flavonoid", "tannin", "fatty acid", "pharmacolog", "antioxidant", "anti-inflammatory", "wild-harvested NTFPs", "genetic reservoirs", "plant diversity conservation", "climate resilience", "conservation strategies", "sustainable utilization", "agroforestry", "domestication"

Search Strategy	Keywords combined with synonyms, alternative spellings, related terms, Boolean operators (AND, OR, NOT, +, -), and wildcard operators (*, ?, ~, !)
Topics Explored	Genetic, phytochemical, pharmacological, ethnobotanical, and conservation studies on Irvingia and NTFPs; Nigerian data prioritized
Inclusion Criteria	English-language documents; published primary/secondary literature; student theses; peer-reviewed articles; technical/institutional reports
Exclusion Criteria	Non-empirical commentary/opinion/marketing; duplicates without new data; missing metadata (sample origin/locality); outside the thematic scope of Irvingia biology, chemistry, or conservation
Limitations	Possible overlook of unpublished theses, conference proceedings, and grey literature

Data Analysis

Given the heterogeneity of genetic markers, phytochemical assays, and pharmacological models across studies, a narrative synthesis approach was adopted. Extracted data were organized into thematic categories and summarised descriptively. Genetic diversity indices were tabulated and compared across species, regions, and marker types. Sampling localities were georeferenced and mapped using available GPS coordinates to visualize spatial patterns in research coverage. Phytochemical and pharmacological data were synthesized qualitatively, with compounds grouped into major classes and pharmacological outcomes categorized by assay type. Ethnobotanical findings were analyzed thematically to identify recurring patterns in traditional knowledge, use practices, and conservation perceptions.

Results

Search results and study characteristics

The search identified 3,412 research articles, with 2,946 unique articles after deduplication; full texts assessed for eligibility were 312 and 86 studies were included in the review (genetic n≈18 (21%); phytochemical/pharmacology n≈34 (39%); ethnobotany/market studies n≈20 (23%); conservation/program evaluations n≈14 (17%)). (Figure 2).

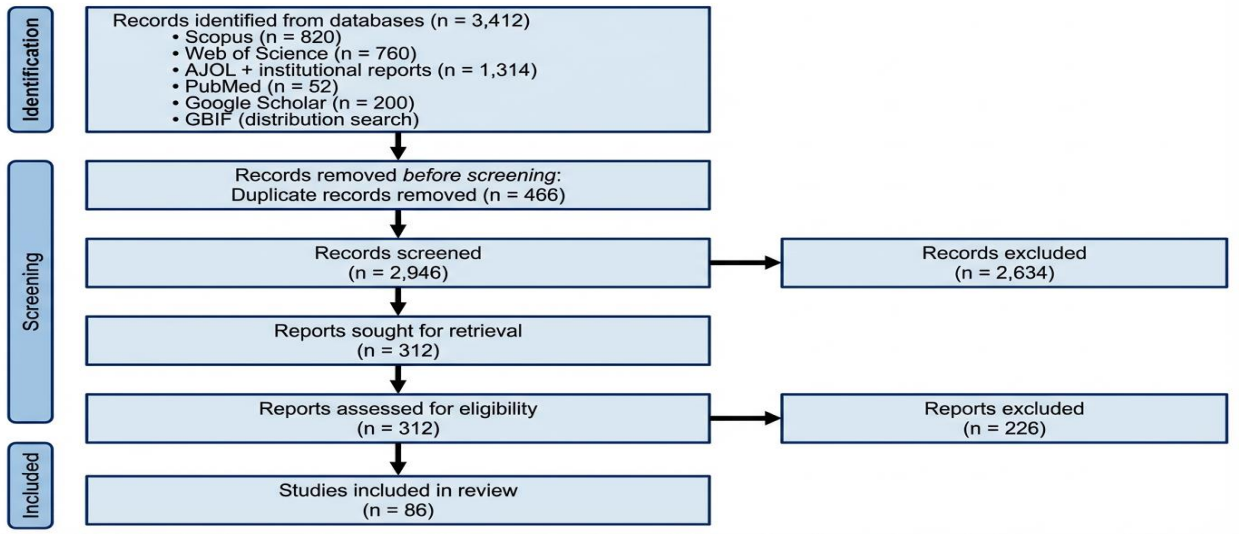


Figure 2: **PRISMA flow diagram showing the selection process for studies included in the systematic review of genetic diversity and conservation research on *Irvingia* species (2015–2025).**

Distribution and ecological context

Irvingia gabonensis and *I. wombolu* occur in humid lowland forest blocks across West and Central Africa (Febnteh & Yani, 2024) (Figure 3). Verified occurrence records from the Global Biodiversity Information Facility (GBIF) and specimen databases indicate presence in southern Nigeria, including Cross River, Edo, Delta, Anambra, Oyo, Ondo, and Ekiti (Raphael, 2021; GBIF, 2023; Odeyale *et al*., 2025). Royal Botanic Gardens, Kew, and Plants of the World Online (Kew/POWO), as well as ecological niche modelling studies, likewise place *Irvingia* distributions within Lower Guinea forest blocks and predict vulnerability in some regions under future climate scenarios (Royal Botanic Gardens Kew, 2023). The species prefers wet lowland tropical forest (annual rainfall >1,200 mm), gallery forest and some agroforestry settings. (Ishoro *et al*., 2023). In Nigeria, *Irvingia* populations are associated with remnant forest patches and farm-trees in agroforestry mosaics; conservation measures must therefore consider both forest protection and on-farm genetic management.

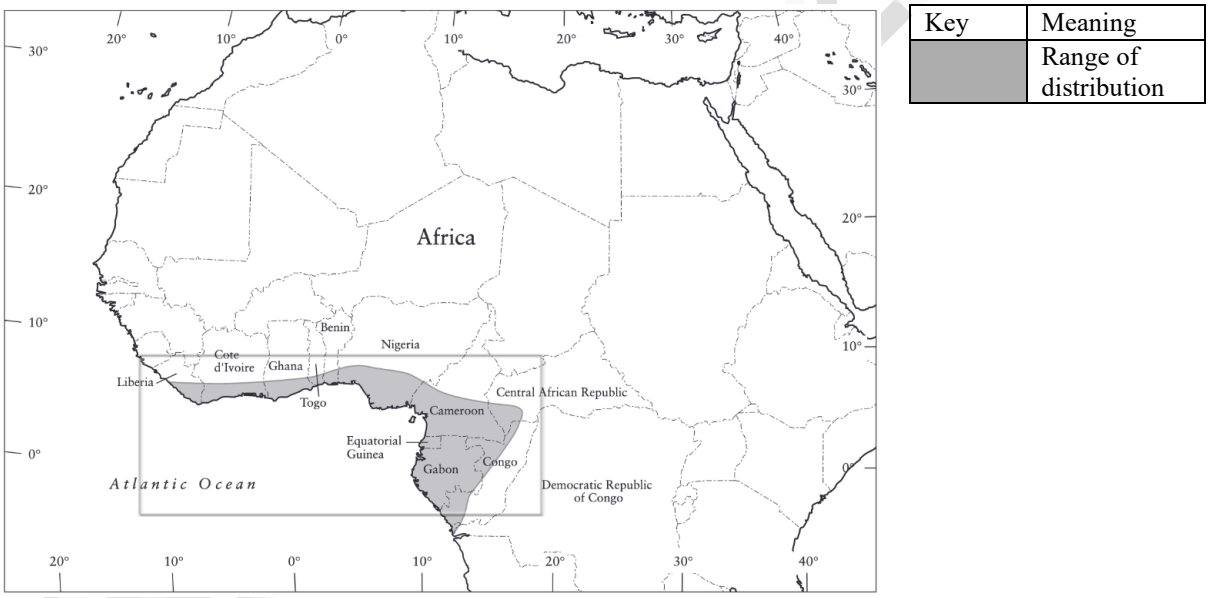


Figure 3: Map of *Irvingia* distribution and genetic sampling locations in West and Central Africa (Source: Morris and Nair, 2022)

Genetic diversity and population structure

Table 1 shows that older studies (1998 - 2015) primarily used Random Amplified Polymorphic DNA (RAPD), Simple Sequence Repeat (SSR) and Amplified Fragment Length Polymorphism (AFLP) markers to characterize diversity and differentiation among populations; these documented significant among-population structure and identified regional diversity hotspots in southern Nigeria and southern Cameroon (Jepkemboi & Ojola, 2023). Recent studies (2018 -

2022) have employed Diversity Arrays Technology (DArT) sequencing (DArTseq)/ In silico Diversity Arrays Technology (SilicoDArT), as well as Single Nucleotide Polymorphism (SNP)-based panels, enabling higher-resolution Analysis of population structure. Jepkemboi and Ojola (2023) reported analyses of 60 samples and 6,532 SilicoDArT markers, with overall Nei's gene diversity (He ≈) 0.117 and a percentage of polymorphic loci ≈ 39.6%; pairwise and Analysis of Molecular Variance (AMOVA) analyses indicated substantial differentiation among populations (phiPT ≈ 0.301, P = 0.001). Early AFLP and SSR studies flagged southern Nigeria as having high allelic richness and private alleles, corroborated by more recent DArTseq work, which indicates Nigerian provenances often have higher diversity than some central Gabon populations (Vihotogbé *et al*., 2019; Jepkemboi & Ojola, 2023). The study by Jepkemboi and Ojola (2023) also suggests that gene flow occurs between wild and managed trees in agroforestry landscapes. However, habitat fragmentation and deforestation reduce local connectivity and effective population sizes. Their documented FST values and AMOVA results indicate structured differentiation by geography, consistent with isolation-by-distance and anthropogenic fragmentation. Hence, wild populations in Nigeria harbour valuable allelic variation (fruit/kernel traits, potential stress tolerance loci) that occurs both within- and among-populations, making wild stands important reservoirs of adaptive potential.

Phenotypic variation and domestication potential

Field phenotyping and participatory domestication efforts (CIFOR/ICRAF) revealed substantial variation in fruit and kernel phenotypes (e.g., fruit mass, kernel mass, kernel oil content) across villages and regions (Table 1). This enables farmer selection and shows potential for on-farm selection and cultivar development (Onyekwelu *et al*., 2015; Leakey *et al*., 2022). Therefore, breeding/domestication strategies must balance selection for marketable traits with the maintenance of genetic diversity; participatory approaches show promise for both improving yields and conserving variation.

Table 2: Summary of genetic studies in *Irvingia species*

Study	Marker	Sample Size (N)	Marker Loci (L)	Geographic Coverage	He (Nei)	% Polymorphic Loci	FST /ϕPT	Key Findings
Jepkemboi and Ojola (2023)	SilicoDArT	60	6,532	Nigeria, Cameroon, Gabon	0.117	39.60%	ϕPT ≈0.301	High population differentiation; Cameroon is identified as the centre of distribution. Moderate overall diversity, strong structuring.
Vihotogbé *et al.* (2015)	cpSSR / AFLP	59	161	Benin, Togo, Nigeria, Cameroon, Dahomey Gap	0.251	70.80%	GST ≈0.108	Fragmented bitter populations show low diversity, while domestication increases sweet variety

								polymorphism. Combined genomic datasets effectively distinguish geographic groups. .
Ude *et al*. (2006)	AFLP	15	384	Nigeria, Cameroon, Gabon	-	-	-	High genetic distance (avg. 59%); Cameroon acts as a "bridge" between Nigerian and Gabonese populations. Older marker
Anegbeh *et al*. (2003).	Morphometrics	100	10 traits	Ugwuaji village, SE Nigeria	-	-	-	Significant tree-to-tree variation in fruit/kernel mass; 93% of trees were farmer-planted, indicating active selection.
Lowe *et al*. (2000)	RAPD	130	74	Central/West Africa (NG, CM, GA)	-	-	-	Historic baseline, confirmed genetic integrity of I. *gabonensis* and I. *wombolu*; identified "hotspots" in SE Nigeria.

Phytochemistry and pharmacological activity

Recurring classes of phytochemicals across studies include tannins (ellagic acid derivatives), flavonoids, phenolic acids, saponins and seed fatty acids (Table 2). Reviews and primary studies (2015 - 2024) summarise these findings and link compounds to traditional uses (Hassan *et al*., 2024). In pharmacological studies involving in vitro antioxidant assays, antimicrobial (Minimum Inhibitory Concentration (MIC) testing, anti-inflammatory animal models, and a limited number of human metabolic trials (weight/lipid endpoints) have been reported. Clinical evidence for metabolic benefits is mixed (small Randomized Controlled Trials (RCTs) with heterogeneous preparations) (Olorundare *et al*., 2020). Also, studies report qualitative variation in chemotypes among populations (Otitolaiye *et al*., 2022; Nguena-Dongue *et al*., 2023), but quantitative studies linking genotype to chemotype (using metabolomics and Genome-Wide Association Study (GWAS) are largely missing. Hence, chemotypic diversity in wild stands exists and is potentially valuable for drug discovery, but robust mapping of chemical variation to genetic loci is an urgent research gap.

ISTF-NIG 2026

Table 3: Phytochemical classes and representative pharmacological findings

Plant part	Major phytochemical classes	Representative pharmacological evidence	Key refs
Seeds/kernels	Fatty acids, sterols, tannins, flavonoids	Antioxidant assays; metabolic modulation (lipids); mixed clinical evidence on weight/lipids	Mateus-Reguengo *et al*., 2020; Onakpoya 2013.
Bark	Phenolics, tannins, saponins, flavonoids,	Anti-inflammatory and antimicrobial in animal models / in vitro	Hassan 2024; Nguena-Dongue 2023, Otitolaiye *et al*., 2023.
Leaves	Flavonoids, phenolics	Antioxidant, anti-diabetic in animal models	Various primary reports (2010–2022).

Socioeconomics and harvesting impacts

Market and household surveys in Nigerian states show that ogbono trade is important to household income (especially for women vendors), with seasonal harvesting peaks and variable value chains. Some localities show evidence of overharvesting of wild fruit and bark, with impacts on recruitment and age structure. Where smallholder agroforestry integrates *Irvingia* trees, gene flow helps maintain variation; where wild stands are extracted without regeneration, the risk of genetic erosion is higher (Arowosoge, 2017).

Climate resilience relevance

While direct genotype-by-environment trials for adaptive traits in *Irvingia* are rare, the presence of structured genetic variation suggests standing genetic variation that could confer differential responses to drought, phenological shifts, and pests (Jepkemboi & Ojola, 2023). Ecological niche modelling indicates habitat contraction under some future climate scenarios, pointing to particular states and forest blocks in southern Nigeria as priority in-situ conservation targets. (Vihotogbé *et al*., 2019a, Vihotogbé *et al*., 2019b)

Table 4: Conservation threats and recommended interventions

Threat	Evidence	Recommended immediate action	Mid/long-term strategy
Deforestation/land conversion	Range contraction in niche models; loss of remnant stands	Map remnant stands; community awareness	Protected in-situ conservation; integrate into reforestation
Overharvesting and unsustainable bark/fruit collection	Market surveys show intensive harvest in hotspots	Harvest regulations; seasonal limits; sustainable harvest guidelines	Community seed orchards; alternative income programs
Genetic erosion from fragmentation	Genetic structuring and reduced connectivity were reported	Prioritise germplasm collection from hotspots	Conservation genomics to guide priorities; ex-situ seed banking

Discussion

This review synthesizes convergent evidence that wild-harvested non-timber forest products (NTFPs), such as *Irvingia*, serve as important genetic reservoirs. Genetic analyses spanning

multiple marker types and decades consistently demonstrate substantial within-population variation alongside structured among-population differentiation, with clear geographic hotspots, notably in southern Nigeria. These patterns in *Irvingia* mirror broader trends documented across tropical forest species, in which molecular studies reveal high genetic diversity within populations but distinct geographic clustering due to historical refugia, habitat fragmentation, and localized domestication or management practices. For instance, population genetic studies of *Jatropha curcas* highlight that most genetic variation resides within local populations, while regional provenance drives clustering (Guo *et al*., 2024). Similarly, microsatellite analyses of *Osmanthus serrulatus* and dipterocarps reveal substantial within-population diversity but moderate differentiation shaped by ecological gradients and limited seed dispersal (Chen *et al*., 2021; Tito de Morais, 2016). Comparable spatial structuring has also been reported in medicinal plants such as *Fritillaria cirrhosa*, where regional centres of diversity act as evolutionary hotspots (Huang *et al*., 2024).

Parallel findings emerge in indigenous African tree crops such as *Dacryodes edulis* and *Vitellaria paradoxa*, where morphological and genetic diversity across West African agroforestry parklands reflects both environmental gradients and long-term farmer selection through participatory domestication and local management practices (Jamnadass *et al*., 2020; Leakey *et al*., 2022; Attikora *et al*., 2024; Nasare *et al*., 2025). Studies on *Parkia biglobosa* further demonstrate how traditional agroforestry parklands sustain high allelic richness and extensive gene flow across landscapes despite increasing habitat fragmentation (Dobeš *et al*., 2019; Lompo *et al*., 2020; Omonhinmin *et al*., 2024; Yabi *et al*., 2025). The climate resilience of these species is largely anchored in standing genetic variation, which provides a pre-existing pool of adaptive alleles governing traits such as drought tolerance and water-use efficiency. Phenological plasticity in flowering and fruiting cycles further buffers populations against erratic rainfall and temperature variability, sustaining reproductive success under shifting climatic regimes (Viger *et al*., 2016; Messina *et al*., 2023; Walde *et al*., 2025; Vihotogbé *et al*., 2025).

This high diversity is maintained by robust gene flow between wild populations and agroforestry systems. Unlike monocultures, traditional agroforestry landscapes facilitate pollen and seed dispersal across forest–farm boundaries, preventing genetic bottlenecks and maintaining connectivity among populations. Such exchange allows adaptive traits from wild populations to be continually incorporated into managed germplasm, enhancing resilience and evolutionary potential (Lompo *et al*., 2020; Omonhinmin *et al*., 2024; Udawatta *et al*., 2021; Jamnadass *et al*., 2020). While phytochemical and pharmacological studies support the existence of chemotypic diversity in *Irvingia* and related species, direct genotype–chemotype mapping remains limited, representing a critical frontier for linking genetic variation to functional traits. Together, these findings reinforce the interpretation that diversity hotspots in southern Nigeria and other tropical regions reflect common processes shaping genetic variation in forest species, while also underscoring the role of traditional agroforestry systems in sustaining genetic reservoirs essential for climate resilience and future domestication.

Practical implications

i. Conservation genomics: Targeted sampling of diversity hotspots and application of SNP/WGS approaches are necessary to identify adaptive loci and prioritize populations for in-situ protection

and ex-situ capture. High-density marker datasets, as demonstrated by Jepskemboi and Ojola's DArTseq work, can effectively resolve genetic structure, enabling conservation prioritization.

ii. Breeding and domestication: Participatory domestication programs can be enhanced by integrating genomic selection, allowing farmers to select desirable phenotypes while maintaining diversity, and accelerating breeding for resilience.
iii. Pharmacology and metabolomics: Untargeted metabolomics combined with GWAS/ Gene-by-Environment interaction (GxE) studies can map bioactive compounds to genetic loci, identifying chemotypes for drug discovery and value-added products.

iv. Policy and governance: NTFP genetic resources should be integrated in national biodiversity and agricultural strategies; equitable benefit-sharing and community rights (Nagoya Protocol) must be fronted in any exploitation of genetic/chemical resources.

Limitations & Knowledge gaps

Several limitations hinder the current understanding of Irvingia species. Firstly, the use of disparate molecular markers (AFLP, SSR, and SNP) compromises direct comparability across studies. Furthermore, georeferenced sampling is uneven, with some Nigerian states underrepresented. The scarcity of integrated genotype-phenotype-chemotype datasets precludes robust inferences regarding adaptive traits. Additionally, clinical pharmacological evidence is sparse and methodologically heterogeneous. Addressing these knowledge gaps requires a collaborative, cross-disciplinary approach that involves consortia, community engagement, and comprehensive sampling, sequencing, phenotyping, and chemotyping across Nigeria's distributional range.

Recommendations

1. **Conservation Genomics:** A coordinated conservation genomics program is needed to generate high-resolution genetic data across Nigeria. Systematic sampling should cover all geopolitical zones, with intensified efforts in diversity hotspots, such as the southeastern and south-south regions of Nigeria. High-throughput genotyping (e.g., DArTseq or SNP arrays) combined with low-coverage whole-genome sequencing can enable detection of adaptive variation. Genomic data should be integrated with demographic modelling to estimate effective population sizes, detect bottlenecks, and identify vulnerable populations. Germplasm capture should be complemented by community-managed seed orchards and decentralized ex situ seed banks with well-documented accession records.

2. **Metabolomics and Pharmacology:** Untargeted metabolomics using Liquid Chromatography–Mass Spectrometry (LC-MS) and Gas Chromatography–Mass Spectrometry (GC-MS) should be integrated with dense SNP genotyping to enable genome-wide association studies linking genetic variants with bioactive metabolites and agronomic traits. Candidate loci should be validated through targeted metabolite quantification and gene expression analyses, with priority given to compounds of pharmacological or nutritional relevance.

3. **Participatory Domestication:** Participatory breeding programs should incorporate farmer selection criteria such as taste, kernel yield, oil composition, and phenology into breeding

objectives. Community-based selection trials and value-chain development, including certification and traceability systems, can promote sustainable production while conserving genetic diversity.

4. **Policy and ABS Frameworks:** Strengthening policy frameworks for non-timber forest products should include implementing access-and-benefit-sharing mechanisms, ensuring prior informed consent, and supporting equitable benefit distribution and community participation in genetic resource management.

Conclusion

Wild-harvested NTFPs such as *Irvingia* represent important reservoirs of genetic and chemical diversity with implications for climate resilience, food security, and pharmacological discovery. Evidence from genetic and ecological studies indicates substantial population structuring and diversity hotspots, particularly in southern Nigeria. Beyond their nutritional and medicinal roles, *Irvingia* species contribute to climate resilience by supporting agroforestry systems that buffer communities against climate shocks, enhance carbon sequestration, and stabilize degraded landscapes. However, deforestation and unsustainable harvesting threaten these resources. Integrating conservation genomics, participatory domestication, and community-based management will be critical not only for safeguarding *Irvingia* genetic diversity but also for harnessing their ecological functions in climate-smart agriculture. By embedding *Irvingia* into sustainable land-use strategies, communities can strengthen resilience to climate variability while sustaining livelihoods.

References

Acquaah, G. (2009). Principles of plant genetics and breeding. John Wiley & Sons.

Alaje, V. I., Akhideno, L. O., Amadi, J. O., Oyedeji, O. F., Adebusuyi, G. A., & Geply, O. A. (2025). Morphological variation and interrelationship among traits of Bitter bush mango [*Irvingia gabonensis*] accessions from Nigeria. *Tanzania Journal of Forestry and Nature Conservation*, *94*(1): 59–73.

Alowanou-Kélé, B., Missihoun, A. A., Agbo, R. I., Sedah, P., Ewédjè, E. E., Yédomonhan, H., and Agbangla, C. (2025). Morphological Diversity and Phytogeographic Patterns of *Chrysophyllum albidum* (Sapotaceae) in Benin. *International Journal of Plant & Soil Science*, *37*(2), 290-305.

Anegbeh, P. O., Usoro, C., Ukafor, V., Tchoundjeu, Z., Leakey, R. R. B., and Schreckenberg, K. (2003). Domestication of *Irvingia gabonensis*: 3. Phenotypic variation of fruits and kernels in a Nigerian village. *Agroforestry systems*, *58*(3), 213-218.

Arowosoge, O. G. E.(2017). "Marketing and Utilization of Irvingia Kernels 'ogbono' in Ado-Ekiti Metropolitan Area of Ekiti State, Nigeria". *Journal of Agriculture and Ecology Research International* 13 (1):1–10.

Attikora, A. J. P., Yao, S. D. M., Dago, D. N., Silué, S., De Clerck, C., Kwibuka, Y., Diarrassouba, N., Alabi, T., Achigan-Dako, E.G. and Lassois, L. (2024). Genetic diversity and population structure of superior shea trees (Vitellaria paradoxa subsp. paradoxa) using SNP markers for the establishment of a core collection in Côte d'Ivoire. *BMC Plant Biology*, *24*(1), 913.

Chen, L., Pan, T., Qian, H., Zhang, M., Yang, G., & Wang, X. (2021). Genetic diversity and population structure revealed by SSR markers on endemic species *Osmanthus serrulatus* Rehder from Southwestern Sichuan Basin, China. *Forests*, *12*(10), 1365.

Dobeš, C., Steccari, I., Köstenberger, S., & Lompo, D. (2019). Relative genome size variation in the African agroforestry tree *Parkia biglobosa* (Fabaceae: Caesalpinioideae) and its relation to geography, population genetics, and morphology. *Genome*, *62*(10), 665–676.

FAO (Food and Agriculture Organisation) 2019. The State of the World's Biodiversity for Food and Agriculture, J. Bélanger and D. Pilling (eds.). FAO Commission on Genetic Resources for Food and Agriculture Assessments. Rome. 572 pp. (http://www.fao.org/3/CA3129EN/CA3129EN.pdf)

Febnteh, E. B., & Yani, J. P. (2024). Assessment of the natural regeneration status of *Irvingia gabonensis* (Bush Mango) in Gashaka Gumti National Park, Taraba State, Nigeria. Theses.

Guo, G., Tang, L., and Xu, Y. (2024). Genetic diversity and population genetic structure of *Jatropha curcas* L. accessions from different provenances revealed by amplified fragment-length polymorphism and inter-simple sequence repeat markers. *Forests*, *15*(9), 1575.

Hassan, Y. R., El-Shiekh, R. A., El Hefnawy, H. M., and Michael, C. G. (2024). *Irvingia gabonensis* Baill.(African Mango): A comprehensive review of its ethnopharmacological significance, unveiling its long-standing history and therapeutic potential. *Journal of Ethnopharmacology*, *326*, 117942.

Huang, J., Hu, X., Zhou, Y., Peng, Y. J. and Liu, Z. (2024). Phylogeny, genetic diversity and population structure of *Fritillaria cirrhosa* and its relatives based on chloroplast genome data. *Genes*, *15*(6), 730.

Irvingia gabonensis (Aubry-Lecomte ex O'Rorke) Baill. in GBIF Secretariat (2023). GBIF Backbone Taxonomy. Checklist dataset https://doi.org/10.15468/39omei accessed via GBIF.org on 2026-03-13.

Ishoro, A. P., Alaba, U. O., Chukwudi, C. E., Yahuza, T., & Luke, S. T. (2023). Occurrence and ecological niche modelling of *Irvingia gabonensis* at Cross River State, Nigeria. *Journal of Wildlife and Biodiversity*, *7*(supplementary issue), 96–127.

Jamnadass, R., Mumm, R. H., Hale, I., Hendre, P., Muchugi, A., Dawson, I. K, Powell, W., & Van Deynze, A. (2020). Enhancing African orphan crops with genomics. *Nature Genetics*, *52*(4), 356–360.

Jepkemboi, S. & Ojola, P. (2023). Genetic diversity and population structure of *Irvingia specie*s using DArTseq-generated markers. *Forests, Trees and Livelihoods*, 32(1): 42–54.

Leakey, R. R., Tientcheu Avana, M. L., Awazi, N. P., Assogbadjo, A. E., Mabhaudhi, T., Hendre, P. S., ... & Manda, L. (2022). The future of food: Domestication and commercialization of indigenous food crops in Africa over the third decade (2012–2021). *Sustainability*, *14*(4), 2355.

Lompo, D., Vinceti, B., Konrad, H., Duminil, J., & Geburek, T. (2020). Fine-scale spatial genetic structure, mating, and gene dispersal patterns in *Parkia biglobosa* populations with different levels of habitat fragmentation. *American Journal of Botany*, *107*(7), 1041-1053.

Mateus-Reguengo, L., Barbosa-Pereira, L., Rembangouet, W., Bertolino, M., Giordano, M., Rojo-Poveda, O., and Zeppa, G. (2020). Food applications of *Irvingia gabonensis* (Aubry-Lecomte ex. O'Rorke) Baill., the 'bush mango': A review. *Critical reviews in food science and nutrition*, *60*(14), 2446–2459.

Messina, C. D., Gho, C., Hammer, G. L., Tang, T., & Cooper, M. (2023). Two decades of harnessing standing genetic variation for physiological traits to improve drought tolerance in maize. *Journal of Experimental Botany*, *74*(16), 4847–4861.

Morris, I., & Nair, N (2022). *Irvingia gabonensis*: The Dika Diet https://scalar.usc.edu/works/plants-and-people/irvingia-gabonensis-the-dika-diet

Nguena-Dongue, B. N., Pone Kamdem, B., Lunga, P. K., & Fekam Boyom, F. (2023). Ethnomedicinal uses, phytochemistry, and pharmacological activity of the *Irvingia species*. *Drugs and Drug Candidates*, *2*(4): 827–864.

Odeyale, O., Jayeoba, F. M., Aluko, A. K., & Bankole, J. F. (2025). Ethno-botanical survey of *Irvingia gabonensis* and *Irvingia wombolu* in selected markets in Akinyele Local Government Area, Oyo State, Nigeria. *Fudma Journal of Sciences*, *9*(11), 48–54.

Olorundare, O., Adeneye, A., Akinsola, A., Kolo, P., Agede, O., Soyemi, S., Alban Mgbehoma, Ikechukwu Okoye, Ralph Albrecht, ... and Mukhtar, H. (2020). *Irvingia gabonensis* seed extract: an effective attenuator of doxorubicin-mediated cardiotoxicity in Wistar rats*: oxidative medicine and cellular longevity*, *2020*(1), 1602816.

Omonhinmin, C. A., Taiwo, N. S., Okonkwor, P. B., Ajayi, I. M., Akinduti, P. A., Aworunse, O. S., & Popoola, J. O. (2024). Dataset on rbcL-based intra-specific diversity and population structure of *Parkia biglobosa* (Jacq.) in Nigeria—*data in brief*, *53*, 110146.

Onakpoya, I., Davies, L., Posadzki, P., & Ernst, E. (2013). The efficacy of Irvingia gabonensis supplementation in the management of overweight and obesity: a systematic review of randomized controlled trials. *Journal of dietary supplements*, *10*(1), 29-38.

Onyekwelu, J. C., Olusola, J. A., Stimm, B., Mosandl, R., & Agbelade, A. D. (2015). Farm-level tree growth characteristics, fruit phenotypic variation and market potential assessment of three socio-economically important forest fruit tree species. *Forests, Trees and Livelihoods*, *24*(1), 27–42.

Otitolaiye, C., Omonkhua, A., Oriakhi, K., Okello, E., Onoagbe, I., & Okonofua, F. (2023). Phytochemical Analysis and in vitro Antioxidant Potential of Aqueous and Ethanol Extracts of *Irvingia gabonensis* Stem Bark. *Pharmacognosy Research*, *15*(2).

Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, *et al.* (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ. 372(71) doi:10.1136/bmj.n71

Raphael, O. (2021). Phenological Study of *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Growing in Ihiala, Anambra State, South-East, Nigeria—*Journal of Advances in Biology & Biotechnology*.

Royal Botanic Gardens, Kew/ Plants of the World Online (POWO) (2023): *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill.https://powo.science.kew.org/taxon/urn%3Alsid%3Aipni.org%3Anames%3A813766-1?utm_source=chatgpt.com

Salgotra, R. K., & Chauhan, B. S. (2023). Genetic diversity, conservation, and utilization of plant genetic resources. *Genes*, *14*(1), 174.

Tito de Morais, C. (2016). Fine-scale genetic structure, gene flow and mating systems in dipterocarp forests (Doctoral dissertation, ETH Zurich).

Udawatta, R. P., Rankoth, L. M., & Jose, S. (2021). Agroforestry for biodiversity conservation. In *Agroforestry and ecosystem services* (pp. 245–274). Cham: Springer International Publishing.

Viger, M., Smith, H. K., Cohen, D., Dewoody, J., Trewin, H., Steenackers, M., Bastien, C. and Taylor, G. (2016). Adaptive mechanisms and genomic plasticity for drought tolerance identified in European black poplar (Populus nigra L.). *Tree physiology*, *36*(7), 909–928.

Vihotogbé, R., Idohou, R., Gebauer, J., Sinsin, B., & Peterson, A. T. (2019a). Estimation of cultivable areas for *Irvingia gabonensis* and *I. wombolu* (Irvingiaceae) in Dahomey-Gap (West Africa). *Agroforestry Systems*, *93*(3), 937–946.

Vihotogbé, R., Missihoun, A. A., Sinsin, B., & Sosef, M. S. M. (2015). Genetic diversity of bitter and sweet African bush mango trees (*Irvingia* spp., Irvingiaceae) in West and Central Africa. *African Journal of Biotechnology*, 14(45): 3062–3074.

Vihotogbé, R., Raes, N., Van den Berg, R. G., Sinsin, B., & Sosef, M. S. M. (2019b). Ecological niche information supports taxonomic delimitation of *Irvingia gabonensis and I. wombolu* (Irvingiaceae). *South African Journal of Botany*, *127*, 35–42.

Walde, M. G., Vitasse, Y., & Wolkovich, E. M. (2025). Rethinking the interpretation of spring phenological temperature sensitivity. *npj Science of Plants*, *1*(1), 3.

Yabi, C. C., Ayena, J. I. K., Biaou, S., Adomou, S., Houehanou, T. D., & Gouwakinnou, G. N. (2025). Climate change-induced shifts in the ecological niches of *Parkia biglobosa* (Jacq.) and Vitellaria paradoxa CF Gaertn, two species of agroforestry parks in Benin, West Africa. *Trees, Forests and People*, *20*, 100830.

Zhang, F., & Batley, J. (2020). Exploring the application of wild species for crop improvement in a changing climate. *Current Opinion in Plant Biology*, *56*, 218–222.

Zimmerer, K. S., de Haan, S., Jones, A. D., Creed-Kanashiro, H., Tello, M., Carrasco, M., Meza, K., Amaya, F.P., Cruz-Garcia, G.S., Tubbeh, R. and Olivencia, Y. J. (2019). The biodiversity of food and agriculture (Agrobiodiversity) in the Anthropocene: Research advances and conceptual framework. *Anthropocene*, *25*, 100192.

POPULATION ECOLOGY OF CLIMBERS IN THE DEPARTMENT OF FORESTRY AND WILDLIFE ARBORETUM, UNIVERSITY OF UYO, UYO, NIGERIA

***Gideon, I. K.,[1] Etigale, E. B.[1] and Akpan, U. U.[1]**

[1] *Department of Forestry and Wildlife, Faculty of Agriculture, University of Uyo, Nigeria.*
Corresponding Email: idorenyingideon@uniuyo.edu.ng/08038256051

ABSTRACT
The study assessed the population ecology of climbers in the Department of Forestry and Wildlife Arboretum, University of Uyo. A 100m transect was laid 5m away from the path into the arboretum, serving as a baseline. Along the transect, four (4) 10m × 10m quadrats were established at a regular interval of 20m. In each quadrat, climber species were identified, enumerated and classified. The data obtained were analysed using descriptive statistics. The diversity index of the climbers was determined using Simpson's diversity index. The results revealed a total of 729 individuals belonging to twelve (12) climber species and 11 families. *Smilax anceps* had the highest number of 150 individuals with a corresponding population density of 3750/ha. This was followed by *Mucuna pruriens (Fabaceae)* with 139 individuals and 3480/ ha and *Dissotis rotundifolia* of *Melastomataceae* with 120 individuals and 3000/ha. In contrast, *Combretum zenkerii* of the *Combretaceae* family recorded the least number of individuals (10), followed by *Pteridum aquilinum* with 15 individuals and *Tricilisia subcordata* with 20 individuals per hectare. Additionally, the Fabaceae family had the highest relative abundance, at 22%, followed by Smilacaceae (20.6%), while Dioscoreaceae had the lowest relative abundance (0.33%). Vines represented the most abundant climbers in the arboretum, accounting for seven (7) out of the twelve (12) species recorded. The diversity index (D) of the species was low (D = 0.138). A high population of climbers could be detrimental to the health of trees. Hence, there is a need for regular and safe removal of climbers before they become too thick and reach the canopy, to improve overall tree health.
Keywords: Population, ecology, climbers, diversity, arboretum

INTRODUCTION
The tropical rainforest is biologically diverse and complex, featuring a wide array of trees and other life forms, including climbers. Climbers are plants with a distinct structure to climb on a host. All forms of climbers, climbing vines, climbing shrubs, and lianas are known classes of tropical climbers (Kokou *et al*., 2002). While climbing vines sprawl, climbing shrubs climb using the cracked bark of trees as support. Lianas characteristically climb large trees using them as support. Climbers are excellent forest colonizers due to their easy seed propagation, their laterally growing roots and their inherent capacity for high growth rate. Though climbers mostly grow from the soil, their stems require support for climbing (Bongers *et al*., 2015). Climbers have a wide ecological distribution, and they can be found in all forest types. They tend to be comparatively more abundant than other lifeforms in the forest. Their abundance and distribution are influenced by the size of the trees within a given vegetation area, their nearness to forest margins and the influence of human activities around the area, which tend to accelerate their establishment and invasion (Ali *et al*., 2016).
Climbers have been found to provide a valuable source of food and medicine for both man and animals (Gideon *et al*., 2026). They can also be predictors of vegetation parameters. Again, they

influence large forest ecosystem processes (such as nutrient cycling) and protect soil against erosion (Iwara *et al*., 2017; Rahman *et al*., 2020). Nonetheless, climbers help increase accessibility to tree canopies for lower animals, many of which play a significant role in tree seed dispersal (Jansen *et al.,* 2011). Contrastingly, climbers can increase tree mortality by suppressing tree regeneration, thereby influencing forest dynamics and reducing carbon sequestration (Schnitzer and Bongers, 2002; Yamamoto, 2012). Given the above, the occurrence and abundance of climbers are more important in tropical forests.

Population ecology is an ecological study that examines the dynamics of populations through their abundance, spatial distribution, structure, growth rates, and interactions with the environment (Olson and Stenlid, 2022; Divya, 2023). In a managed ecosystem, such as an arboretum, these dynamics of climber population can differ from those in a natural forest due to management practices (such as planting and pruning). Thus, the output from this kind of study will offer valuable insights into climber biology, as arboretums function as living laboratories with diverse but labelled tree species and long-term records.

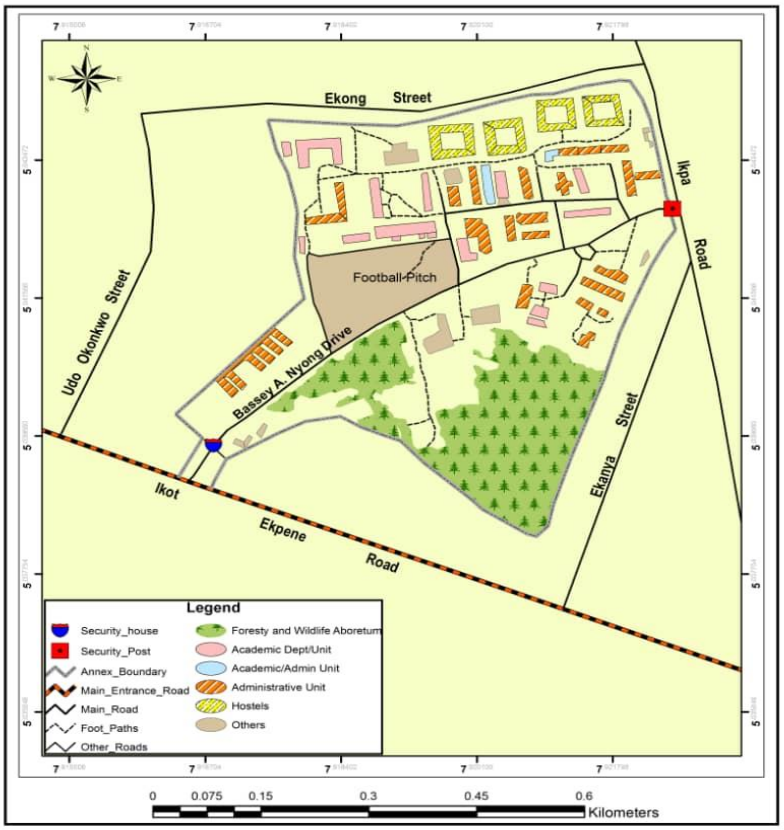
In an arboretum, where trees and shrubs are the primary focus, climbers grow within the microclimate of trees (Li *et al.*, 2022). Their populations are often smaller and patchier than in natural tropical forests, where lianas (for example) can comprise up to 25% of woody species richness and heavily influence forest structure (Phillips *et al*., 2008). Their density (measured as individuals per unit area) is influenced by disturbance regimes, management practices (e.g. planting, pruning), light conditions and species composition. Hence, climbers may show a clumped distribution, concentrating around trees with rough bark, suitable branch angles or gaps in the canopy that allow light penetration.

Despite the importance of climbers in the overall ecological functioning of the forest, they are frequently overlooked in forest population studies. Most researchers focus more on the composition of the rainforest ecosystem with comparatively less attention on the diversity of tree species and undergrowth species, non-timber forest products and the general plant composition of the forest (Olajide and Robert, 2013; Kissa *et al*., 2025). It is estimated that extinction rates in climbers are about three times higher than those of hardwood tree species and approximately five times higher than those of gymnosperms (Gilliam, 2007). Thus, threats to forest biodiversity are more often a function of threats to the climber species layer. Hence, there is a need to assess the population ecology of climbers within a given vegetation cover.

MATERIALS AND METHODS

Study Area

This study was conducted in the Arboretum of the Department of Forestry and Wildlife situated within the University of Uyo Annex campus. The Arboretum is situated between Latitudes 4º235' and 4º235'N and Longitudes 7º 35' and 8º 25'E in Uyo Local Government Area, Akwa Ibom State (Ijeomah *et al.,* 2014). The major seasons of the State are the dry and wet seasons. The annual rainfall ranges from 1800 to 3200mm per annum. The dry season spans mid-November to February, whereas the wet season begins in March to October (Akpabio *et al*., 2004). The annual temperature ranges from 22.8 °C to 30.13 °C. The climate of the area favours luxuriant tropical rainforest, which harbours a large population of plants. The soil is fertile and supports a wide range of subsistence and commercial agricultural practices.



MAP OF ANNEX CAMPUS SHOWING DEPARTMENT OF FORESTY AND WILDLIFE ARBORETUM

Fig. 1: Annex campus of the University of Uyo showing the study area.

Sampling Technique

A baseline of 5m was established from the access road. A transect of 100m was cut 5m away from the path into the arboretum, which served as the baseline. A 5m gap was provided to avoid the edge effect. Along a transect measuring 100m, four (4) 10m × 10m quadrats at a regular interval of 20m were established. In each quadrat, climber species were identified, enumerated and classified into scientific name, family and climber group.

Data Analysis

The data obtained were analysed using descriptive statistics in the form of frequencies, percentages and tables.

The diversity index of climber plant species was determined using Simpson's diversity (Simpson, 1949)

$$D = \sum_{i=1}^{s} \frac{\mathrm{ni}(\mathrm{ni}-1)}{\mathrm{N}(\mathrm{N}-1)} \qquad \text{……Equation 1}$$

Where,

D = diversity index
ni = the total number of individuals of the ith species
N = the total number of individuals of all the species

The abundance of each species and families (which is expressed in terms of the population density) was calculated with equation 2

$$D = \frac{x}{A \times n} \quad \text{..... Equation 2}$$

Where,
D = population density of species (no of individuals per ha)
X = numbers of individuals of the species enumerated

A = area of each sampling plot ($100m^2$)

n = number of sampling plots enumerated (4)

The relative abundance (which is expressed in terms of relative density) of each species found in the study area was calculated as expressed below:

$$RD = \frac{ni}{N} \times 100 \quad \text{..... Equation 3}$$

Where,

RD= Relative Density

ni = number of individuals of the ith species
N = total number of individuals of all the species

The total population of climber species in the study area was estimated with Equation 4

$$Pt = D \times A \quad \text{.....Equation 4}$$

Where Pt = Total population of species
D = Population density (No. per ha)
A = Total area of the habitat (per ha)

RESULTS

A total of 729 individuals belonging to twelve (12) climber species and 11 families were identified and enumerated in the study (Table 1). The families include: Combretaceae, Convolvulaceae, Dennstaedtiaceae, Apocynaceae, Fabaceae, Smilacaceae, Piperaceae, Gnetaceae, Dioscoriaceae, Menispermaceae, and Melastomataceae. In terms of family diversity, the Fabaceae was represented by two different species (*Calopogonium mucunoides and Mucuna pruriens)* while the remaining identified families have a single representative species. *Smilax anceps (belonging to Smilacaceae)* had the highest number of 150 individuals with a corresponding population density of 3750/ha. This was followed by *Mucuna pruriens (Fabaceae)* with 139 individuals and 3480/ ha and *Dissotis rotundifolia* of *Melastomataceae* with 120 individuals and 3000/ha. In contrast, *Combretum zenkerii* of the *Combretaceae* family recorded the least number of individuals (10), followed by *Pteridum aquilinum* with 15 individuals and *Tricilisia subcordata* with 20 individuals per ha (Table 1).
In terms of climber groups, vines represented the most abundant climbers in the arboretum, accounting for seven (7) out of the twelve (12) species recorded (Table 1).

The diversity index (D) of the species was calculated to be 0.138 (Table 2).

Table 1: Species, Family diversity, Groups, Population Density and Relative Abundance of Climbers in the Department of Forestry Arboretum

S/N	Scientific Names	Family	Group of Climber Species	Number of individuals	Population Density (no. of Individuals per ha)	Relative Abundance (%)
1	*Combretum zenkerii* Engl and Diels	*Combretaceae*	Climbing Shrub	10	250	1.372
2	*Ipomea involucrate* P. Beauv.	*Convolvulaceae*	Climbing Shrub	22	550	3.018
3	*Pteridum aquilinum* (L.) Kunn	*Dennstaedtiaceae*	Climbing Shrub	15	380	2.058
4	*Gongronema latifolium* Benth	*Apocynaceae*	Vine	105	2630	14.403
5	*Calopogonium mucunoides* Desv.	*Fabaceae*	Liana	23	580	3.155
6	*Smilax anceps* Willd.	*Smilacaceae*	Vine	150	3750	20.576
7	*Piper guineensis*	*Piperaceae*	Vine	43	1080	5.898
8	*Gnetum Africana* Welw.	*Gnetaceae*	Vine	39	980	5.350
9	*Mucuna pruriens*	*Fabaceae*	Vine	139	3480	19.067
10	*Dioscorea villosa* L.	*Dioscoriaceae*	Vine	20	500	2.743
11	*Tricilisia subcordata* Oliv.	*Menispermaceae*	Climbing Shrub	43	1080	5.898
12	*Dissotis rotundifolia* (Sm,) Triana	*Melastomataceae*	Liana	120	3000	16.461

Table 2: Diversity Index of Climbing Plant Species in the Study Area

Study Area	Diversity Index
Arboretum	**0.138**

ISTF-NIG 2026

DISCUSSION

Diversity, Population Density and Relative abundance of climbers

This study recorded a relatively higher number of individual climber species compared to the observations by Addo-Fordjour et al. (2008), who recorded 951 individuals in a 2ha KNUST botanical garden in Ghana and Muoghalu and Okeesan (2005), with 49 individuals in a 0.24ha secondary forest Ile-Ife, Nigeria. A high abundance of climber species can contribute to high biodiversity and an increase in the structural complexity of the arboretum. However,

The species diversity in this study was lower than that observed in Addo-Fordjour et al. (2008) and Kerio and Njenga (2024). As observed, the four most abundant species are in the order *Smilax anceps> Mucuna prurien> Dissotis rotundifolia>* and *Gongronema latifolium*, making up roughly 70.5% of all climbers identified. These species hold a high relative abundance, causing a decline in the diversity index due to low evenness of the ecosystem. The low diversity is connected to the design priorities of the arboretum, which emphasize tree diversity for education, research and conservation over climber species (Teixeira and Ferreira, 2025). The arboretum is a managed ecosystem where pruning, cutting or removal of climbers is done to protect trees. However, where regular maintenance is lacking, it encourages the dominance of fast-growing and aggressive colonizers such as Smilax and Mucuna species. Therefore, their high abundance suggests that these hardy climbers quickly spread and smother slower-growing species.

The low population density of *Combretum zenkerii* and *Pteridum aquilinum* suggests out-competition by other species, as human extraction for medicinal purposes has impacted their density. On the whole, management practices such as pruning, removal, weeding of unwanted species and disturbance control, especially at the early age of the arboretum, may have discouraged their abundance.

In terms of diversity in families, Fabaceae had more species than the other families. Addo-Fordjour *et al*. (2008) and Wang and Zhang (2025) had similar observations, where Fabaceae, among other families, dominated their study sites. In contrast, Rahman *et al*. (2020) found Apocynaceae, Leguminosae and others to be the most abundant families in their study.

In terms of climber groups, vines represented the most abundant in the arboretum, accounting for seven (7) out of the twelve (12) species recorded. Although vines have been reported to be few in a forest ecosystem, thereby affecting their overall contribution to the forest structure as noted by Addo-Fordjour et al. (2008) and Muoghalu and Okeesan (2005), the higher abundance in this study suggests their persistence as primary colonizers utilizing gaps provided by tree spacing in the arboretum and a lack of regular maintenance. This has significant implications; reduced tree growth and vigour due to aggressive competition for light, water and nutrients, as well as higher tree mortality and structural failure in the arboretum.
Contrastingly, lianas had two species: *Calopogonium mucunoides* and *Dissotis rotundifolia*. Lianas are known to proliferate after natural or logging-related gaps are created, and their abundance and diversity vary with several factors, including soil type, altitude and site disturbance (Birhanu et al., 2025). In arboretums, controlled and planned disturbances limit opportunities for the establishment of

lianas. The result of this study aligns with the observation by Birhane *et al*. (2020) that liana species diversity was greater in moderately disturbed sites than in the rarely and highly disturbed sites. On the other hand, climbing shrubs had three (3) species, such as *Combretum zenkerii*, which often start as self- supporting shrubs before utilizing nearby vegetation for vertical growth.

CONCLUSION

The study assessed the population ecology of climbers in the Department of Forestry and Wildlife Arboretum, University of Uyo. Although the arboretum was originally managed for trees (climbers were removed), the findings revealed a high number of individual climbers, low diversity of climbers, dominance of *Smilax anceps,* and the prevalence of vines in the arboretum. Therefore, the high population of the climbers could be detrimental to tree health. Hence, there is a need for regular monitoring of the arboretum for climbers, especially vines, and their safe removal before they become too thick and reach the canopy. This will improve tree health and the overall outlook of the arboretum.

REFERENCES

Addo- Fordjour, P., Anning, A.K., Atakora, E.A. and Agyei, P. S. (2008). Diversity and distribution of climbing plants in a semi-deciduous rainforest, KNUST botanical garden, Ghana. International Journal of Botany, 4(2): 186-195.

Ali, M., Isah, T., Dipti, and Mujib, A. (2016). Climber plants: Medicinal importance and conservation strategies. In: Shahzad *et al*. (eds), Biotechnological strategies for the conservation of medicinal and ornamental climbers. Pp 101-138.

Akpabio, I. A. and Chukukere, O. C. (2004) Profitability of poultry eggs production in Uyo Metropolis of Akwa Ibom State, Nigeria. Discussion paper No 10. Department of Agricultural Economics and Extension, University of Uyo. Pp. 29

Birhane, E., Fekensa, Z., Tewolde-Berhan, S., Rannestad, M. M., Solomon, N. (2020). The diversity and distribution of lianas under various disturbance regimes in Chilimo dry Afromontane Forest, Ethiopia. *Global Ecology and Conservation*, 23, ISSN 2351-9894, https://doi.org/10.1016/j.gecco.2020.e01045. (https://www.sciencedirect.com/science/article/pii/S2351989419307760)

Birhanu, A., Birhanu, E., Giday, K. and Egziabher, Y. G. (2025). Species composition, diversity, and abundance of lianas along an altitudinal gradient in a dry Afromontane forest, Ethiopia. *Global Ecology and Conservation*, 65(2025) e03855. https://doi.org/10.1016/j.gecco.2025.e03855

Bongers, F., Doorter, L., Hawthorne, W. D. and Sheil, D. H. (2015). The intermediation disturbance hypothesis applies to tropical forests, but disturbance contributes little to tree diversity. *Ecology letter*,12:798-805.

Divya, U. (2023). Population ecology: Understanding the dynamics of life in numbers. *Perspective*, 13(4):52-54.

Gideon, I.K., Akpan, U.U. and Ibanga, E.U. (2026). Climbers in the arboreum of the University of Uyo and their utilization values in the surrounding communities. *Journal of Sustainable Environmental Management*, 18:63-72.

Ijeomah, H. M., Okoli, C. I. C and Iyah, E. I. (2014). Ecotourism resources of the University of Uyo, Nigeria, The arboretum and the ravine destination in perspective. *Ethiopian Journal of Environmental Studies and Management*, 7(3):327-338.

Iwara, A. I., Ewa, E. E., Njar, G. N. and Maduka, S. O. (2017). Relationships between Vegetation Characteristics and Soil Erosion in the Rainforest Zone of Southern Nigeria, *Confluence Journal of Environmental Studies*, 11 (2): 27-36.

Kerio, S. J. and Njenga, P. K. (2024). Brackenhurst Botanical Garden, Kiambu County, Central Kenya. *Asian Plant Research Journal*, 12(1): 13-21

Kissa, D.O., Nzunda, E. F., Tweheyo, M., Lussetti, D., Ssekuubwa, E. and Sheil, D. (2025). Composition and Diversity of Understory and canopy species vary along a logging gradient in an African semi-deciduous tropical rainforest. Foests, 16(1); https://doi.org/10.3390/f160100006.

Kokou, K., and Couteron, P., Martin A. and Cabelle, G. (2002). Taxonomic diversity of lianas and vines in forest fragments of Southern Togo. *Rev. Ecol*., 57:3-18.

Li, B., Zhang, Y.,Luan, F., Yaun,Z. Ali, A., Chu, C., and Bin, Y. (2022). Habitat Conditions and Tree species shape liana distribution in a tropical forest. Forest,13(9), 1358.http://doi.org/10.3390/f13091358

Moughalu, J. I. and O.O. Okeesan (2005). Climber species composition and relationship with trees in a Nigerian secondary forest. *Afr. J. Ecol*., 43: 258-266

Olajide, O. and Robert, U. (2013). Undergrowth species of Socio-economic values in Akwa Ibom State, Nigeria. In: Labode Popoola, Kayode Ogunsanwo and Felix Idumah (eds), Forestry in the Context of Millennium Goals. Proceedings of the Forestry Association of Nigeria Held in Osogbo, Osun State, Nigeria.

Olson, A. and Stenlid, J. (2022). Population dynamics of forest. In: Fred O. Asiegbu and Andriy Kovalchu(eds) Forest tree health, Vol., 2. https://www.sciencedirect.com/book/edited-volume/9780323850421/forest-microbiologyhttps://www.sciencedirect.com/book/edited-volume/9780323850421/forest-microbiology

Phillips, O. L., Martínez, R. V., Arroyo, L., Baker, T. R., Killeen, T., Lewi,s S. L, Malhi, Y., Mendoza, A. M., Neill, D., Vargas, P. N., Alexiades, M., Cerón, C., Di Fiore, A., Erwin, T., Jardim, A., Palacios, W., Saldias, M. and Vinceti, B. (2008). Increasing dominance of large lianas in Amazonian forests. *Nature*, 418:770–773.

Rahman, U. R.; Khan, S. M., Saqib, Z., Ullah, Z., Ahmad, Z., Ekercin, S., Mumtaz, A. S. and Ahmad, H. (2020). Diversity and Abundance of Climbers in Relation to their Hosts and Elevation in the Monsoon Forests of Murree in the Himalayas, Amjad. *Pak. J. Bot*., 52(2), Doi: http://Dx.Doi.Org/10.30848/Pjb2020-2(17)

ISTF-NIG 2026

Schnitzer, S. A. and Bongers, F. (2002). The ecology of lianas and their role in forests. *Trends in Ecology & Evolution*, 17(5): 223-230

Teixeira, C. P., and Ferreira, V. R. (2025). Arboretum research: Trends, gaps, and opportunities for biodiversity conservation, society and climate resilience. *Plant People Planet*, 2025: 1-19.

Wang, H. and Zhang, G. (2025). Diversity, pattern, and environmental drivers of climbing plants in China. *Plants*, 14(21), 3281; https://doi.org/10.3390/plants14213281

Yamamoto, S. (2012). Forest gap dynamics and tree regeneration. *Journal of Forest Research*, 5(4):223-229, DOI: 10.1007/BF02767114.

ISTF-NIG 2026

SEEDS POSITIONING AND SOWING DEPTH FOR THE GROWTH OF *Adansonia digitata* Linnaeus IN THE SUDAN SAVANNAH ECOZONE OF NIGERIA

[1]Salami, K. D., [2]Adesanmi, V. S., [2]Ogunbela A.A. [2]Apenah, M.O., [2]Agboola, J. O., [2]Abdulrahaman M. A and [2]Zubairu M. A.

[1]Department of Forestry and Wildlife Management, Federal University Dutse, Jigawa State, Nigeria
[2]Forestry Research Institute of Nigeria, Jericho, Ibadan, Oyo State, Nigeria
Corresponding author's email: foristsalam@yahoo.com; 07034294371

Abstract

The study assessed the effects of seed positioning and sowing depth on the early growth performance of *Adansonia digitata* (baobab) seedlings in the Sudan Savannah, aiming to determine the optimal positioning and planting depth for the species. A Completely Randomized Design (CRD) was used, with four seed orientations (vertical, horizontal, slanting, and tip-down) and three planting depths (1 cm, 2 cm, and 3 cm), yielding 12 treatment combinations with 10 replicates each. Data were collected on seedling Height (cm), stem diameter (mm), and Number of leaves, and analyzed using Analysis of Variance. The results revealed that seed orientation significantly influenced seedling growth. Vertically oriented seeds planted at shallow depths (1–2 cm) produced the highest growth values across all measured parameters: Shoot Height **(**18±0.17, 16±0.19); Stem diameter (17±0.18, 17±0.18) and Number of leaves **(**9±0.33), indicating superior germination efficiency and seedling vigor. Growth declined progressively with increasing depth, while horizontal, slanting, and tip-down placements performed worse than vertical placement. Planting depth had a mild effect relative to seed positioning, but deeper sowing (3 cm) generally reduced emergence and vigor. The study concludes that vertical seed placement at shallow depths enhances the establishment and early development of *A. digitata* seedlings. It recommends that nursery managers and farmers adopt vertical sowing at a depth of 1–2 cm to improve baobab propagation success and support sustainable cultivation, conservation, and afforestation efforts in the Sudan Savannah region.

Keywords: *Adansonia Digitata,* Depth, Growth, Orientation, Placement and Sudan Savannah

Introduction

Adansonia digitata Linn, commonly known as the baobab tree, is a multipurpose species indigenous to the African savannahs (Adesina & Zhu, 2022). It provides food, medicine, shelter, and plays an important role in ecological balance. Despite its importance, seed propagation is challenging due to inherent dormancy and sensitivity to planting conditions. The effects of seed positioning and planting depth on germination and seedling development are important for enhancing cultivation practices and ensuring sustainable utilization (Masilamani *et al.,* 2023). The combined effects of seed positioning and planting depth on the germination and early growth of *Adansonia digitata* are crucial for developing effective propagation protocols (Motbaynor *et al.,* 2025). Such knowledge can inform reforestation efforts, conservation strategies, and the establishment of baobab plantations for commercial purposes. Given the increasing interest in *Adansonia digitata* for its nutritional and economic potential, optimizing propagation techniques is essential to meet the growing demand and ensure the sustainability of this valuable species

(Salami *et al.,* 2025). The growth and establishment of *Adansonia digitata* seedlings are significantly influenced by the positioning and depth at which their seeds are planted (Magava et al., 2026). As an iconic species adapted to arid climates, understanding how seed positioning impacts germination and early growth is critical for optimizing propagation methods, especially in large-scale restoration projects.

Seed depth plays a vital role in regulating access to water, oxygen, and Light, which are essential for the successful germination and survival of seedlings (Kumar *et al.,* 2026). While shallow seed planting generally enhances Light availability and promotes quicker emergence, deeper seed placement may offer protective advantages against environmental stresses such as drought and soil temperature fluctuations (Ekanayake, 2026). Given that *Adansonia digitata* is increasingly utilized in afforestation and reforestation initiatives across Africa. Determining the ideal seed positioning can significantly improve seedling survival and establishment rates. Research by Magava *et al.* (2026) and Amonum *et al.* (2020) highlights the importance of such assessments, providing insights that could inform best practices for cultivating this drought-resistant species (Salami & Lawal, 2018). *Adansonia digitata* is a valuable tree species in the Sudan Savannah, providing food, medicine, and income (Salami *et al.,* 2026). Despite their importance, cultivation practices are not well established (Rafiu *et al.,* 2026). Seed positioning and sowing depth significantly impact germination and seedling growth (Jawad *et al.,* 2026). However, research on optimal techniques for *A. digitata* in the Sudan Savannah is scarce. This finding can contribute to improved tree establishment, supporting livelihoods and environmental conservation in the region. Effective cultivation can enhance food security and economic opportunities (Salami *et al.,* 2020; Salami *et al.,* 2019).

Adansonia digitata is a vital multipurpose tree species native to sub-Saharan Africa, valued for its nutritional, medicinal, and economic importance. Its fruits, leaves, and seeds are sources of essential nutrients, while its bark and wood are used for fiber and fuel. Despite its significance, the natural regeneration and propagation of *Adansonia digitata* remain limited, which poses a major challenge to its conservation and widespread cultivation (Salami *et al.,* 2020; Salami *et al.,* 2019). One of the primary constraints is its low germination rate, mainly caused by hard seed coats that impose physical dormancy. Over the years, several studies have explored different scarification techniques and thermal treatments to overcome this dormancy. However, even with pre-treatment methods, successful germination and healthy seedling development still depend heavily on additional factors such as planting depth and seed positioning (Salami & Lawal, 2018). Unfortunately, these factors have not been given sufficient attention in baobab propagation studies. In many rural and semi-urban areas where *Adansonia digitata* is cultivated or conserved, seeds are sown without standardized planting procedures, resulting in poor emergence, weak seedlings, and high mortality (Rafiu *et al.,* 2026). This poor understanding of optimal planting conditions leads to inconsistent results, limiting the success of seed-based propagation efforts. This study aims to assess the impact of seed positioning and planting depth on early seedling growth of *Adansonia digitata*, with a view to evaluating seedling vigor and survival.

Materials and Methods

Description of the Study Site

The study was carried out in the Department of Forestry and Wildlife Management, which is situated at coordinates $11^0$42' 04"N, 9020'31"E and $11^0$70'11"N, 9·3041'94"E, with an altitude of

460 meters above sea level. The area, characterized by a tropical climate, receives a mean annual rainfall of 750mm, which provides a favorable condition for agricultural activities (Gidado *et al.,* 2023). The area's mean annual temperature supports the growth of a variety of plants. The area's relatively uniform climate and soil conditions ensured that the study's results were reliable and applicable to similar agroecological zones. The area's topography is generally flat, with a high point of approximately 750 meters. The soil type in this region is predominantly sandy-loam, as reported in previous studies (Garba *et al*., 2021). This soil type is characterized by a mix of sand, silt, and clay, providing a suitable medium for plant growth.

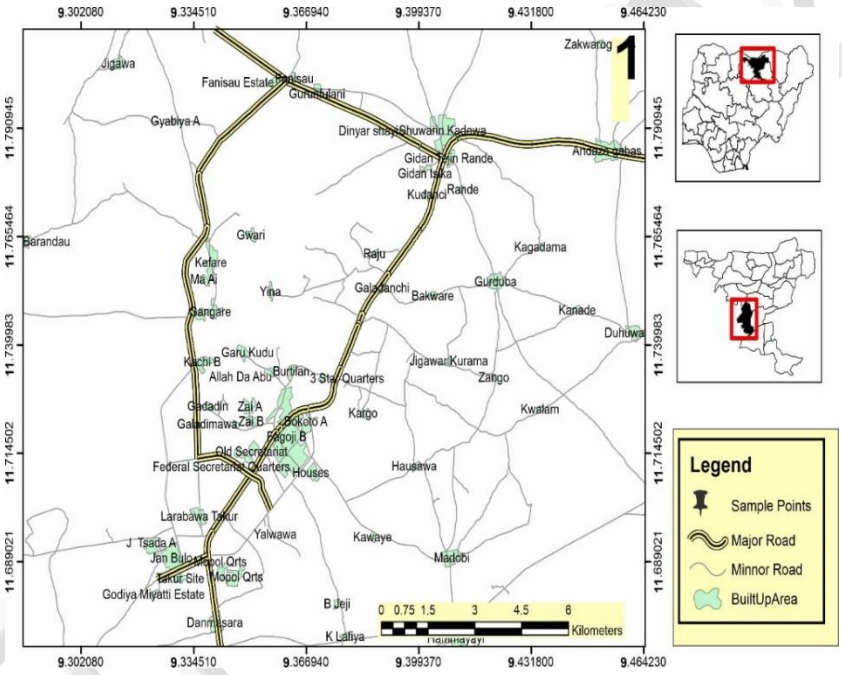


Figure 1: Map of Dutse Local Government

Source: Salami *et al.,* 2020

Data Collection

Seeds and soil

The mature seed of *Adansonia digitata* was collected from Jaudi village under the Dutse Local Government Area, Jigawa State, from the plantation species to avoid inbreeding and facilitate proper crossbreeding. The dormancy of the seeds was first broken using hot water at 100°C, as described by Oyebamiji *et al.* (2019). The seeds were raised inside a seedbed in the nursery before transplanting. Watering was done twice a day. Topsoil will be collected from the nursery and filled into each polythene bag.

Sampling Design

A complete Randomized Design was adopted, with seeds placed at different positions (vertical, horizontal, slanting, and tip of the seed) and at different depths. i.e., 1cm, 2cm, 3cm, with 2 factors, 12 treatment combinations, and 10 replicates. This method ensures that each seed has an equal chance of being placed in any treatment, thereby minimizing experimental bias.

Table 1: Sampling Layout

Depth / Positioning	Vertical	Horizontal	Slanting	Top
D1	D1V	D1H	D1S	D1T
D2	D2V	D2H	D2S	D2T
D3	D3V	D3H	D3S	D3T

NOTE: D1V: sowing at 1cm in a vertical form; **D2V:** sowing at 2cm in a vertical form; **D3V**: sowing at 1cm in a vertical form; D1H: sowing at 1cm in a horizontal form; **D2H:** sowing at 2cm in a horizontal form; **D3H:** sowing at 3cm in a horizontal; **D1S:** sowing at 1cm in a slanting form; **D2S:** sowing at 2cm in a slanting form; **D3S:** sowing at 3cm in a slanting form; **D1T:** sowing at 1cm in slanting form; **D2T:** sowing at 2cm in a slanting form; **D3T:** sowing at 3cm in a slanting form

Data Analysis

Collected data was subjected to statistical analysis using Analysis of Variance (ANOVA) to determine the significance of the effects of seed orientation, planting depth, and their interaction on germination and seedling growth parameters with the aid of the Statistical Package for the Social Sciences (SPSS) version 19

Results and Discussion

Results

The data suggests that seed positioning has a significant impact on plant growth, with vertical positioning at shallower depths (x1cm and x2 cm) resulting in the highest growth values for Number of leaves, Height, and stem diameter. As the depth of seed positioning increases, growth values tend to decrease, indicating that shallower planting is more favorable for plant growth. The results also show that horizontal, slanted, and tip-down seed positions result in lower growth values than vertical positioning. These findings have implications for agricultural practices and suggest that optimizing seed positioning can improve plant growth and productivity.

Table 2: Mean of the Growth variables in the study area

Treatment	Positioning of the seed	Number of leaves	Shoot Height (cm)	Stem diameter (mm)

ISTF-NIG 2026

1	Vertical x 1cm	7±0.43	18±0.17	17±0.18
2	Vertical x 2 cm	9±0.33	16±0.19	17±0.18
3	Vertical x 3 cm	8±0.38	15±0.2	15±0.2
4	Horizontal x 1 cm	8±0.38	12±0.25	5±0.6
5	Horizontal x 2 cm	10±0.3	10±0.30	5±0.6
6	Horizontal x 3 cm	7±0.43	8±0.38	3±1.0
7	Slanting x 1 cm	9±0.33	11±.27	4±0.75
8	Slanting x 2 cm	7±0.43	8±0.38	3±1.0
9	Slanting x 3 cm	5±0.6	5±0.6	1±0.33
10	Tip x 1 cm	5±0.6	6±0.5	2±1.5
11	Tip x 2 cm	4±0.75	5±0.6	1±3.0
12	Tip x 3 cm	3±0.1.0	2±1.5	1± 3.0

Table 2: **Correlation of Seed Positioning and Sowing Depth**

Variables / Positioning	Vertical	Horizontal	Slanting	Top
Leave Number	-0.5	-0.07	-0.90	0.99
Shoot Height (cm)	-0.99	-0.99	-0.99	-0.09
Stem diameter (mm)	0.87	0.87	0.99	-0.76

Discussion

Seed positioning plays a crucial role in plant growth, with recent studies highlighting the benefits of vertical positioning at shallower depths (Paul *et al.,* 2026). The result suggests that seed positioning has a significant impact on plant growth, with vertical positioning at shallower depths

ISTF-NIG 2026

resulting in the highest growth values for Number of leaves, Height, and stem diameter (Ettl *et al.,* 2026). The experimental results from the different treatments of seed positioning and planting depth provide detailed insights into the early growth performance of *Adansonia digitata* (baobab), a species well known for its ecological resilience and economic importance across sub-Saharan Africa. The data clearly demonstrate that both seed orientation and planting depth play critical roles in determining seedling vigor, as measured by leaf number, shoot height, and stem diameter. Across all treatments, vertically positioned seeds, particularly at shallow depths (1–2 cm), consistently produced superior growth outcomes compared to other orientations. For example, vertical placement at 1 cm depth resulted in the highest shoot height (18±0.17 cm) and One of the largest stem diameters (17±0.18 mm), while vertical placement at 2 cm depth produced the highest Number of leaves (9±0.33). This suggests that vertical orientation allows the radicle and plumule to align naturally with gravitational forces, promoting efficient emergence and rapid establishment. Such findings align with general principles of seed biology, in which proper orientation minimizes the energy required for seedling emergence and enhances early growth performance. (Minello *et al.,* 2026).

In contrast, horizontal and slanting seed placements showed moderate growth but were clearly inferior to vertical orientation, particularly in structural development. For instance, although horizontal placement at 2 cm depth recorded the highest leaf number overall (10±0.3), it showed reduced shoot height (10±0.30 cm) and significantly smaller stem diameter (5±0.6 mm). This indicates that while leaf initiation may not be strongly inhibited, biomass allocation to structural components is compromised. The likely explanation is that horizontally placed seeds require additional metabolic energy to reorient their growth upward, thereby reducing the energy available for stem thickening and elongation. Similarly, slanting orientations produced intermediate results, with reasonable leaf production but reduced stem diameter and shoot height, especially as planting depth increased. These observations highlight that any deviation from optimal vertical alignment introduces mechanical and physiological constraints that limit seedling performance (Guidi *et al.,* 2026). The poorest growth was observed in seeds planted in the "tip" orientation across all depths. For example, at 3 cm depth, tip-oriented seeds produced only 3±1.0 leaves, a shoot height of 2±1.5 cm, and a stem diameter of 1±3.0 mm, indicating severely stunted growth. This poor performance can be attributed to the improper positioning of the embryonic axis, which delays radicle emergence and forces the seedling to expend additional energy to correct its growth direction. Such stress conditions can significantly hinder early establishment, making seedlings more vulnerable to environmental challenges. These findings reinforce the importance of correct seed placement in nursery practices for baobab propagation.

Planting depth also had a pronounced effect on seedling growth across all orientations. In general, shallow depths (1–2 cm) supported better growth, while deeper planting (3 cm) resulted in reduced shoot height, fewer leaves, and smaller stem diameters. This trend is consistent with previous studies on *Adansonia digitata*, which report that increasing planting depth can delay seedling emergence and reduce survival rates due to greater mechanical resistance and limited oxygen availability in deeper soil layers (Fredrick *et al.,* 2026). However, some studies also note that moderate depth can enhance germination percentage and early growth under certain conditions, suggesting that the relationship between depth and growth is complex and influenced by additional factors such as soil type, moisture, and temperature (Xu *et al,* 2026). In the present data, the decline in performance at 3 cm depth across all orientations suggests that this depth may lie outside the optimal range for rapid emergence and early vigor under the given experimental conditions.

The physiological basis of these observations can be further understood in the context of baobab seed characteristics. *Adansonia digitata* seeds possess a hard, impermeable seed coat that imposes dormancy and restricts water uptake, requiring scarification or environmental triggers such as heat to initiate germination (Ray *et al.,* 2026). Once dormancy is broken, successful germination and seedling establishment depend heavily on environmental conditions that facilitate water absorption, oxygen availability, and efficient growth orientation. Proper seed positioning ensures that the radicle can penetrate the soil quickly while the shoot emerges with minimal resistance, thereby optimizing resource use during the critical early stages of development. Conversely, improper orientation or excessive depth can exacerbate the inherent challenges posed by the seed's testa, leading to delayed emergence and reduced vigor (Sahayaraj *et al.,* 2026). From an applied perspective, these findings have significant implications for the cultivation and domestication of *Adansonia digitata*. The species is highly valued for its nutritional, medicinal, and economic benefits, including its nutrient-rich seeds, which contain substantial amounts of carbohydrates, proteins, and beneficial oils (Kidane *et al.,* 2026). Efficient propagation techniques are therefore essential for enhancing its production and supporting agroforestry initiatives. The results suggest that nursery operators and farmers should prioritize vertical seed placement at shallow depths (1–2 cm) to maximize seedling performance. Avoiding deeper planting and improper orientations, such as tip placement, can significantly improve germination success, growth rate, and overall plant quality.

Furthermore, the relatively small standard errors observed across treatments indicate consistency and reliability in the data, strengthening the validity of the conclusions. The clear trends observed, superior performance of vertical orientation, decline in growth with increasing depth, and poor outcomes under tip positioning, provide a robust framework for developing best practices in baobab seedling production. These findings also contribute to a broader understanding of how physical planting parameters influence plant development, complementing existing research on seed dormancy, pre-treatment methods, and environmental factors influencing baobab growth. The correlation values obtained for the different seed orientations of *Adansonia digitata* provide important insights into how planting position influences relationships among key growth parameters, leaf number, shoot Height, and stem diameter. For vertically positioned seeds, the correlation shows a moderate negative relationship with leaf number (-0.5) and a very strong negative correlation with shoot height (-0.99). At the same time, stem diameter exhibits a strong positive correlation (0.87). This suggests that under vertical orientation, increases in certain growth factors may slightly reduce leaf production and are strongly associated with reduced shoot elongation, but significantly enhance stem thickening, indicating a tendency toward sturdier seedlings rather than taller ones. In the horizontal orientation, a weak negative correlation with leaf number (-0.07) suggests little relationship, whereas the very strong negative correlation with shoot height (-0.99) indicates that factors influencing this orientation severely limit vertical growth. However, the strong positive correlation with stem diameter (0.87) suggests that even though Height is restricted, some biomass allocation still favors stem girth. Slanting orientation presents a stronger negative correlation with leaf number (-0.90) and again a very strong negative correlation with shoot height (-0.99), indicating that both leaf production and elongation are adversely affected under this positioning; however, the nearly perfect positive correlation with stem diameter (0.99) implies that any growth achieved is highly concentrated in stem thickening.

In contrast, the "top" orientation displays a very strong positive correlation with leaf number (0.99), suggesting that this positioning favors leaf production. However, it has a weak negative

relationship with shoot height (-0.09), indicating minimal influence on elongation, and a strong negative correlation with stem diameter (-0.76), reflecting poor structural development. These correlations reveal that while some orientations may promote specific growth traits (such as leaf production in top positioning or stem thickening in slanting placement), vertical positioning tends to be more balanced for overall development. In contrast, unfavorable orientations tend to create trade-offs between growth parameters, often limiting shoot height and structural stability.

Conclusion

The study concluded that seed orientation significantly influences the early growth and establishment of *Adansonia digitata*. Vertically oriented seeds exhibited the best performance in Height, stem diameter, and root development due to proper root–shoot alignment, which facilitates efficient nutrient and water transport. Horizontally oriented seeds also showed moderate growth, likely because of increased lateral root branching. In contrast, slanting and tip-down orientations negatively affected germination and seedling vigor by disrupting the embryo's natural polarity. Planting depth within 1–3 cm did not significantly affect seedling growth, suggesting that shallow planting is sufficient as long as seeds are not buried too deeply to hinder emergence. Deviations from this optimal configuration, particularly deeper planting and unfavorable orientations, result in significant reductions in growth performance. These insights are valuable for improving propagation techniques, enhancing seedling survival, and supporting the sustainable utilization of this iconic and economically important tree species. Therefore, seed orientation plays a more crucial role than planting depth in determining early seedling success in *A. digitata.*

Recommendations

i. Seeds of *Adansonia digitata* should be sown vertically, with the micropyle facing downward, to ensure proper root establishment and healthy seedling growth.

ii. Planting depth of 1–2 cm is optimal to allow easy emergence and adequate soil moisture contact.

iii. Further studies should investigate long-term field performance of seedlings from different orientations to confirm the persistence of early growth advantages.

iv. Farmer and nursery managers in savannah regions should adopt vertical planting techniques for efficient germination and vigorous growth.

References

Adesina, J. A., & Zhu, J. (2022). A review of the geographical distribution, indigenous benefits and conservation of the African baobab (*Adansonia digitata* L.) tree in sub-Saharan Africa. *Preprint*.

Adewumi, A. A. & Olayemi, F. F. (2021). Effects of seed orientation and planting depth on germination and seedling performance of forest tree species. *Journal of Forestry Research*, 32(3): 567–575.

Africa, S. S. (2023). Irrigation Practices in Moderately Warm Arid Regions of Sub-Saharan Africa. Handbook of Irrigation Hydrology and Management: *Irrigation Case Studies,* 115.

Aikins, S. H. M., Afuakwa, J. J., and Osei-Bonsu, E. (2020). Effects of sowing depth and orientation on germination and emergence of maize (*Zea mays* L.). *Journal of Agriculture and Crop Researc*h, 8(1): 1-8.

Alhassan, A. A. (2020). Effects of seed orientation and sowing depth on germination and seedling growth of shea (*Vitellaria paradoxa* C.F. Gaertn.). *Journal of Plant Sciences*, 8(3): 55-62.

Bilal, M. (2024). Study of reproductive biology and variability in cone, seed and seedling characteristics among half-sib progenies of *Pinus wallichiana* AB Jackson.

Chaudhary, S., & Chopra, N. K. (2017). Effect of seed orientation and sowing depth on germination and seedling growth of wheat (*Triticum aestivum* L.). *Journal of Applied and Natural Science* 9(1), 533–538.

Ekanayake, U. (2026). The effect of integrated crop management (ICM) on crop-weed competition, weed phenology and weed seed dormancy.

Ettl, G. J., Bobsin, C. R., Bormann, B. T., & Holt, D. E. (2026). Variable Density Planting: Using Marigolds as a Model System to Describe a Silvicultural Approach to Increase Structural Diversity. *Forests*, 17(4), 401.

FAO. (2020). Tree Seed Technology Manual. Food and Agriculture Organization of the United Nations, Rome

Fredrick, O., Muchiri, Z., Osir Owiro, E., Wafula, M., Mwaura, O., & Kigathi, R. (2026). Complete chloroplast genome of African Baobab (Adansonia digitata L.): structural characterization, comparative genomics, and phylogenetic placement within Malvaceae. *Bio Rxiv*, 2026-02

Gan, Y., Hamel, C., & O'Donovan, J. (2012). Lentil response to seeding depth and soil water availability. Crop Science 52(3), 1333–1342.

Garba, A., Salami, K. D., & Akanbi, W. B. (2021). Assessment of endangered economic tree species and conservation techniques in Jigawa State, Nigeria. *FUDMA Journal of Agriculture and Agricultural Technology*, *7*(2), 116–123.

Gidado, H. A. Salami, K. D. Kareem, A. A., Jibo, A. U., Adam F. & Oginni, D. O. (2023). Effect of frequencies of watering and water volumes on the growth performance of Adansonia digitata (Linn) Seedlings. *Australian Journal of Science and Technology* ISSN Number (2208–6404) Volume 7, Issue 1, March 2023 Australian

Guidi, L., Rosellini, E., Riccio, G., & Cascone, M. G. (2026). Advancements and Challenges in Tissue-Engineered Heart Valves: Integrating Biomechanics, Biomaterials, and Biomimetic Design for Functional Maturity. *Biomimetics*, *11*(3), 185.

Hartmann, H. T., Kester, D. E., Davies, F. T., & Geneve, R. L. (2018). Plant Propagation: Principles and Practices. 9th Edition. Pearson Education.

Ibrahim, M. B. & Musa, S. M. (2019). Influence of planting orientation on germination and early seedling growth of Adansonia digitata L. in semi-arid environments. *Nigerian Journal of Ecology,* 18(2), 45–52.

Jawad, A., Hussain, S., Akram, M. Z., Ameen, A., Naeem, A., Ali, M., & Nazeer, S. (2026). Impact of Seeding Depth on Emergence and Seedling Establishment of Different Rice Cultivars. *Seeds*, *5*(1), 10.

Kidane, T. T., Hussein, J. B., & Ndoro, J. T. (2026). Empowering communities: The importance of underutilized, nutrient-rich indigenous crops in Sub-Saharan Africa. In *Processing, Nutrition and Value Addition Principles of Neglected and Underutilized African Foods* (pp. 513–535). Academic Press.

ISTF-NIG 2026

Kumar, V., Jaiswal, D. K., Ansari, W. A., Sahu, P. K., & Kumar Baranwal, V. (2026). Unveiling Nature's Dormancy Code: The Pivotal Role of Brassinosteroids in Seed Germination. Journal of Plant Growth Regulation, 1–14.

Magava, K., Chigu, N., Chisango, T., & Masaiti, T. (2026). Geo-Nutritional Variability of Baobab (Adansonia digitata) Seeds across Diverse Agroecological Zones in Zimbabwe: Insights into Macro-nutrients, Micro-nutrients and Anti-nutritional Factors.

Masilamani, P., Venkatesan, S., Navamaniraj, K. N., Rajarathinam, P., Alagesan, A., & Thiagu, K. (2023). Impact of the orientation of seed placement and depth of its sowing on germination: A review—*Journal of Applied and Natural Science*, *15*(1), 314.

Minello, L. V. P., Aguzzoli, C., Nunes, A., Oliveira, E. R., Maraschin, M., da Paschoa, R. P., ... & Sperotto, R. A. (2026). Seed Nanopriming with Spirulina-Derived Carbon Dots Enhances Rice (Oryza sativa L.) Germination, Crop Establishment, and Seedling Metabolic Performance. *Plants* 15(5), 770.

Motbaynor, K., Alemu, A., & Gebremariam, Y. (2025). Seed quality parameters and optimum pre-sowing treatments for *Adansonia digitata* L. seed germination in Northwest Ethiopia. *Forest Science and Technology*, *21*(3), 233-242

Nawaz, A., Farooq, M., & Cheema, S. A. (2013). Effect of seed orientation and sowing depth on emergence and seedling growth of maize (Zea mays L.). *Journal of Animal and Plant Sciences,* 23(2), 445–450.

Ofori, W. E. (2019). Effects of sowing depth and orientation on germination and seedling growth of mahogany (Swietenia macrophylla King). *Ghana Journal of Forestry*, 35, 1-10.

Oyebamiji, N.A., Abdulrahman, H. D. & Ogor, A. A. (2019). Improvement of *Adansonia* Seedling Growth using Various Seed Dormancy Breaking Technologies in Different Soil Media. *World News of Natural Sciences,* 22:139 – 150.

Paul, H., Hossen, M. A., Nath, B., Paul, S., Islam, S., Bhuiyan, M. G. K., & Ahmmed, M. M. (2026). Rice Seedling Raising and Mechanical Transplanting: A Review and Perspectives. *Agricultural Engineering International: CIGR Journal*, *28*(1).

Rafiu, B. O., Omotoso, A. B., Omotayo, A. O., Lawal, I. O., & Aremu, A. O. (2026). From farm to resilience: evaluating the role of indigenous food plants in nutrition, market access, and livelihoods in the forest agroecological zone of Nigeria. *Agroforestry Systems*, *100*(4), 100.

Ray, M. A., Berry, N., Priya, S. & Bhatt, K. (2026). Augmenting Pre-sowing Methodologies for Effective Establishment of Chironji (*Buchanania cochinchinensis* Lour.) based agroforestry models in Madhya Pradesh. *Agroforestry Systems*, *100*(1), 37.

Sahayaraj, S. R. E., Chandel, A. K., Jagwe, P., Vennam, R. R., Balota, M., & Manimozhian, A. (2026). Toward Advanced Sensing and Data-Driven Approaches for Maturity Assessment of Indeterminate Peanut Cropping Systems: Review of Current State and Prospects. *Sensors*, *26*(7), 2208.

Salami, K. D. & Lawal, A. A. (2018). Description of Economical Tree and Shrub Species in the Northern Part of Nigeria and Their Potentials. A proceeding of the 6th Biennial National Conference of the Forests and Forest Products Society. April 23th-27th, 2016, Pp136-144.

Salami, K. D., Akinyele, A. O., & Jibo, A. U. (2025). Influence of Soil Forms and Light Intensity on Selected Physiological and Quantitative Morphological Responses of *Adansonia digitata* (Linnaeus) Del. at the early stage. Page 503 of 778. Proceedings of the 1st Faculty of Renewable Natural Resources, University of Ibadan Conference, 16 - 20 June, 2025 | ISBN: 978-978-697-875-8

Salami, K. D., Akinyele, A. O. and W.O. and Folorunso (2020). Effect of Pre-Treatments, Inorganic Fertilizer and Varying Soil Volumes on the Early Growth Performance of *Adansonia digitata* (Linn) Baobab. Nigeria *Journal of Horticultural Science, Horticultural Society of Nigeria*. 25 (1): 1–10.

Salami, K. D., Akinyele, A.O. and W. O. Folorunso (2020). Effect Of Pre-Treatments, Inorganic Fertilizer, and Varying Soil Volumes on The Early Growth Performance Of *Adansonia Digitata* (Linn) Baobab, Nigeria. *Journal Of Horticultural Science, Horticulture Society of Nigeria*, 25 (2020).

Salami, K. D., Bellu Z., Jibo A. U. & Nazil A. (2026). Influence of Different Mulching Materials on Growth of Adansonia Digitata Linneous Seedlings—NL *Journal of Agriculture and Biotechnology* 3:2 . doi: 10.71168/NAB.03.02.14

Salami, K. D., Odewale, M. A., Gidado, A. H., & Adam, Z. A (2019). Pre-germination Treatments on Seeds of *Balanites aegyptiaca* (L) Delile and Influence of Potting Mixtures on the Early Growth. *Journal of Forestry Research and Management.* 16(1).107-117; 2019, ISSN 0189-8418. www.Jfrm.org.ng IBADAN

Willenborg, C. J., Wildeman, J. C., Miller, A. K., Rossnagel, B. G., & Shirtliffe, C. J. (2005). Oat seedling emergence and early growth responses to seeding depth and orientation. *Crop Science*, 45(6), 2549-255

Xu, J., Liu, M., Mei, S., Yang, Q., Zhang, J., Yi, J. & Tan, Y. (2026). Characteristics and controlling factors of soil micro-climate in a subtropical re-vegetation catchment: Insights from continuous moisture and temperature observations. *Plant and Soil*, *519*(1), 469-488.

ISTF-NIG 2026

CHLOROPHYLL AND NUTRITIONAL LEVELS OF SELECTED INDIGENOUS PLANT LEAFY VEGETABLES IN SUDAN SAVANNAH OF NIGERIA

[1]Salami, K. D., [2]Adesanmi, V. S., [2]Ogunbela A.A. [2]Apenah, M.O., [2]Agboola, J.O., [2]Abdulrahaman M. A., [1]Musa, M. N. and [3]Soba, T. M

[1]Department of Forestry and Wildlife Management, Federal University Dutse, Jigawa State, Nigeria
[2]Forestry Research Institute of Nigeria, Jericho, Ibadan, Oyo State, Nigeria
[3]Department of Forestry, Wildlife and Ecotourism, Nasarawa State University, Keffi, Nigeria
foristsalam@yahoo.com, 07034294371

Abstract

This study assesses chlorophyll content and the nutritional composition of selected indigenous leafy species at the Federal University Dutse, Jigawa State, Nigeria. The research examined four indigenous species: *Moringa oleifera, Adansonia digitata, Hibiscus sabdariffa, and Amaranthus spinosus*. Leaf samples were collected and analyzed using ethanol extraction and SPAD chlorophyll meter readings. Also, leaf samples were collected and air-dried to form a powder, which was conveyed to the laboratory for proximate analysis. Nutritional contents, such as % Ash, % Fat, % Protein, % Carbohydrate, and % Crude fiber, were examined. Analysis of Variance was used to analyze the collected data, and the least significant difference was used to separate the means. Results showed significant variations ($p<0.05$) in chlorophyll and nutrient content among the species. *Moringa oleifera* recorded the highest chlorophyll (52.60±0.34) and nutrient levels: Moisture (12.003±.0.11), % Ash (8.896±0.21), % Fat (2.520±0.32), % Protein **(**22.969±0.32), indicating superior photosynthetic efficiency and nutritional value, while *Amaranthus spp*. exhibited higher carbohydrate content (73.688±0.31) but lower chlorophyll concentration (4.221±0.50). This study highlights *Moringa oleifera's* exceptional nutritional profile, making it ideal for food supplementation and biomass production. *Adansonia digitata and Amaranthus spinosus* offer energy-rich options, while *Hibiscus sabdariffa* supports digestive health with its high dietary fiber. Integrating these species into food strategies can address nutritional deficiencies. We recommend incorporating *Moringa oleifera* into supplementation programs, utilizing *Adansonia digitata* and *Amaranthus spinosus* as energy sources, and leveraging *Hibiscus sabdariffa* for digestive health, particularly in regions with abundant access to these plants.

Keywords: Chlorophyll, Nutritional Contents, Indigenous Plant Leafy Vegetable

Introduction

The importance of leaves and chlorophyll in plant biology cannot be overstated, as leaves are the primary organs responsible for photosynthesis, growth, and development. In contrast, chlorophyll plays a crucial role in capturing Light energy to drive photosynthetic reactions (Chen *et al.,* 2022). Indigenous leafy vegetables are pivotal in addressing micronutrient deficiencies prevalent in regions in the Sudan savanna, where malnutrition remains a significant challenge (Abdellatef *et al.,* 2026). These vegetables, often overutilized and overlooked, are reservoirs of essential nutrients, including vitamins A, C, and E, minerals such as calcium, iron, and zinc, and an array

of phytochemicals (Wani, 2026). These bioactive compounds are crucial for combating malnutrition, boosting immunity, and preventing diseases. The consumption of these nutrient-dense vegetables can significantly help alleviate dietary deficiencies, particularly in communities where access to diverse food sources is limited (Ziso *et al.,* 2022). Their adaptability to local environments and potential resilience to climate change underscore their importance in sustainable food systems. Unlike exotic species, indigenous leafy vegetables are often better suited to the local climate, requiring fewer external inputs and making them a viable option for resource-constrained farmers (Singh *et al.,* 2023). This adaptability not only ensures their availability throughout the year but also positions them as a key component in strategies to enhance food security and nutritional sufficiency. Despite their potential, the nutritional and phytochemical profiles of many indigenous leafy vegetables remain undocumented, creating a knowledge gap that hinders their optimal utilization. Understanding these profiles is essential for informing dietary recommendations, promoting their cultivation, and integrating them into food-based interventions. Elucidating the nutrient composition can also enhance awareness and encourage their consumption, moving them from the status of "wild" or "weedy" plants to recognized contributors to health and nutrition.

Furthermore, promoting and utilizing indigenous leafy vegetables can yield broader socio-economic benefits, particularly for women and marginalized communities who often rely on these plants as a source of nutrition and income. Empowering these communities with knowledge about the nutritional value of these vegetables can improve their livelihoods and contribute to achieving nutritional sufficiency in resource-constrained settings. In Nigeria, and specifically Jigawa State, documenting and promoting indigenous leafy vegetables could offer a sustainable strategy to tackle malnutrition and enhance food security. Chlorophyll, a green pigment found in chloroplasts, is essential for photosynthesis, and its concentration serves as an indicator of plant physiological status, vitality, and photosynthetic efficiency (Li *et al.,* 2022). Chlorophyll, the green pigment in plants, offers potential health benefits when consumed, including antioxidant properties that help protect cells from damage, possible detoxification effects, and anti-inflammatory actions. Found abundantly in leafy vegetables, chlorophyll is a marker of nutrient density and freshness. While research on direct health benefits is ongoing, eating chlorophyll-rich foods contributes to a nutrient-rich diet, supporting overall health and well-being. Incorporating these foods into meals can be a simple way to boost nutritional intake. Assessing chlorophyll concentration is crucial for understanding plant health, photosynthetic activity, nutrient status, and environmental stress responses, with generally accepted ranges including high concentrations above 30-50 µg/cm², moderate concentrations between 15-30 µg/cm², and low concentrations below 15 µg/cm² (Ghani *et al.*, 2021). The importance of chlorophyll concentration is further underscored by its role in informing strategies to optimize photosynthetic efficiency, diagnose nutrient deficiencies, and detect early signs of stress. (Khan *et al.*, 2021).

Indigenous tree species, which are native to specific regions or ecosystems, play a vital role in maintaining ecosystem stability and resilience by providing habitat and food for wildlife, regulating water cycles, preventing soil erosion, sequestering carbon, and supporting biodiversity (Naidoo *et al.,* 2021). However, micronutrient deficiencies pose a significant global public health challenge, affecting over two billion individuals, predominantly in low to middle-income countries, with vulnerable groups including young children, pregnant and lactating women, and the elderly. Moreover, the study of leaves and chlorophyll can provide valuable insights into the

intricate mechanisms that govern plant growth and development, while also shedding Light on the critical role that plants play in maintaining the delicate balance of ecosystems (Schurr *et al.,* 2006). Indigenous leafy vegetables are vital for food security and nutrition in Nigeria, particularly in Jigawa State. However, their chlorophyll and nutrient content remain undocumented, creating a knowledge gap that hinders optimal utilization. These aspects can promote these vegetables as a sustainable solution for addressing nutritional challenges. While studies in Nigeria have evaluated the nutrient composition of various leafy vegetables, highlighting their value (Adeyeye & Omolayo, 2011; Ifesan *et al.,* 2015; Ogunka-Nnoka *et al*., 2019), research specific to Jigawa State is scarce. A local study on the effects of fertilizer on Amaranthus and Jute Mallow shows interest in optimizing their cultivation (Abu *et al.,* 2017). This study aims to bridge the knowledge gap on chlorophyll and nutrient levels of selected indigenous leafy vegetables in the Sudan savanna, with a view to recommending the best diet and promoting the sustainability of the leafy vegetables.

Material and Method

Description of study site

The study was carried out at Forestry Nursery of the Department of Forestry and Wildlife Management, Federal University Dutse, Jigawa State. It lies between latitudes 11.00°N and 13.00°N and longitudes 8.00°E and 10.15°E (Gidado *et al.,* 2023). The study area, Dutse, is covered by the Sudan and characterized by a hot, wet summer and a cool, dry winter, with an average rainfall season of 3-5 months (644 m) (Jibo *et al.,* 2022). Sunshine hours indicate that the town receives 10-11 hours of sunshine per day, depending on the season. The topography is characterized by a high land area of almost 750m. Soil tends to be fertile, ranging from sandy-loam (Salami & Lawal, 2018). The area's mean annual temperature supports the growth of a variety of plants. The area's relatively uniform climate and soil conditions ensured that the study's results were reliable and applicable to similar agroecological zones. The area's topography is generally flat, with a high point of approximately 750 meters. The soil type in this region is predominantly sandy-loam, as reported in previous studies (Garba *et al*., 2021). This soil type is characterized by a mix of sand, silt, and clay, providing a suitable medium for plant growth

ISTF-NIG 2026

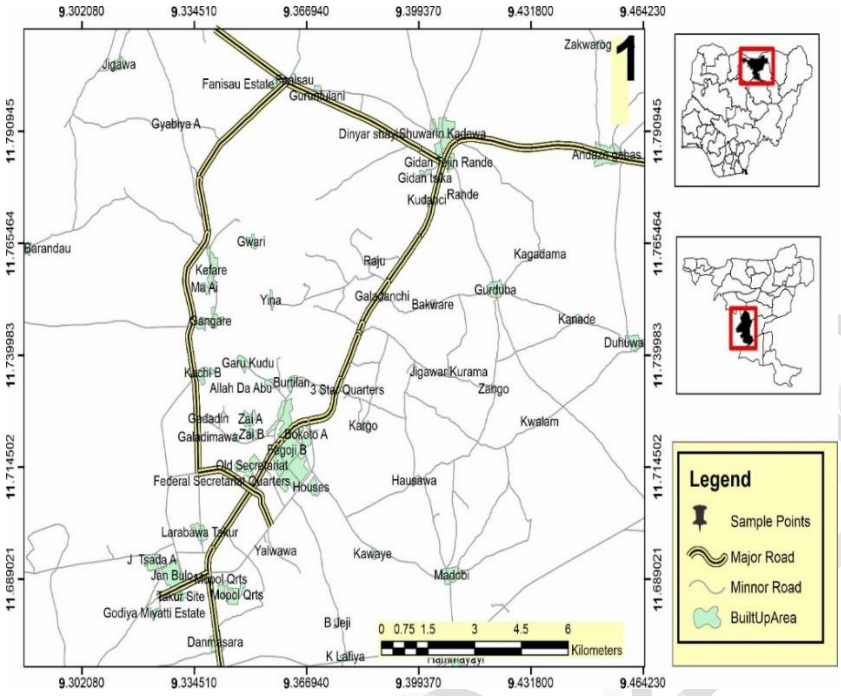


Figure 1: Map of Dutse Local Government

Source: Salami *et al*., 2020

Data collection

Leaf

Four (4) indigenous Leaf vegetable plant species, such as *Moringa oleifera, Adansonia digitata, Hibiscus sabdariffa and Amaranthus spinosus*, were selected for this study. A total of ten (10) healthy leaves were collected from the upper canopy of each Plant to avoid collecting leaves with physical damage and discoloration. Leaf samples were then subjected to chlorophyll extraction with solvents such as ethanol, enabling the measurement of chlorophyll concentration for each species (Kumar *et al.,* 2022).

Procedure

Step 1: Preparation

Plant Selection

The leaves of *Adansonia digitata* (Baobab) were selected for analysis, ensuring they were representative of the Plant's health and free from visible damage or disease.

Sampling Time

Leaf samples were collected daily at 10:00 am to maintain consistency, as chlorophyll levels are known to fluctuate with diurnal changes in Light intensity.

Check Calibration: The SPAD meter was checked and calibrated according to the manufacturer's instructions prior to taking measurements. The device was set to automatically calibrate before each use, ensuring accurate chlorophyll content readings for leaf samples.

Step 3: Taking Measurements

Select the Leaf Section: A healthy section of the leaf was selected for measurement, avoiding damaged, diseased, or discolored areas. Measurements were taken midway between the leaf veins and away from the edges to ensure representative chlorophyll readings.

Clamping the Leaf: The SPAD meter's clamp was opened, and the selected leaf section was placed between the sensor heads, ensuring it was flat and fully covered the sensor area. This positioning ensured accurate chlorophyll content readings were obtained.

Record the Value: The clamp was closed, and the measure button was pressed. The SPAD meter displayed a numerical value indicating the relative chlorophyll content (SPAD value). This process was repeated three times on different leaves to ensure consistency and account for variability.

Step 4: Collection of observations

Repeat Measurements: Multiple readings were taken from different leaves of the Adansonia digitata plant to obtain a representative sample of chlorophyll content. This approach helps account for variability within the Plant and provides a more accurate estimate of overall chlorophyll levels.

Document Variability: Variations in leaf age (young, mature, old), position on the Plant (top, middle, bottom), and environmental conditions (sun-exposed, shaded) were documented, as these factors were noted to influence chlorophyll content measurements. This aided in interpreting the data and accounting for potential sources of variability**.**

Step 5: Analysis and Interpretation

The average SPAD value of 38.5 ± 2.1 indicated the Plant's chlorophyll content was within the normal range for healthy Adansonia digitata.

Step 6: Reporting

Report Findings: Prepare a report summarizing the findings, including the SPAD values, conditions under which the measurements were taken, and any recommendations for plant care or further testing.

Proximate Composition Procedure

Step 1: Preparation

Select the Plant: samples were selected from the healthy mother plant, ensuring they were representative of the Plant's overall health and free from visible damage or disease.

Time of the Day: Conduct measurements at a consistent time of day, as chlorophyll levels can fluctuate due to Light intensity and other diurnal factors.

Data analysis

ISTF-NIG 2026

Mean Rate of Chlorophyll and nutritional contents from all the treatments were analyzed with the use of Analysis of Variance (ANOVA) ($p < 0.05$). At the same time, Fisher's Least Significant Difference (LSD) was applied for the separation of significantly different means at 5%.



Plate 1: ***Hibiscus sabdarifa***



Plate 2: ***Amaranthus spinosus***



Plate 3: ***Adansonia digitata***



Plate 4: ***Moringa oleifera***

Results and Discussion

Results

The data show that *Moringa oleifera* had the highest chlorophyll content (52.60±0.34), significantly higher than that of the other species (Table 1). *Hibiscus sabdariffa* comes next with a moderate rate (36.16±0.21), while *Adansonia digitata* and *Amaranthus spinosus* have relatively lower chlorophyll levels (30.9±0.12 and 29.53±0.11, respectively).

Table 1: Chlorophyll rate of the Plant

Species	*Moringa oleifera*	*Amaranthus Spinosus*	*Hibiscus sabdarifa*	*Adansonia digitata*
Rate	52.60 ± 0.34^{a}	29.53 ± 0.11^{bc}	36.16 ± 0.21^{b}	30.9 ± 0.12^{bc}

The nutrient analysis of the plant powder samples shows that *Moringa oleifera* (MRG) had the highest protein content (22.97%), making it a rich source of plant protein. It also had good fat content and moderate carbohydrate levels. *Adansonia digitata* (ADSN) showed moderate protein and higher carbohydrate values (over 64%), indicating its energy-rich potential. *Amaranthus spinosus* (AMRT) had the highest carbohydrate content (around 73.7%) but the lowest protein content, making it more suitable for energy than for body-building nutrients. *Hibiscus sabdariffa* (HSBC) had a balanced profile, with moderate protein and the highest crude fiber content (above 8.9%), indicating potential digestive health benefits. Moringa stood out for protein, Amaranthus for energy, and Hibiscus for fiber.

Table 2: Mean Nutrient Content from the Powder Leaf Samples of Plant Vegetables

S/No	Sample	%Moisture	% Ash	% Fat	% Protein	% Carbohydrate	% Crude fiber
1	MRG	12.003±.0.11a	8.896±0.21a	2.520±0.32a	22.969±0.32a	55.856±0.44c	6.600±0.44
2	ADSN	9.800±.0.10b	7.644±0.32b	1.889±0.11b	16.406±0.23bc	65.554±0.31b	7.196±0.49
3	AMRT	8.367±0.09bc	3.912±0.03c	2.002±0.23ab	12.031±0.24c	73.688±0.31a	4.221±0.50
4	HSBC	10.762±0.11b	6.554±0.06bc	1.447±0.24b	13.125±0.24c	68.112±0.32ab	8.965±0.50

Note: *Moringa oleifera* (MRG), *Adansonia digitata* (ADSN), *Amaranthus Spinosus* (AMRT) and *Hisbiscus sabdarifa* (HSBC)

Discussion

Chlorophyll rate of the Plant

The chlorophyll data clearly underscore the exceptional photosynthetic capacity of *Moringa oleifera*, which recorded a notably higher rate (52.60 ± 0.34a) compared to the other species. This elevated chlorophyll content suggests that Moringa can capture sunlight more efficiently, contributing to its rapid growth and high nutritional profile (Irshad *et al*., 2025). Supporting research confirms that Moringa leaves contain significantly high levels of chlorophyll, which remain relatively stable during postharvest storage and indicate strong potential for both nutritional and agricultural uses (Sifiso *et al.,* 2024). In comparison, *Hibiscus sabdariffa*, *Adansonia digitata* and *Amaranthus spinosus* recorded lower chlorophyll rates (36.16, 30.9 and 29.53, respectively),

ISTF-NIG 2026

which may reflect lower photosynthetic output or distinct ecological strategies. The higher chlorophyll rate in Moringa positions it as a prime species for biomass production and food supplementation, particularly in regions where maximizing leaf yield and nutrient capture is crucial. The exceptional chlorophyll content in *Moringa oleifera* (52.60 ± 0.34) has significant implications for consumption. Its high photosynthetic capacity translates to rapid growth, high biomass yield, and a nutrient-dense profile, making it an ideal choice for food supplementation, especially in regions with nutritional deficiencies. Moringa's stable chlorophyll levels postharvest add to its value as a reliable nutritional source. In contrast, species like *Hibiscus sabdariffa, Adansonia digitata*, and *Amaranthus spinosus*, with lower chlorophyll content, may be better suited for specific dietary needs, such as energy sources or digestive health support. Incorporating Moringa into diets could enhance nutrient intake and support sustainable food systems.

Nutrient content from the Plant powder samples

The nutrient content of the powder leaf samples of the selected plant vegetables reveals significant variations (Table 2). *Moringa oleifera* (MRG) stands out with the highest protein content (22.969% ± 0.32), surpassing other species like *Adansonia digitata* (ADSN) (16.406% ± 0.23), *Amaranthus spinosus* (AMRT) (12.031% ± 0.24), and *Hibiscus sabdariffa* (HSBC) (13.125% ± 0.24). This is consistent with recent findings highlighting *Moringa oleifera's* exceptional nutritional profile, particularly its high protein content, making it a valuable resource for food supplementation (Kumar *et al.,* 2022). This aligns with findings by Leone *et al.* (2015), who emphasized Moringa's rich protein and micronutrient profile, making it ideal for addressing protein-energy malnutrition, especially in developing regions. In contrast, *Adansonia digitata* (ADSN) and *Amaranthus spinosus* (AMRT) exhibit higher carbohydrate levels, with AMRT showing the highest carbohydrate content (73.688% ± 0.31), indicating their potential as energy-rich food sources. *Hibiscus sabdariffa* (HSBC) has a higher dietary fiber content (8.965% ± 0.50), supporting its role in promoting digestive health (Saeed *et al.,* 2020). These findings underscore the importance of integrating species-specific leafy plants into food strategies, aligning plant choice with targeted dietary needs, particularly in regions facing nutritional deficiencies. *Adansonia digitata* (baobab) had a moderate protein content but a high carbohydrate content (over 64%), indicating its utility as an energy-dense food, consistent with earlier reports by Chadare *et al*. (2009) on baobab's caloric and mineral contributions. *Amaranthus spinosus,* while having the lowest protein content, had the highest carbohydrate content (approx. 73.7%), supporting its use primarily for energy. This aligns with studies showing its role in providing caloric support to communities with limited food access (Shukla *et al.,* 2006). *Hibiscus sabdariffa* offered a more balanced nutrient profile, with moderate protein and the highest crude fiber content (>8.9%), suggesting its value in digestive health and metabolic regulation, as noted by (Da-Costa-Rocha *et al.,* 2014)

Conclusion

The study confirms the exceptional nutritional and physiological potential of *Moringa oleifera,* which demonstrated the highest chlorophyll rate and protein content among the tested species, making it ideal for food supplementation and biomass production. While *Adansonia digitata* and *Amaranthus spinosus* are energy-rich due to their high carbohydrate levels*, Hibiscus sabdariffa* provides superior dietary fiber, supporting digestive health. These findings highlight the value of

integrating species-specific leafy plants into food and health strategies, especially in regions facing nutritional deficiencies, by aligning plant choice with targeted dietary needs.

Recommendations

Consider incorporating *Moringa oleifera* into food supplementation programs due to its high levels of chlorophyll and protein. *Adansonia digitata* and *Amaranthus spinosus* can serve as energy-rich food sources, while *Hibiscus sabdariffa* can support digestive health due to its high dietary fiber. This can help address nutritional deficiencies, particularly in regions where these plants are readily available.

References

Abdellatef, E., Gebre, Y. G., & Bauer, P. (2026). Prospects of indigenous African wild food plants in alleviating severe iron deficiency anaemia in Sub-Saharan Africa. *Plants, People, Planet* 8(2), 486–498.

Abu, S. A., Aliyu, B., & Yakubu, M. (2017). Effect of NPK fertilizer on chlorophyll pigment of Amaranth (Amaranthus cruentus) and Jute Mallow (*Corchorus olitorius*) vegetables. *Journal of Agriculture and Veterinary Science* 10(9), 1–6.

Adeyeye, E. I., and Omolayo, F. B. (2011). Proximate composition, mineral and phytate contents of some selected edible leafy vegetables in Nigeria. *Journal of Food Research*, 1(3), 1-12.

Aurora, W. I. D. (2026). Micronutrient Deficiencies and Their Public Health Impact: An Epidemiological Narrative Review. *Journal of Tropical Community And One Health*, *1*(1), 23–35.

Barbarossa, V., Schipper, A. M., Andringa, I., van Oorschot, M., Sonter, L. J. and Marques, A. (2026). The Many Pathways of Mining Impacts on Biodiversity. *Conservation Letters*, *19*(1), e70000

Chadare, F. J., Linnemann, A. R., Hounhouigan, J. D., Nout, M. J., & van Boekel, M. A. (2009). Baobab food products: A review of their composition and nutritional value. Critical Reviews in Food Science and Nutrition, 49(3), 254–274. https://doi.org/10.1080/10408390701856330

Chen, M., & BlankenshiChep, R. E. (2011). Expanding the solar spectrum used by photosynthesis. *Trends in Plant Science*, 16(8), 427–431.

Chen, S., Wang, H., Zhang, Y., Li, J., & Liu, X. (2022). Chlorophyll fluorescence imaging for monitoring the physiological status of plants under environmental stresses: A review. *Journal of Experimental Botany*, 73(3), 1011–1031.

Da-Costa-Rocha, I., Bonnlaender, B., Sievers, H., Pischel, I., & Heinrich, M. (2014). Hibiscus sabdariffa L. – A phytochemical and pharmacological review. Food Chemistry, 165, 424–443. https://doi.org/10.1016/j.foodchem.2014.05.002

Feng, L., Chen, X., Wu, W., & Li, Y. (2021). Assessment of the nutritional status of urban roadside plants using chlorophyll fluorescence. *Ecological Indicators*, 125, 107488.

Garba, A., Salami, K. D. & Akanbi, W. B. (2021). Assessment of Endangered Economic Tree Species and Conservation Techniques in Jigawa State, *FUDMA Journal of Agriculture and Agricultural Technology*, 7(2), 116-123

Ghani, S. B. A., Muharam, F. M., Sahid, I. B., & Zain, M. F. M. (2021). Estimation of chlorophyll content of paddy plants based on visible and near-infrared spectral data using machine learning models. *Remote Sensing*, 13(3), 424.

Gidado, H. A. Salami, K. D. Kareem, A. A., Jibo, A. U., Adam Fatima, Oginni, D. O. (2023). Effect of frequencies of watering and water volumes on the growth performance of Adansonia digitata (Linn) Seedlings. *Australian Journal of Science and Technology* ISSN Number (2208–6404) 7(1).

Irshad, S., Matloob, A., Mehmood, K., Nawaz, M., Iqbal, S., Wahid, M. A., ... & Khan, S. (2025). Moringa dried leaf extract as a bio-foliar fertilizer for revitalizing the performance and nutritional status of soybean. *Scientific Reports*, *15*(1), 20431

Ifesan, B. O. T., Ebong, U. E., & Ifesan, B. T. (2015). Nutritional and phytochemical evaluation of some leafy vegetables consumed in Okitipupa, *Nigeria. Journal of Food Science and Technology,* 52(12), 8234-8241.

Jibo, A., Salami, K., Lawal, A., & Muhammad, Y. (2022). Influence of Soil Amendments on the Growth Performance of *Eucalyptus camaldulensis* (Dehnh) Seedlings.

Khan, L., Abbasi, A. M., Naseem, R., Qoryog'diyev, Z., Shukurov, O., & Shah, M. H. (2026). Elemental Profiling and Health Risk Assessment of Aromatic Oils Used for Oral and Topical Applications. *Biological Trace Element Research*, 1–20.

Khan, M. A., Amiri, M. E., & Alobaidi, A. (2021). Monitoring maize crop nitrogen status using remotely sensed chlorophyll data assimilation. *Remote Sensing*, 13(5), 936.

Khan, M., Khan, S., & Khan, R. (2019). Nanotechnology: A Promising Solution for Enhancing Chlorophyll Content and Plant Growth. *Journal of Nanobiotechnology*, 17(1), 1–16.

Kumar, V., et al. (2022). Nutritional and bioactive properties of Moringa oleifera: A review. *Journal of Food Science and Technology,* 59(1), 1-14.

Leone, A., Spada, A., Battezzati, A., Schiraldi, A., Aristil, J., & Bertoli, S. (2015). Cultivation, genetic, ethnopharmacology, phytochemistry and pharmacology of *Moringa oleifera* leaves: An overview. *International Journal of Molecular Sciences*, 16(6), 12791–12835. https://doi.org/10.3390/ijms160612791

Li, Y., Huang, Y., & Guo, X. (2022). Leaf anatomy and ultrastructure as indicators of drought resistance in cultivated and wild soybean. *Plant Physiology and Biochemistry*, 172, 76-84.

McDowell, N. G., Allen, C. D., & Anderson-Teixeira, K. J. (2021). Understanding plant ecohydrology in a changing climate. *Nature Plants*, 7(10), 1217–1227.

Naidoo, R., Davis, A., & Smith, R. (2021). Valuing local and indigenous knowledge in land use planning: A case study from South Africa. *Land Use Policy*, 105, 105427.

Ogunka-Nnoka, C. U., Okafor, D. C., & Onwuka, G. I. (2019). Proximate and mineral composition of some indigenous leafy vegetables consumed in Port Harcourt, Nigeria. *Journal of Food Science and Technology*, 56(1), 45–52.

Phillips, K.M. (2014). Nutrient composition of selected traditional United States Northern Plains Native American plant foods *J. Food Compos. Anal*. (2014)

Saeed, M. (2020). *Hibiscus sabdariffa* L.: A review on its phytochemistry, pharmacology, and nutritional aspects. *Journal of Food Biochemistry,* 44(10), e13433

Saha, S. & Amat Camacho, N. (2026). Burden and associated risk factors of undernutrition among displaced pregnant and lactating women: A scoping review. *Global Public Health*, *21*(1), 2611211.

Salami, K. D., and Lawal, A. A (2018). Tree Species Diversity and Composition in the Orchard of Federal University Dutse, Jigawa State. *Journal of Forestry Research and Managemen*t. ISSN 0189-8418, *www.jfrm.org.ng*,15(2):112-122

Sarfaraz, M. Y., Achak, J., & Haqmal, A. Lead Toxicity and Health Effects-A Comprehensive Review.

Schurr, U., Walter, A., & Rascher, U. (2006). Functional dynamics of plant growth and photosynthesis–from steady-state to dynamics–from homogeneity to heterogeneity. *Plant, Cell & Environment*, *29*(3), 340-35

Setia, A. F. (2021).. Phytoavailability and human risk assessment of heavy metals in soils and food crops around the Sutlej River, India. *Chemosphere* (2021)

Shukla, S., Bhargava, A., Chatterjee, A., Srivastava, A., & Singh, S. P. (2006). Genetic variability in vegetable amaranth (*Amaranthus tricolor* L.) for foliage yield and its contributing traits over successive cuttings and years. *Euphytica,* 151, 103–110. https://doi.org/10.1007/s10681-006-9127-3

Sifiso N., Samson O. B., Aniekan M. U. and Ida R. (2024).. Optimal chlorophyll extraction conditions and postharvest stability in Moringa (*M. Oleifera*) leaves. 18:1611–1626.

Singh, P., Pandt, B. A., Ganie, M. A., Rather, T. R., & Singh, L. (2023). Diversification of small farms from the perspective of Climate Change: Problems and Prospects.

Wani, S. A. (2026). Utilization of underutilized vegetables. In *Sustainable Plant Foods* (pp. 97–110). Academic Press.

Ziso, D., Chun, O. K., & Puglisi, M. J. (2022). Increasing access to healthy foods through improving food environment: a review of mixed methods intervention studies with residents of low-income communities. *Nutrients,* 14(11), 2278.

ISTF-NIG 2026

Proceedings of the 4th ISTF-NIGERIA International Conference. Held at the Faculty of Renewable Natural Resources Management, College of Agriculture and Renewable Natural Resources, Osun State University, Nigeria, from 19th – 21st of May, 2026.
Theme: Forest Ecosystem Conservation: A Roadmap Fop Resilient Economies And Environmental Sustainability

EARLY GROWTH RESPONSE OF GINGER (*Zingiber officinale* ROSCOE) TO LEAF LITTERS OF SELECTED NITROGEN-FIXING ALBIZIA TREES

Adelani, D.O[1], Iroko, O.A[2]., Rasheed, F.M[3] and Aderibigbe, R[3]

[1]Federal College of Forestry, Ibadan, P.M.B 5087, Dugbe, Ibadan, Nigeria
[2]Forest-Based Rural Resource Center, Ikija Ijebu, Ogun State
Forestry Research Institute of Nigeria, P.M.B 5054, Jericho, Ibadan, Nigeria
[3]Federal College of Forestry Mechanization, P.M.B 2273, Afaka, Kaduna, Nigeria
**Correspondence author: adelani.olusegun@yahoo.com*
ORCID iD-0009-0009-6632-890X

Abstract

Little information is available on the effects of plant-based fertilizers on the Growth of *Zingiber officinale*. To enhance the Growth of *Zingiber officinale*, leaf litter from selected nitrogen-fixing Albizia trees was used. A completely randomized design (CRD) with five replications was adopted to assess the early growth response of *Z. officinale* to leaf litter from selected nitrogen-fixing Albizia trees (*Albizia zygia, Albizia coriaria, Albizia ferruginea, Albizia lebbeck,* and *Albizia saman*) and the control. A propagule represented a replicate. A total of thirty (30) propagules were involved in the experiment. The propagules were planted in the heap (3kg) with and without (300g) leaf litter. 500ml of Water per heap was applied before and after planting the propagules during the experimental period. Growth parameters were monitored every 2 weeks for 12 weeks, beginning 4 weeks after propagule planting. The collected data were subjected to analysis of variance (ANOVA). Significant means were accomplished using Fisher's Least Significant Difference(LSD). Leaf litter of nitrogen-fixing Albizia trees notably ($p< 0.05$) enhanced the Growth of *Z. officinale.* Significant height (25.15cm), girth (2.14cm), number of leaves (8.00), leaf area (13.12cm^2) and leaf area index (1.80) were recorded from seedlings established in the soil influenced with leaf litter of *A.coriaria* relative to others. Leaf litter of *A. coriaria* boosts the Growth of *Z.officinale.*

Keywords: Leaf litter, Propagules, Plant-based manure, Adopted, Nitrogen-fixing Albizia trees, Growth

Introduction

Spices are foods in the World. The basic effects of spices used in cooking are to enhance or modify flavour properties, endow food with pungency, preserve food for longer periods, modify colour characteristics, and mask the undesirable odours of raw food materials (Li *et al.,* 2016). Ginger is One of the most popular spices. Ginger, *Zingiber officinale*, belongs to the family Zingiberaceae and is an important commercial crop grown for its aromatic rhizomes, which are consumed as a spice, in medicine, and as a delicacy and special vegetable in daily diets worldwide (Egbuchua & Enujeke, 2013). Sarvade *et al*. (2014) reported that One of the major constraints to a bumper harvest of *Z. officinale* is low soil fertility resulting from land degradation. Tropical soils face the challenge of poor soil fertility, which limits nutrient supply. The choice of animal manure as a favourable candidate for soil restoration has been challenged by insufficiency, bulkiness, offensive odour, and disease outbreaks (Adelani *et al*., 2014). Moreover, Adelani *et al*. (2014) and Reza

(2015) asserted that the use of synthetic fertilizers, which are high-priced and difficult to access, contaminates the environment, causes a range of health-related problems, and threatens the conservation of flora and fauna. The way out of these challenges is the practice of agroforestry through the biomass transfer method, which uses the litter of agroforestry trees to restore soil fertility. Many studies have shown that leaf litter is rich in nutrients, offering considerable potential to improve soil productivity and increase crop yield (Gaisie *et al.,* 2016). Little information is available on the use of leaf litter from selected agroforestry trees to enhance the Growth of *Z. officinale* in the Northern Guinea Savanna of Nigeria. In this Light, an investigation was conducted into the growth response of *Z. officinale* to litter from selected nitrogen-fixing Albizia trees in Kaduna State.

Materials and methods

The research was supervised in the screen house at the Federal College of Forestry Mechanization, Afaka, Kaduna. The College is located in the Northern Guinea Savannah ecological zones of Nigeria. It is established in Igabi Local Government Area of Kaduna State, Nigeria. It lies between latitude10º35'and 10º34'and longitude 7º21'and7º20'(Adelani, 2015). The mean annual rainfall is nearly 1000mm. The vegetation is open woodland with tall broad trees, usually with small boles and broad leaves (Otegbeye *et al.,* 2001).

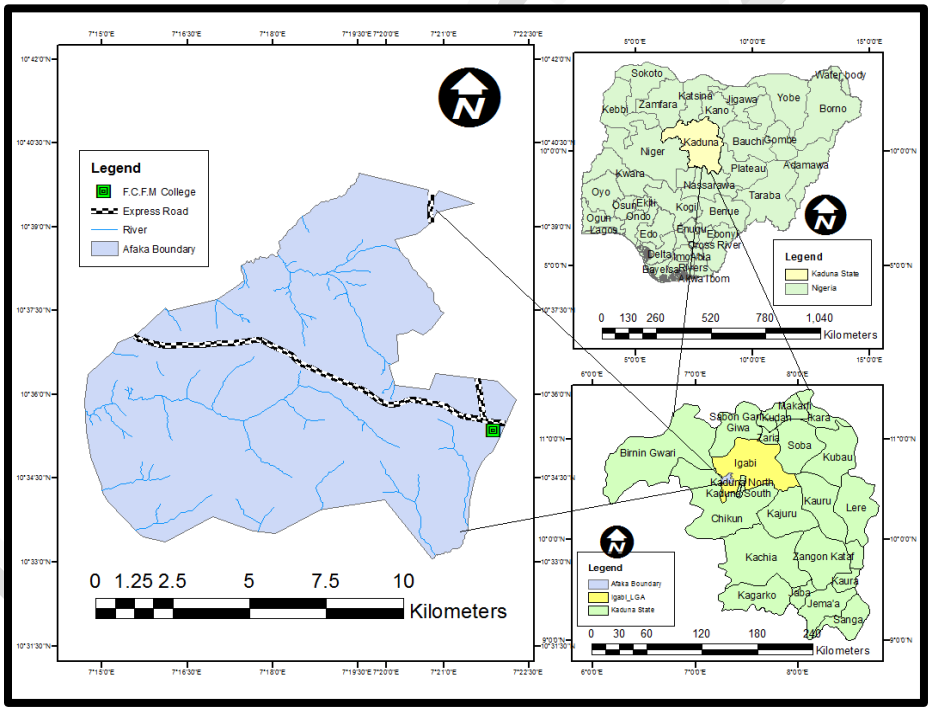


Fig 1: The location of Federal College of Forestry Mechanization, Afaka, Kaduna State, Nigeria

Experimental materials

The ginger rhizomes were sourced from farmers in the Kagarko Local Government Area of Kaduna State. The propagules were washed and air-dried for 30 minutes. The propagules were cut into approximately equal sizes, labelled and weighed (30g). The heap of about 3kg was made on the field. Leaf litter from nitrogen-fixing Albizia trees was collected from different locations using theusing the biomass transfer method.

Chemical Analysis of Leaf Litter Applied:

Total nitrogen was determined using the macro-Kjeldahl method. Available phosphorus (P) was extracted using the Bray-1the Bray-1 method and determined colorimetrically. Extracts from the digestion of the leaves of the agroforestry tree species were used to determine potassium by flame photometry.

Experimental design

A completely randomized design (CRD) with five replications was adopted to assess the early growth response of *Z. officinale* to leaf litter from selected nitrogen-fixing Albizia trees (*Albizia zygia, Albizia coriaria, Albizia ferruginea, Albizia lebbeck,* and *Albizia saman*) and the control. A propagule represented a replicate. A total of thirty (30) propagules were involved in the experiment. A side-placement method was used to place each 300g leaf litter at a depth of 5 cm and a radius of 5 cm from the propagules in the heap of 3kg soil. 500 ml of Water per heap was applied before and after planting the propagules during the experimental period. Seedling assessment started after four weeks of planting. Growth parameters were monitored every two weeks for 12 weeks. Growth parameters assessed include: seedling height (using a meter rule); girth (using a vernier caliper); the number of leaves was counted manually, and leaf area was obtained by linear measurement of leaf length and leaf width, as described by Clifton-Brown and Lewandowski (2000).

$$LA=0.74xLxW \qquad (1)$$

Where, LA =Leaf area is the outcome of the linear dimension of the length and width at the widest part of the leaf. L=length of the leaf, W = width at the widest part of the leaf. The fresh and dry weights were determined using a Mettler Top Loading Weighing Balance, with the dry weight obtained after oven-drying the seedlings at 70 °C for 72 hours. The mean of the growth constants was used for tabulations.

Data analysis

The data collected was subjected to analysis of variance (ANOVA) using SAS (2003). Significant differences were determined using Fisher'swereFisher's Least Significant Difference (LSD) at the 5% level of significance.

Results

Growth constants were significantly ($P<0.05$) different. Significant height (25.15cm), girth (2.14cm), number of leaves (8.00), leaf area (13.12cm^2) and leaf area index (1.80) were recorded from seedlings established in the soil influenced with leaf litter of *A.coriaria.* The least values of

5.35cm (height), 0.70cm (girth), 2.20 (number of leaves), 5.50cm^2 (leaf area) and 0.01(leaf area index) were recorded from seedlings planted in the unamended soil (control).

Table 1: Early growth response of *Z. officinale* to selected leaf litters of nitrogen-fixing Albizia trees

NFAT	H(cm)	G(cm)	NL	LA (cm^2)	LAI
A.saman	14.95^{b}	1.50^{ab}	4.60^{b}	8.81^{ab}	0.45^{c}
A.coriaria	25.15^{a}	2.14^{a}	8.00^{a}	13.12^{a}	1.80^{a}
A.zygia	15.86^{b}	1.52^{ab}	4.80^{b}	9.85^{ab}	0.50^{bc}
A.lebbeck	14.37^{b}	1.36^{ab}	5.30^{ab}	12.86^{a}	0.62^{b}
A.ferruginea	13.40^{b}	1.01^{b}	3.50^{b}	6.55^{b}	0.01^{d}
Control	5.35^{c}	0.70^{b}	2.20^{b}	5.50^{b}	0.01^{d}
SE±	2.27	0.29	1.11	2.14	0.05

Means on the same column having different superscripts are significantly different ($p<0.05$)

Significant fresh weight of leaf (1.69g) and shoot (2.59g) were recorded from seedlings planted in the soil amended with the leaf litter of *A.lebbeck*. Significant total fresh weight (62.56g) and total dry weight (2.86g) were recorded from seedlings planted in the soil fertilized with leaf litter of *A. coriaria*. Significant fresh (60.38g) and dry weight (2.60g) of roots were recorded from seedlings planted in the soil enhanced with leaf litter of *A.coriaria.* The least values of 18.20g (total fresh weight) and 1.36g (total dry weight) were recorded from seedlings planted in the soil without the enhancement of leaf litter (control).

Table 2: Early growth response of *Z.officinale* fresh and dry weight to leaf litter of selected nitrogen-fixing Albizia trees

NFAT	FW			TFW		DW		TDW
	L	S	R		L	S	R	
A.saman	1.14^{b}	2.04^{b}	51.60^{b}	54.78^{b}	0.15^{a}	0.07^{b}	2.10^{b}	2.32^{ab}
A.coriaria	0.84^{c}	1.34^{c}	60.38^{a}	62.56^{a}	0.15^{a}	0.11^{b}	2.60^{a}	2.86^{a}
A.zygia	0.89^{c}	0.44^{d}	19.24^{d}	20.57^{d}	0.10^{a}	0.05^{b}	1.58^{b}	1.73^{b}
A.lebbeck	1.69^{a}	2.59^{a}	24.24^{c}	28.52^{c}	0.11^{a}	0.12^{b}	1.75^{b}	1.98^{ab}
A.ferruginea	0.39^{d}	0.79^{d}	18.00^{e}	19.18^{e}	0.03^{a}	0.44^{a}	1.35^{b}	1.82^{b}
Control	0.15^{e}	0.33^{e}	17.72^{e}	18.20^{f}	0.02^{a}	0.04^{b}	1.30^{b}	1.36^{b}
SE±	0.06	0.15	0.29	0.35	0.03	0.04	0.24	0.38

Means on the same column having different superscripts are significantly different ($p<0.05$)

The highest nitrogen (20.66%), phosphorus (25.70%) and potassium (61.10%) were recorded from leaf litter of *A.coriaria, A. lebbeck*, and *A. saman*, respectively. The least values of 0.04% (nitrogen), 0.70% (phosphorus) and 0.15% (potassium) were recorded from soil not amended with leaf litter (control).

ISTF-NIG 2026

Table 3: NPK composition for leaf litter of selected nitrogen-fixing Albizia trees

NFAT	N%	P%	K%
A.saman	19.37	16.04	61.10
A.coriaria	20.66	21.92	51.09
A.zygia	17.25	15.19	49.64
A.lebbeck	16.91	25.70	52.87
A.ferruginea	18.32	24.03	47.98
Control	0.04	0.70	0.15

Discussion

The highest growth constants reported from seedlings embedded in soil amended with leaf litter of *A. coriaria* indicated its ability to retain and supply the soil with better nutrients, particularly nitrogen, relative to other investigated species. Thicker litter content than the other tree species, with higher nutrient release, is Thihereafter, litter content of nutrient effectiveness is better for the Growth of arable crops (Rajani & Singh, 2014). The capacity of all agroforestry trees studied to improve the Growth of *Zingiber officinale* compared to the control could be connected to their ability to fix nitrogen. Nitrogen is an essential element for plant growth. Krzysztof and Grzegorz (2023) reported that nitrogen fertilization enhances the leaf area and trunk cross-sectional area of *Prunus cerasus.* Nitrogen application strongly improved the *Growth of Phyllanthus emblica* and *Terminalia chebula* compared to other species studied (Khurana & Singh, 2004). Nitrogen regulates developmental processes such as germination (Alboresi *et al.,* 2005) and seedling Growth. Sinfield *et al.* (2010) reported that nitrogen is a component of various enzymes that catalyze and control the plant's lowest processes. It is a constituent of chlorophyll (Derson, 2015). Root value amendment indicates that plants grown as nitrogen-fixing leaf litter are rich in nutrients and can influence Growth. It can be inferred that the leaf litter of nitrogen-fixing Albizia trees improves the Growth of the plant. Similar reports have been made by Adelani *et al.* (2020) (*Zingiber officinale*) and Adelani (2023) (*Chrysophyllum albidum*).

Conclusion

The investigation into the early growth response of *Zingiber officinale to* leaf litter of selected nitrogen-fixing Albizia trees revealed that *Z. officinale* planted in soil amended with A. coriaria leaf litter showed the highest growth parameters relative to others. Leaf litter of *A.coriaria* enhances the Growth of *Z.officinale.*

References

Adelani, D.O. (2015). Effects of pre-germination treatments and sowing depths on early Growth of sesban (*Sesbania sesban*).*Applied Tropical Agriculture,* 20(1),31-36.https://www.futa.edu.ng/journal/home/paperd/363/12/11

Adelani, D.O.(2023). Influence of leaf litter of selected nitrogen-fixing Albizia trees on the Growth of African star apple (*Chrysophyllum albidum* G.Don) seedlings—*Australian Journal of Science and Technology,*7(2), 110-118. www.aujst.com.

Adelani, D.O., Ogunsanwo, J.A., & Awobona, T.A (2020).Effect of leaf litter of selected nitrogen-fixing Albizia trees on the Growth and yield of ginger (*Zingiber officinale* Roscoe)*.Journal of Research in Forestry, Wildlife and Environment,*12(3),1–9. ***http://www.ajol.info/index.php/jrfwe***

Adelani, D.O**.,** Suleiman, R.A., Aduradola, M. A., & Akesode, H.A. (2014). Assessment of leaf litter of some tree species on the Growth of *Zea mays* (L) in the Northern Guinea Savanna ecology. *Journal of Organic Agriculture and Environment,* 2, 117–130.

Alboresi, A., Gestin, C., Leydecker, M. T., Bedu, M., Meyer, C., & Truong, H.N. (2005).Nitrate, a signal relieving seed dormancy in Arabidopsis.*Plant Cell and Environment*, 28,500-512.https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-3040.2005.01292

Anderson, P. (2015). NPK and Fe, what are they good for?www.Limbwalker Tree Service 1(1), 1-4. Accessed on 1/16/2015.

Clifton-brown, J.C., & Lewandowski, I. (2000). Water use efficiency and biomass partitioning of three different Miscanthus genotypes with limited and unlimited water supply. *Annals of Botany*, 86, 191–200.

Egbuchua, C. N., &Enujeke, E. C. (2013). Growth and yield responses of ginger (*Zingiber officinale*) to three sources of organic manure in a typical Rainforest Zone of *Nigeria. Journal of Horticulture and Forestry,* 5 (7), 109–114. http://www.academicjournals.org/JHF http://www.academicjournals.org/AJAR, doi: 10.5897/AJAR2013.8300.

Gaisie, E., Sadick, A., Agyeman, K., Adjei-Gyapong, T., & Quansah, G. (2016). Leaf decomposition and the nutrients released from multipurpose trees for crop production. *International Journal of Scientific Research in Engineering Technology*, 2, 345-352

Khurana, E., & Singh, J.S. (2004). Impact of elevated nitrogen inputs on seedling Growth of five dry tropical tree species as affected by life-history traits*. Canadian Journal of Botany*, 82(2), 158–167. Doi.10.1139/b03-132.

Krzysztof Rutkowski., & Grzegortz P.tysiak (2023). Effect of nitrogen fertilization on tree growth and nutrient content in soil and cherry leaves (*Prunus cerasus* L.). *Agriculture* 2023, 13(3),578, 13(3), 1-23.https://doi.org/10.3390/agriculture 13030578

Li, J.L., Tu, Z.C., Zhang, L., Sha, X.M., Wang, H., Pang, J.J., & Tang, P.P. (2016).The effect of ginger and garlic addition during cooking on the volatile profile of grass carp(*Ctenopharyngodon idella*) soup*. Journal of Food Science and Technology*, 53(8),3253–3270. doi: 10.1007/s13197-016-2301-1.

Otegbeye, G. O., Owonubi, J.J., & Oviasauyi, P.K. (2001). Interspecific variation in the Growth of Eucalyptus growing in Northern Nigeria. *In:* Popoola L, Abu, J.E., Oni, P.I., editors. *Proceedings of 27th Annual Conference of the Forestry Association of Nigeria;* p. 12–16.

Rajani, A. P., & Singh, L. (2014). Nutrient release dynamics of different agroforestry tree species in an Arable crop field, *National Academy of Science Letters*, 37(1), 31–38

Reza, S. (2015).Introducing nitrogen-fixing trees: Nature's solution to curing N_2 deficiency. Permaculture News. Introducing nitrogen-fixing trees: Nature's solution to curing N_2 deficiency - *The Permaculture Research Institute (permaculturenews.org).*Accessed on 20/09/22.Pp 10.

Sarvade, S., Mishra, H. S., Kaushal, R., Chaturvedi, S., Tewari, S., & Jadhav, T.A.(2014). Performance of wheat (*Triticum aestivum* L) crop under different spacings of trees and fertility levels*. African Journal of Agricultural Research,* 9 (9), 866–873.

Shen, J.P., Zhang, L.M., Guo, J.F., Ray, J.L., & He, J.Z.(2010).Impact of long-term fertilization practices on the abundance and composition of soil bacterial communities in Northeast China. *Applied Soil Ecology*, 46(1),119–124.Doi:10.1016/j.apsoil.2010.06.015

Sinfield, J.V., Fagerman, D., & Colic, O. (2010). Evaluation of sensing technologies for on-the-go detection of macronutrients in cultivated soil. *Computers and Electronics in Agriculture*, 70, 1–18.

ISTF-NIG 2026

EFFECTS OF *Moringa oleifera* LEAF EXTRACT ON THE GROWTH AND YIELD OF TOMATO (*Lycopersicum esculentum*)

Adewoye, A. A.[1] Aderemi, F.T., Yusuf, A.A., Elesho. R.O., Adeniran. T., Ohaegbulam, J.C.

[1]Department of Horticultural Technology, Federal College of Forestry, Jericho, Ibadan, Nigeria.

Abstract

This study evaluated the effect of *Moringa oleifera* leaf extract (MLE) on the growth and yield of tomato (*Lycopersicum esculentum*). The experiment was conducted at the Federal College of Forestry, Jericho, Ibadan (latitude 7°23′N, longitude 3°35′E). Four treatments were applied as foliar sprays: T1 (control: 100 ml water), T2 (50% dilution: 50 ml extract + 50 ml water), T3 (75% dilution: 75 ml extract + 25 ml water), and T4 (100% pure extract). The experiment was laid out in a Completely Randomized Design (CRD) with four replicates per treatment, giving a total of 16 experimental units, each containing 5 kg of loamy soil. Thirty-two seeds were initially sown in seed trays; after germination, two seedlings were transplanted per bucket and thinned to One after three weeks. Treatments were applied weekly via foliar spray from three weeks after planting (WAP) through seven WAP. Growth parameters - plant height, stem diameter, leaf production, and number of branches - were measured weekly, while fruit yield was recorded from 12 to 16 WAP. Data were analyzed using Analysis of Variance (ANOVA), and treatment means were separated using Duncan's Multiple Range Test (DMRT) at the 5% probability level. Results showed that most vegetative growth parameters did not differ significantly among treatments during the early weeks (3–6 WAP). However, by 7 WAP, stem diameter was significantly higher in T3 (2.23 mm) and T4 (2.13 mm) compared to T1 (1.98 mm) and T2 (1.90 mm) ($p = 0.023$). Most notably, fruit yield differed significantly among treatments ($p < 0.05$): T3 produced the highest number of fruits (18.50), followed by T4 (12.00), T2 (7.75), and T1 (6.75). The 75% MLE concentration consistently outperformed all other treatments across growth and yield parameters. It is concluded that *Moringa oleifera* leaf extract at 75% concentration serves as an effective natural bio-stimulant for enhancing the growth and yield of tomato and is recommended for adoption by smallholder farmers.

Keywords: *Moringa oleifera*, leaf extract, tomato, *Lycopersicum esculentum*, bio-stimulant, growth, yield, foliar spray

Introduction

Tomato (*Lycopersicum esculentum*) is One of the most widely cultivated vegetables globally, valued for its nutritional content, including vitamins, minerals, lycopene, and beta-carotene (OECD, 2008). It belongs to the family Solanaceae and requires relatively cool temperatures for optimum yield, with fruit setting inhibited above 30°C and below 16°C (Abdelmageed *et al*., 2003). Despite its economic importance, optimizing tomato growth and yield remains a persistent challenge, particularly in sub-Saharan Africa, where access to synthetic fertilizers and growth regulators is often limited and where environmental sustainability concerns are increasing (Kumar & Agarwal, 2017; Adekiya *et al*., 2017). The contribution of *Lycopersicum esculentum* to the economy of Nigeria and other countries cannot be overemphasized (Mvumi, 2013). In recent times, however, the potential for *Lycopersicum esculentum* to grow is manifesting in its

contribution to the economic needs of the people. Using moringa extract as a natural growth enhancer for the growth and yield of *Lycopersicum esculentum* could hasten tomato germination and yield (El-Awady, 2003).

Moringa oleifera Lam., commonly known as the "Miracle Tree," has gained considerable attention as a natural bio-stimulant due to its rich composition of bioactive compounds, including cytokinins (particularly zeatin), auxins, gibberellins, vitamins, minerals, antioxidants, and proteins (Siddhuraju & Becker, 2003; Makkar et al., 2007; Fahey, 2005). Previous studies have demonstrated that foliar application of *Moringa oleifera* extract (MLE) can increase crop yield by 20–35% and enhance plant height, crop growth rate, and net assimilation rate in various crops, including tomato, maize, sorghum, and snap beans (Foidl et al., 2001; Muhamman et al., 2013; Emongor, 2007; Bashir et al., 2014). The growth-promoting effects of MLE have been attributed to its high zeatin content (5–200 mcg/g of fresh leaves), which stimulates cell division, increases leaf area, and enhances assimilate loading and unloading across phloem tissues (El-Awady, 2003; Abdalla, 2013). The objective of this study was to evaluate the effect of different concentrations of *Moringa oleifera* leaf extract on the growth and yield of *Lycopersicum esculentum* and to determine the optimal concentration for maximizing performance.

Materials and Methods

Experimental Site

The experiment was conducted at the experimental plot of the Federal College of Forestry, Jericho, Ibadan, Nigeria (latitude 7°23′N, longitude 3°35′E). The area has a tropical rainforest climate with annual rainfall of 1,300–1,500 mm, a dry season from November to March, and a rainy season from April to October (FRIN, 2024).

Experimental Materials and Preparation

Seeds of *Lycopersicum esculentum* were purchased from a certified seed merchant in Ibadan. Fresh *Moringa oleifera* leaves were harvested from mature trees within the college premises, rinsed with distilled water, air-dried for five days, and ground into powder. Eight kilograms of powdered moringa leaves were extracted using ten litres of ethanol to obtain the Extract. Loamy soil was collected from the Forestry Research Institute of Nigeria (FRIN) ornamental nursery.

Experimental Design and Treatments

The experiment was laid out in a Completely Randomized Design (CRD) with four treatments and four replicates, giving 16 experimental units. Each unit consisted of a perforated polythene pot containing 5 kg of loamy soil. The treatments were:

T1 (Control): 100 ml water + 5 kg soil

T2 (50% dilution): 50 ml MLE concentrate + 50 ml water + 5 kg soil

T3 (75% dilution): 75 ml MLE concentrate + 25 ml water + 5 kg soil

T4 (100% concentration): 100 ml pure MLE + 5 kg soil

Tomato seeds were pre-soaked in MLE for 15 hours before sowing in seed trays (control seeds were soaked in water). After germination, two seedlings were transplanted per pot, then thinned to

One seedling per pot at three WAP. Treatments were applied weekly as foliar sprays using a hand sprayer from three WAP through the experimental period.

Data Collection

The following parameters were assessed weekly from 3 to 7 WAP:

1. Plant height (cm): measured from base to apex using a metre rule
2. Stem diameter (mm): measured at the base using a vernier caliper
3. Leaf production: by direct counting
4. Number of branches: by direct counting
5. Number of fruits: counted at harvest (12–16 WAP)

Soil and Extract Analysis

Physico-chemical properties of the soil and the chemical composition of the MLE were analyzed at the Biochemistry Laboratory of the Forestry Research Institute of Nigeria (FRIN), Ibadan.

Statistical Analysis

All data were subjected to Analysis of Variance (ANOVA), and treatment means were separated using Duncan's Multiple Range Test (DMRT) at the 5% probability level.

Results

Soil and Extract Properties

According to Table 1, the soil used in the study was a sandy loam (sand at 89.5%, clay at 8.8%, and silt at 1%). It was slightly acidic with a pH of 6.9 and contained 3.61% organic carbon, 6.23% organic matter, and 0.31% total nitrogen. As for the MLE, it was primarily composed of manganese (0.055%), phosphorus (0.018%), calcium (0.016%), potassium (0.011%), sodium (0.007%), and traces of zinc, iron, copper, and magnesium.

Vegetative Growth Parameters

At 3 WAP (Table 3), no significant differences were observed among treatments for stem diameter, leaf production, or plant height. However, the number of branches was significantly higher in T3 and T4 (5.00 each) compared to T1 (3.25) and T2 (4.00) ($p < 0.05$). At 4 and 5 WAP, all vegetative parameters - stem diameter, leaf production, plant height, and number of branches - showed no statistically significant differences among treatments. However, T3 consistently showed numerically higher values for most parameters.

ISTF-NIG 2026

At 6 WAP, numerical differences were observed, with T3 recording the highest leaf production (40.75) and plant height (24.00 cm), but these differences were not statistically significant. At 7 WAP (Table 7), stem diameter differed significantly among treatments ($p = 0.023$). T3 (2.23 mm) was significantly higher than T1 (1.98 mm) and T2 (1.90 mm). T3 also had the highest leaf production (45.50) and plant height (27.25 cm), although these were not statistically significant.

Fruit Yield

Fruit yield differed significantly among treatments ($p < 0.05$) (Table 3). T3 (75% MLE) produced the highest mean number of fruits (18.50), which was significantly higher than T4 (12.00), T2 (7.75), and T1 (6.75). T1 and T2 were not significantly different.

Table 1: Physico-Chemical Properties of the Soil

PARAMETERS	TOPSOIL
Soil PH	6.9
O.C (%)	3.610
O.M (%)	6.225
TN (%)	0.31
(%) Sand	89.5
(%) Clay	8.8
(%) Silt	1.7
P (mg/kg)	9.715
Ca (Cmol/kg)	1.48
Mg (Cmol/kg)	0.92
Na (Cmol/kg)	0.30
K (Cmol/kg)	0.20
H +	0.52
Al3+	0.05
ECEC	2.20
Base Saturation (%)	72.4o

ISTF-NIG 2026

Table 2: Physical and Chemical Properties Of *Moringa Oleifera* Leaf Extract

Parameters	Moringa Extract
Phosphorus %	0.018
Zinc%	0.00047
Iron %	0.00001
Copper %	0.000026
Magnesium %	0.000027
Manganese %	0.055
Calcium %	0.016
Sodium %	0.0066
Potassium %	0.0109

Table 3: Effect of MLE on the growth of *L. esculentum* at 3 WAP

Treatments	Stem Diameter	Leaf production	Plant Height	Number Of Branches
Treatment1	1.3750a	9.7500a	13.1000a	3.2500[a]
Treatment 2	1.3750a	10.0000a	13.2250a	4.0000a
Treatment 3	1.3750a	10.7500a	13.4500a	5.0000[b]
Treatment 4	1.4000a	12.7500a	13.7750a	5.0000[b]

Mean values followed by different letters within a column are statistically different at p =0.05 (DMRT).

Table 4. Effect of MLE on the growth of *L. esculentum* at 4 WAP

Treatments	Stem Diameter	Leaf production	Plant Height	Number of Branches
Treatment1	1.5500a	15.2500a	14.7500a	3.0000a

ISTF-NIG 2026

Treatment 2	1.6250a	17.2500a	16.2500a	3.2500a
Treatment 3	1.7500a	18.7500a	17.7500a	4.0000a
Treatment 4	1.6500a	18.0000a	16.250a	3.7500a

Table 5. Effect of MLE on the growth of *L. esculentum* at 5 WAP

Treatments	Stem Diameter	Leaf production	Plant Height	Number Of Branches
Treatment1	1.7750	36.7500	24.2500	6.2500
Treatment 2	1.8000	36.7500	24.7500	6.2500
Treatment 3	1.7250	35.7500	23.7500	6.5000
Treatment 4	1.7000	36.2500	23.7500	6.2500

Table 6. Effect of MLE on the growth of *L. esculentum* at 6 WAP

Treatments	Stem Diameter	Leaf production	Plant Height	Number of Branches
Treatment1	1.9500	29.5000	20.0000	5.7500
Treatment 2	6.6000	32.7500	21.7500	6.2500
Treatment 3	2.0750	40.7500	24.0000	6.7500
Treatment 4	6.5250	33.5000	21.0000	5.7500

IST-NIG 2026

Table 7. Effect of MLE on the growth of *L. esculentum* at 7 WAP

Treatments	Stem Diameter	Leaf production	Plant Height	Number Of Branches
Treatment1	1.9750a	32.0000a	23.5000a	6.5000a
Treatment 2	1.9000a	37.0000a	24.5000a	9.7500a
Treatment 3	2.2250b	45.5000a	27.2500a	8.0000a
Treatment 4	2.1250c	37.5000a	24.0000a	6.2500a

Means with different letters within a column are significantly different at p = 0.05 (DMRT).

Table 8. Effect of treatments on the yield of tomato fruits

Treatment	Number of fruit harvested
T1 Control	6.75c
T2 50 %dilution	7.75c
T3 75 %dilution	18.50a
T4 100 %concentration	12.00b

Discussion

The results of this study demonstrate that *Moringa oleifera* leaf extract has a concentration-dependent effect on tomato growth and yield. During the early growth stages (3–5 WAP), most vegetative parameters did not differ significantly among treatments, suggesting that the bio-stimulatory effects of MLE require cumulative application over time before becoming manifest. This is consistent with the findings of Hossain (2022), who reported progressive improvements in tomato growth with sustained MLE application.

By 7 WAP, significant differences emerged in stem diameter, with T3 (75% MLE) and T4 (100% MLE) outperforming the control and the 50% dilution. This delayed response may be attributed to the gradual accumulation of cytokinins, particularly zeatin, which stimulate cell division and enlargement over time (Abdalla, 2013; Moyo *et al.*, 2011). The rich nutritional composition of MLE - including calcium, potassium, and magnesium - likely complemented soil nutrients, enhancing physiological functions such as cell wall formation, photosynthesis, and stomatal regulation (Faregia et al., 2010). The most striking finding was the significant effect of MLE concentration on fruit yield. The 75% concentration (T3) produced approximately 2.7 times as many fruits as the control (T1), representing a substantial yield improvement. This is consistent

ISTF-NIG 2026

with the reports of Muhamman et al. (2013) and Bashir *et al.* (2014), who observed that increasing foliar applications of MLE enhanced all growth and yield parameters of tomato. Fuglie (2000) confirmed that cytokinin-related hormones in moringa leaf extract increase crop yields when applied as a foliar spray.

Interestingly, T4 (100% concentration) did not outperform T3 (75%), suggesting that excessively high concentrations of MLE may have an inhibitory effect, possibly due to supra-optimal levels of growth regulators or osmotic stress from high solute concentrations. This finding aligns with the general principle in plant physiology that growth regulators exhibit optimal activity within specific concentration ranges, beyond which their effects may plateau or become inhibitory (Prosecus, 2023). The superior performance of the 75% concentration can be attributed to the synergistic balance of bioactive compounds — including cytokinins, auxins, gibberellins, vitamins, and minerals — at this dilution level, which provides sufficient growth stimulation without the adverse effects associated with higher concentrations. The presence of endogenous cytokinins (zeatin, dihydrozeatin, and isopentyladenine) in MLE stimulates cell division, resulting in greater leaf area and increased loading and unloading of assimilates across phloem membrane boundaries, thereby creating new source–sink relationships that favour fruit production (Emongor 2007; Chattha *et al*., 2015).

Conclusion

This study demonstrates that foliar application of *Moringa oleifera* leaf extract significantly enhances the growth and yield of tomato (*Lycopersicum esculentum*). Among the concentrations tested, the 75% dilution (75 ml MLE concentrate + 25 ml water) consistently produced the best results, particularly in stem diameter and fruit yield. The 100% concentration also showed positive effects but was less effective than the 75% dilution, suggesting an optimal concentration threshold beyond which additional Extract provides diminishing returns. The control treatment consistently showed the lowest performance across all parameters. These findings support the use of MLE as a cost-effective, environmentally friendly natural bio-stimulant for tomato production. It is recommended that smallholder farmers adopt the 75% MLE concentration for foliar application to enhance tomato growth and yield. Future studies should investigate additional concentration ranges, different application frequencies, and field-scale trials across multiple agro-ecological zones to validate these findings.

References

Abdalla, M.M. (2013). The potential of *Moringa oleifera* extract as a biostimulant in enhancing the growth, biochemical and hormonal contents in rocket (*Eruca vesicaria* subsp. sativa). *International Journal of Plant Physiology and Biochemistry,* 5(3), 42–49.

Abdelmageed, A.H., Friday, N., & Gregor, B. (2003). Effect of high temperature and heat shock on tomato (*Lycopersicum esculentum* Mill.) genotypes under controlled conditions. Conference for International Agricultural Research for Development, October 8–10, Göttingen, pp. 1–7.

Adekiya, T.M., Agbede, J.T., & Ogeh, J.T. (2017). Growth, yield and fruit quality of tomato (*Solanum lycopersicum)* as influenced by poultry manure and NPK fertilizer. *Scientia Horticulturae,* 215:71–76.

Bashir, K.A., Bawa, J.A., & Mohammed, I. (2014). Efficacy of leaf extract of drumstick tree (*Moringa oleifera* Lam.) on the growth of local tomato (*Lycopersicon esculentum*). IOSR *Journal of Pharmacy and Biological Sciences,* 9(4), 74–79.

Chattha, M.U., Sana, M.A., Munir, H., Ashraf, U., Ihtisham-ul-Haq, & Ibni-Zamir, S. (2015). Exogenous application of plant growth-promoting substances enhances the growth, yield, and quality of maize (*Zea mays* L.). *Plant Knowledge Journal*, 4(1): 1–6.

El-Awady, A. (2003). The moringa tree: nature's pharmacy. Available at: http://www.islamonline.net/english/science/2003/02article06.shtml

Emongor, V.E. (2007). Effects of Accel on growth, yield and yield components of snap bean (*Phaseolus vulgaris*). *Botswana Journal of Agriculture and Applied Science*, 4(1): 52–61.

Fahey, J.W. (2005). *Moringa oleifera*: A review of the medical evidence for its nutritional, therapeutic, and prophylactic properties. *Trees for Life Journal*, 1: 5.

Foidl, N., Makkar, H.P.S., & Becker, K. (2001). The potential of *Moringa oleifera* for agricultural and industrial uses. In: L. Fuglie (ed.), The Miracle Tree: The Multiple Attributes of Moringa. CTA Publications, Wageningen, The Netherlands.

Fuglie, L.J. (2000). New uses of moringa studied in Nicaragua. ECHO Development Notes, 68.

Fuglie, L.J. (2001). Introduction to the multiple uses of moringa. In: L. Fuglie (ed.), The Miracle Tree: The Multiple Attributes of Moringa. CTA Publications, Wageningen, The Netherlands, pp. 7–9.

Hossain, M.A. (2022). Application of moringa leaf extract improves growth and yield of tomato (*Solanum lycopersicum*) and Indian Spinach (*Basella alba*). *Plant Science Today,* 9(1): 137–143.

Kumar, V., & Agarwal, V. (2017). Effect of *Moringa oleifera* leaf extracts on seed germination and seedling growth of tomato. *International Journal of Agriculture, Environment and Biotechnology,* 10(1): 63–67.

Makkar, H.P.S., Francis, G., & Becker, K. (2007). Bioactivity of phytochemicals in some lesser-known plants and their effects and potential applications in livestock and aquaculture production systems. *Animal,* 1: 1371–1391.

Moyo, B., Masika, P.J., Hugo, A., & Muchenje, V. (2011). Nutritional characterization of moringa (*Moringa oleifera* Lam.) leaves. *African Journal of Biotechnology,* 10(60):12925–12933.

Muhamman, M.A., Auwalu, B.M., Manga, A.A., & Jibrin, J.M. (2013). Effects of aqueous Extract of moringa (*Moringa oleifera* Lam.) and nitrogen rates on some physiological attributes and yield of tomato. *International Journal of Chemical, Environmental and Biological Sciences*, 1(1), 67–74.

OECD (2008). Consensus document on the biology of *Solanum lycopersicum* (tomato)—series on Harmonisation of Regulatory Oversight in Biotechnology, No. 44.

Prosecus, P. (2023). Biosynthesis — Plant Hormones and Growth Regulators: Chemistry and Biology. Biosynth AG. Co., Switzerland.

Siddhuraju, K., & Becker, K. (2003). Antioxidant properties of various solvent extracts of total phenolic constituents from three different agroclimatic origins of drumstick tree (*Moringa oleifera* Lam.) leaves. *Journal of Agricultural and Food Chemistry*, 51(8), 2144–2155.

EVALUATION OF PROXIMATE AND PYTOCHEMICAL COMPOSITIONS OF SOME SELECTED FOREST FRUITS

Adeniran Semilore Hannah[1]* and Olusola Johnson Adeyinka[2]

[1]Department of Forestry and Wood Technology, Federal University of Technology, Akure
[2]Department of Forestry and Environmental Technology, Federal College of Agriculture, Akure
adeniransemilore959@gmail.com, 08161724413

Abstract

Tropical forests are home to a variety of significant native tree species that are edible and have socioeconomic value; because of their high nutrient content, vitamins, minerals, antioxidants, and low antinutrient content, these fruits have been included in human diets. This study examines the proximate, phytochemical and mineral composition of (*Adansonia digitata, Chrysophyllum albidum, Ivringia gabonensis and Parkia biglobosa*) pulp and seed. The analysis of the pulp and seed was carried out using the AOAC method (Association of Official Analytical Chemists, 2016). The results reveal that the moisture content was higher in the pulp of all species than in the seed (17-66%) and in the fibre content (8-16%). *Ivringia gabonensis* seed is a better source of protein (18%), *Adansonia digitata* seed has the highest fat content (19%) and also the highest ash content (9%). The Phytochemical analysis revealed that *Adansonia digitata* pulp hat the highest content of Tannin(0.43mg/g), Saponin(47.47 mg/g), Cyanide(3.46 mg/g), Vitamin C(19.22 mg/g), and Alkaloid(5.92 mg/g) The examination of the mineral contents revealed that the*Chrusopyllum albidum* pulp has the highest composition of Potassium (4.11 mg/g), Magneium (2.55 mg/g), Calcium (5,61 mg/g) and Iron (0.30 mg/g)This research indicates both nutritional and treatment possibilities of these forest fruits in dealing with malnutrition and aiding in the functioning of the immune system, suggesting the incorporation of these fruits as dietary and food security supplements, and sustainable methods of harvesting these fruits to preserve them.

Introduction

The forest, which is One of the most significant natural and renewable resources, is essential to preserving the sustainability and biodiversity of natural ecosystems, which provide a wide variety of wild edible fruits (Rabiei *et al.,* 2022). Tropical forests are home to a variety of significant native tree species that are edible and have socioeconomic value; because of their high nutrient content, vitamins, minerals, antioxidants, and low antinutrient content, these fruits have been included in human diets. (Onyekwelu *et al.,* 2015). Antinutritional factors are primarily associated with compounds or substances, of natural or synthetic origin, that interfere with the absorption, digestion, and utilization of nutrients and may produce other adverse effects (Thakur *et al.*, 2019). Antinutrients are often associated with plant-based, raw, or vegan diets. They are naturally synthesized in plants (Gemede & Ratta, 2014). It is impossible to overstate how important these edible fruits are to residents' nutritional needs and dietary requirements. Particularly during the off-farm season (the dry season), the majority of rural inhabitants in Africa rely on wild fruits and vegetables from the forest to obtain vitamins and minerals (Oladele *et al.,* 2020). Fruits are an excellent source of natural vitamins that support a healthy body and are essential for immune protection (Oladele *et al.,* 2020). The majority of energy needs are met by staple foods, which are also essential for maintaining life and fostering development. (Dike-iheanyi *et al.,* 2024).

Antioxidants can be used as supplements in food manufacturing because they are concentrated in some species; hence, they are good sources of natural antioxidants (Adeduntan *et al.,* 2016).

Timber and non-timber forest products (NTFPs), which are vital to the livelihoods of communities surrounding forest areas, have received little attention despite their contributions to livelihoods, their potential to create jobs, and the opportunities they offer for NTFP-based businesses (David, 2019). Therefore, non-timber forest products can be defined as any biological material capable of utilization in the home, sold, or having social, cultural, and religious significance, other than industrial round wood and derived sawn timber, wood chips, wood-based panels, and pulp. They. They can be harvested from ecosystems and controlled plantations.

Materials and methods

The fruits of *Adansonia digitata*, *Chrysophyllum albidum, Ivringia gabonensis,* and *Parkia biglobosa* were collected from Ekiti State, the places are: Erio-Ekiti(7.73727°N, 5.008852°E), Ayebaju (7.793449° N, 5.22853°E) and Ifaki(7.800736° N, 5.493676°E) in Ekiti, respectively. The samples of the selected fruit trees were extracted from the fruit pods, dried and ground to a powder using a mortar and pestle. The analysis was carried out at the Biochemistry Postgraduate Research Laboratory of the Federal University of Technology, Akure (FUTA), Ondo State, Nigeria.

Determination of the Proximate Composition

Determination of moisture content

The moisture content of the Sample was determined using a hot-air oven according to the method of the Association of Official Analytical Chemists (AOAC, 2016) by measuring 1 g of the finely ground Sample into a clean, dried, pre-weighed crucible. The samples will be placed in the oven maintained at 105°C for some hours, after which they will be placed in a desiccator, cooled, and weighed. The process is repeated until a constant weight is attained.

$$Moisture\ content\{\%\} = \frac{W_1 - W_2}{W_1} \times 100$$

W_1 is the initial weight of the Sample

W_2 is the final weight of the Sample

Determination of crude protein

The crude protein content of the samples was determined by the micro-Kjeldahl method (AOAC, 2016). In a 500 ml round-bottom Kjeldahl flask, ten grammes (10 g) of dried, finely powdered material were weighed. After that, 20 ml of concentrated H_2SO4 was added, followed by 2.0 g of digesting catalyst (K_2SO4 and H_2O combination). The flask was slowly heated until it stopped foaming. The heat was raised until the digest turns colorless or Light green. After cooling, the digested Sample was diluted to 5 mL with purified water. After that, 20 ml of the diluted digest was added to the distillation flask, followed by 25 ml of 4 M NaOH solution, and the mixture was then distilled. The distillate was collected in a receiver with 10 mL of boric acid as an indicator

ISTFNIG 2026

solution. To obtain the pale endpoint, a 0.1 M HCl solution was used. Using a conversion ratio of 6.25, crude protein was computed by multiplying the nitrogen content by the conversion factor.
Crude Protein = % N ×Converting factor (6.25)

$$\%N = \frac{V_2 - V_1 \times MHCL \times mass\ of\ Nitrogen(N) \times 1.4}{weight\ of\ the\ sample} \times 100$$

Determination of fat

The total fat content of the Sample was determined using the Soxhlet method (AOAC, 2016), with a Soxhlet extractor at the boiling temperature of the extracting solvent (60°C). Each Sample was weighed onto a filter paper and placed within a Soxhlet Extractor Column, where it was extracted for 6 hours with Petroleum Ether (60°C). After carefully removing the defatted samples, the solvent evaporates at 40°C until a constant weight is achieved. After that, the crude fat percentage was computed as follows:

$$Fat(\%) = \frac{W_1 - W_2 \times 100}{weight\ of\ sample}$$

Where W1 = weight of filter paper + Sample before drying
W2 =weight of filter paper + Sample after drying

Determination of crude fiber

The crude fiber content was determined according to the AOAC method (AOAC, 2016). 1.0 g of each digested Sample was weighed, and 1.25% H2SO4 was added. A watch glass will be placed over the beaker, and the mixture will be slowly cooked on a hot plate for 30 minutes. The residue was decanted into a beaker using a sintered glass crucible. On a hot plate, 200 ml of a solution containing 1.25 g of carbonate-free NaOH per 100 ml was gently heated in a beaker covered with a watch glass for 30 minutes. After removing the alkali, the Sample was washed twice with 50 mL boiling water. The contents were oven-dried at 105°C, then allowed to cool before weighing to ensure consistent weight. The fiber content was calculated by dividing the difference by the reported sample weight and expressing the result as a percentage.

$$\%\ Crude\ fibre\ = \frac{weight\ of\ ash(W_1 - W_2)}{Weight\ of\ sample\ \times 100}$$

Where:
W1 is the weight of the Sample before digestion
W 2 is the weight of the Sample after digestion.

Determination of ash content

The ash content of the Sample was determined by the gravimetric method (AOAC, 2016). 1 g of the Sample was weighed into a clean, dried, pre-weighed crucible with lid (W_1). The crucible was transferred to a muffle furnace and heated to 550 °C to incinerate the samples until a constant weight was attained. The Ashing was continued until a white ash was observed. The crucible was cooled in a desiccator, and the weight was recorded after cooling was W_2. The ash was kept for elemental analysis.

ISTF-NIG 2026

$$\% \text{ Ash} = \frac{W_2 - W_1}{\text{Weight of dried sample}} \; x\; 100$$

Determination of carbohydrate

Total carbohydrate content was determined using **the "difference method"**,

Carbohydrate (%) = 100% − (%Moisture+%Protein+%Fat+%Ash+%Crude Fiber)

Determination of Phytochemical Properties

Determination of Saponin

The spectrophotometric method of Brunner (1994) was used to determine Saponin. 0.1 g of the finely ground Sample will be weighed into a 250 ml beaker, and 100 ml of Isobutyl alcohol (But-2-ol) will be added. A shaker was used to mix the mixture for 5 hours to ensure uniform mixing. The mixture was filtered with No. 1 Whatman filter paper into a 100 ml beaker containing 20 ml of a 40% saturated solution of magnesium carbonate (MgCO3). The mixture was again filtered through No. 1 Whatman filter paper to obtain a clean, colourless solution. 1 ml of the colourless solution was taken into a 50 ml volumetric flask using a pipette, 2 ml of 5% iron (iii) chloride ($FeCl_3$) solution was added and made up to the mark with distilled water. It was allowed to stand for 30 minutes for the colour to develop. The absorbance is read against the blank at 380nm.(Osuntokun *et al.,* 2020).

Determination of Phytate

Phytate was determined according to the method of Wheeler and Ferrel (1971). 1 g Sample was soaked in 100 ml of 2% HCl for 3 hours, then filtered through a No. 1 Whatman filter paper. 25 of the filtrate was taken out was taken out, placed inplaced a conical flask,, and 5 ml of 0.3% ammonium thiocyanate solution was added as an an indicator. After which 53.5 0f distill water was added to give it the proper acidity, and this was titrated against 0.00566 g per milliliter of standard iron (iii) chloride solution that contains about 0.00195 g of iron per milliliter until a brownish yellow coloration persisted for 5min.

Determination of Alkaloid

0.25 g of the Sample was weighed into a 250 ml beaker, and 200 ml of 10% acetic acid in ethanol was added, and the mixture was allowed to stand for 4 hours. This was filtered, and the extract was concentrated in a water bath to one-quarter of the original volume. Concentrated ammonium hydroxide was added dropwise to the extract until the precipitation was completed. The whole solution was allowed to settle, and the precipitate was collected, washed with dilute ammonium hydroxide, and then filtered. The residue was then an alkaloid, which was dried and weighed.

$$\%\text{Alkaloid} \; = \frac{W_3 - W_2}{W_1} \times 10$$

Determination of tannin

Tannin determination was as described by Makkar and Goodchild.

Determination of Vitamin C

The vitamin C content was determined using ascorbic acid as the reference compound. 200 ml of the extract was pipetted and mixed with 300 ml of 13.3% TCA and 75 microliters of DNPH. The mixture was incubated at 37℃ for 3 hours, and 500ml of 65% H2SO4 was added, and the absorbance was read at 520nm.

$$\text{Conc.}\left(\frac{\text{mg}}{\text{g}}\right) = \frac{\text{Abs. Of the}}{\text{slope of the standard}}$$

Determination of Cyanide

A sample of 1 g was weighed in a 200-mL Erlenmeyer flask and mixed well with citrate buffer (10mL). A wet picric acid test strip with 20 uL of 1 M sodium carbonate solution was hung on a cork stopper. The cork stopper was placed on the flask, and the flask was incubated in a water bath at 30℃ for 3 hours. 2g of tartaric acid was added, and the flask's cork stopper was immediately put on. Place the flask in a water bath heated to 55℃ for One hour. The picric acid test strip was transferred to a 10-mL test tube, and the formed red color was extracted with 5.0 mL of 50% aqueous ethanol. They measured the absorbance of the extract at 500 nm against the 50% aqueous ethanol solution.

Determination of Mineral Composition

The mineral constituents of the samples were analyzed using the solution obtained by dry ashing the samples at 5500C and dissolving the ash in 50 ml of 10% HCl, prepared with deionized distilled water. The minerals were analyzed using an atomic absorption spectrophotometer (AOAC, 2016).

Statistical analysis

The data for proximate, phytochemical, and mineral compositions were analyzed using descriptive statistics (mean and standard error) and analysis of variance (ANOVA). The follow-up was computed using Duncan's Multiple Range Test (DMRT). Values were considered significantly (statistically) different when $P<0.05$.

Results and discussion

Table 1: Nutritional composition of the seed parts of *Adansonia digitata, Ivringia gabonensis and Parkia biglobosa*

Parameter		Seed	
%	*Ivringia gabonensis*	*Parkia biglobosa*	*Adansonia digitata*

ISTF-NIG 2026

Moisture content	30.07 ± 0.32^{a}	14.13 ± 0.15^{b}	10.84 ± 0.12^{b}
Fibre	2.04 ± 0.02^{c}	11.73 ± 0.13^{a}	4.79 ± 0.05^{b}
Protein	18.31 ± 0.09^{a}	8.88 ± 0.09^{c}	10.54 ± 0.12^{b}
Ash content	0.10 ± 0.00^{c}	4.07 ± 0.04^{b}	9.04 ± 0.10^{a}
Fat	16.43 ± 0.71^{b}	8.752 ± 0.20^{c}	19.36 ± 0.21^{a}
Carbohydrate	33.05 ± 0.27^{c}	52.44 ± 0.63^{a}	45.42 ± 0.18^{b}

Each value is the mean of three replicates, ± standard error. Means within the same row and followed by different letters are significantly different ($P<0.05$).

Table 2: Nutritional composition of the pulp parts of *Adansonia digitata, Chrysophyllum albidum, Ivringia gabonensis and Parkia biglobosa*

Parameter	Pulp			
%	*Ivringia gabonensis*	*Chrysophyllum albidum*	*Parkia biglobosa*	*Adansonia digitata*
Moisture content	66.00 ± 0.35^{b}	67.61 ± 0.55^{a}	24.58 ± 0.26^{c}	17.12 ± 0.18^{d}
Fibre	8.59 ± 0.64^{c}	8.92 ± 0.05^{c}	16.79 ± 0.35^{a}	16.01 ± 0.18^{b}
Protein	8.04 ± 0.40^{c}	7.89 ± 0.45^{d}	17.06 ± 0.19^{a}	13.78 ± 0.15^{b}
Ash content	0.31 ± 0.00^{d}	0.81 ± 0.01^{c}	5.30 ± 0.06^{a}	3.05 ± 0.03^{b}
Fat	7.18 ± 0.08^{a}	5.67 ± 0.08^{b}	1.51 ± 0.02^{d}	3.70 ± 0.00^{c}
Carbohydrate	9.87 ± 0.04^{c}	9.09 ± 0.12^{c}	34.75 ± 0.88^{b}	46.83 ± 0.55^{a}

Each value is the mean of three replicates, ± standard error. Means within the same row and followed by different letters are significantly different ($P<0.05$).

Fruits can provide numerous nutritional benefits and significantly improve the quality of the food people consume. According to this research, the pulp and seeds of the four fruits contributed to a healthy body, as they had relatively low ash and fiber levels and relatively high levels of protein, fat, carbohydrates, and moisture. As the results indicate, the nutritional content of the fruit pulp and seed of the *Parkia biglobosa* has a significant variation ($P<0.005$ The moisture content was 14.13 to 24.58, the carbohydrate content was 34.75 to 52.44, the ash content was 4.07 to 5.30, the fiber content was 11.73to 16.79, the fat was 1.51 to 87.72, and the protein was 8.88 to 17.06. Ash contents, crude fibers, fat, crude protein, moisture and carbohydrate of the pulp and seed of *Adansonia digitata* fruit were found to be in the range of 3.05 to 9.04% ash content, 4.79 to 16.01% crude fiber, 3.07 to 19.36% fat, 10.54 to 13.78% crude protein, 10.84 to 17.12% moisture, and 45.42 to 46.33% carbohydrate. Compared to carbohydrate (9.87-34.05), the fruit pulp and seed of *Ivringia gabonensis* contained a smaller amount of ash content (0.10-0.31), fiber content (2.04-8.59), fat content (7.18-16.43), protein content (8.04-18.31), and moisture content (30.07-66). *Ivringia gabonensis* pulp has a relatively high moisture content, which means its shelf life is short when poorly preserved, as high moisture levels encourage microbial growth (FAO, 2010).

Most of the forest fruits are not yet perceived as being staple fruits because they are a seasonal forest tree type with great potential; their fruit sap has been reportedly used to make juice and wine (Kadiri *et al.,* 2016), thus some of the forest fruits that are not yet considered staples in our diets are rich in protein and can help to maintain food security. Minerals also support physiological functions and the quality of nutrition. Similar trends were also reported by Aremu *et al.* (2015),

who noted that ash content was quite high in indigenous Nigerian fruits, with varying mineral accumulation.

Frequently used forest fruit species with a long tradition of use include *Adansonia digitata* and *Parkia biglobosa*. The pulp and seeds of both species can be consumed. *Parkia biglobosa* seeds are used as a condiment in soup, whereas *Adansonia digitata* (baobab) seeds are commonly used as a coffee alternative and thickener (Abubakar *et al.,* 2015). The fruit pulp and seeds contained high levels of crude fiber. Nevertheless, the seed of *Parkia biglobosa* is more sensitive as a source of crude fiber. The crude fiber content of raw *Parkia biglobosa* seeds was high (5-10), compared with the values reported by Sobola (2019). Dietary fiber is important for its physiological effects in maintaining the internal distention of the digestive tract. A sufficient amount of dietary fiber from various foods would prevent colon cancer and control blood lipids, thereby reducing the risk of cardiovascular disease (Aremu *et al.,* 2015).

Table 3: Phytochemical composition of the pulp parts of *Adansonia digitata, Chrysophyllum albidum, Ivringia gabonensis and Parkia biglobosa*

Parameter	Pulp			
	Ivringia gabonensis	*Chrysophyllum albidum*	*Parkia biglobosa*	*Adansonia digitata*
Tannin	0.15 ± 0.00^{d}	0.29 ± 0.00^{c}	0.31 ± 0.00^{b}	0.43 ± 0.00^{a}
Saponin	10.81 ± 0.11^{d}	29.88 ± 0.29^{b}	15.95 ± 0.16^{c}	47.47 ± 0.46^{a}
Cyanide	0.91 ± 0.02^{c}	2.50 ± 0.03^{b}	2.43 ± 0.03^{b}	3.46 ± 0.04^{a}
Vitamin. C	8.10 ± 0.19^{b}	2.38 ± 0.14^{d}	4.78 ± 0.16^{c}	19.22 ± 0.30^{a}
Alkaloid	8.98 ± 0.09^{a}	3.68 ± 0.03^{c}	3.68 ± 0.03^{c}	5.92 ± 0.06^{b}
Phytate	11.00 ± 0.11^{b}	11.00 ± 0.11^{b}	26.59 ± 0.28^{a}	10.08 ± 0.11^{c}

Each value is the mean of three replicates, ± standard error. Means within the same row and followed by different letters are significantly different ($P<0.05$).

Table 4: Phytochemical composition of the seed parts of *Adansonia digitata, Ivringia gabonensis and Parkia biglobosa.*

Parameter	Seed		
	Ivringia gabonensis	*Parkia biglobosa*	*Adansonia digitata*
Tannin	0.22 ± 0.00^{b}	0.26 ± 0.00^{a}	0.15 ± 0.00^{c}
Saponin	48.75 ± 0.48^{a}	8.43 ± 0.08^{b}	47.84 ± 0.47^{a}
Cyanide	2.89 ± 0.13^{c}	12.40 ± 0.13^{b}	14.52 ± 0.15^{s}
Vitamin. C	3.64 ± 0.15^{b}	1.35 ± 0.13^{c}	16.92 ± 0.28^{a}
Alkaloid	3.27 ± 0.03^{c}	5.31 ± 0.06^{b}	5.71 ± 0.06^{a}
Phytate	37.59 ± 0.39^{b}	28.42 ± 0.30^{c}	109.11 ± 1.13^{a}

Each value is the mean of three replicates, ± standard error. Means within the same row and followed by different letters are significantly different ($P<0.05$).

The pulp and seed products of *Parkia biglobosa* indicate that the tannin content was between 0.26 and 0.31 mg/g. The content of Cyanide was between 2.43 and 12.39 mg/g, the Vitamin. C was

between 1.35 and 4.78 mg/g, the Phytate was between 26.59 and 28.42 mg/g, the Alkaloid was between 3.68 and 5.31 mg/g, and the Saponin was between 8.43 and 15.95 mg/g. In *Adansonia digitata* fruit, pulp and seed level of tannin was 0.15-0.43mg/g, Cyanide was 3.46-14.53mg/g, Vitamin C was 16.92-19.22mg/g, Phytate was 5.71-5.92mg/g, Alkaloid was 47.47 47.84mg/g, and Saponin was 5.0. The Tannin content was 0.15 to 0.22 mg/g/kg of pulp and seed, the cyanide content was 0.91 to 2.89mg/g/kg of Vitamin, the Phytate was 11 to 37.59mg/g/kg of Phytate, and the Saponin was 10.81 to 48.75mg/g/kg of Saponin. *Chrysophyllum albidum* fruit pulp has a Tannin concentration of 0.29 mg/g, Cyanide concentration of 2.50 mg/g, vitamin C concentration of 11 mg/g, Phytate concentration of 3.68 mg/g, Alkaloid concentration of 29.88mg/g and Saponin concentration of 29.88mg/g.

In the fruit pulps of *Adansonia digitata*, the result showed the highest levels of tannins (0.43 mg/g), saponins (47.47 mg/g), cyanide (3.46 mg/g), and vitamin C (19.22 mg/g). The high vitamin C content supports its traditional use in Nigeria for immune boosting and treatment of scurvy (Olawuyi & Alare, 2014). Vitamin C is a water-soluble essential micronutrient that acts as an antioxidant and is involved in iron metabolism, the biosynthesis of carnitine, intermolecular cross-linking of collagen, and various enzymatic and hormonal processes as a cofactor (Ugbogu & Ogodo, 2015). Tannins and saponins, though considered antinutritional factors, have demonstrated beneficial medicinal properties, including antioxidant and antimicrobial effects (Akinmoladun *et al.,* 2020). Saponins were markedly high in *Ivringia gabonensis* seed (48.75 mg/g). When saponins are present in large amounts, they can impart their distinctive bitter taste to food and cause it to foam in aqueous solution (Lim *et al.,* 2020), while Cyanide was highest in *Adansonia digitata* seed (14.52 mg/g), which warrants caution considering Cyanide's toxicity but also reflects traditional detoxification methods employed in local food processing to reduce antinutrient effects (Akinmoladun *et al.,* 2020). Phytate, an antinutrient that affects mineral bioavailability, was highest in *Adansonia digitata* seeds (109.11 mg/g), which may impede mineral absorption but can be reduced by processing methods such as soaking and fermentation (Aremu *et al.,* 2015).

Table 5: Mineral composition of the pulp parts of *Adansonia digitata, Chrysophyllum albidum*, *Ivringia gabonensis* and *Parkia biglobosa.*

Parameter	Pulp			
	Ivringia gabonensis	*Chrysophyllum albidum*	*Parkia biglobosa*	*Adansonia digitata*
Zinc	0.32 ± 0.00^{b}	0.28 ± 0.00^{c}	0.33 ± 0.00^{a}	0.25 ± 0.00^{d}
Sodium	1.44 ± 0.01^{c}	2.93 ± 0.01^{a}	2.43 ± 0.01^{b}	0.85 ± 0.01^{d}
Copper	0.01 ± 0.00^{a}	0.01 ± 0.00^{b}	0.01 ± 0.00^{b}	0.01 ± 0.00^{b}
Potassium	2.11 ± 0.01^{c}	4.11 ± 0.01^{a}	3.29 ± 0.01^{b}	1.14 ± 0.01^{d}
Magnesium	1.21 ± 0.00^{a}	2.55 ± 0.01^{a}	1.61 ± 0.00^{c}	1.73 ± 0.01^{b}
Manganese	0.01 ± 0.00^{b}	0.01 ± 0.00^{b}	0.02 ± 0.00^{c}	0.01 ± 0.00^{a}
Iron	0.18 ± 0.00^{b}	0.30 ± 0.00^{a}	0.18 ± 0.00^{c}	0.25 ± 0.00^{b}
Calcium	2.25 ± 0.01^{d}	5.61 ± 0.01^{a}	2.45 ± 0.01^{c}	3.23 ± 0.01^{b}

Each value is the mean of three replicates, ± standard error. Means within the same row and followed by different letters are significantly different ($P<0.05$).

Table 6: Mineral composition of the seed parts of *Adansonia digitata, Ivringia gabonensis and Parkia biglobosa*

Parameter	SEED		
	Ivringia gabonensis	*Parkia biglobosa*	*Adansonia digitata*
Zinc	0.37 ± 0.00^{c}	0.41 ± 0.00^{b}	0.43 ± 0.00^{a}
Sodium	2.35 ± 0.01^{b}	3.10 ± 0.01^{a}	1.21 ± 0.01^{c}
Copper	0.01 ± 0.00^{b}	0.01 ± 0.00^{a}	0.01 ± 0.00^{c}
Potassium	3.26 ± 0.01^{b}	4.32 ± 0.01^{a}	1.66 ± 0.01^{c}
Magnesium	2.51 ± 0.00^{a}	1.03 ± 0.00^{b}	2.51 ± 0.01^{a}
Manganese	0.02 ± 0.00^{b}	0.02 ± 0.00^{a}	0.01 ± 0.00^{c}
Iron	0.17 ± 0.00^{b}	0.15 ± 0.00^{c}	0.20 ± 0.00^{a}
Calcium	5.19 ± 0.01^{a}	2.19 ± 0.01^{c}	5.17 ± 0.01^{b}

Each value is the mean of three replicates, ± standard error. Means within the same row and followed by different letters are significantly different ($P<0.05$).

The seed mineral content showed that zinc was highest in *Adansonia digitata* (0.43 mg/g), sodium in *Parkia biglobosa* (3.10 mg/g), and calcium in *Irvingia gabonensis* (5.19 mg/g). Minerals are essential to human health and help sustain enzyme activity, bone formation, and electrolyte homeostasis (Aremu *et al.,* 2015). Zinc plays a significant role in immune and growth functions, and its sufficient availability makes these fruits complementary sources of the micronutrient, which has been widely used to curb zinc deficiency in Nigeria (Akinmoladun *et al.,* 2020). Calcium has been indicated to play a role in skeletal structure and muscle functioning. In contrast, magnesium, being a macro-element, is involved in ionic balance and as a cofactor for enzymes (Arunachalam *et al.,* 2014). The highest calcium (5.61 mg/g), potassium (4.11 mg/g), magnesium (2.55 mg/g) and iron (0.30 mg/g) were found in the fruit pulps of *Chrysophyllum albidum* pulp (Gnansounou *et al.,* 2014). The healthy daily intake levels of sodium and potassium, at 2400 mg and 4700 mg, respectively, are not exceeded (Sajib *et al.,* 2014). The recommended value of magnesium is 400 mg/kg/day in men and 310 mg/kg/day in women aged 19-30 and 19-39, respectively (Islam *et al.,* 2015). Manganese (Mn) is an essential nutrient for growth and health; it is associated with antioxidant systems and carbohydrate and fat metabolism (Avila *et al.,* 2013).

Conclusion

This study has also shown that the chosen forest fruits, *Adansonia digitata, Chrysophyllum albidum, Irvingia gabonensis,* and *Parkia biglobosa*, are good sources of essential nutrients, phytochemicals, and minerals that can significantly contribute to human nutrition and health. Proximate analysis indicates high levels of moisture, protein, fat, fiber, carbohydrates, and ash, suggesting they can be used as supplementary food sources, especially in rural Nigerian society, where malnutrition is a major problem. Even though antinutritional compounds such as Cyanide and phytates were observed, their concentrations are similar to those found in other edible plants. They can be controlled through appropriate food processing methods. Analysis of the mineral composition has shown that the given fruits contain important macro- and microelements, such as calcium, potassium, magnesium, iron, and zinc, which play an important role in physiological processes and overall health. Taken together, the results suggest that these forest fruits have nutritional and therapeutic potential and should be prioritized to improve food security and human health in Nigeria. Cultivation and industrial utilization of the fruits are therefore recommended.

References

Abubakar S; Veronica E; David B; and Michael A (2015): Nutraceutical evaluation of baobab (*Adansonia digitata*) seeds and physicochemical properties of its oil. *Annals of Biological Sciences* 3(2): 13-19

Adeduntan, S. A., Olawale, A. E., Adeniyi, M. M & Oyerinde, O.V. (2016). Antioxidant properties of *Blighia sapida* K.D Koenig in rainforest and savanna areas of southwest Nigeria, *The International Journal of Engineering and Science*. 5(3): 05–15.

Akinmoladun, F. O., Abideen, O. A. & Olaleye, T. M. (2020). Phytochemical analysis and health implications of Nigerian indigenous fruits. *Nigerian Journal of Pharmaceutical Sciences*, 19(1), 23–34.

Aremu, M. O., Olawore, N. O., Makinde, J. M., & Teli, S. (2015). Proximate, phytochemical and mineral composition of selected indigenous fruits from Nigeria. *American Journal of Food Science and Technology*, 3(1), 1–9.

Arunachalam K, & Parimelazhagan T. (2014). Evaluation of Phenolic Content, Antioxidant Activity, and Nutritional Composition of *Cordia evolutior* (Clarke) Gamble. *International Journal of Food Properties*; 17: 226–238.

Association of Official Analytical Chemists (AOAC). Official method of analysis of (AOAC 930.30, 2016).

Avila D.S, Puntel R.S., and Ashener M (2013). Metal ions in Life Sciences; Manganese in health and disease;13:199-227.

David, E. O., Jimoh, K. A., Oyewole, S. O., & Ayeni, A. E. (2019). Non-Timber Forest Products (NTFPs) as a Means of Livelihood and Safety Net among the Rurals in Nigeria: A Review. *American Journal of Service Science and Management*. 6(1): 27-31

Dike-Iheanyi E. I., Okoye C. J., Okoroigwe F. C., Ezeanyanwu V. C., & Ifemeje J. C. (2024). Determination of Proximate Content and Phytochemical Analysis of Some Selected Grains, Fruits and Vegetables Commercially Sold in Eke Awka Market, Awka, Anambra State, Nigeria: *Research invention journal of public health and pharmacy.* 3(2): 53–62.

Gemede H.F and Ratta N (2014). Antinutritional factors in plant foods: potential health benefits and adverse effects. *International Journal of Nutrition and Food Science*; 3(4): 284-9

Gnansounou S.M, Noudogbessi J. P, Yehouenou B, and Sohounhloue D. (2014). Proximate composition and micronutrient potentials of *Dialium guineense* wild growing in Benin. *International Food Research Journal.* 21(4): 1603–1607.

Harborne, J. B. (1999). An overview of antinutritional factors in higher plants. In J. C. Caygill and I. Mueller-Harvey (Eds.), *Secondary plant products: Antinutritional and beneficial actions in animal feeding* (pp. xx–xx). Nottingham University Press.

Islam M. Z, Hoque M. M, Asif-Ul-Alam S. M, & Monalisa K. (2015). Chemical composition, Antioxidant capacities and storage stability of *Citrus macroptera* and *Garcinia pedunculata* fruits. Emir*ates Journal of Food and Agriculture*. 27(3): 275-282.

Kadiri, O; Kolawole, J. T; Olawoye, B, and Kadiri, A. P., (2016). Economic Studies on the Production of Fruit Juice from a Locally Sourced Fruit: African Star Apple. *Turkish Journal of Agriculture – Food Science and Technology*. 4(6): 438-445.

Makkar A.O.S and Goodchild A.V., Quantification of tannins: laboratory manual. Aleppo, Syria: ICARDA; 1986; IV +25 pp.

Oladele, A. T., Ofodile, E. A.U, Udi, B. T, Alade, G. O. (2020). Proximate and Mineral Elements Composition of Three Forest Fruits Sold in Port Harcourt. *Nigeria Journal of Applied Science and Environment Management*. 24 (11) 1899-1908

Olawuyi, I. F., & Alare, A. O. (2014). Vitamin C content and antioxidant activity of *Adansonia digitata* fruit. *International Journal of Plant Biology*, 5(3), 75–82.

Onyekwelu J. C, Olufunmilayo Oyewale, Bernd Stimm & Reinhard Mosandl (2015). Antioxidant, nutritional and antinutritional composition of *Garcinia kola* and *Chrysophyllum albidum* from the rainforest ecosystem of Ondo State, Nigeria. *Journal of Forestry Research*. (2) 6:417-424

Osuntokun, O. T., Yusuf-Babatunde, M. A., & Fasila, O. O. (2020). Components and bioactivity of Ipomoea batatas (L.)(sweet potato) ethanolic leaf extract. *Asian Journal of Advanced Research and Report*, *10*(1), 10–26.

Rabiei, J., Khademi, M. S., Bagherpour, S., Ebadi, N., Karimi, A., & Ostad-Ali-Askari, K. (2022). Investigation of fire risk zones using heat–humidity time series data and vegetation. *Application of Water Science*. 12:216.

Sajib M.A.M, Jahan S, Islam M.Z, Khan T.A, and Saha B.K. (2014). Nutritional evaluation and heavy metal content of selected tropical fruits in Bangladesh. *International Food Research Journal*. 21(2): 609–615.

Sobola O.O (2019). Nutritional and Antinutritional Composition of Parkia biglobosa and Adansonia digitata in the Guinea Savanna Region, Taraba State, Nigeria. 7(2): pp 10- 18

Thakur, A., Sharma, V., & Thakur, A. (2019). An overview of antinutritional factors in food. *International Journal of Chemistry Stud*ies, *7*(1), 2472–2479.

Ugbogu O.C, and Ogodo A.C. (2015). Microbial flora, proximate composition and vitamin content of juices of three fruits bought from a local market in Nigeria. *International Journal of Chemical Engineering and Applications.* 6(6): 112–134.

Wheeler E.L and Ferrel R.E (1971). A method of phytic acid determination in wheat and wheat fractions, Cereal Chemistry. 48; 312–320.

ISTF-NIG 2026

Proceedings of the 4th ISTF-NIGERIA International Conference. Held at the Faculty of Renewable Natural Resources Management, College of Agriculture and Renewable Natural Resources, Osun State University, Nigeria, from 19th – 21st of May, 2026.
Theme: Forest Ecosystem Conservation: A Roadmap Fop Resilient Economies And Environmental Sustainability

THE IMPACT OF EXTERNAL FUNDING SUPPORT IN BIODIVERSITY CONSERVATION IN NIGERIA: CASE STUDY OF THE RUFFORD FOUNDATION

***MOSHOOD Farhan Jimba and AMUSA Tajudeen Okekunle**

Department of Forest Resources Management, University of Ilorin, Ilorin, Nigeria
** Corresponding author: moshood.fj@unilorin.edu.ng; moshoodfarhan@gmail.com*

Abstract

Nigeria is One of Africa's most ecologically diverse countries. However, its biodiversity is increasingly threatened by habitat degradation, weak and outdated law enforcement mechanisms, and insufficient funding. In response, international donors such as the Rufford Foundation have emerged as pivotal supporters of grassroots conservation in Nigeria. This study examines the impact of Rufford Foundation-funded projects in Nigeria between 2001 and May 2025, assessing their contributions to biodiversity conservation, local engagement, and capacity building. Using a mixed-method, retrospective longitudinal case study approach, the study reviewed project-level data obtained from the Rufford Foundation's public database. Descriptive statistics and thematic analysis were used to evaluate 106 projects implemented across Nigeria. The findings reveal that Nigeria accounts for only 1.6% of Rufford projects globally and 5.3% within Africa. By estimate, over £600,000 ($811,859) has been invested across projects spanning all six geopolitical zones, with concentrations in Plateau (23), Cross River (20) and Bauchi (10) States. Thematically, animal conservation dominated (55.7%), followed by habitat/community/location-focused conservation (17.9%), conservation Education (17.0%), and plant conservation (9.4%). Most projects were one-time grants (1st Rufford Grant; 67.9%), with only a small proportion advancing to booster (10.3%) or completion (2.8%) funding levels. Despite a slow uptake in 2001, project volume increased significantly with peak funding in 2023 and 2024 (12 projects each). Although Rufford-funded projects have supported key biodiversity areas and species in Nigeria, the uneven geographic Distribution and limited funding continuity point to gaps in national coverage and project sustainability. The study recommends that standardized monitoring and evaluation frameworks that would make it easy to assess the long-term impact of funded conservation efforts should be put in place.

Keywords: Nigeria; Rufford Foundation; Biodiversity; Conservation; Funding

Introduction

Biodiversity conservation in Nigeria remains a pressing environmental challenge amidst growing anthropogenic pressures, habitat degradation and weak institutional capacity (Imarhiagbe *et al*., 2019; Mafiana *et al*., 2022). As One of Africa's most biologically diverse countries, Nigeria harbours thousands of plant and animal species, many of which are endemic or threatened. Borokini (2014a) examined threatened plant species in Nigeria according to the classification of the International Union for Conservation of Nature (IUCN) and concluded that 16 plant species were critically endangered, another 16 were endangered, and 132 were vulnerable. Similarly, Borokini (2014b) reported 91 endemic plant species distributed across several states in Nigeria. On the other hand, Idowu and Morenikeji (2015) reported over 140 threatened animal species in the country, of which 50% are vulnerable, 30% are endangered, and 20% are critically endangered.

However, the country's conservation efforts have historically struggled due to chronic underfunding, limited technical capacity and weak law enforcement (Usman & Adefalu, 2010). To this end, external funding from international conservation donors has played a pivotal role in bridging gaps and supporting grassroots interventions targeted at safeguarding Nigeria's rich biological heritage.

Over the last two decades, the role of international funding agencies has evolved from merely supporting short-term conservation projects to enabling long-term capacity building, research, and community-based biodiversity management (Johnson *et al*., 2022). Among these, the Rufford Foundation stands out as a significant funder of small-scale conservation projects globally, having awarded over 2,000 grants in Africa since its inception. These grants, typically awarded to early-career conservationists and researchers, have been instrumental in promoting locally led solutions to biodiversity loss, especially in underfunded rural and peri-urban areas. Nigeria's biodiversity hotspots, such as the Cross River rainforest, the savanna ecosystems of the North Central and Northwest, as well as other ecosystems, flora, and fauna of conservation concern, have benefited from these micro-grants. The grants have supported initiatives ranging from species monitoring, habitat restoration, and environmental Education to the development of alternative livelihoods for communities dependent on forest exploitation. The structure of the Rufford Small Grants, characterized by year-round accessibility and minimal bureaucratic hurdles, has made it particularly impactful in contexts where larger funding mechanisms are inaccessible or impractical.

Despite the contributions of international funding agencies, there remains a dearth of empirical evaluations of the tangible impacts of such funding on biodiversity conservation outcomes in Nigeria. Most studies often focus either on biodiversity trends or on conservation policy frameworks, overlooking the influence of international philanthropic support at the local and national scales (Ferraro & Pattanayak, 2006). Understanding how these external funds translate into ecological and socio-economic benefits is critical, not only for informing donor strategies but also for strengthening national conservation planning and resource allocation (Miller *et al*., 2015). Against this backdrop, this study examined the Rufford Foundation's role in supporting biodiversity conservation in Nigeria. It also explores the extent to which Rufford-funded projects have contributed to biodiversity protection, community engagement and capacity building within the Nigerian conservation landscape. The study seeks to contribute to the growing body of literature on conservation financing worldwide, especially in Sub-Saharan Africa, and to offer relevant insights for conservation funders, practitioners, and decision-makers working to halt biodiversity loss and promote the conservation of natural resources under resource-constrained conditions.

Methodology

Research Design

The study employs a retrospective longitudinal case study design to evaluate the Rufford Foundation's conservation funding activities in Nigeria from 2001 to May 2025. The case study approach was chosen to allow an in-depth exploration of patterns, trends, and thematic emphases over time. The design integrates both qualitative and quantitative data sources, enabling a

comprehensive understanding of project distribution, funding levels, thematic focus, and reported outcomes.

Data Collection

Data for the study were sourced exclusively from secondary sources**,** with the Rufford Foundation Grant Database as the primary source. This publicly accessible database (https://www.rufford.org) contains detailed information on individual projects, including project titles, grantee names, thematic focus areas, geographical locations, funding categories, and summaries. Additional data were extracted from publicly available documents linked to individual project pages, such as grantee-submitted updates, final reports, promotional materials, and project-related publications. Supplementary sources, such as peer-reviewed articles authored by grantees, reports from conservation NGOs, and other publications acknowledging Rufford funding, were identified through citation tracking and academic search engines, including Google Scholar and ResearchGate.

Inclusion Criteria

To ensure consistency, the following criteria were used to filter the data from the database:

i. *Geographic scope*: only projects implemented in Nigeria and whose primary location is identified as Nigeria on the Rufford website.
ii. *Timeframe*: projects approved between 2001 and May 2025
iii. *Funding type*: all levels of Rufford Small Grants, 1st Rufford Small Grants, 2nd Rufford Small Grants, Booster Grant, Second Booster Grants (this has been phased out in 2024) and Completion Grant
iv. *Data availability*: projects with at least a basic description of objectives and location. Several projects whose final reports/detailed reports were not submitted or are yet to be submitted (such as projects awarded in 2024 or 2025) were labelled as either "data deficient" or "ongoing projects".

Projects that did not meet these criteria were excluded to maintain consistency and data reliability, especially those in which Nigeria was not clearly identified as the primary location. Furthermore, all identified projects implemented in Nigeria between 2001 and May 2025 were included, regardless of data completeness. Projects tagged as "Ongoing" or "Data Deficient "were retained for descriptive analysis.

Data Collection Process

Figure 1 illustrates the data collection process for the study. It outlines the number of Rufford projects funded globally (as of May 2025) as listed on the website, the filtering steps applied (e.g., country, period, grant type), and how many were included in the final analysis and how many were tagged as ongoing or data deficient.

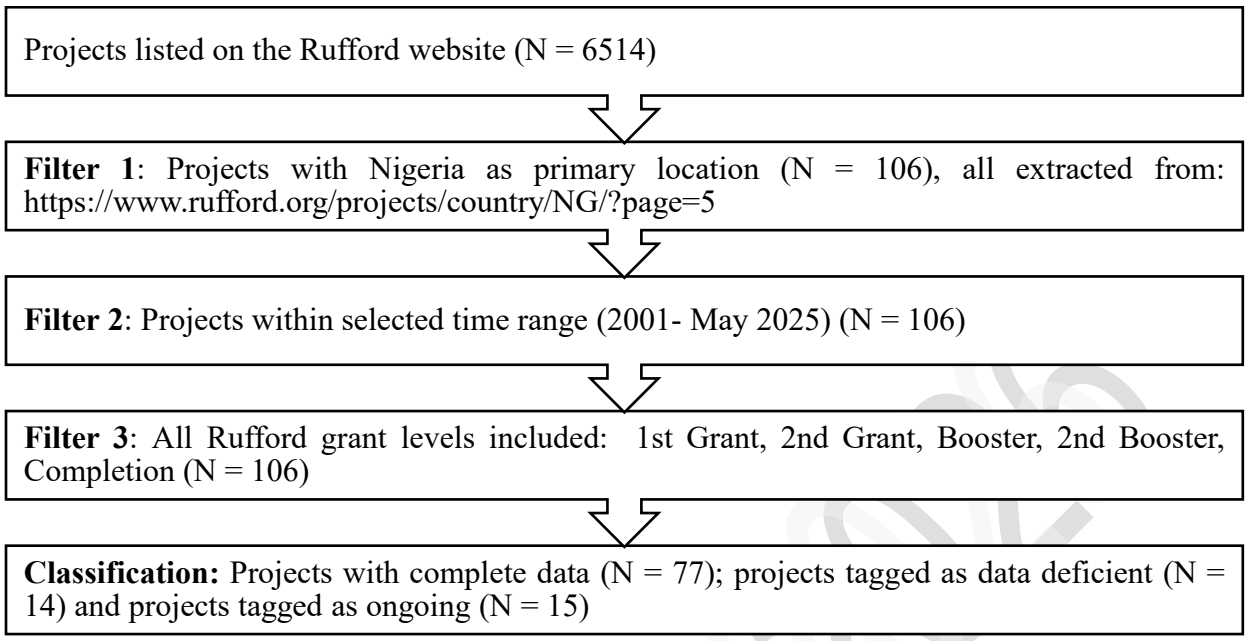


Figure 1: Flow diagram showing data selection process for Rufford Foundation-funded projects in Nigeria (2001– May 2025)

Variable Analysis

The following variables, among others, were extracted and organized for each project:

i. *Project title*: name of the project as listed by the Rufford Foundation
ii. *Primary location*: the Nigerian state where the project was primarily implemented. "Nigeria" was recorded for projects carried out across the country.
iii. *Year*: the year the project was approved
iv. *Closest focus area*: the project categories of Rufford projects were classified as either focused on: (i) animal, (ii) plant, (iii) Education, or (iv) habitat/location/community.
v. *Grant level*: the grant level was identified as One of the following: (i) 1st Rufford Small Grants; (ii) 2nd Rufford Small Grant; (iii) Booster Grant; (iv) Second Booster Grants (this has been phased out); (v) Completion Grant
vi. *Follow-up grant*: whether the project received a follow-up grant or not.

Some variables, such as "closest focus area," were manually coded based on project summaries. To ensure consistency, categories were defined before coding.

Data Analysis

Descriptive statistics (e.g., frequencies and charts) were used to analyze the data. Quantitative data were analyzed in Microsoft Excel to generate frequency tables and charts. Qualitative data, such as project summaries and final reports, were thematically reviewed.

Geographic Visualization of Projects Primary Location

To better understand where conservation efforts have been concentrated, a heat map was created to show the geographic Distribution of Rufford-funded projects across Nigeria. Each project was linked to the state where it was primarily implemented, and states were shaded according to specific ranges of the number of projects they hosted. This visual representation highlighted conservation hotspots and underrepresented areas.

Ethical Consideration

All data used in the study are publicly available and do not involve confidential or sensitive information. No personal identifiers were extracted or analyzed.

Limitations of Methodology

Some project information, especially for recent grants, is either incomplete or not yet publicly available. Also, in classifying focus areas, some subjectivity was unavoidable, as project summaries vary in detail and clarity. Furthermore, the absence of standardized monitoring or evaluation data means the study could not fully assess the long-term impacts of funded projects.

Results and Discussion

Impacts and Distribution of Rufford-funded Projects in Nigeria by Year

The Rufford Foundation has funded 6514 projects worldwide, including 2015 projects in Africa. It has funded only 106 projects in Nigeria (Table 1), representing about 1.6% globally and 5.3% in Africa. While this figure may be generally low, it shows that the foundation has laid a good foundation that can inspire more local applications and capacity-building efforts. Conversely, the figure suggests that despite Nigeria's rich biodiversity, ecological diversity, and conservation needs, the nation remains underrepresented in Rufford-sponsored projects worldwide. This also reveals low project uptake or proposal submission in the country, possibly due to limited awareness and access to information on biodiversity conservation among local and early-career conservationists. Akindele *et al*. (2021) noted the low awareness and concluded that it is necessary to establish biodiversity conservation campaigns in Nigeria. Our findings show that the Rufford Foundation has spent over £600,000 ($811,859) on conservation projects in Nigeria, both completed and ongoing. These funds go to projects related to animal and plant conservation, Education, and the conservation of habitats, communities, and specific locations. These amounts have been spent between 2001 and May 2025, with peak funding years in 2023 and 2024 (12 each), followed by 2022 (7 projects), while the fewest projects were funded in 2001, 2002, 2003, 2004, and 2005, with 1 project each (Figure 2).

ISTF-NG 2026

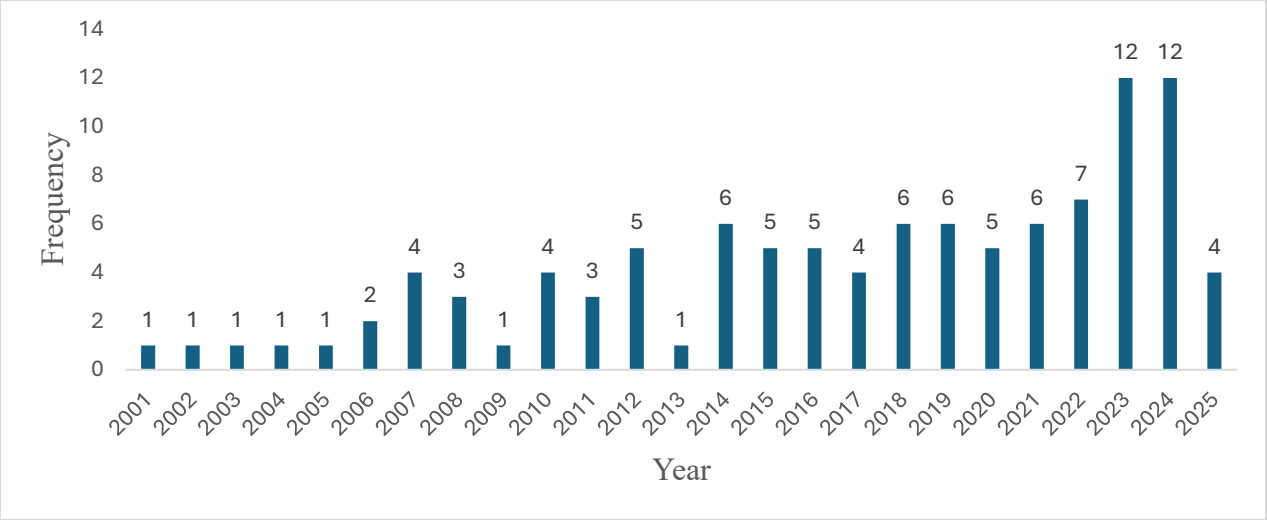


Figure 2: Distribution of Rufford Foundation-funded projects in Nigeria per year

Geographical Distribution of Rufford-Funded Projects in Nigeria

These funded projects are spread across several states in Nigeria, with Plateau State being the highest beneficiary (23 projects), followed by Cross River State (20 projects) and Bauchi State (10 projects). Other states, such as Benue, Edo, Imo, Rivers, and Bayelsa, recorded One project each (Figure 3). Several other states in Nigeria, such as Abia, Akwa Ibom, Kano, Borno, and Sokoto, among others, have yet to benefit from any sponsored project.

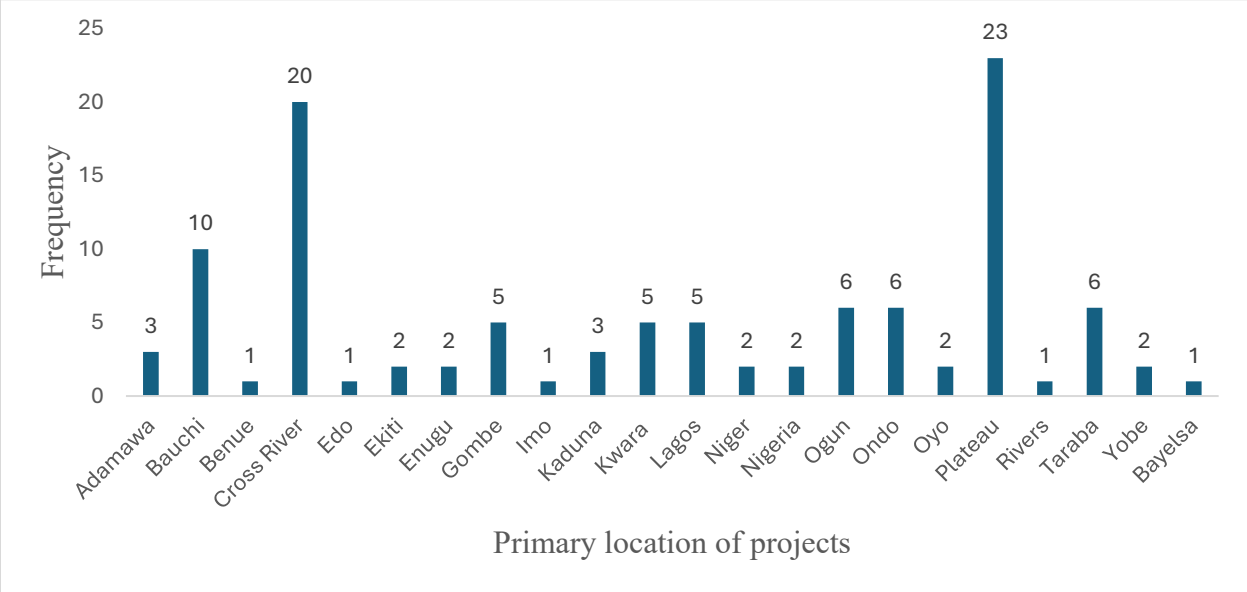


Figure 3: Distribution of Rufford Foundation-funded projects based on primary location (states in Nigeria)

Heat Map Analysis of Ruford-funded Projects across States in Nigeria

The heat map (Figure 4) shows that Plateau, Cross River, and Bauchi States have emerged as key hotspots for conservation activity, likely due to their rich biodiversity and active local conservation groups. This uneven spread shows that there is still a lot of work to be done in raising awareness and building conservation capacity in parts of the country that have been left out. Reaching these areas is important to ensure that conservation efforts are more inclusive and spread more evenly across Nigeria.

ISTF-NIG 2026

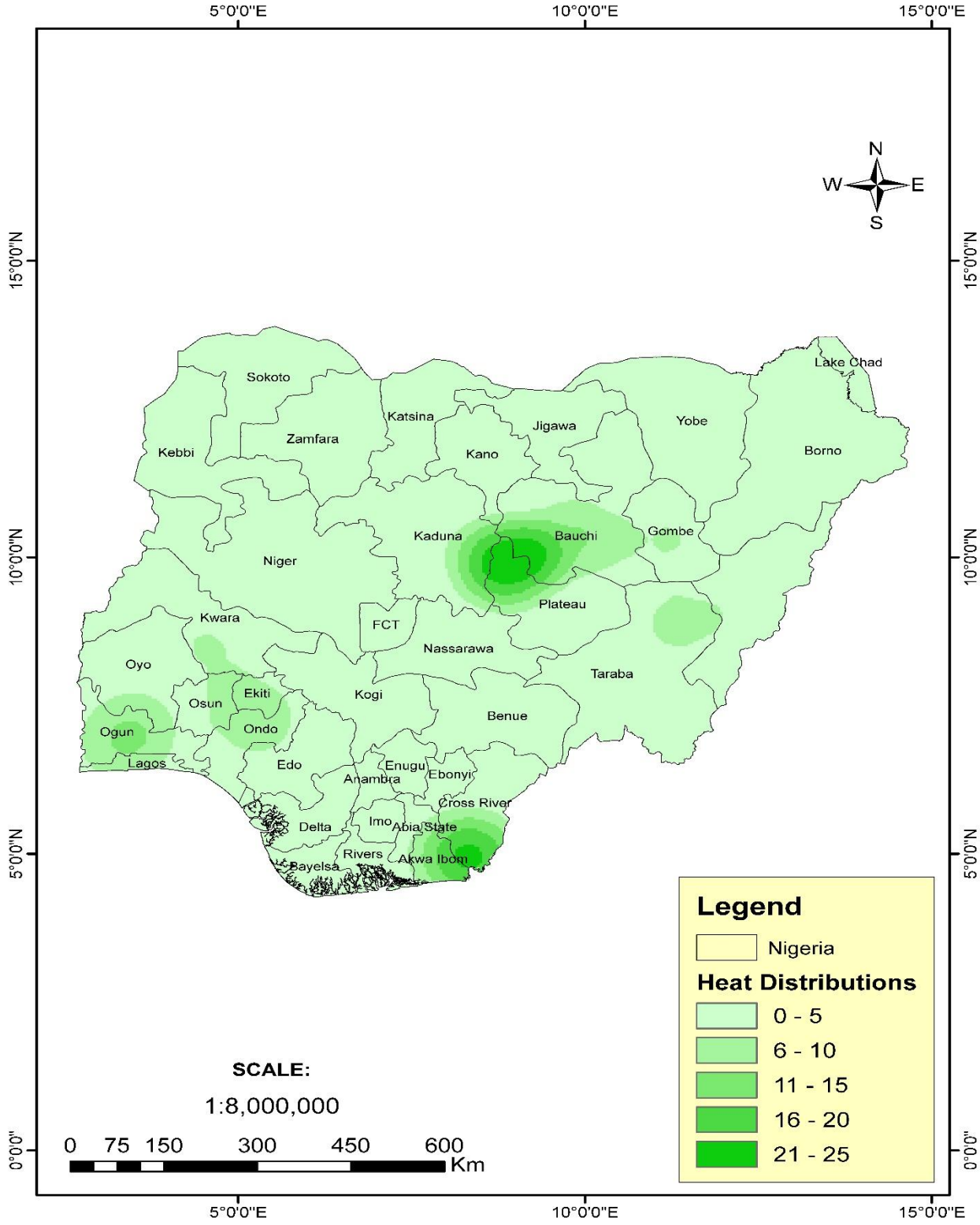


Figure 4: Heat map showing the Distribution of Rufford Foundation-funded projects across Nigerian states (2001 – May 2025)

Thematic Focus of Rufford-funded Conservation Projects in Nigeria

The foundation has funded projects in different conservation categories, with animal conservation covering about 55.7%, habitat/location/community conservation covering about 17.9% and conservation Education and plant conservation covering about 17.0% and 9.4%, respectively (Figure 5). Animal species/classes that have been the major focus of Rufford-sponsored conservation projects in Nigeria include primates, cane rats, guenons, pangolins, butterflies, birds, elephants, gorillas, monkeys, and chimpanzees, among others. The foundation has also spent to conserve plant species such as Figs, *Azanza garckeana*, *Lophira alata*, *Dombeya ledermannii* and *Pterocarpus erinaceus*, among others. The result shows that wildlife protection has been the primary concern of grant recipients. The animals most frequently targeted are those that are more likely to be threatened/highly disturbed in their natural habitats, endemic, or of ecological and cultural importance. Although fewer in number, plant-focused projects have addressed the conservation of species that are valuable for both biodiversity and local livelihoods.

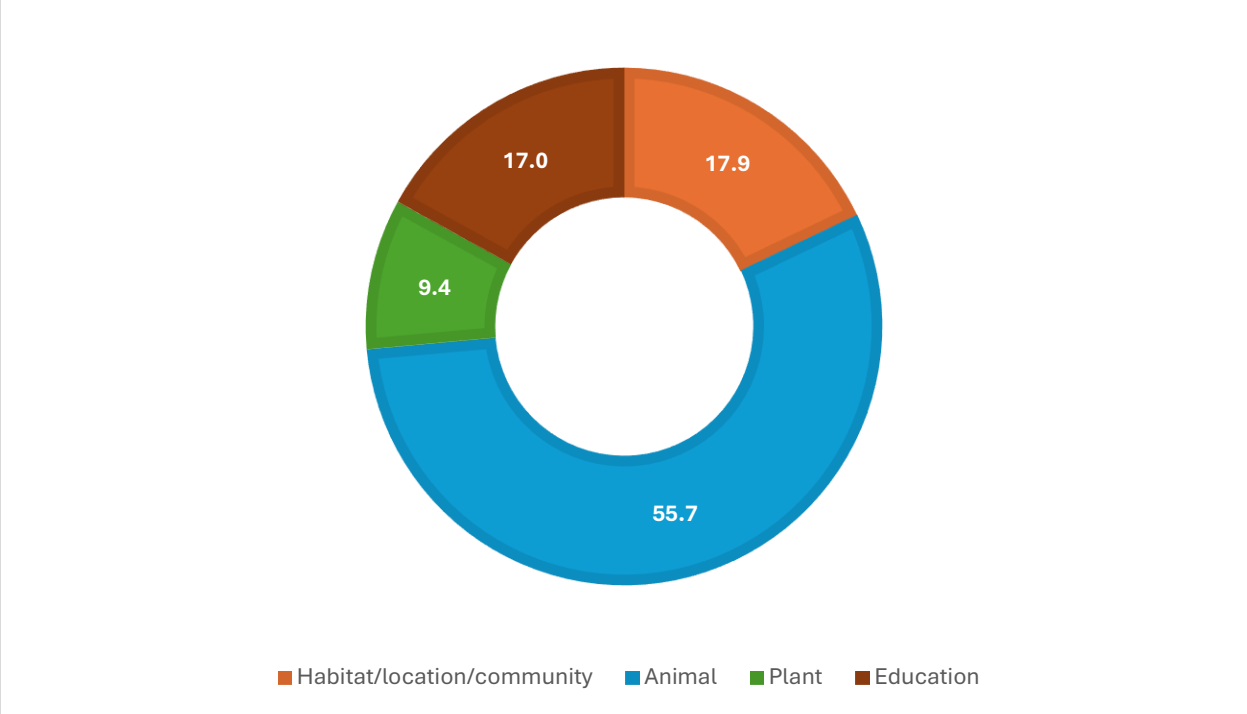


Figure 5: Focus area of Rufford Foundation-funded projects in Nigeria

Status Analysis of Rufford-funded Projects in Nigeria by Focus Area

Of the total funded projects, 59 projects focused on animal conservation, with 46 completed (77.97%), 8 classified as data deficient (13.56%), and 5 still ongoing (8.47%). For plant conservation, 10 projects were implemented; 7 have been completed (70%), and 3 are ongoing (30%), with no data-deficient projects recorded (0%). Habitat, location, and community conservation accounted for 19 projects in total: 15 were completed (78.95%), 4 were data deficient

(21.05%), and none were ongoing (0%). Conservation Education recorded 18 projects; 9 have been completed (50%), 2 are data deficient (11.11%), and 7 are ongoing (38.89%) (Figure 6).

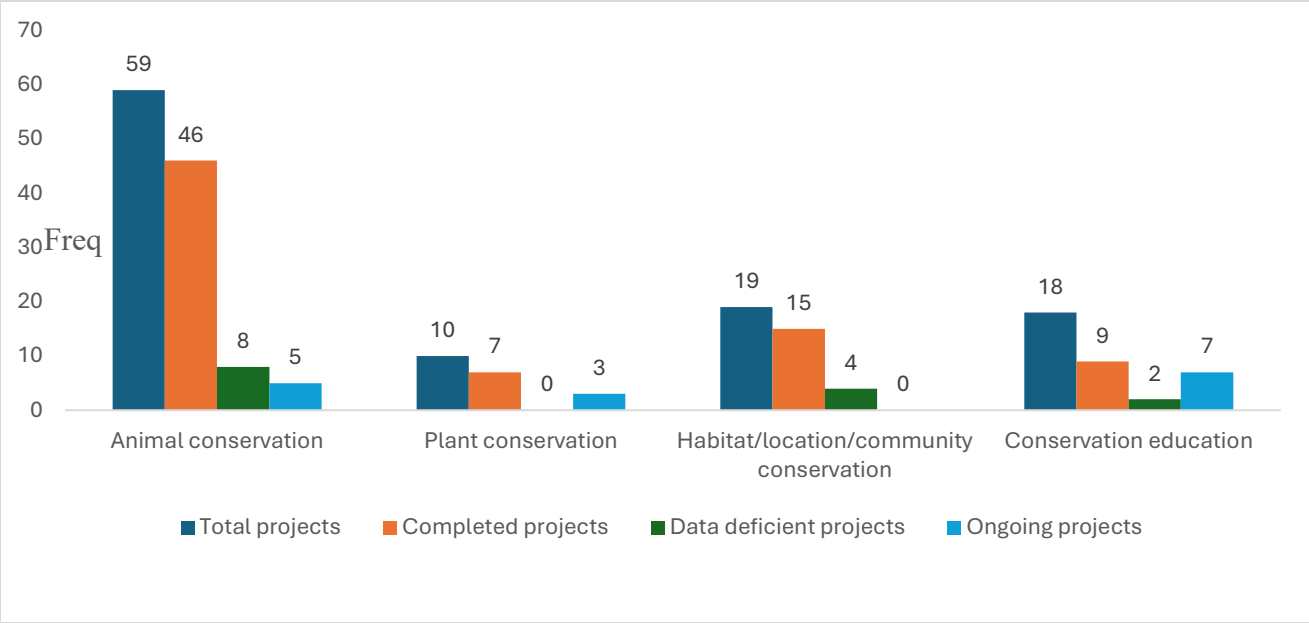


Figure 6: Distribution of Rufford Foundation-funded projects in Nigeria by focus area and project status

Distribution of Rufford-funded Projects in Nigeria by Grant Types

The highest funding grant is the 1st Rufford Grant (72 projects, 67.9%), followed by the 2nd Rufford Grant (20 projects, 18.9%) and the Booster Grant (8 projects, 7.5%), while the 2nd Booster Grant and the Completion Grant cover 3 projects each (2.8%) (Figure 7). It shows a significant drop-off in continued funding beyond the initial grant stage, possibly due to challenges in project scalability, follow-up support, or meeting eligibility criteria for advanced grants.

ISTF-NIG

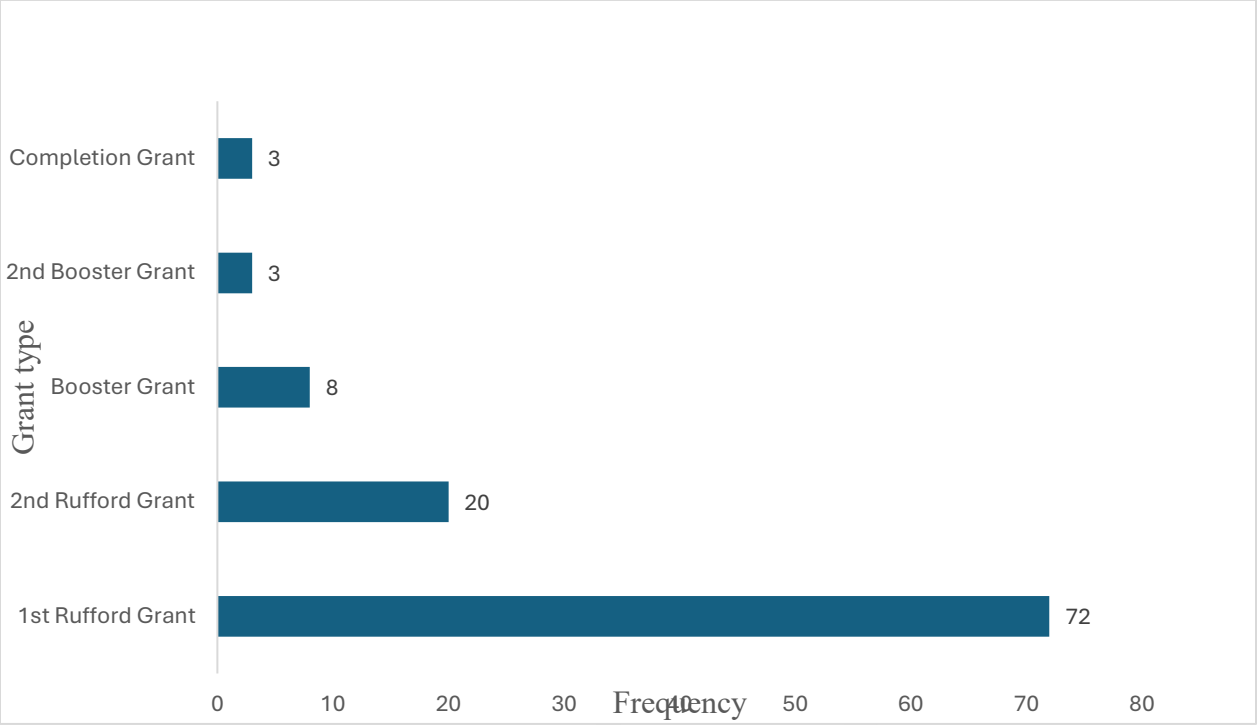


Figure 7: Grant types of funded projects

Catalogue of Rufford-funded Projects Across Nigeria

Table 1 shows 106 Rufford-funded conservation projects implemented across Nigeria between 2001 and May 2025, their primary locations, year of approval, closest focus area, grant level, and follow-up projects and their unique codes. These projects spanned states in all six geopolitical zones, with notable concentrations in Plateau, Cross River, and Bauchi States. Key biodiversity hotspots such as Cross River National Park, Yankari Game Reserve and Omo Forest Reserve featured prominently as primary locations. A total of 77 projects (72.6%) were completed, while 14 projects (13.2%) and 15 projects (14.2%) are tagged data deficient and ongoing, respectively (Table 1).

Table 1: Funded Rufford Foundation projects in Nigeria between 2001 and May 2025

S/N	Project Title	Primary Location	Year	Closest Focus Area	Grant Level	Follow-Up Grant	Code for Follow-up Project
1	Community Institutions Enhancement and Forest Protection in Buan, Ogoni-Land, Niger Delta **	Rivers	2001	Habitat/location /community	1st Rufford Grant	No	-
2	Biodiversity within the Remote, Plant-Rich Forests of Taraba and Adamawa States, Nigeria **	Adamawa/ Taraba	2002	Habitat/location /community	1st Rufford Grant	Yes	A
3	Endangered Primates in Southern Nigeria **	Cross River	2003	Animal	1st Rufford Grant	Yes	B
4	Domestication and Breeding of Cane-Rat for Controlling Indiscriminate Bush-Burning **	Nigeria	2004	Animal	1st Rufford Grant	No	-
5	Seed Dispersal and the Long-Term Survival of Nigeria's Montante Forests	Taraba	2005	Habitat/location /community	2nd Rufford Grant	No	A
6	Saving the Natural Habitats of the Jos-Plateau: Which Threatened Indigenous Fuelwood Species Should be Planted?	Plateau	2006	Habitat/location /community	1st Rufford Grant	Yes	C
7	The Nigerian Guenon in Southern Nigeria: Outlook Good or Just Hanging On?	Bayelsa	2006	Animal	2nd Rufford Grant	Yes	B
8	Distribution and Abundance of Wetland Birds in Yankari Game Reserve, Bauchi, Northern Nigeria	Bauchi	2007	Animal	1st Rufford Grant	No	-
9	Survey of Forest Elephants in Ifon Forest Reserve	Ondo	2007	Animal	1st Rufford Grant	No	-

ISTF-NG 2026

10	Primates of the Amurum Reserve: Their Conservation Status	Plateau	2007	Animal	1st Rufford Grant	No	-
11	Conservation Education for Children in Plateau State, Nigeria: The Children for Nature Project (CNFP) I	Plateau	2007	Education	1st Rufford Grant	Yes	D
12	Conservation Education and Capacity Building: Rural Participation in Conservation and Production of Fuel-Efficient Stoves	Plateau	2008	Education	1st Rufford Grant	Yes	E
13	How Important are Figs in the Conservation Effort at Amurum Forest Reserve, Laminga?	Plateau	2008	Plant	1st Rufford Grant	No	-
14	Strengthening Community-Based Biodiversity Conservation in King Forests in Oke-Ogun Area of Oyo State, Nigeria	Oyo	2008	Habitat/location /community	1st Rufford Grant	No	-
15	Fire Regimes and Their Implications on Trees and Tree Species Utilized by Birds for Nesting in the Savanna Woodlands of Yankari Game Reserve, Nigeria	Bauchi	2009	Plant	1st Rufford Grant	Yes	F
16	Participatory Survey and Conservation of Endangered Savannah Elephants of Kamuku and its Environment, Nigeria	Kaduna	2010	Animal	1st Rufford Grant	Yes	G
17	Investigating Ecological and Anthropogenic Factors that Determine the Distribution and Conservation of the Critically Endangered Cross River Gorilla	Cross River	(2010).	Animal	1st Rufford Grant	No	-
18	Road Construction in Protected Areas Good for Ecotourism but Bad for Biodiversity Conservation	Bauchi	2010	Habitat/location /community	1st Rufford Grant	No	-

ISTF-NIG 2026

	– A Case Study of Yankari Game Reserve						
19	Threatened Primates of Nigeria: Conservation of Sacred Monkeys in Igboland and a Relict Population of Chimpanzees in the Niger Delta	Imo	2010	Animal	Booster Grant	No	B
20	Tree Selection and Nursery Programme for Buffer Zone Support in Yankari Game Reserve, Bauchi State, Nigeria	Bauchi	2011	Habitat/location /community	1st Rufford Grant	No	-
21	Survey for Population Status of Nigeria-Cameroon Chimpanzee and Habitat Threat Assessment in the Oban Hills of Cross River National Park, Cross River, Nigeria	Cross River	(2011).	Animal	1st Rufford Grant	No	-
22	Increasing Urbanization towards the Amurum Forest Reserve and the Jos Wildlife Park: Where Do We Draw the Line to Protect Local Fauna?	Plateau	2011	Habitat/location /community	2nd Rufford Grant	No	C
23	Promoting Rural Participation in Conservation through Rural Empowerment	Plateau	2012	Education	2nd Rufford Grant	No	E
24	Understanding Movement Patterns and Resource Needs of Kamuku Elephants Along Migration Routes in Nigeria	Kaduna	2012	Animal	2nd Rufford Grant	Yes	G
25	Fire and Herbivory Impacts Savanna Woodland Vegetation: Saving the Largest Protected Woodland in the Guinea Savanna Region of Nigeria	Bauchi	2012	Habitat/location /community	2nd Rufford Grant	Yes	F
26	Status Surveys to Determine the Population Viability of the	Ekiti	2012	Animal	1st Rufford Grant	Yes	H

ISTF-NG 2026

	Nigerian-Cameroon Chimpanzee in the Nigerian Lowland Rainforests of Southwestern Nigeria						
27	Conservation of a Primate Community in Cross River State, Nigeria through an Integrated Approach Including Research, Patrols, and Community Involvement	Cross River	(2012).	Animal	1st Rufford Grant	No	-
28	Conservation Education for Children in Plateau State, Nigeria: The Children for Nature Project (CFNP) II	Plateau	2013	Education	2nd Rufford Grant	Yes	D
29	Nigerian – Cameroon Chimpanzee (*Pan troglodytes ellioti*) Research and Conservation in Southwestern Nigerian Forests	Ondo	2014	Animal	2nd Rufford Grant	Yes	H
30	Trade on Avian Body Parts: Implications for Biodiversity Conservation in South-Eastern Nigeria	Cross River	(2014).	Animal	1st Rufford Grant	Yes	I
31	Plant Species Diversity, Composition and Structure of a Savannah Woodland in North-Eastern Nigeria	Gombe	2014	Plant	1st Rufford Grant	Yes	J
32	The Mushere Forest Conservation Project	Plateau	2014	Habitat/location /community	1st Rufford Grant	No	-
33	Predicting Roost Choice in Cave Dwelling Bats and Preserving Cave Bat Communities by Local Community Conservation Education	Enugu	2014	Education	1st Rufford Grant	Yes	K

ISTF-NIG 2026

34	Assessment of the Potentials of Faith-Based Groups in the Conservation of Wildlife Consumed as Bushmeat in Cross River State, Nigeria	Cross River	(2014).	Animal	1st Rufford Grant	No	-
35	Spatial Distribution and Conservation of Forest Elephants (*Loxodonta africana cyclotis*) in Southwestern Nigeria	Ondo	2015	Animal	Booster Grant	Yes	G
36	Fire and Herbivory Impact Savanna Vegetation: Understanding the Fire, Herbivore and Woodland Community Interplay in One of Nigeria's Foremost Game Reserves	Bauchi	2015	Habitat/location /community	Booster Grant	Yes	F
37	Vegetation Patterns and Species Diversity of Naraguta Mountains in Jos, North-Central Nigeria	Plateau	2015	Habitat/location /community	1st Rufford Grant	No	-
38	Effects of Human Activities in Pandam Wildlife Park: Do Breeding Birds Benefit from Cattle Grazing and Poaching?	Plateau	2015	Animal	1st Rufford Grant	No	-
39	Effect of Habitat Degradation on Avian Species Diversity and Abundance in a Guinea Savannah Woodland of North East Nigeria	Gombe	2015	Animal	2nd Rufford Grant	No	J
40	Ecology of the African Pouched Rat (*Cricetomys Sp.*): Implications for Seed Dispersal and Conservation of Large Seeded Species	Plateau	2016	Animal	1st Rufford Grant	No	-
41	Mitigating Trade on Avian Derivatives in Southeast Nigeria	Cross River	2016	Animal	2nd Rufford Grant	Yes	I

ISTF-NIG '2026

42	Reversing the Human-Induced Decline of Fruit Plants in an Important Bird Area in Nigeria: Consequences for Bird Diversity	Plateau	2016	Plant	1st Rufford Grant	No	-
43	Nigerian – Cameroon Chimpanzee Research and Conservation Efforts in Southwestern Nigerian Forests	Ondo	2016	Animal	Booster Grant	Yes	H
44	The Birds of Elizade University Forest and Surrounding Environment: A Step to the Conservation of Elizade Ecosystem	Ondo	2016	Animal	1st Rufford Grant	No	-
45	Efficient Fuelwood Use as a Strategy for Reducing Household Pressure on Natural Forests of the Guinea Savanna Zone of Nigeria	Kwara	2017	Habitat/location /community	1st Rufford Grant	Yes	L
46	Feeding Pattern, Community Education and Rehabilitation of Conservation Facilities for Forest Elephants in Omo Forest Reserve, Southwestern Nigeria	Ogun	2017	Animal	2nd Booster Grant	Yes	G
47	Forest Interior Insectivorous Bats on Elevational Gradients: Response to Forest Structure, Species Richness Pattern and Conservation of the Vulnerable *H. curtus*	Cross River	(201 7).	Animal	2nd Rufford Grant	No	K
48	Biodiversity Assessment and Conservation of Amphibians and Reptiles of Gashaka Gumti National Park, Nigeria	Adamawa/ Taraba	2017	Animal	1st Rufford Grant	Yes	M
49	Environmental Clubs and Tree Planting Campaigns as Tools to Mitigate Desertification and Loss of Biodiversity in Gombe State, North-Eastern Nigeria	Gombe	2018	Education	1st Rufford Grant	No	-

ISTF-NIG 2026

50	Integrated Conservation Approach for Hooded Vultures in a New Range, in Lagos, Nigeria	Lagos	2018	Animal	1st Rufford Grant	No	-
51	Understanding the Drivers of Nature Knowledge, Perceptions and Attitudes in Nigerian Children: Implications for Conservation	Plateau	2018	Education	Booster Grant	No	D
52	Reaching the Unreached: Rural Biodiversity Conservation Education in Southern Bauchi State, North-East, Nigeria	Bauchi	2018	Education	1st Rufford Grant	Yes	N
53	Introduction of Efficient Biomass Cook Stove as a Strategy to Reduce Household Pressure on Natural Forests of the Guinea Savanna Zone of Nigeria	Kwara	2018	Habitat/location /community	2nd Rufford Grant	No	L
54	Assessing the Prevalence and Drivers of Wildlife Poisoning in a Tropical Biodiversity Hotspot	Cross River	(2018).	Animal	Booster Grant	No	I
55	Assessment and Impact of Land Use and Anthropogenic Activities on Insectivorous Bat Species Composition in Omo Forest Reserve, Southwest, Nigeria	Ogun	2019	Animal	1st Rufford Grant	No	-
56	Land Degradation and Its Impacts on Ecosystem Services in the Nigerian Guinea Savannah: Insights for Sustainable Land Management	Niger	2019	Habitat/location /community	1st Rufford Grant	Yes	O
57	Reconciling Biodiversity Conservation and Agricultural Production for Food Security in Nigeria: A Land Use Optimization Modelling Approach **	Nigeria	2019	Habitat/location /community	1st Rufford Grant	No	-

ISTF-NIG 2026

58	Why Hunt: Assessing Drivers and Sustainability of Intense Egyptian Fruit Bat Hunting to Guide Conservation Intervention **	Cross River	(2019).	Animal	1st Rufford Grant	No	-
59	Strengthening Monitoring Systems for Adaptive Management and Protection of Forest Elephants in Omo Forest Reserve, Southwestern Nigeria	Ogun	2019	Animal	Completion Grant	No	G
60	Advancing Integrated Participatory Conservation Actions for Chimpanzees in Southwestern Nigeria	Ondo	2019	Animal	2nd Booster Grant	Yes	H
61	Ecological Studies and Community-Based Conservation Activities for Amphibians and Reptiles of Gashaka Gumti National Park, Nigeria	Adamawa/ Taraba	2020	Animal	2nd Rufford Grant	Yes	M
62	Ecology and Conservation of the Endangered White-Bellied Pangolin (*Phataginus tricuspis*) in Cross River, Nigeria	Cross River	(2020).	Animal	1st Rufford Grant	No	-
63	Conservation Assessment of Threatened Arboreal Mammals in Omo Forest Reserve, Southwest, Nigeria**	Ogun	2020	Animal	1st Rufford Grant	No	-
64	Reviving Vulture Populations Within and Around Jos Metropolis	Plateau	2020	Animal	1st Rufford Grant	Yes	P
65	Effects of Burn Severity and Frequency on Northern Ground-Hornbill in a Sudan Savanna Landscape	Bauchi	2020	Animal	1st Rufford Grant	No	-
66	Survey of the Endangered Yellow Waxtail Damselfly (*Ceriagrion*	Ogun	2021	Animal	1st Rufford Grant	No	-

ISTF-NIG 2026

	citrinum) and Related Insects of Ecotourism in Sunmoge, Omo Forest Reserve, Nigeria						
67	Distribution, Conservation Status and Environmental Correlates of a Poorly Known and Most Threatened Stingray (*Fontitrygon margarita*) in Nigeria	Lagos	2021	Animal	1st Rufford Grant	Yes	Q
68	Historical Appraisal of the Diversity of Amphibians and Threats to their Conservation Across Nigeria	Cross River	(2021).	Animal	1st Rufford Grant	No	-
69	Protecting a Unique Group of Chimpanzees and its Habitat in Ise Forest Conservation Area, Southwest of Nigeria	Ekiti	2021	Animal	Completion Grant	No	H
70	Identifying Habitat Associations and Dependence on Urban Wetlands by Waterbirds in Lagos, Nigeria	Lagos	2021	Animal	1st Rufford Grant	No	-
71	Habitat Utilization of Wading Birds in Hadejia-Nguru Wetlands, Nigeria	Yobe	2021	Animal	1st Rufford Grant	Yes	R
72	Conservation of *Azanza garckeana*, a Poorly Studied and locally Threatened Plant Species in Nigeria	Gombe	2022	Plant	1st Rufford Grant	No	-
73	Wildlife-Friendly Farming: Incorporating Biodiversity Conservation Knowledge to Agricultural Training and Transforming Farmers to Partners in Conservation **	Gombe	2022	Education	1st Rufford Grant	No	-
74	Improving Afromontane Forest Conservation through Increasing	Plateau	2022	Habitat/location /community	1st Rufford Grant	No	-

ISTF-NIG 2026

	Awareness by Forest-Edge Communities of the Ecosystem Services Montane Forests Provide						
75	Conservation of *Lophira alata*, an Economically Important and Vulnerable Tree Species in Nigeria	Cross River	(2022).	Plant	1st Rufford Grant	Yes	S
76	Community-Based Ecosystem Services and Livelihood Security as a Tool for Restoration and Conservation of Human Degraded Landscape in Niger State, Nigeria	Niger	2022	Habitat/location /community	2nd Rufford Grant	No	O
77	Enhancing Studies and Sustainable Conservation Actions for Amphibians and Reptiles in Highly Biodiverse and Threatened Nigerian Montane Regions	Plateau	2022	Animal	Booster Grant	Yes	M
78	To Promote the Conservation of the Hooded Vulture in North-Central Nigeria **	Kaduna	2022	Animal	1st Rufford Grant	No	-
79	Intensifying Conservation Actions for the Protection of Red List Threatened Stingrays in Nigerian Lagos Lagoon	Lagos	2023	Animal	2nd Rufford Grant	Yes	Q
80	Roost Site Suitability Survey and Conservation Campaign for Bat Roost Protection in Plateau State, Nigeria: A Focus on Straw-Coloured Fruit Bats	Plateau	2023	Animal	1st Rufford Grant	No	-
81	Delivering Better Ecological and Social Outcomes in Nigeria's Foremost National Park at the Brink of Losing its Conservation Value **	Bauchi	2023	Habitat/location /community	2nd Booster Grant	No	F

ISTF-NG 2026

82	Developing Capacity for Monitoring Three Endemic and Data-Deficient Butterfly Species on the Jos Plateau Ecoregion, Nigeria **	Plateau	2023	Animal	1st Rufford Grant	No	-
83	Ecological Survey of the Threatened and Relict Damselflies on the Obudu Plateau, Nigeria	Cross River	(2023).	Animal	1st Rufford Grant	No	-
84	Assessing the Threat, Distribution and Conservation of African Rosewood in Akwete Community Forest, Benue State, Nigeria	Benue	2023	Plant	1st Rufford Grant	No	-
85	Populations, Distribution and Habitat Utilization of the Endangered Mount Kupe Bushshrike, and Other Birds of Conservation Concern on the Obudu Plateau, Nigeria **	Cross River	(2023).	Animal	1st Rufford Grant	No	-
86	Conservation of Pangolins and other Endangered Wildlife Species through the Initiation of Wildlife Conservation Clubs in Schools in Ibadan, Nigeria **	Oyo	2023	Education	1st Rufford Grant	No	-
87	Conserving Critically Endangered Vultures in Nigeria: A Study on Vegetation Structure, Tree Species, and Community Engagement in the Hadejia Nguru Wetland Complex	Yobe	2023	Animal	2nd Rufford Grant	No	R
88	Catch them Young: Climate Change Education in Primary Schools in Ilorin, Kwara State, Nigeria.	Kwara	2023	Education	1st Rufford Grant	Yes	T

ISTF-NIG 2026

89	Parasite Diversity and Conservation of Cave-Dwelling Bats in Enugu State, Nigeria	Enugu	2023	Animal	1st Rufford Grant	No	-
90	Improving the Population Trends of the Hooded Vulture and Related Species within Central Nigeria **	Plateau	2023	Animal	2nd Rufford Grant	No	P
91	Assessing Vulture Population Status, Trends, Distribution, and Chemical Threats Across Nigeria through Spatial Modeling and Environmental Contaminant Analysis	Cross River	(2024).	Animal	2nd Rufford Grant	No	N
92	Conservation of the Vulnerable Population of the Northern Ground-Hornbill: A Community-Based Survey and Conservation Education Program in Bauchi State, Nigeria *	Bauchi	2024	Education	1st Rufford Grant	No	-
93	From Classroom to Community: Engaging Nigerian Children in Vulture Conservation and Combating Traditional Beliefs *	Plateau	2024	Education	1st Rufford Grant	No	-
94	Saving the Last Remaining Populations of the Highly Threatened Nigerian Montane Herpetofauna Through Conservation Education and Community Awareness Programmes *	Cross River	(2024).	Education	Completion Grant	No	M
95	Developing Community-based Conservation Strategies for Improved Management of Stingrays in Nigeria *	Lagos	2024	Animal	Booster Grant	No	Q

ISTF-NIG 2026

96	Conserving the Critically Endangered *Dombeya Ledermannii* in and Around Amurum Forest Reserve, Jos Plateau, Nigeria *	Plateau	2024	Plant	1st Rufford Grant	No	-
97	Transforming our Future by Fostering Environmental Awareness Through Student Engagement: a Novel Community Science Approach to Campus Bird Surveys *	Kwara	2024	Education	1st Rufford Grant	No	-
98	Inventory of Butterfly Biodiversity for Conservation in Gashaka Gumti National Park *	Taraba	2024	Animal	1st Rufford Grant	No	-
99	Ecological Survey and Conservation Education Approach to Mitigate the Impact of Human Activities on the Distribution of the Vulnerable Bannerman's Weaver *	Plateau	2024	Education	1st Rufford Grant	No	-
100	Conservation of the Endangered Grey Parrot and Birds of Conservation Concern in Afi River Forest Reserve, Nigeria: Population Status and Conservation Campaign *	Cross River	(2024).	Animal	1st Rufford Grant	No	-
101	Enhancing the Conservation of a Rapidly Declining Large Frugivorous Forest Bird in Southeast Nigeria: the Yellow-Casqued Hornbill *Ceratogynna elata* *	Cross River	(2024).	Animal	1st Rufford Grant	No	-
102	Population Survey and Intensifying Conservation Action for the Protection of the Vulnerable Red-eared Guenon (*Cercopithecus*	Cross River	(2024).	Animal	1st Rufford Grant	No	-

ISTF-NG 2026

	Erythrotis camerunensis) in Nigeria *						
103	Improving Sustainable Conservation of Red Ironwood Within Communities Surrounding Some Protected Areas in Nigeria *	Edo	2025	Plant	2nd Rufford Grant	No	S
104	Combating Climate Change Through Education, Nursery Establishment and Tree Planting in Secondary Schools in Ilorin, Kwara State, Nigeria *	Kwara	2025	Education	2nd Rufford Grant	No	T
105	Promoting the Conservation of Pangolins Through School Conservation Education and Community Awareness in Ogun State, Nigeria *	Ogun	2025	Education	1st Rufford Grant	No	-
106	Conservation and Ecology of Two Critically Endangered Plant Species: Understanding Their Distribution, Habitat Requirements, Threats and Conservation Strategies *	Taraba	2025	Plant	1st Rufford Grant	No	-

***Note**: Projects with the same letter are related to One another (i.e., follow-up projects are represented by the same letter).*

** Data-deficient projects

* Ongoing projects

ISTF-NIG 2026

Conclusion

This study provides a first-of-its-kind national analysis of Rufford Foundation-funded conservation projects in Nigeria, examining the scope, Distribution, and focus of small grants awarded between 2001 and May 2025. It reveals that although Nigeria is a biodiversity-rich country with high conservation needs, it remains underrepresented in global conservation philanthropy, with only 106 projects supported out of over 6,500 funded worldwide. Nonetheless, the steady increase in project volume, especially in recent years, suggests a likely gradual shift in local conservation awareness and capacity, potentially driven by increased access to funding, training opportunities and a growing network of conservationists. The study confirms that animal-focused conservation dominates Rufford-supported initiatives in Nigeria, particularly targeting threatened or culturally significant species. However, the relatively low number of plant-focused projects and limited representation of several Nigerian states show geographic and thematic imbalances that could constrain broader biodiversity outcomes. Equally concerning is the sharp decline in follow-up or advanced-stage grants, suggesting challenges in sustaining conservation momentum and meeting eligibility benchmarks. Despite these gaps, the data reflects promising efforts by local researchers who are navigating difficult environmental, institutional and financial landscapes to deliver grassroots conservation. This work, therefore, highlights the Rufford Foundation's contributions to biodiversity protection in Nigeria. Thus, strengthening support systems, improving the visibility of funding opportunities and investing in long-term project continuity can significantly promote the reach and impact of these conservation efforts.

Recommndation

One important observation from this review is that many grantees did not have their scientific publications uploaded to their Rufford project pages. As a result, valuable findings, local experiences, and conservation lessons often remain inaccessible to others who could benefit from them. To bridge this gap, the Rufford Foundation should place greater emphasis on encouraging (or even requiring) grantees to submit any research outputs, scientific publications, or community reports related to their projects for upload to their project web pages. Making this a regular part of the post-project reporting process would help build a shared knowledge base and inspire others working in similar fields or regions. Another gap that became apparent is the lack of a standardized way to track the outcomes or longer-term impacts of funded projects. Because each grantee reports results differently, it is difficult to know which projects are truly making a lasting difference on the ground. The Rufford Foundation could help address this by introducing a simple, user-friendly monitoring and evaluation (M&E) framework for grantees to follow. This does not have to be complex or time-consuming, but just enough to ensure that key results are consistently captured and reported. In the long run, this would not only help Rufford understand the real impact of its funding but also help the grantee reflect on and improve their work.

References

Akindele, E. O., Ekwemuka, M. C., Apeverga, P., Amusa, T. O., Olajuyigbe, S., Coker, O. M., Olaleru, F., Fasona, M., Usen, E. N., Ringim, A. S., Adedoja, O. A., Nsude, C. C., Ota, A. C., Oluowo, F. E., Onatunji, A. B., Adedapo, A. M. & Kolawole-Daniels, A. (2021). Assessing awareness on biodiversity conservation among Nigerians: The Aichi

Biodiversity Target 1. *Biodiversity and Conservation 30*(7): 1947–1970. https://doi.org/10.1007/s10531-021-02175-x

Borokini, T. I. (2014a). A systematic compilation of IUCN Red-listed threatened plant species in Nigeria. *International Journal of Environmental Sciences* 3(3): 104–133.

Borokini, T. I. (2014b). A systematic compilation of endemic flora in Nigeria for conservation management. *Journal of Threatened Taxa* 9(11): 6406–6426. http://dx.doi.org/10.11609/JoTT.o4010.6406-26

Ferraro, P. J. & Pattanayak, S. K. (2006). Money for nothing? A call for empirical evaluation of biodiversity conservation investments. *PLoS Biology* 4(4): e105. https://doi.org/10.1371/journal.pbio.0040105

Idowu, M. A. & Morenikeji, O. A. (2015). Wild fauna conservation in Nigeria. *Environment and Natural Resources Research 5*(3): 98–108. http://dx.doi.org/10.5539/enrr.v5n3p98

Imarhiagbe, O., Egboduku, W. O. & Nwankwo, B. J. (2020). A review of the biodiversity conservation status of Nigeria. *Journal of Wildlife and Biodiversity* 4(1): 73–83. https://doi.org/10.22120/jwb.2019.115501.1096

Johnson, A., Saypanya, S., Hansel, T. & Rao, M. (2022). More than an academic exercise: Structuring international partnerships to build research and professional capacity for conservation impact. *Conservation Science and Practice* 4(5): e539. https://doi.org/10.1111/csp2.539

Mafiana, C. F., Jayeola, O. A. & Iduseri, E. O. (2022). Impact of environmental degradation on biodiversity conservation in Nigeria. *The Zoologist* 20: 41–50. http://dx.doi.org/10.4314/tzool.v20i1.6

Miller, D. C., Minn, M., & Sinsin, B. (2015). The importance of national political context to the impacts of international conservation aid: Evidence from the W National Parks of Benin and Niger. *Environmental Research Letters* 10(11): 115001. http://dx.doi.org/10.1088/1748-9326/10/11/115001

Usman, B. A. & Adefalu, L. L. (2010). Nigerian forestry, wildlife and protected areas: Status report. *Biodiversity* 11(3–4): 54–62. https://doi.org/10.1080/14888386.2010.9712664

ISTF-NIG 2026

ACUTE TOXICITY AND PISCICIDAL POTENTIAL OF *Calotropis procera* EXTRACT ON *Clarias gariepinus* FINGERLINGS

Akinyemi, I. G., *Ajagbe, S. O., Ayoola, O. A., Aderemi, T. F., Shorungbe, M. F. and Atobaale, O. Y.

[1]*Department of Wildlife and Ecotourism, Forestry Research Institute of Nigeria, P.M.B. 5054, Jericho, Ibadan, Nigeria*
[2]*FPDU, Forestry Research Institute of Nigeria, P.M.B. 5054, Jericho, Ibadan, Nigeria*
[3]*Department of Horticultural Technology, Federal College of Ibadan, Jericho, Ibadan, Nigeria*
[4]*Department of Science Laboratory Technology, Abraham Adesanya Polytechnic, PMB 1020, Ijebu-Igbo, Ogun State*
**Corresponding Author: stephenoajagbe@gmail.com*

Abstract

The search for environmentally friendly alternatives to synthetic chemicals in aquaculture has increased interest in plant-derived piscicides. This study evaluated the acute toxicity and piscicidal effects of aqueous extract of *Calotropis procera* on *Clarias gariepinus* fingerlings under controlled laboratory conditions. A static bioassay was conducted using five concentrations (10, 20, 40, 80, and 160 ml/L) alongside a control, with 10 fish per treatment over a 48-hour exposure period. Mortality increased progressively with concentration, ranging from 0% in the control to 100% at 160 ml/L, indicating a clear dose–response relationship. Probit analysis yielded a 48-hour LC_{50} of 35.56 ml/L (95% confidence limits: 24.5–51.5 ml/L), confirming the extract's high toxicity. Behavioral responses observed in exposed fish included erratic swimming, rapid opercular movement, air gulping, excessive mucus secretion, and loss of equilibrium before death. Water quality parameters (temperature, pH, dissolved Oxygen, conductivity, and total dissolved solids) remained within acceptable limits throughout the experiment, indicating that mortality was primarily due to the plant extract's toxic effects. The findings demonstrate that *Calotropis procera* possesses strong piscicidal properties and may serve as a potential botanical agent for fish control. However, its application should be carefully managed to minimize ecological risks to non-target aquatic organisms.

Keywords: *Calotropis procera*; *Clarias gariepinus*; Piscicidal activity; LC_{50}; Probit analysis; Fish toxicity; Botanical piscicide; Aquatic toxicology

Introduction

Aquatic ecosystems play a vital role in food security, biodiversity conservation, and economic development, particularly in developing countries such as Nigeria, where fisheries and aquaculture contribute significantly to livelihoods (Sinha & Banerjee, 2025). Among cultured fish species, *Clarias gariepinus* (African catfish) is widely recognized for its rapid growth, high tolerance to environmental fluctuations, and commercial importance in aquaculture. However, sustainable fish production is often challenged by the need for effective, environmentally safe management practices, including population control, pond preparation, and selective harvesting.

The use of synthetic chemicals for fish control and pond management has raised concerns due to their persistence, bioaccumulation, and potential adverse effects on non-target organisms and the environment. Consequently, attention has shifted towards plant-derived piscicides as eco-friendly alternatives. Botanical piscicides are biodegradable, locally available, and often less hazardous when properly applied (Souto *et al*., 2021; Khaliq *et al*., 2016). *Calotropis procera*, a perennial shrub widely distributed in tropical and subtropical regions, has been traditionally used for various medicinal and agricultural purposes. The plant contains bioactive compounds, including cardenolides, alkaloids, flavonoids, and saponins, which possess toxic properties against a wide range of organisms. Previous studies have reported its insecticidal, antimicrobial, and toxicological effects, suggesting its potential application as a natural pesticide (Waheed *et al*., 2016; Verma *et al*., 2012).

Despite increasing interest in botanical piscicides, there is limited information on the acute toxicity and piscicidal effects of *C. procera* on economically important fish species such as *Clarias gariepinus*. Understanding the toxicological profile, including behavioral responses, mortality patterns, and lethal concentration thresholds, is essential for evaluating its potential application and environmental implications. Therefore, this study aimed to assess the toxicity and piscicidal effects of aqueous extract of *Calotropis procera* on *Clarias gariepinus* fingerlings by:

i. Evaluating changes in water quality parameters, and
ii. Documenting behavioral responses of exposed fish.
iii. Determining mortality response across different concentrations,
iv. Estimating the median lethal concentration (LC_{50}) using probit analysis,

Materials and Methods

Experimental Fish and Acclimatization

Two hundred and fifty (250) healthy fingerlings of *Clarias gariepinus* were obtained from a reputable hatchery and transported to the laboratory in aerated containers. The fish were acclimatized for 7 days under laboratory conditions in dechlorinated water at the Department of Wildlife and Ecotourism, Forestry Research Institute of Nigeria, Ibadan. During this period, fish were fed with commercial feed and monitored daily to ensure good health. Feeding was discontinued 24 hours before the commencement of the experiment to minimize metabolic interference.

Preparation of Plant Extract

Fresh leaves of *Calotropis procera* (Figure 1) were collected from natural vegetation, thoroughly washed to remove debris, and air-dried under shade. The dried leaves were ground into fine powder using a laboratory grinder. The plant was soaked in distilled water and allowed to stand for 24 hours, after which it was filtered using muslin cloth to obtain the aqueous extract (Odulate *et al*., 2016). The extract served as the stock solution for subsequent dilutions.



Figure 1: *Calotropis procera*

Experimental Design and Toxicity Bioassay

A static bioassay method was employed following standard procedures (APHA, 2012). Fish were exposed to five concentrations of *C. procera* extract (10, 20, 40, 80, and 160 mL/L) and a control (0 mL/L). Each treatment consisted of 10 fish per container, with three replicates, giving a total of 180 fish used for the assay out of the 250 fish procured. The experiment was conducted in rectangular, transparent plastic containers measuring 60 × 30 × 25 cm, each containing a fixed volume of the test solution. Fish were exposed to each concentration and monitored over a 96-hour period. Each container was covered with a 1 mm mesh-size net mounted on a wooden frame. Mortality was recorded at regular intervals, and dead fish were removed immediately to prevent deterioration of water quality.

Determination of Water Quality Parameters

Physicochemical parameters of the test media, including temperature, pH, dissolved Oxygen (DO), conductivity, and total dissolved solids (TDS), were measured using standard procedures (APHA, 2012). Measurements were taken to ensure that water quality remained within acceptable limits and did not confound the observed toxic effects.

Behavioral Observations

Fish were closely observed throughout the exposure period for any changes in behavior, including swimming patterns, opercular movements, equilibrium, mucus secretion, and responses to external stimuli. These observations were recorded qualitatively and used as supportive indicators of toxic stress.

Statistical Analysis

Mortality data were expressed as percentages and subjected to probit analysis as described by Finney (1971) to determine the median lethal concentration (LC_{50}). Percentage mortality values were transformed to probit units and regressed against the logarithm (base 10) of concentration to establish a dose–response relationship. The LC_{50} value was estimated from the probit regression at probit 5, and 95% confidence limits were calculated to assess the precision of the estimate. The goodness-of-fit of the model was evaluated using the chi-square (χ^2) test, while the coefficient of determination (R^2) was used to assess the strength of the regression relationship.

Results and Discussion

Water quality parameters during exposure

The measured water quality parameters across the different concentrations of *Calotropis procera* extract are presented in Table 1. Overall, the physicochemical conditions remained relatively stable throughout the exposure period, with only slight variations observed across treatments. Water temperature ranged from 29.0 ± 0.02°C in the control to 30.07 ± 0.14°C at 160 ml/L. These values fall within the optimal temperature range for tropical fish species such as *Clarias gariepinus*, suggesting that temperature did not impose additional stress on the fish or confound the observed toxic effects. Temperatures between 25 and 32°C are generally suitable for tropical freshwater systems and warm-water fish species such as tilapias and catfish (Faiza *et al*., 2022).

The pH values increased gradually with increasing extract concentration, from 7.4 ± 0.53 in the control to 8.3 ± 0.52 at the highest concentration. Although slightly alkaline conditions were observed at higher concentrations, the values remained within acceptable limits for fish survival (6.5–9.0), as recommended by the World Health Organization and other aquaculture standards (Boyd, 1990; Marimuthu *et al*., 2019). The slight increase in pH may be attributed to the biochemical constituents of *C. procera*, which could alter the water's ionic composition.

Dissolved oxygen (DO) levels showed a slight declining trend with increasing concentration, decreasing from 5.80 ± 0.12 mg/L in the control to 5.40 ± 0.27 mg/L at 160 ml/L. Despite this reduction, DO levels remained above the critical threshold of 5 mg/L required for the normal physiological functioning of fish (Small *et al*., 2014). This suggests that oxygen depletion was minimal and unlikely to be the primary cause of mortality observed in the bioassay. Conductivity values remained relatively constant across all treatments, ranging from 32 to 33 µS/cm. Similarly, total dissolved solids (TDS) showed minimal variation (16–17 mg/L). These parameters indicate that adding the plant extract did not significantly alter the ionic strength or dissolved solids content of the water. However, the slight reduction in dissolved Oxygen and increase in pH at higher concentrations may have contributed marginally to physiological stress, potentially enhancing the extract's toxic effect. However, these changes were not severe enough to independently cause

mortality. This supports the conclusion that *C. procera* possesses strong piscicidal properties, likely due to bioactive compounds such as cardenolides, alkaloids, and saponins, which have been reported to interfere with respiratory and metabolic processes in fish (Ostrand & Wilde, 2004).

Table 1: Water quality parameters of test media during exposure of *Clarias gariepinus* fingerlings to aqueous extract of *Calotropis procera*

Concentration (ml/L)	Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	TDS (mg/L)
Control	29.0 ± 0.02	7.4 ± 0.53	5.80 ± 0.12	33 ± 0.06	16 ± 0.03
10	29.0 ± 0.11	7.5 ± 0.07	5.90 ± 0.09	32 ± 0.03	17 ± 0.01
20	29.5 ± 0.01	7.6 ± 0.02	5.90 ± 0.05	32 ± 0.13	16 ± 0.03
40	29.5 ± 0.02	8.0 ± 0.04	5.70 ± 0.14	32 ± 0.08	16 ± 0.05
80	29.0 ± 0.04	8.1 ± 0.03	5.70 ± 0.07	32 ± 0.06	16 ± 0.01
160	30.07 ± 0.14	8.3 ± 0.52	5.40 ± 0.27	32 ± 0.06	16 ± 0.13

Behavioral Responses and Toxicological Symptoms

During exposure to aqueous extract of *Calotropis procera*, *Clarias gariepinus* fingerlings exhibited a range of observable behavioral and physiological changes that intensified with increasing concentration. In the control group, fish maintained normal behavior, characterized by active swimming, regular opercular movement, and uniform distribution within the test containers. At lower concentrations (10–20 ml/L), mild behavioral alterations were observed, including slight restlessness and occasional surfacing, which may indicate early stress response (Orpin *et al*., 2023). At an intermediate concentration (40 ml/L), fish displayed pronounced behavioral disturbances, including erratic swimming, rapid opercular movement, loss of equilibrium, and intermittent air gulping. These symptoms suggest respiratory distress and possible impairment of gill function. At higher concentrations (80–160 ml/L), severe toxicological symptoms were evident. Fish exhibited hyperactivity followed by lethargy, excessive mucus secretion on the body surface, loss of reflex, and eventual immobility before death. The progression from hyperactivity to sluggishness is a common response in fish exposed to toxicants, reflecting initial nervous stimulation followed by physiological exhaustion. The observed mucus secretion may represent a protective response to toxic irritation, particularly at the gill surface, which can impair gas exchange and contribute to hypoxia. Similar behavioral and physiological responses have been reported in fish exposed to plant-derived toxicants containing saponins and alkaloids (Orpin *et al*., 2023; Odulate *et al*., 2016; Sogbesan & Ngadina, 2015).

The mortality of *Clarias gariepinus* fingerlings increased progressively with increasing concentrations of aqueous extract of *Calotropis procera* (Table 2). No mortality was observed in the control group, indicating that the experimental conditions were suitable and that the mortality in the treatment groups was due to the plant extract's toxic effect. At lower concentrations (10 and 20 ml/L), minimal mortality (10%) was observed, suggesting a relatively low toxic effect at these exposure levels. However, a marked increase in mortality occurred at 40 ml/L, where 40% of the fish died. At higher concentrations, the toxic effect became more pronounced, with 90% mortality

recorded at 80 ml/L and complete mortality (100%) at 160 ml/L. This dose-dependent increase in mortality demonstrates the strong piscicidal potential of *C. procera* extract on *C. gariepinus* fingerlings. The results clearly indicate that higher concentrations of the extract exert acute toxic effects, leading to rapid fish mortality (Orpin *et al*., 2023; Odulate *et al*., 2016).

Table 2: 48-hour mortality of *Clarias gariepinus* fingerlings exposed to aqueous extract of *Calotropis procera*

Concentration (ml/L)	Number of Fish	Mean Mortality	Percentage Mortality (%)
Control	10	0	0
10	10	1	10
20	10	1	10
40	10	4	40
80	10	9	90
160	10	10	100

Probit Regression and LC_{50} Estimation

The regression analysis yielded a coefficient of determination (R^2) of 0.9306 (Figure 2), indicating that approximately 93.06% of the variation in mortality was explained by the concentration of *Calotropis procera* extract. This demonstrates a strong and reliable relationship between probit mortality and log concentration. Probit analysis was used to determine the median lethal concentration (LC_{50}) of aqueous extract of *Calotropis procera* on *Clarias gariepinus* fingerlings, following the method of Finney (1971). The logarithm of concentration was regressed against probit-transformed mortality values, yielding the regression equation (Table 3):

$$log_{10}C = 3.26P - 0.056$$

Where C is the concentration (ml/L), and P is the probit mortality.

At probit 5 (50% mortality), the LC_{50} was calculated as:

A linear regression of probit (Y) against log_{10} concentration (X) yielded the equation:

$$log_{10}C = 3.26P - 0.056$$

Using this equation, the LC_{50} value (probit = 5) was estimated:

$$5 = 3.26P - 0.056$$

$$P = \frac{5+0.056}{3.26}$$

$$P = 1.55$$

LC_{50} = Antilog 1.55

LC_{50} = 35.56 ml/L

Thus, the 48-hour LC_{50} was 35.56 ml/L. The corresponding 95% confidence limits were estimated to range from 24.5 to 51.5 ml/L, indicating moderate precision and a reliable dose–response relationship (Table 4). Confidence limits were estimated using a regression-slope approximation because no full probit variance output was available (Finney, 1971).

Table 3: Probit Transformation of Mortality Data for *Clarias gariepinus* Exposed to *Calotropis procera*

Concentration (ml/L)	Log_{10} Concentration	% Mortality	Probit Value
10	1.00	10	3.72
20	1.30	10	3.72
40	1.60	40	4.75
80	1.90	90	6.28
160	2.20	99*	7.33

*100% mortality was corrected to 99% to allow probit transformation.

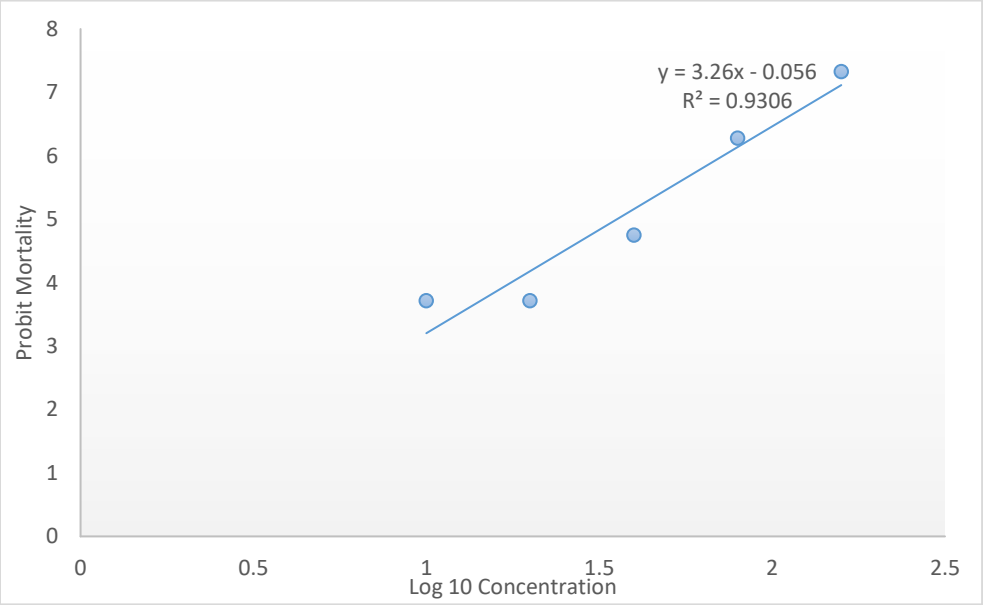


Figure 2: Probit regression showing the relationship between log_{10} concentration and probit mortality of *Clarias gariepinus* fingerlings exposed to aqueous extract of *Calotropis procera* (48-hour exposure).

Table 4: Lethal Concentration of *Calotropis procera* on *Clarias gariepinus* Fingerlings

Parameter	Value
Exposure Time	48 hours

Parameter	Value
LC_{50}	35.56 ml/L
Lower CL	24.5 ml/L
Upper CL	51.5 ml/L
Confidence Limits	24.5 – 51.5 ml/L

Conclusion

This study demonstrated that aqueous extract of *Calotropis procera* exerts pronounced toxic and piscicidal effects on *Clarias gariepinus* fingerlings under short-term exposure conditions. Mortality increased consistently with rising extract concentrations, confirming a clear dose–response relationship. The estimated 48-hour LC_{50} value of 35.56 ml/L, with corresponding confidence limits of 24.5–51.5 ml/L, indicates that the extract is highly toxic to the test species even at relatively moderate concentrations. The observed behavioral alterations, such as erratic swimming, increased opercular activity, air gulping, excessive mucus secretion, and loss of equilibrium, further demonstrate that the extract disrupts normal physiological functions, likely affecting respiratory and metabolic processes. Importantly, the stability of water quality parameters throughout the exposure period confirms that mortality was primarily attributable to the toxic constituents of *C. procera* rather than environmental stress. The findings highlight the potential of *Calotropis procera* as an effective botanical piscicide for fish control and pond management. However, its application should be carefully regulated due to possible adverse effects on non-target aquatic organisms and ecosystem integrity. Future studies should focus on chronic toxicity, sublethal physiological effects, and environmental persistence to better inform safe and sustainable utilization in aquaculture and fisheries management.

References

APHA (2012). *Standard Methods for the Examination of Water and Wastewater*.

Boyd, C.E. (1990). Water Quality in Ponds for Aquaculture. Alabama Agricultural Experiment Station, Auburn University, Alabama, USA, pp.482.

Faiza, M., Adamu, K. M. & Yakubu, M. M. (2022). Anthropogenic impact on some water-quality characteristics of the Wupa River, Federal Capital Territory, Abuja, Nigeria. *Issues in Biological Sciences and Pharmaceutical Research* 10(3),pp.30-38

Finney, D.J. (1971). *Probit Analysis*. Cambridge University Press.

Khaliq, A., Aslam, F., Matloob, A., Javaid, A., Tanveer, A., Hussain, S., & Muhammad, Z. I. (2016). Phytotoxicity of parthenium against wheat and canola varies with plant parts and bioassay techniques. Planta Daninha 34: 11–24.

Marimuthua, K., Palaniandya, H. & Muchlisin, Z. A. (2019). Effect of different water pH on hatching and survival rates of African catfish *Clarias gariepinus* (Pisces: Clariidae). *Aceh Journal of Animal Science* (2019) 4(2): 80-88 DOI: 10.13170/ajas.4.2.13574

Odulate, D. O., Agbon, A. O., Ajagbe, S. O., Abdul, W. O., & Abdulsalami, S. A. (2016). Piscicidal effects of aqueous leaf extract of *Calotropis procera* on *Clarias gariepinus* fingerlings. *Environtropica, Environtropica*, Vols. 12 & 13, 28-34 ISSN 1597-815X

Orpin, C.A., Bichi, A.H., Dauda, A.B. & Orpin, J.B. (2023). Lethal Toxicity of Aqueous Extract of Sodom Apple (*Calotropis procera*) on African Catfish (Clarias gariepinus) (Burchell,

1822) Juveniles. *Sahel Journal of Life Sciences FUDMA,* 1(1): 221-228. DOI: https://doi.org/10.33003/sajols-2023-0101-024

Ostrand K. G. & Wilde G. R. (2004). Temperature, dissolved Oxygen, and salinity tolerances of five prairie stream fishes and their role in explaining fish assemblage patterns—*Transactions of the American Fisheries Society* 130: 742 749.

Sinha, G., & Banerjee, M. (2025). Economic Impact of Fisheries and Aquaculture on Rural Livelihoods: A Review. *The Bioscan* 20(3): 68-79, 2025 www.thebioscan.com

Small K., Kopf R. K., Watts R. J., Howitt J. (2014). Hypoxia, blackwater and fish kills: experimental lethal oxygen thresholds in juvenile predatory lowland river fishes. *PLoS One*. 2014 Apr 11;9(4):e94524. doi: 10.1371/journal.pone.0094524. PMID: 24728094; PMCID: PMC3984153.

Sogbesan, O. A., and Ngadina, Y. E. (2015). Survey and Availability of Some Piscicidal Plants Used by Fishermen in Adamawa State, Nigeria *Journal of Environmental Science, Toxicology and Food Technology* ISSN: 2319-2402, p-ISSN: 2319-2399. 9(2):28.

Souto A. L., Sylvestre M., Tölke E. D., Tavares J. F., Barbosa-Filho J. M., Cebrián-Torrejón G. 2021. Plant-Derived Pesticides as an Alternative to Pest Management and Sustainable Agricultural Production: Prospects, Applications and Challenges. *Molecules*. 2021 Aug 10;26(16):4835. doi: 10.3390/molecules26164835. PMID: 34443421; PMCID: PMC8400533.

Verma, R., Satsangi, G. P. & Shrivastava, J. N. (2012). Analysis of phytochemical constituents of the ethanolic and chloroform extracts of *Calotropis procera* using gas chromatography-mass spectroscopy (GC-MS) technique. *J. Med. Plant Res*. 7: 2986–2991.

Waheed N., Jabeen K., Iqbal S., Javaid A. (2016). Biopesticidal activity of *Calotropis procera* L. against *Macrophomina phaseolina*. *Afr. J. Tradit. Complement Altern. Med*. 2016 Sep 29;13(6):163–167. doi: 10.21010/ajtcam.v13i6.23. PMID: 28480374; PMCID: PMC5412188.

LIVELIHOOD BENEFITS, EXPLOITATION CONSTRAINTS, AND COMMUNITY PERCEPTIONS OF NON-TIMBER FOREST PRODUCTS IN ISEYIN LOCAL GOVERNMENT AREA, NIGERIA

***Ajagbe, R. O., Obadimu, O. O., Bolaji, K. A., Olapade, O. G., Odediran, F. A. and Kolade, R. I.**

Department of Forest Economics and Extension, Forestry Research Institute of Nigeria, P. M. B 5054, Jericho, Ibadan.
Corresponding Email: rutholuaa@gmail.com

Abstract

Non-timber forest products (NTFPs) play a significant role in supporting rural livelihoods, particularly in forest-dependent communities. This study examined the livelihood benefits, exploitation constraints, and community perceptions of NTFPs in Iseyin Local Government Area of Oyo State, Nigeria. A multistage sampling technique was used to select 120 respondents, and data were collected using structured questionnaires. Descriptive statistics were employed to analyze the data. The results revealed a high level of involvement in NTFP exploitation, with 93.3% of respondents actively engaged in forest-based activities. The primary motivations for engagement included multiple livelihood needs (29.2%), resource availability (25.8%), and use as raw materials (17.5%). A majority of respondents (60.8%) had been involved in NTFP activities for 10 years or less. In terms of livelihood benefits, 87.5% of respondents reported deriving benefits from forest resources, with medicinal plants (71.7%) being the most commonly utilized products, followed by combinations of timber, fuelwood, bushmeat, and fruits. The most prominent challenge was wildlife attacks (44.1%), followed by poor road infrastructure (11.7%) and resource-use conflicts (10.0%). Respondents' suggested solutions emphasized protective gear (50.8%), regulation of cattle herders (11.7%), and policy reforms (6.7%). These findings underscore the vital role of NTFPs in enhancing household income, food security, and health, while also highlighting the need for integrated forest management strategies that prioritize safety, infrastructure development, and sustainable exploitation to balance livelihood needs with conservation goals.

Keywords: NTFPs, Rural livelihoods, Forest exploitation, Community perception.

Introduction

Globally, non-timber forest products (NTFPs) are essential to the livelihoods and economic resilience of over 2 billion people (Azeez *et al*., 2025). While forests have traditionally been valued for their timber and wood-based outputs, they also offer a wide array of biological materials that are not timber-derived, commonly known as NTFPs. These include both wild and cultivated resources such as fruits, seeds, nuts, roots, tubers, fibers, latex, resins, bushmeat, bamboo, rattan, and ropes. NTFPs are deeply embedded in the cultural, spiritual, and socioeconomic systems of many forest-dependent communities, fulfilling both subsistence needs and commercial functions (Azeez *et al.,* 2025). In Nigeria, forest ecosystems are rich in diverse edible and non-edible NTFPs, with their availability varying across ecological zones and communities. These products contribute

significantly to household nutrition, income generation, and employment, particularly in underserved and rural areas (Valeld, 2007; Heubach *et al*., 2011). In addition to their role as food items, such as honey, fruits, insects, nuts, and game, NTFPs are also sources of livestock fodder, raw materials for housing and crafts, traditional medicine, fuel, fertilizers, and natural dyes. Their uses further extend to cosmetics, essential oils, industrial oils, phytochemicals, spices, and decorative materials. They are derived from an expansive range of flora (trees, shrubs, herbs, and palms) and fauna (birds, insects, reptiles, and mammals), as well as abiotic forest resources.

The increasing demand for forest-based resources has raised critical concerns over the sustainability of forest ecosystems and the long-term effects of anthropogenic pressure. This has brought global attention to the need for sustainable forest management (SFM), rooted in the broader goals of sustainable development. The widely cited Brundtland Report defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). A variety of studies have examined strategies for ensuring sustainable forest utilization (Aplet *et al*., 1993; Burley, 2001; Fujimori, 2001; Floyd, 2002), while global forest resource monitoring has been championed by organizations like the FAO and the USDA Forest Service (FAO, 2000; USDA-FS, 2003). In parallel to the SFM discourse, the Sustainable Livelihood (SL) framework offers a broader lens for evaluating rural development and poverty reduction. Unlike conventional poverty measures that focus on income, the SL framework emphasizes a multidimensional understanding of well-being, including access to resources, exposure to shocks, and social marginalization. Chambers and Conway (1992) define a sustainable livelihood as One that can withstand external shocks, sustain or enhance its resource base, and contribute positively to both current and future well-being. This holistic approach gained global prominence through the Brundtland Report and was further elaborated at the 1992 United Nations Conference on Environment and Development.

In Nigeria, and specifically within Iseyin Local Government Area (LGA) of Oyo State, NTFPs constitute a central component of rural survival strategies (Babatunde *et al*., 2022). Women, in particular, are heavily involved in NTFP collection and marketing, driven by their proximity to forest areas, limited access to formal employment, and the relatively profitable nature of forest-based trade. However, the growing exploitation of NTFPs, often unregulated and poorly managed, poses significant threats to forest health and resource sustainability. Amusa *et al*. (2012) and Fernande and Ghislaine (2014) noted that while NTFP utilization offers substantial economic benefits for rural households, it simultaneously necessitates careful resource governance to prevent ecological degradation. A striking example is the widespread reliance on fuelwood, which remains the primary energy source for over 70% of Nigerian households, with national consumption estimated at 27.5 million kilograms daily (Ogunsanwo & Ajala, 2002; Zaku *et al.,* 2013). In recent decades, the function of NTFPs in Nigeria has evolved from basic subsistence use to a more complex, market-oriented system that includes cross-border trade. Nonetheless, many forest-dependent communities remain constrained by poor infrastructure, inadequate market access, and limited institutional support, leaving them vulnerable to both environmental and economic instability. This persistent dependence on forest resources highlights the urgent need for integrated strategies that align environmental conservation with rural livelihood development.

Despite the critical importance of NTFPs in poverty reduction and household resilience, there remains a dearth of empirical data on their role in livelihood diversification, particularly within

Iseyin LGA. Moreover, Nigeria lacks a comprehensive national system for documenting, valuing, and monitoring FPFPs, which continues to obscure their full economic and ecological significance (FAO, 2012). This study, therefore, aims to fill this knowledge gap by investigating the livelihood benefits, exploitation constraints, and community perceptions of non-timber forest products in Iseyin Local Government Area, Oyo State, Nigeria.

Materials and Methods

Study Area

This study was conducted in Iseyin Local Government Area (LGA) in the Oke-Ogun region of southwestern Nigeria, within Oyo State. The LGA comprises multiple rural communities, including Ado-Awaye, Akinwumi/Osoogun, Ekunle I, Ekunle II, Faramora, Ijemba/Oke Ola, Isalu I, Isalu II, Koso I, Koso II, and Ladogan/Oke Eyin. Geographically, the LGA lies at approximately latitude 7°58′0″N and longitude 3°36′0″E. Iseyin town, the administrative headquarters of the LGA, is situated roughly 100 kilometers north of Ibadan and is connected by road to key urban centers such as Ibadan, Oyo, Abeokuta, and Ogbomosho (Figure 1).

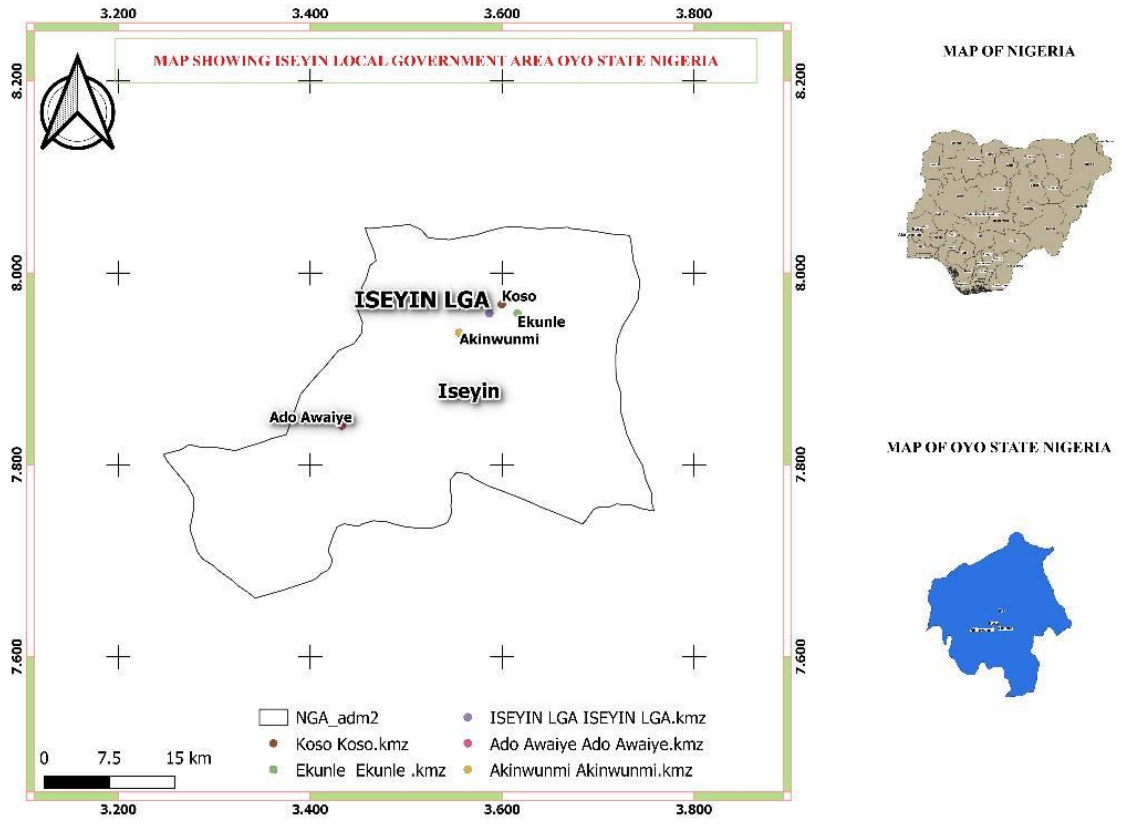


Figure 1: Map of the Study Area

Climatically, the region experiences a tropical climate with distinct wet and dry seasons. The average annual temperature is approximately 26.1°C, while the mean annual rainfall is estimated

at 1,171 mm. Rainfall is typically at its highest in January, averaging about 7 mm, and peaks in September w, averaging 95 mm. March is generally the warmest month, recording an average temperature of 28.2°C, while August is the coolest, with a mean of 24.0°C. The annual temperature variation across the area is relatively moderate, averaging 4.2°C. The LGA is drained by several rivers, including the Ogun, Owu, Amaka, and Oowe Rivers, which are vital for agricultural irrigation, domestic use, and biodiversity support (Babatunde *et al*., 2022).

Data Collection

. Data were gathered through structured questionnaires and complemented by direct personal observations across selected communities within the LGA. A multistage random sampling technique was adopted to ensure a representative sample and reduce selection bias. In the first stage, four wards: Ado-Awaye, Akinwumi, Koso, and Ekunle, were randomly selected from the eleven administrative wards within Iseyin LGA. In the second stage, thirty (30) households were randomly selected from each of the four wards, resulting in a total sample size of 120 respondents.

The questionnaire was designed to collect data on key indicators, including the types and uses of non-timber forest products (NTFPs), their contribution to household income, the seasonal patterns of harvesting, and respondents' perceptions regarding forest resource sustainability and environmental conservation. Additionally, observational notes were used to validate some responses and to provide a contextual understanding of community interactions with forest resources.

Data Analysis

The data collected were analyzed using descriptive statistical methods. Frequencies and percentages were used to summarize the socio-demographic characteristics of the respondents, patterns of NTFP utilization, and community perceptions of the economic and ecological relevance of NTFPs.

Results and Discussion

The results in Table 1 reveal a high level of engagement in non-timber forest product (NTFP) exploitation, with 93.3% of respondents actively involved. This indicates that NTFPs constitute a central component of rural livelihood systems in Iseyin Local Government Area. Such widespread participation suggests a strong dependence on forest resources for survival, aligning with findings from rural livelihood studies across Nigeria, where forest products serve as safety nets for households. This is consistent with the findings by Ofihi *et al*. (2023), who reported similar levels of dependence among rural dwellers in Quan Pan LGA, Lateau Lateefu State, Nigeria. Reshad *et al*. (2017) also documented the contribution of NTFPs to livelihood security in forest-adjacent communities. Globally, NTFPs are recognized for their multifunctionality in poverty alleviation, nutrition, health, and cultural continuity (Rahman *et al*., 2021).

The motivations for engagement further reinforce the livelihood relevance of NTFPs. A considerable proportion of respondents (29.2%) reported multiple motivations**,** indicating that NTFPs serve diverse functions, including income generation, subsistence support, and the

provision of raw materials. The prominence of "readily available" (25.8%) highlights the role of accessibility and low entry barriers, which is typical of forest-dependent economies where capital constraints limit alternative livelihood options. Income generation (15.0%) and raw materials for production (17.5%) also featured prominently, underscoring the economic importance of NTFPs both as direct and indirect livelihood sources. This suggests that beyond subsistence use, NTFPs contribute to local value chains and small-scale enterprises**,** thereby enhancing household income and resilience.

This finding aligns with the work of Dash & Behera, (2013), Rahman *et al.* (2021), and Ruiz-Pérez *et al.* (2004), who noted that forests often serve as fallback resources during economic hardship, sometimes contributing up to 50% of household income. The economic appeal of easily accessible products, such as wood, charcoal, and wrapping leaves, further explains this trend (Rasul *et al*., 2008; Babatunde *et al*., 2020). Market demand, particularly for honey, mushrooms, medicinal herbs, and spices, influenced 12.5% of respondents. This suggests a shift toward the commercial use of forest products. According to Mushi *et al*. (2020) and Rahman *et al*. (2021), household size and market access significantly influence NTFP collection behavior. Lawal *et al.* (2010) and Yimer and Tebkew (2025) highlighted the growing role of medicinal plants and other NTFPs in both local industries and international trade. The distribution of respondents by length of involvement shows that a majority (60.8%) have participated in NTFP activities for 10 years or less, indicating relatively recent or increasing engagement. This trend may reflect growing economic pressures, unemployment, or declining agricultural productivity, pushing more individuals toward forest-based livelihoods. However, the presence of long-term participants (over 20 years) suggests that NTFP exploitation is not merely a coping strategy but also a sustained livelihood practice embedded in local culture and economy**.**

Table 1: Respondents' Engagement and Livelihood Dependence on Non-Timber Forest Products (NTFPs)

Variable	Frequency	Percentage (%)
Engagement in NTFP Exploitation		
Yes	112	93.3
No	8	6.7
Reasons for Engagement in NTFP Exploitation		
Readily available	31	25.8
Source of income	18	15
Market demand	15	12.5
Raw materials for production	21	17.5
Multiple motivations	35	29.2
Length of Involvement in NTFP Activities		
≤ 10 years	73	60.8
11–20 years	18	15
21–30 years	17	14.2
31–40 years	6	5
>40 years	6	5

Source: Field Survey, 2022

Table 2 highlights the major constraints to the exploitation of non-timber forest products (NTFPs) in the study area, along with respondents' suggested mitigation strategies. The most prominent challenge identified is wildlife attacks (44.17%), indicating that interactions between humans and wildlife constitute a major risk to NTFP collectors. This finding suggests that forest-dependent livelihoods are not only economically constrained but also physically hazardous, which may reduce productivity and discourage participation, particularly among vulnerable groups such as women and the elderly.

Other notable constraints include poor road networks (11.67%) and resource-use conflicts (10.0%), reflecting infrastructural and socio-institutional barriers. Poor accessibility limits the efficient transportation of harvested products to markets, thereby reducing income potential. According to Adelesi (2024), limited access to forests not only raises transportation costs but also restricts market opportunities, thereby affecting profitability. Similarly, conflicts possibly between local users, external actors, or competing land uses highlight underlying issues of resource governance and tenure insecurity, which are common in forest-dependent communities. Deforestation reduces resource availability, while unfavorable policies may limit access or impose restrictions that affect livelihood activities. Additionally, cattle herder activities (3.3%) point to land-use competition, which can lead to resource depletion and conflict.

The suggested solutions provide insight into community perceptions and adaptive strategies. The majority of respondents (50.0%) advocated for the provision of protective gear, emphasizing the urgent need to reduce exposure to wildlife-related risks. This aligns directly with the identified dominant constraint, demonstrating a strong link between perceived problems and proposed interventions. Suggestions such as regulating cattle herders (17.5%) and policy reform (6.67%) indicate a demand for improved governance and conflict-management mechanisms. Meanwhile, infrastructure improvement (5.0%) reflects the need for better access to markets and forest areas, which could enhance the economic viability of NTFP activities. Interestingly, very few respondents suggested afforestation (0.83%) or financial support (0.83%), which may imply limited awareness of long-term sustainability strategies or limited expectations from external support systems. This highlights a potential gap in extension services and policy outreach.

Table 2: Constraints to NTFP Exploitation and Suggested Mitigation Measures in Iseyin LGA

Category	Item	Frequency	Percentage (%)
Constraints	Wildlife attacks	53	44.17
	Poor road network	14	11.67
	Resource-use conflicts	12	10.00
	Lack of funds	6	5.00
	Deforestation	6	5.00
	Restrictive government policies	6	5.00
	Cattle herder activities	4	3.33
	No response	19	15.83
Suggested Solutions	Provision of protective gear	60	50.00

Regulation of cattle herders	21	17.50
Combined measures (gear and regulation)	23	19.17
Infrastructure improvement	6	5.00
Policy reform	8	6.67
Afforestation programmes	1	0.83
Financial support	1	0.83

Source: Field Survey, 2022

The findings in Table 3 demonstrate that a substantial majority of respondents (87.5%) derive benefits from forest resources, underscoring the critical role of forests in supporting rural livelihoods in the study area. This high level of dependence confirms that forests function as essential livelihood assets, providing both subsistence and economic opportunities (Adaaja *et al.*, 2024). The types of benefits derived reveal that medicinal plants (71.67%) constitute the most prominent forest product, highlighting the importance of forests in traditional healthcare systems. This suggests that forest resources contribute not only to income but also to household well-being and health security, particularly in rural areas where access to formal healthcare may be limited. Other product combinations, such as timber, fuelwood, bushmeat, and fruits, further demonstrate the diversity of NTFPs and their multifunctional roles in sustaining livelihoods (Rafiu *et al*., 2026).

Despite these benefits, community perceptions of forests are somewhat mixed. While a slight majority (52.5%) indicated that forests do not negatively affect them, a significant proportion (47.5%) reported experiencing negative impacts. This indicates a dual perception of forests as both beneficial and problematic, reflecting the complex relationship between rural communities and forest ecosystems. The nature of negative perceptions provides further insight. A considerable number of respondents agreed that forests are too dark (45.0% combined strongly agree and agree) and may harbor criminals (48.3%), suggesting concerns related to safety and security. Similarly, beliefs about the presence of "evil" in forests (39.1% agreement) point to cultural and spiritual interpretations of forest environments, which may influence how people interact with forest resources.

Additionally, the perception that forests compete with farmland (39.1%) reflects concerns about land-use pressure and the trade-off between forest conservation and agricultural expansion. This is particularly important in rural economies where agriculture remains a primary livelihood activity. Also, the results indicate that while forests provide substantial livelihood benefits, they are also associated with social, cultural, and economic concerns. These mixed perceptions suggest the need for policies and interventions that not only promote sustainable utilization of forest resources but also address security, land-use conflicts, and community awareness.

Table 3: Livelihood Benefits of Forest Resources in Iseyin LGA

Variable	Frequency	Percentage (%)
Derivation of Benefits from Forests		
Yes	105	87.50
No	10	8.33

Not yet	5	4.17
Types of Benefits Derived		
Medicinal plants	86	71.67
Timber and medicinal plants	11	9.17
Fuelwood, bushmeat, and fruits	11	9.17
Fuelwood only	3	2.50
Other products	9	7.50
Perception of Negative Effects of Forests		
Yes	57	47.50
No	63	52.50

Source: Field Survey, 2022

Table 4 shows that a notable proportion of respondents expressed concern that forests are dark, with 94.2% indicating agreement (19.2% strongly agree; 75.0% agree). This perception reflects the physical characteristics of dense forest environments, which may limit visibility and create a sense of insecurity. Such conditions can discourage frequent forest use, particularly among vulnerable groups, and may reduce the efficiency of NTFP collection activities. Similarly, the perception that forests harbor criminals was supported by 97.5% of respondents. This highlights significant security concerns, suggesting that forests may be viewed as unsafe spaces. This finding aligns with broader research indicating that fear of crime and insecurity can influence how rural populations interact with natural resources, often limiting access and utilization (Amadu & Miller, 2024).

Cultural interpretations also shape perceptions. About 88.3% of respondents agreed that evil or spiritual forces are present in forests. This reflects deeply rooted traditional beliefs and cosmological views common in many African rural settings. Such perceptions may affect patterns of forest use, including restrictions on when and how individuals access forest areas. Studies have shown that cultural beliefs significantly influence environmental behavior and resource utilization in forest-dependent communities (N'tambwe Nghonda *et al*., 2023). In addition, 88.3% of respondents perceived that those forests compete with farmland, indicating concerns about land-use conflicts. This suggests that forests are sometimes viewed as limiting agricultural expansion, which remains a primary livelihood activity in rural Nigeria. This perception reflects the broader challenge of balancing forest conservation with agricultural needs, especially in regions experiencing population pressure and increasing demand for arable land (Adeyemi et al., 2024).

Table 4: Community Perceptions of Forest Resources in Iseyin LGA

Parameter	Strongly Agree (%)	Agree (%)	Undecided (%)	Disagree (%)
Forests are dark	19.2	75	5	0.8
Forests hide criminals	25.9	71.6	0	2.5
Presence of evil/spiritual fear	17.5	70.8	5.8	5.9
Forests compete with farmland	25	63.3	2.5	9.2

Source: Field Survey, 2022

Conclusion

This study demonstrates that non-timber forest products (NTFPs) constitute a critical pillar of rural livelihoods in Iseyin Local Government Area, Nigeria. The overwhelming participation of respondents in NTFP exploitation and the high proportion deriving tangible benefits underscore the economic, nutritional, and health significance of forest resources. Products such as medicinal plants, fuelwood, bushmeat, and fruits not only support household subsistence but also contribute to income generation and local enterprise development. However, the study also reveals that a combination of ecological, infrastructural, and socio-institutional challenges constrains NTFP exploitation. Prominent among these are wildlife-related risks, poor road networks, resource-use conflicts, and policy limitations. These constraints reduce the efficiency and safety of forest resource utilization, thereby limiting the full realization of livelihood benefits. In addition, community perceptions of forests are ambivalent. While forests are widely recognized as beneficial, they are also associated with insecurity, cultural fears, and competition with agricultural land. Such perceptions, shaped by both lived experiences and traditional beliefs, influence the extent and manner of forest use. The coexistence of dependence and concern highlights the complex relationship between rural communities and forest ecosystems. Therefore, the study underscores the importance of integrating NTFP exploitation into broader rural development and forest conservation strategies. Promoting sustainable harvesting practices, enhancing community awareness, and investing in infrastructure and policy support will be essential to ensuring that NTFPs continue to serve as valuable assets for both rural welfare and forest sustainability.

References

Adaaja, B. O., Akemien, N. N., Alawiye, M. A., Zaman, E. Y., Yahaya, U., & Khidir, H. Y. (2024). Economic and ecological sustainability of non-timber forest products (NTFPs) in Nigeria: A review. *FUDMA Journal of Sciences, 8*(6), 196–204. https://doi.org/10.33003/fjs-2024-0806-2909

Adelesi, O. O. (2024). Understanding farmers' diversity in non-timber forest products activities in Ogun State, Nigeria—*Scientific African* 25:1-14 e02331.

Adeyemi, A. A., et al. (2024). Understanding farmers' diversity in non-timber forest products activities in Ogun State, Nigeria. *Scientific African*.

Amadu, F. O., & Miller, D. C. (2024). Food security effects of forest sector participation in rural Liberia. *Food Security, 16*, 1099–1124.

Amusa, T. O., Jimoh, S. O., & Azeez, I. O. (2012). Non-timber forest products in Nigeria: An overview. *Journal of Environmental Management and Safety*, 3(1), 118–129.

Aplet, G. H., Johnson, N., Olson, J. T., & Sample, V. A. (1993). *Defining sustainable forestry*. The Wilderness Society.

Azeez, I. O., Ajagbe, R. O. & Akanbi, A. M. (2025). Contribution of NTFPs to Rural livelihoods in Iseyin Local Government Area, Oyo State, Nigeria. Proceedings of 47th Annual Conference of the Forestry Association of Nigeria (FAN) - Urban Forestry and Sustainable Development- held in Lagos, 24th -29th November, 2025. Pp409-419

Babatunde, T.O., Olawuyi, B.E., Babatunde, O.O., Odeyale, O.C., Babatunde, K.O., and Akinbosoye, T.S. (2022). Marketing of non-timber forest products as a means of income generation in Oja-obabaarket, Iseyin Local Government Area, Oyo State. AROC in Agriculture, 1 (1); 33-40, https://doi.org/10.53858/arocagr01013340

Burley, J. (2001). Forestry research and development. *Unasylva*, 52(206), 3–10.

Dash, M. & Behera, B. (2013). Biodiversity conservation and local livelihoods: a study on Similipal Biosphere Reserve in India. *J. Rural Dev*. 32 (4), 409–426.

FAO. Global forest resource assessment 2000: Main Report. UN Food and Agriculture Organization, Rome, Italy; 2000.

Floyd, D. W. (2002). *Forest sustainability: The history, the challenge, the promise*—the Forest History Society.

Fujimori, T. (2001). *Ecology and silviculture of mixed forests*. Springer.

Heubach, K., Wittig, R., Nuppenau, E. A., and Hahn, K. (2011). The economic importance of non-timber forest products for rural livelihoods in West Africa: Examples from Burkina Faso and Benin. *Ecological Economics*, 70(11), 1991–2001.

Lawal, I. O., Igboanugo, A. B. I., Osikarbor, B., Duyilemi, O. P., Adesoga, A. A. & Borokini, T. I. (2010). Evaluation of plant-based non-timber forest products (ntfps) as potential bioactive drugs in Southwestern Nigeria, J. Clin. Med. Res. 3 (4) 61–66. http://www.academicjournals.org/app/webroot/article/article1379660986_ Lawal et al.pdf.

Mushi, H., Yanda, P. Z. & Kleyer, M. (2020). Socioeconomic factors determining the extraction of non-timber forest products on the slopes of Mt. Kilimanjaro, *Tanzania. Hum. Ecol*. 48, 695–707.

N'tambwe Nghonda, D., Muteya, H. K., Moyene, A. B., Malaisse, F., Sikuzani, Y. U., Kalenga, W. M., and Bogaert, J. (2023). Socioeconomic value and availability of plant-based non-timber forest products. *Sustainability, 15*(20), 14943.

Ogunsanwo, O. Y., & Ajala, O. O. (2002). Fuelwood consumption pattern in selected local government areas of Oyo State, Nigeria. *Journal of Tropical Forest Resources*, 18(2), 18–24.

Rafiu, B. O., Omotoso, A. B., Omotayo, A. O., & Lawal, I. O. (2026). From farm to resilience: Evaluating the role of indigenous food plants in nutrition, market access, and livelihoods in Nigeria's forest agroecological zone. *Agroforestry Systems*. https://doi.org/10.1007/s10457-026-01439-1 Brundtland, G. H. (1987). *Our common future: Report of the World Commission on Environment and Development*. Oxford University Press.

Rahman, H., Roy, B. & Islam, S. (2021). Contribution of non-timber forest products to the livelihoods of the forest-dependent communities around the Khadimnagar National Park in northeastern Bangladesh. *Regional Sustainability* (2): 280–295

Rasul, G., Karki, M. and Sah, R. (2008). The role of non-timber forest products in poverty reduction in India: prospects and problems, Dev. Pract. 18 (6) (2008) 779–788, https://doi.org/10.1080/09614520802386876.

Reshad, M., Mohammed, M., Mohammed, A. and Beyene, A (2017). Socioeconomic Importance of Non-Timber Forest Products and Its Implication on Natural Forest Conservation: The Case of Jello-Muktar Forest, Southeastern Ethiopia. *Journal of Economics and Sustainable Development* ISSN 2222-1700 (Paper) ISSN 2222-2855 (Online) 8(17):45-52

Ruiz-Pérez, M., Belcher, B., Achdiawan, R., Alexiades, M., Aubertin, C., Campbell, B., Clement, C., Cunningham, T., Fantini, A., Foresta, H., Fernández, C.G., Gautam, K.H., Martínez, P.H., De Jong, W., Kusters, K., Kutty, G., López, C., Fu, M., Angel, M., Alfaro, M., Nair, T.K.R., Ndoye, O., Ocampo, R., Rai, N., Ricker, M., Schreckenberg, K., Shackleton, S., Shanley, P., Sunderland, Y., Youn, Y., (2004). Markets drive the specialization strategies of forest peoples. *Econ. Soc.* 9 (2), 4.

Vihi, S. K., Selzing, P. M., Jesse, B. & Adeniyi, F.O. (2023). Assessment of Non-Timber Forest Products Utilization and Its Contribution to Household Income among Farmers in Quan' Pan Local Government Area of Plateau State, Nigeria. *J. Appl. Sci. Environ. Manage.* 27 (12) 2799-2808

Yimer A. H. and Tebkew M. (2025). Non-Timber Forest Products and Their Income Contributions to Rural Households in Kalu District, Northeast Ethiopia. *Journal of Landscape Ecology* (2025), 18(1):25-40

Zaku, S. G., Kabir, A., & Tukur, A. A. (2013). Wood fuel consumption in Nigeria and the energy ladder: A review. *Journal of Petroleum Technology and Alternative Fuels*, 4(5), 132–140.

ISTF-NIG 2026

FLORISTIC COMPOSITION OF TREE SPECIES AND STRUCTURE IN EMERALD FOREST, IKOYI, OSUN STATE, NIGERIA

Ige P. O* and Olasupo T. B.

Department of Social and Environmental Forestry, University of Ibadan, Ibadan, Nigeria
**Corresponding Email: igepetero@gmail.com, +2348035826907*

ABSTRACT

A quantitative assessment of species diversity is thus essential for effective biodiversity conservation and management. There is limited empirical data on the floristic composition of privately owned forest estates in Nigeria. Hence, this study examined the floristic composition, structure, and distribution of diversity in Abayomi Farm Estate (AFE), a private forest in Ikoyi, Osun State, Nigeria. Systematic line transect sampling was used to collect data on tree species ≥10 cm DBH across eight 25m x 25m plots. Tree dbh, total height (m) and merchantable height (m) of all trees in each plot were measured. Species diversity indices were estimated. Data were analysed using descriptive statistics and a correlation matrix. A total of 352 trees/ha belonging to 40 species and 18 families were recorded. *Triplochiton scleroxylon* was the most abundant species, while Sterculiaceae was the dominant family. The Shannon-Wiener diversity index (3.311), Simpson's index (0.9502), and Margalef's species richness index (6.651) indicated high species diversity and richness. The diameter distribution showed a reverse J-shaped curve, suggesting healthy regeneration potential. Height class distribution revealed more co-dominant trees than dominant ones. Slenderness coefficient analysis indicated that most trees exhibited good vigor and resilience to environmental stresses. The study area demonstrated characteristics of a natural forest with high species diversity and structural density. These findings provide valuable baseline data for forest management and conservation efforts in the region. The presence of numerous indigenous tree species could enhance carbon sequestration, underscoring the importance of conserving such ecosystems. This study contributes to the understanding of tropical forest ecology and can inform future management strategies for protected areas, particularly in the face of climate change and other anthropogenic pressures.

Keywords: Species diversity, species richness, floristic composition, co-dominant, anthropogenic pressures.

Introduction

Conservation is a fundamental concept in the world's ever-changing environment, encompassing efforts to preserve and protect natural habitats, wildlife, and cultural heritage (Polly *et al*., 2019). It is a response to the pressing need to safeguard the delicate balance of ecosystems, ensure the survival of endangered species, and sustainably manage the planet's finite resources. Conservation not only reflects a responsibility to future generations but also acknowledges the intrinsic value of biodiversity and the importance of maintaining the planet's unique beauty and ecological integrity. Conservation planning is a rapidly evolving field that aims to minimize biodiversity loss by selecting areas for conservation action (Polly *et al*., 2019). Diversity and structure are the most crucial traits of a forest community. The stability, productivity, and trophic structure of a forest

ecosystem are influenced by community diversity, and regions with high diversity are likely to have highly productive, stable ecosystems.
On the other hand, a forest's structure is a product of self-organization, shaped by competition, environmental factors, and myriad interactions among individual trees (Gadow *et al.,* 2011; Bano *et al.,* 2018). According to Su *et al.* (2010), stand structure helps understand forest ecosystems and biodiversity. To ensure the sustainable conservation and management of forest resources, it is necessary to assess the composition, structure, and regeneration status of species (Teketay, 2005; Mishra *et al*., 2013). Sustainable management of tropical forests has become an essential global issue, as it is key to maintaining ecosystem stability. Besides becoming a habitat for a diverse array of species, tropical forests play a crucial role in preventing soil erosion and reducing the risk of saltwater intrusion (Sadono *et al*., 2020). This ecosystem also contributes significantly to climate change mitigation by storing large amounts of carbon in biomass from its vegetation and in soils (Taillardat *et al.,* 2018; Zuleta *et al.,* 2023). By capturing atmospheric carbon and storing it in tree biomass (Gebeyehu *et al*., 2019; Mackey *et al*., 2020), tropical forest ecosystems play a significant role in global carbon sequestration (Phillips & Lewis, 2014; Sullivan *et al.,* 2017).

Nigeria is naturally endowed with vast forestlands that host many tree species that produce wood (Badejo *et al.,* 2008). Adequate supporting information is required for sustainable management and continuous access to these benefits. However, forest managers know little detail about the forests they manage, including their sizes, resource quantities and qualities, and how these resources change over time. Abayomi Farm Estate was formerly a secondary community/family-forested land. Still, it was later converted into a private forest estate to develop a nature reserve to prevent plant species from going extinct (Olasupo, 2023). The forest has just been elevated as One of the four Key Biodiversity Centres in Nigeria. Vegetative composition and structural diversity are two important features for biodiversity conservation and carbon storage, suggesting a positive relationship between stand structure and carbon storage. By integrating these components, the study aims to enhance understanding of the forest estate's ecological dynamics in preparation to assess its carbon sequestration capacity. However, effectively managing and conserving forests requires a comprehensive understanding of their stand structure, regeneration potentials, and carbon stock dynamics.

Methodology

Study Area

This study was carried out in Abayomi Farm Estate (AFE), Emerald Forest, situated at Ikoyi, via Ikire, Osun State. The forest is located between latitudes 7°24' to 7°7'N and longitudes 4°48' to 4° 24' E (Figure 1) with an average temperature of 24° C. It is a private forest estate, a 120-ha pristine forest conservatory on the bank of the Osun River. It is situated on the confluence of the Aworin Osun and Akinrin streams that flow into the Osun River. It is nestled between rocky mountains, with a riverside forest that supports the Osun River's echo habitat (Olasupo, 2023). It lies in the lowland rainforest zone of Nigeria. It is about 398.70 m above sea level (asl). The climate is characterized by a dry and a rainy season. The dry season starts in November and ends in March, while the dry-cold Harmattan wind and rainy season start in April and run through early November, with Occasional strong winds and thunderstorms. It has a maximum temperature range from 28°C

to 34°C. The forest used to experience a bimodal rainfall pattern, with rainfall peaking between 1300 and 1500mm, occurring between May and September. The mean daily relative humidity ranges from 64% to 83%. The forest has a low-lying, gently undulating topography with an elevation range of 243m and 292m. The parent rock materials of the soil are derived from underlying crystalline and banded gneiss, which weathers to form site-specific soils. In the upland areas, lateral soils, clay, and sandy loams are the predominant soil types, while the valley bottom has alluvial soils. Emerald Forest has highly diverse plant species.

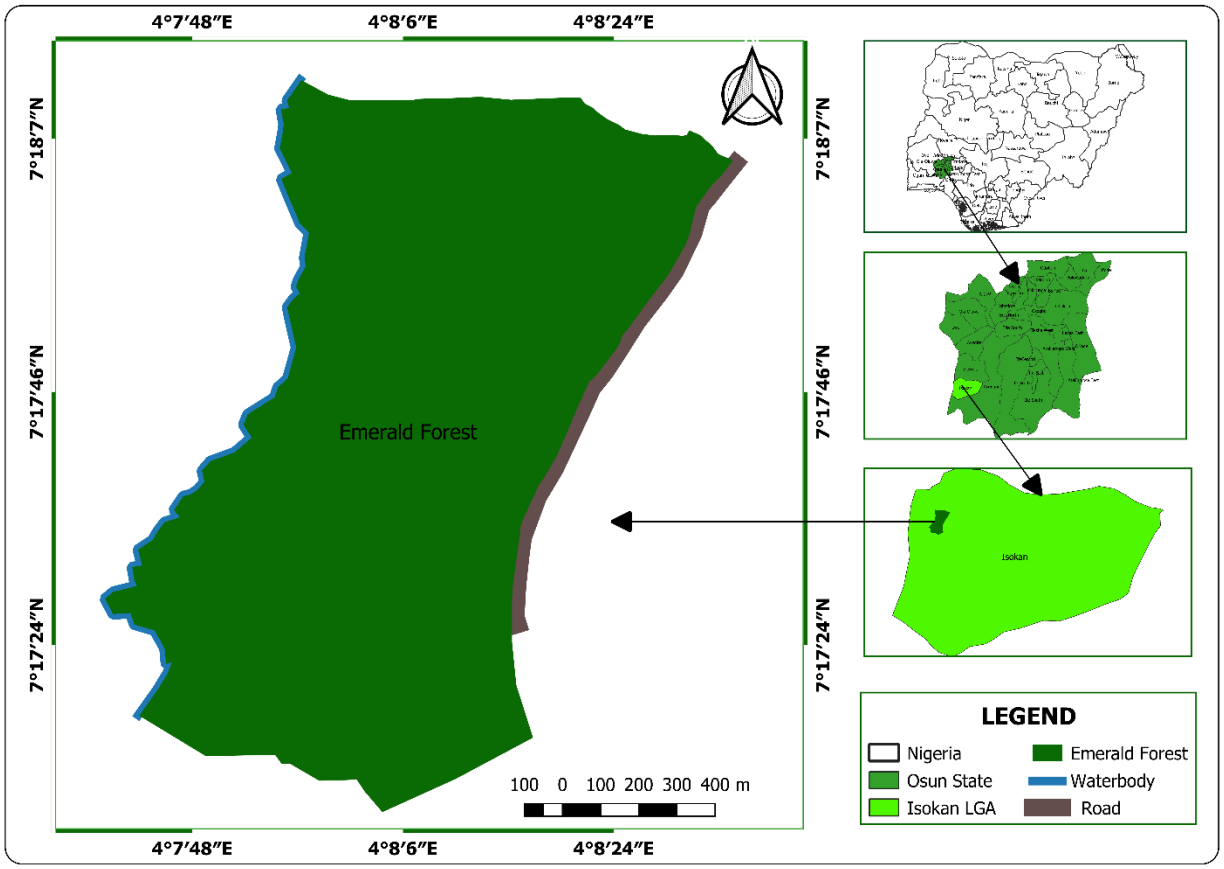


Figure 1: Abayomi Forest Estate, Ikoyi, Osun State

Data Collection and Analysis

Sampling design and technique: The systematic line transect method was used to lay out plots for data collection, as described by Ige and Komolafe (2022). Two parallel transects (200m apart) were laid in the study site after a 50m distance had been taken from the edge of the forest to avoid edge effects (Fig 2). Subsequently, four Temporary Sample Plots (TSPs) of equal size (25m x 25m) were laid (at 50m intervals) along each transect, making a total of eight TSPs. The boundary of each sample plot was marked with a ranging pole. Within each temporary sample plot, all trees with DBH ≥ 10cm were identified to species level. All species were classified into families, and

their frequencies were obtained to assess species diversity and abundance. Trees were grouped into diameter distribution classes based on DBH measurements.

Tree Species Diversity

Shannon-Weiner tree species diversity index (Shannon-Weiner, 1963)

$$H = -\sum_{i=1}^{s} Pi \ln Pi \quad \text{..........} \quad (1)$$

Where:

H = Shannon-Weiner tree species diversity index

S = Total number of species in the community

Pi = Proportion (n/N) of individuals of One particular species found (n) divided by the total number of individuals found (N)

ln = natural logarithm

Simpson tree species diversity index (Simpson, 1949)

$$D = \Sigma n_i(n_i-1) / N(N-1) \quad \text{..........} \quad (ii)$$

Where D = dominance index

n = number of individuals of a particular species

N = total number of individuals enumerated

Pielou Evenness Index (*E*): The Pielou Evenness Index, which is a measure of the distribution among species, was computed using the equation by Pielou (Pielou, 1969):

$$E = \frac{H}{lnS} \ldots\ldots\ldots \ (iii)$$

where *H* is the Shannon–Wiener function and *S* is the total number of species

Margalef Index (MI): Margalef index, which is a measure of the number of different species represented in the forest community (species richness), was computed using the equation (Margalef, 1982):

$$MI = \frac{S-1}{lnN} \ldots\ldots\ldots \ (iv)$$

Where *S* is the total number of species, N is the number of individuals of all the tree species, and In is the natural logarithm.

Species Relative Density (*RD*): Species relative density, which is a measure of a given species' relative distribution, was computed as:

$$RD = \frac{Number\ of\ a\ species}{Total\ Number\ of\ all\ species} \times 100 \ldots\ldots\ldots \ (v)$$

Species Relative Frequency (*RF*): Species relative frequency, which is a measure of the frequency of a given species as a proportion of the sum of the frequencies for all species, was computed as:

$$RF = \frac{Frequency\ of\ a\ species}{Total\ frequency\ of\ all\ species} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (vi)$$

Where frequency is computed as:

$$F = \frac{Number\ of\ sampling\ plots\ at\ which\ the\ species\ occur}{red.Total\ number\ of\ plots\ sampled} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (vii)$$

Species Relative Dominance (RDo): Species Relative Dominance, which is a measure of the relative space occupancy of a tree, was computed as (Adekunle *et al.,* 2013):

$$RD_0 = \frac{Summation\ basal\ area\ of\ all\ trees\ of\ a\ species}{,Summation\ of\ basal\ area\ of\ all\ trees} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (viii)$$

Family Importance Value Index (IVI): The importance value index, which is a measure of a species' share in the forest community, was computed as (Adekunle *et al.,* 2013):

$$IVI = RD + RF + RDo \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (ix)$$

Where RDo is the relative dominance, RD is the relative density, and RF is the relative frequency.

Tree Canopy Classification

All trees (DBH ≥ 10cm) in each plot were classified into four canopy strata (Kamarul *et al*., 2014; Whitemore, 1993):

Dominant (TH ≥ 35m);
Co-dominant (TH = 26m to 35m);
Intermediate (TH = 16m to 25m); and
Suppressed (TH = 6m to 15m).

The results were analyzed using descriptive statistics and a correlation matrix, and the findings were presented as percentages and a histogram of canopy structure in AFE.

Results

The total number of sampled trees (≥ 10cm Dbh) measured in the forest was 352/ha. The DBH for the study area ranges from 10 cm to 135 cm, with a mean and standard error of 50.47±5.89cm. The total and merchantable heights range from 7.75m to 38m and 3.75m to 24.31m, respectively, with mean and standard error values of 21.99±1.03m and 13.90±0.82m, respectively. The slenderness coefficient value had a mean value of 67.57±6.58 (Table 1). Table 2 represents tree species abundance per hectare and the growth variables in the study area. *Triplochiton scleroxylon*

ISTF-NIG 2026

of the Malvaceae family had the highest number of stems per hectare (46), relative density of 115, and Important value index of 167.1900, this made the tree the most abundant tree species in the study area followed by *Cola millenii* and *Cola gigantea* which also belong to the Sterculiaceae family had 28 stems/ha and 24stemsha^{-1} with a relative density of 70 and 60 and the important value index of 79.6151 and 73.0744 respectively. *Funtumia elastica* of the Apocynaceae family had 22 stems/ha with a relative density of 55 and an important value index of 61.9720. *Afzelia africana, Albizia adianthifolia, Cleistopholis patens, Holarrhena floribunda, Margaritaria discoidea, Monodora tenuifolia, Nesogordonia papaverifera, Olax subcorpiodea, Trichilia prieuriana, Vocanga Africana,* and *Zanthoxylum zanthoxyloides* have the least (2) number of stems per ha, each with the same relative density of 5.

The family composition of tree species in the study area is presented in Table 3. The most abundant families are Sterculiaceae, with six species, followed by Apocynaceae, with five species, while Fabaceae and Moraceae each have four species. Furthermore, Sterculiaceae had the highest number of individual trees (84), followed by Malvaceae (74) and Apocynaceae (36 stems ha^{-1}).
The families' important value index showed the number of species, number of individual trees per hectare, mean basal area per hectare, families' relative density, relative dominance, and relative frequency for the study as presented in Table 4. A total of 18 different families were encountered. The Malvaceae family had the highest basal area per hectare (79.2973 m^2/ha), followed by Sterculiaceae (20.1241 m^2/ha). Euphorbiaceae and Cannabaceae had basal areas of 12.0578 m^2/ha and 10.4288 m^2/ha, respectively. The family Rutaceae had the lowest basal area of 0.0160 m^2/ha. However, the Sterculiaceae Family had the highest numbers of species, individual trees, relative density, relative dominance, relative frequency, and family importance index, with values of 6, 84, 33.3333, 22.0868, 23.8636, and 79.2837, respectively. Apocynaceae, Malvaceae, Moraceae, and Fabaceae had FIVI values of 56.4107, 48.7328, 46.0376, and 42.0604, respectively. Rutaceae and Meliaceae had the lowest FIVI of 9.8049.

A summary of the tree species diversity and abundance in the study area is presented in Table 5. Based on the result, a total number of three hundred and fifty-two trees (352) were recorded; 40 tree species from 18 families were identified in the study area. Shannon-Weiner index of diversity (H'), Simpson tree species diversity index, Species –Evenness index (e), Margalef's index of species richness (M), Equitability_J, and Dominance_D had a value of 3.311, 0.9502, 0.6852, 6.651, 0.8975 and 0.0498, respectively.

Table 1: Statistical summary of the stand growth characteristics

Stand Growth Variable	Mean ± SE	MIN	MAX	Total/ha
DBH (cm)	50.47 ± 5.89	10	135	
THT (m)	21.99 ± 1.03	7.75	38	
MHT (m)	13.90 ± 0.82	3.75	24.31	
VOL (m^3)	35.37 ± 15.61	0.07	600.89	1414.65
BA (m$^{2)}$	3.77 ± 1.54	0.02	59.04	150.9
CL (m)	9.02 ± 0.64	3	20.5	

CD (m)	7.71 ± 0.68	2.15	16.39
CR (m)	0.43 ± 0.04	0.15	1.34
SLC	67.57 ± 6.58	20.53	178.22
CPA	668.91 ± 243.54	7.26	9704.12
No of trees			352

Where: DBH= Diameter at Breast Height, THT= Tree Total Height, MHT= Merchantable Height, VOL= Volume, BA= Basal Area, CL= Crown Length, CD= Crown Diameter, CR= Crown Ratio, SLC= Slenderness Coefficient, CPA= Crown Projection Area

Table 2: Tree Species Composition and Abundance in the Study Area

Tree No.	SPECIES	Family	Freq/ha	RF	RD	RDo	IVI
1	*Afzelia africana*	Fabaceae	2	0.5682	5	0.4814	6.0496
2	*Albizia adianthifolia*	Fabaceae	2	0.5682	5	1.8973	7.4655
3	*Albizia zygia*	Fabaceae	8	2.2727	20	3.1519	25.4247
4	*Alstonia boonei*	Apocynaceae	4	1.1364	10	0.1003	11.2367
5	*Antiaris toxicaria*	Moraceae	14	3.9773	35	0.2607	39.2380
6	*Baphia nitida*	Leguminosae	4	1.1364	10	0.0654	11.2018
7	*Blighia sapida*	Sapindaceae	8	2.2727	20	0.1063	22.3790
8	*Brachystegia eurycoma*	Leguminosae	4	1.1364	10	2.0744	13.2108
9	*Canthium dicoccum*	Rubiaceae	6	1.7045	15	0.2585	16.9630
10	*Ceiba pentandra*	Malvaceae	14	3.9773	35	13.1133	52.0906
11	*Celtis philippensis*	Cannabaceae	14	3.9773	35	2.4467	41.4240
12	*Celtis zenkeri*	Cannabaceae	16	4.5455	40	4.4642	49.0097
13	*Cleistopholis patens*	Annonaceae	2	0.5682	5	0.2108	5.7790
14	*Cola gigantea*	Sterculiaceae	24	6.8182	60	6.2562	73.0744
15	*Cola millenii*	Sterculiaceae	28	7.9545	70	1.6606	79.6151
16	*Dialium guineense*	Fabaceae	6	1.7045	15	0.1025	16.8071
17	*Ficus exasperata*	Moraceae	6	1.7045	15	1.1558	17.8603
18	*Funtumia elastica*	Apocynaceae	22	6.2500	55	0.7220	61.9720
19	*Hildegardia barteri*	Sterculiaceae	8	2.2727	20	3.9790	26.2517
20	*Holarrhena floribunda*	Apocynaceae	2	0.5682	5	0.0104	5.5786
21	*Malacantha alnifolia*	Sapotaceae	4	1.1364	10	0.0634	11.1998
22	*Margaritaria discoidea*	Euphorbiaceae	2	0.5682	5	0.0731	5.6413

ISTF-NIG 2026

23	*Milicia excelsa*	Moraceae	6	1.7045	15	2.4795	19.1840
24	*Monodora tenuifolia*	Annonaceae	2	0.5682	5	0.0108	5.5790
25	*Nesogordonia papaverifera*	Sterculiaceae	2	0.5682	5	0.0150	5.5832
26	*Olax subcorpiodea*	Olacaceae	2	0.5682	5	0.0150	5.5832
27	*Picralima nitida*	Apocynaceae	6	1.7045	15	0.1572	16.8617
28	*Pterygota macrocarpa*	Malvaceae	14	3.9773	35	0.3136	39.2908
29	*Pycnanthus angolensis*	Myristicaceae	8	2.2727	20	0.2904	22.5631
30	*Ricinodendron heudelotii*	Euphorbiaceae	16	4.5455	40	7.9173	52.4628
31	*Spathodea campanulata*	Bignoniaceae	4	1.1364	10	0.6150	11.7514
32	*Sterculia rhinopetala*	Sterculiaceae	12	3.4091	30	0.3626	33.7716
33	*Sterculia tragacantha*	Sterculiaceae	10	2.8409	25	1.0625	28.9034
34	*Strombosia pustulata*	Olacaceae	6	1.7045	15	1.3700	18.0745
35	*Terminalia superba*	Combretaceae	6	1.7045	15	1.6492	18.3538
36	*Trichilia prieuriana*	Meliaceae	2	0.5682	5	0.8812	6.4493
37	*Trilepisium madagascariense*	Moraceae	6	1.7045	15	1.0537	17.7582
38	*Triplochiton scleroxylon*	Malvaceae	46	13.0682	115	39.1218	167.1900
39	*Vocanga africana*	Apocynaceae	2	0.5682	5	0.0204	5.5886
40	*Zanthoxylum zanthoxyloides*	Rutaceae	2	0.5682	5	0.0106	5.5788

Where: RF=Relative frequency, RD= Relative density, RDo= Relative dominance, IVI= Important value index

Table 3: Family Composition of Tree Species in the Study Area

Families	**NS**	**N/ha**	**Percentage**
Annonaceae	2	4	5.0
Apocynaceae	5	36	12.5
Bignoniaceae	1	4	2.5
Cannabaceae	2	30	5.0
Combretaceae	1	6	2.5
Euphorbiaceae	2	18	5.0
Fabaceae	4	18	10.0
Leguminosae	2	8	5.0
Malvaceae	3	74	7.5
Meliaceae	1	2	2.5

ISTF-NG 2026

Moraceae	4	32	10.0
Myristicaceae	1	8	2.5
Olacaceae	2	8	5.0
Rubiaceae	1	6	2.5
Rutaceae	1	2	2.5
Sapindaceae	1	8	2.5
Sapotaceae	1	4	2.5
Sterculiaceae	6	84	15.0
Total	**40**	**352**	**100**

Table 4: Families' Important Index for the Study Area

Families	NS	N/ha	BA/ha	RD	RDo	RF	FIVI
Annonaceae	2	4	0.3345	11.1111	7.3623	1.1364	19.6097
Apocynaceae	5	36	1.5246	27.7778	18.4056	10.2273	56.4107
Bignoniaceae	1	4	0.9281	5.5556	3.6811	1.1364	10.3730
Cannabaceae	2	30	10.4288	11.1111	7.3623	8.5227	26.9961
Combretaceae	1	6	2.4887	5.5556	3.6811	1.7045	10.9412
Euphorbiaceae	2	18	12.0578	11.1111	7.3623	5.1136	23.5870
Fabaceae	4	18	8.5006	22.2222	14.7245	5.1136	42.0604
Leguminosae	2	8	3.2291	11.1111	7.3623	2.2727	20.7461
Malvaceae	3	74	79.2973	16.6667	11.0434	21.0227	48.7328
Meliaceae	1	2	1.3297	5.5556	3.6811	0.5682	9.8049
Moraceae	4	32	7.4691	22.2222	14.7245	9.0909	46.0376
Myristicaceae	1	8	0.4382	5.5556	3.6811	2.2727	11.5094
Olacaceae	2	8	2.0899	11.1111	7.3623	2.2727	20.7461
Rubiaceae	1	6	0.3900	5.5556	3.6811	1.7045	10.9412
Rutaceae	1	2	0.0160	5.5556	3.6811	0.5682	9.8049
Sapindaceae	1	8	0.1604	5.5556	3.6811	2.2727	11.5094
Sapotaceae	1	4	0.0957	5.5556	3.6811	1.1364	10.3730
Sterculiaceae	6	84	20.1241	33.3333	22.0868	23.8636	79.2837

ISTF-NIG 2026

Where: NS= Number of Species, N/ha= Number of species per hectare, BA/ha=Basal Area per hectare, RF=Relative frequency, RD= Relative density, RDo= Relative dominance, FIVI= Family Important value index

Table 5: Tree Species Diversity and Abundance in the Study Area

Indices	Value
Number of individual trees	352
Number of tree species	40
Number of Families	18
Shannon- Weiner tree species diversity index (H')	3.311
Simpson Tree Species Diversity Index	0.9502
Species-Evenness index €	0.6852
Margalef's index of species richness (M)	6.651
Equitability_J	0.8975
Dominance_D	0.0498

Stand Structure of the Study Area

Table 6 presents the diameter class distribution, along with the relative number of individuals per hectare, the number of species, the number of families, total basal area, and volume per hectare. The 21-40 cm diameter size class had the highest number of individuals (102 trees), followed by the 61-80 cm diameter size class (60 trees). The diameter classes 0-20cm, 81-100cm, and >100cm had 48, 44, and 42 individual trees, respectively, while the fewest, 36, were found in the 41-60cm diameter class. The highest number of species (11) was recorded in the diameter class 0-20cm, and closely followed by 21-40cm (9). The fewest species and families were recorded in the class >100cm. Diameter class >100cm had the highest basal area and volume per hectare, with values of 60.6726 m^2/ha and 626.4333 m^3/ha, respectively, followed by diameter class 0-20cm (36.1507 m^2/ha, 341.955 m^3/ha). The least basal area was recorded in the diameter class 41-60cm, with a value of 3.9856 m^2/ha, and the least volume, 16.4317 m^3/ha, was recorded in the diameter class 81-100cm.

Table 7 shows the classification of height distribution by tree canopy type, along with the relative numbers of individuals per hectare and the corresponding percentages. The heights were grouped into four major classes: Dominant (TH ≥ 35m), Co-dominant (TH = 26m to 35m), Intermediate (TH = 16m to 25m), and Suppressed (TH = 6m to 15m). The height class of co-dominant had the

ISTF-NIG 2026

highest number of individual trees per hectare (130) and a percentage (37%). The dominant class had the fewest 38 individual trees and a percentage of 11%.

Figure 3 shows the classification of the slenderness coefficient (TSLC) into three categories: High, Moderate, and Low Slenderness Coefficient. High slenderness coefficient (Trees with SC > 99); Moderate slenderness coefficient (Trees with SC 70-99); Low slenderness coefficient (Trees with SC < 70), and slenderness coefficient categorization. The results show that 226 trees had a low slenderness coefficient, 48 had a moderate slenderness coefficient, and 78 had a high slenderness coefficient. Table 8 shows the correlation matrix between the tree TSLC and other growth variables. This was done to determine the tree's stability to wind throw. The tree slenderness coefficient shows a strong negative correlation with the entire diameter at different positions. The DBH had the highest negative correlation coefficient (-0.8012), indicating that DBH is a better predictor of the slenderness coefficient. The TSLC was also negatively correlated with the tree's total height and merchantable height.

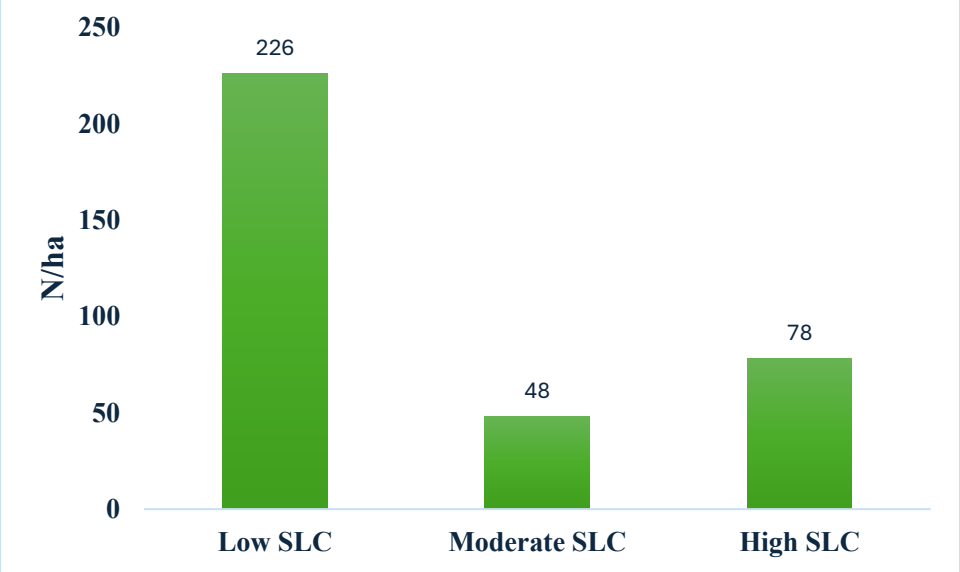


Figure 3: Classification of Tree Slenderness Coefficient into Categories

Table 6: Tree species diameter classes distribution with their relative status

DBH Class (cm)	N/ha	NS	NF	Total BA (m^2/ha)	Total Vol (m^3/ha)
0-20	48	11	10	36.1507	341.955
21-40	102	9	6	28.0098	240.9624
41-60	36	5	5	3.9856	34.792
61-80	60	6	5	14.0467	97.0439

81-100	44	6	6	9.6261	16.4317
> 100	42	3	3	60.6726	626.4333

Where: DBH Class = Diameter Class (cm), N/ha= Number per hectare, NS = Number of species, NF = Number of Frequency, BA = Basal Area, Vol = Volume of trees.

Table 7: Distribution of Tree Species into Height Classes based on the Canopy Classification in the Study Area

Canopy Classification	N/ha	Percentage (%)
≤6m	0	0
Suppressed	76	21
Intermediate	108	31
Co-dominant	130	37
Dominant	38	11

Table 8: Relationship between Tree Slenderness Coefficient and Stand Growth variables

	TSLC	***DBH(m)***	***DB(m)***	***DM(m)***	***DT(m)***	***THT***	***MHT***
TSLC	1						
DBH(m)	-0.8012*	1					
DB(m)	-0.7985*	0.9891*	1				
DM(m)	-0.6370*	0.6887*	0.6802*	1			
DT(m)	-0.6190*	0.5842*	0.5678*	0.9009*	1		
THT	-0.4052*	0.6965*	0.6741*	0.6029*	0.5259*	1	
MHT	-0.1806*	0.5041*	0.5152*	0.3951*	0.3663*	0.7846*	1

ISTF-NIG 2026

Where: TSLC = Tree Slenderness Coefficient, DBH = Diameter at the Breast Height, DB = Diameter at the Base, DM = Diameter at the Middle, DT = Diameter at the Top, THT = Total Height of the tree, MHT = Merchantable Height of the tree.

Discussion

Stand Growth Characteristics

The descriptive summary of tree growth indicates an optimal tree stand density in the study area. The Tree stands structure in the forest had live-standing trees with high mean DBH and mean total tree height. The study area's tree structure was similar to that of the Akure Natural Forest and Oluwa Natural Forest in Ondo State (Ogana *et al.,* 2015) and the Shasha Natural Forest in Osun State (Chenge *et al.,* 2019). The average diameter at DBH suggests that the trees are mature and have grown significantly, with a good balance between the crown size and stem length. An intriguing finding is the inverse relationship observed between crown diameter and the slenderness coefficient. This implied that trees with larger crowns tend to exhibit greater stability (as indicated by a lower coefficient). This can be attributed, in all likelihood, to the presence of thicker trunks, reflected in the DBH, which provide adequate support for the expansive crowns. Furthermore, the strong correlation identified between basal area and crown projection area (CPA) suggests the potential utility of basal area as a reliable proxy for estimating crown size within this study area. The study underscores a positive association between trees with a lower crown ratio (relative to their height) and enhanced growth across various variables. This is evidenced by the negative correlation observed between the crown ratio and all other growth variables.

Species Diversity and Stand Structure

The fundamentals of sustainable forest management primarily center on understanding the diversity, abundance, richness, and species structures of the forest's tree species. The study provided an overview of the forest's tree species composition. Iyagin and Adekunle (2017) and Kanagaraj *et al*. (2017) found that the distribution and density of individual tree species are quantifiable markers of plant diversity. These results are in line with the findings of Salami and Akinyemi (2018). The species that dominates the forest is *Triplochiton scleroxylon*, a member of the Malvaceae family. Some of the other tree species that are relatively few, such as *Afzelia africana, Albizia adianthifolia, Albizia zygia, Cleistopholis patens, and Trichilia prieuriana,* may be a result of past harvesting. Sterculiaceae had the highest relative frequency, relative density, and relative dominance, making it the most dominant family in the forest. The present finding is consistent with research by Ige and Komolafe (2022), Moksia e*t al*. (2012), and Sawadogo *et al.* (2007), which identified the Combretaceae and Sterculiaceae families as the most prevalent in the Savannah and rainforest regions. These studies were conducted in the IITA forest, Ibadan, Nigeria; the Kalfou Forest Reserve in Cameroon; and the Togo Forest in Burkina Faso.

The higher the Shannon-Weiner Diversity Index, the more diverse the population. The Shannon-Wiener Index (H') has a value of 3.311 in this study. The H' yields results comparable to the tree species diversity values reported for the tropical forests of Barro Colorado Island in Panama (4.8) and the Kalakad Reserved Forests in the Western Ghats (3.31 and 3.69; Parthasarathy *et al.,* 1992). The ecosystem's higher Shannon value indicates a higher concentration of rare species, suggesting

that it possesses special environmental conditions that foster the expansion of more rare species and thereby increase the overall diversity of tree species. A high species richness is indicated by the obtained species richness index of 6.651. However, sample size, plot size, site conditions, and other site factors affect quantitative comparisons of species diversity in this study area with those in other studies conducted elsewhere (Young & Swiacki, 2006). The forest has a high level of diversity, which is indicative of a healthy forest, according to the Simpson's Index (D') of 0.9502. It demonstrates that there are more species in the ecosystem. This finding suggests that a wide variety of species coexist in the AFE, with no species predominating over the ecosystem. This is consistent with the findings of Young and Swiacki (2006), who defined diversity as the range of species present and their relative abundance. The result underscores the importance of considering species richness as a measure of biodiversity, as it provides a valuable indicator of an ecosystem's ecological value. A higher species evenness indicates a more stable and resilient ecosystem, as it shows that the various species are present in roughly equal proportions and are not dominated by a single species. This species evenness result implies that AFE is stable. Species evenness is important because a more diverse and even ecosystem can better withstand disturbances like climate change.

The reverse "J-shape" (an inverse "J-shape") diameter distribution in this study indicated healthy regeneration potentials, according to Amonum *et al*. (2019) and Ouedraogo *et al*. (2019). This further implied that it is a natural forest. The observed density of 352 stems per hectare (≥ 10cm DBH) indicates a relatively dense forest cover, suggesting favorable conditions for forest growth and regeneration. This high density is indicative of a healthy and thriving ecosystem, as forests with adequate tree density often exhibit greater resilience to disturbances and provide crucial habitat for diverse flora and fauna. According to the three total height distributions found in this study, there were more single tree stands in the co-dominant stratum than in the dominant stratum. This could be due to competition for sunlight and available space for the expansion of stem and crown diameters, according to Amonum and Japheth (2019) and Vange *et al.* (2017). This could also account for the area's higher tree density and lower number of individual tree stands with dominant heights. The Shasha natural forest in Osun State, Nigeria, and the study area's total tree height distribution exhibited a similar height pattern, according to Chenge *et al*. (2019). The number of horizontal strata, the height and density of each stratum, and specific features such as tree hollows make up the habitat structure, an emerging feature of vegetation. For example, structures affect the microclimate by lowering surface temperatures through shading, and they also provide substrates for activities such as nesting, sheltering, foraging, predator avoidance, and other activities (Brown *et al.,* 2021). The composition of animal communities is influenced by vegetation in natural ecosystems (Louy *et al.,* 2011).

Trees with a TSLC value > 99 were categorized as having a high slenderness coefficient and are known to be unstable, prone to wind damage (Adeyemi & Adesoye, 2016). The result indicated that a larger percentage of the trees exhibited good vigor and resilience to environmental stresses, except for a few trees that are susceptible to wind throw, and this could be a result of the species encountered physiognomy/genetic composition, plot size, tree growth increment, and tree form or pattern over the year. This result is in line with the study conducted by Wang *et al.* (1998), where they found that more than 50% of the sampled trees in the boreal mixed forest had a TSLC greater than 100, an indicator for susceptibility to wind throw, which, however, they noted could be a result of differences in tree form and height growth pattern. The correlation matrix between the tree slenderness coefficient and diameter at different positions and heights was negative. These

findings agree with those of Ige (2017), who reported a negative correlation between TSLC and tree growth characteristics in *Triplochiton scleroxylon* stands in the Onigambari Forest Reserve. Studies have shown that DBH is a better predictor of tree slenderness coefficient (Wang *et al.,* 1998; Ige, 2017; and Oladoye *et al.,* 2020). This study also agrees with this study because the correlation coefficient between DBH and TSLC was the highest among the growth variables.

Conclusion

Based on current findings, the study area harbors a wide variety of tree species. The distribution richness and relative abundance of taxa, which are necessary for making conservation decisions, are quantified by measures of biodiversity. According to the research area's species distribution pattern, each tree species is distributed uniformly throughout the forest. Based on the mean stand density and greater species richness, the current study suggests that the ecosystem as a whole is unique and has the potential to be conserved. As a sign of the health and vitality of the forest, the distribution of DBH classes showed that the forest has a reasonably good potential for recruitment and regeneration. An important characteristic for measuring the quality of the site and vegetation structure is the girth at breast height (dbh) or the basal area of a tree. This study serves as a valuable tool for evaluating potential future alterations in the structure and composition of the forest and for guiding the enhancement of management strategies for protected areas. To safeguard forests against escalating threats such as climate change, energy development, and invasive species, it is imperative to examine the broader factors contributing to inadequate or absent regeneration. It is therefore recommended that the study area be regarded as a living gene bank of tree species and serve as baseline data for other research. The presence of many indigenous tree species in the study area enhances carbon sequestration and encourages their conservation, which is scarce in most natural forest ecosystems.

References

Amonum J. I & Japheth H. D (2019). Application of Developed Crown Bole Diameter Model to Stand Density and Stock Control on Open Grown Trees of *Prosopis africana* (Guill and Perr) Taub; *Applied Tropical Agriculture*; 24 (2): 32–39.

Bano S, Khan S. M, Alam J, Alqarawi A. A, AbdAllah E. F, Ahmad Z, Rahman I. U, Ahmad H, Aldubise A, & Hashem, A (2018). Eco-Floristic studies of native plants of the Beer Hills along the Indus River in the districts of Haripur and Abbottabad, Pakistan, Saud. *J. Biol. Sci.* 254: pp 801–810, *https://doi.org/10.1016/j.sjbs.2017.02.009.*

Brown J, Barton P & Cunningham S. A (2021). Chapter Four - How bioregional history could shape the future of agriculture, Editor(s): David A. Bohan, Adam J. Vanbergen, *Adv. in Eco. Res.,* Academic Press; 64: 149–189.

Chenge I. B, Chukwu O, Japheth H. D & Yager G. O (2019). Tree Species Diversity and Forest Structure of a Natural Forest in Shasha Natural Forest, Nigeria; Forestry Association of Nigeria, Abuja, Nigeria.

Gadow K. V, Zhang C. Y, Wehenkel C, Pommerening A, Corral-Rivas J, Korol M, Myklush S, Hui G. Y, Kiviste A, & Zhao X. H (2011). Forest structure and diversity, in: T. Pukkala, K. Gadow (Eds.), Continuous Cover Forestry, Book Series Managing Forest Ecosystems, Vol 24, pp. 29–84, *https://doi.org/10.1007/978-94-007-2202-6.*

Gebeyehu S, Mokria M, Zewdie S, Yeshitela K., & Mengistu T (2019). Carbon storage and sequestration potential of indigenous agroforestry trees in northwestern Ethiopia. *Journal of Forestry Research,* 30(1), 171–181. *https://doi.org/10.1007/s11676-018-0679-9.*

Ige P. O (2017). Development of Models for Assessing the Slenderness of *Triplochiton scleroxylon* K.Schum Stands in Onigambari Forest Reserve, Nigeria. Nigeria *Journal of Forestry,* 47 (2)44-50.

Iyagin F. O & Adekunle V. A. J, (2017). Phytoecological studies of some protected and degraded forest areas of lowland humid forest, Ondo State, Nigeria. A comprehensive approach. *Tropical Plant Research*, 4(3), pp. 496-513.

Kanagaraj S, Selvaraj M, Das Kangabam R & Munisamy G (2017). Prevalence, utilization and conservation strategies for non-timber forest products in the South Western zone of Nigeria. *Resources and Environment,* 2(1), pp. 46–54.

Mackey B, Watson J. E. M, Hope G, Gilmore S, & Ha K (2020). Ecosystem-based greenhouse accounting: Linking terrestrial carbon and biodiversity. *Global Ecology and Conservation,* 21, e00883. *https://doi.org/10.1016/j.gecco.2019.e00883.*

Mishra A, Behera S, Singh K, Chaudhary L, Mishra R & Singh B (2013). Influence of abiotic factors on community structure of understory vegetation in moist deciduous forests of north India. *Forest Science and Practice* 15:261-273.

Moksia F, Louis Z, Pierre M. M, & Bernard A. N (2012). Woody species composition, structure, and diversity of vegetation of Kalfou Natural Forest, Cameroon. *J. of Eco and the Nat. Env*.; 4(13):333-343.

Ogana F. N, Osho J. S. A Gorgoso-Varela J. J (2015). Comparison of Beta, Gamma Weibull distribution for characterizing tree diameter in Oluwa Forest Reserve, Ondo state, Nigeria. *Journal of Natura Sciences Research,* 5(4), pp. 28-36.

Oladoye A. O, Ige P. O, Baurawa N, Onilude Q. A, & Animashaun Z. T (2020). Slenderness Coefficient models for tree species in Omo Biosphere Reserve, South-western Nigeria. *Journal of the Society for Tropical Plant Research*, 7(3), pp.609–618.

Olasupo T. B. (2023). Assessment of Stand Structure, Regeneration Potentials and Carbon Sequestration of Abayomi Farm Estate, Emerald Forest, Ikoyi, Osun State. A Bachelor of Science (Forestry) Project in the Department of Social and Environmental Forestry, University of Ibadan, Nigeria 135pp

Ouedraogo S, Sanou L, Savadogo P & Zoungrana/Kabore C. Y (2019). Structural characterization and pod yields of populations of the fodder legume trees *Piliostigma thonningii* and *Prosopis africana* along the toposequence in western Burkina Faso; Int. *J. Biol. Chem. Sci.* 13(6): 2433–2448.

Parthasaranthy N, Kinbal V, & Kumar L. P (1992). Plant species Diversity and Human impact in the Tropical Wet Evergreen forests of the Southern Western Ghats. Indo –French Workshop on *Tropical Ecology*, 15–23.

Phillips O. L, & Lewis S. L (2014). Evaluating the tropical forest carbon sink. *Global Change Biology*, 20(7), 2039-2041. *https://doi.org/10.1111/gcb.12569.*

Polly D, Bynum N, & Pezzuti J. (2019). Introduction to Conservation. *Conservation Biology* for All. *https://doi.org/10.1093/oso/9780199554232.003.0001.*

Sadono R, Indah W, Suharjito D, Prasetya B, Kurniawan A. D, & Noor M. R (2020). The Role of Mangrove Forest in Preventing Soil Erosion and Reducing the Risk of Saltwater Intrusion: A Case Study of Mangrove Forest Management in North Java, Indonesia. IOP Conference

Series: *Earth and Environmental Science,* 549, 012002. *https://doi.org/10.1088/1755-1315/549/1/012002.*

Salami A. T, & Akinyele I. O (2018). Tree species composition and diversity of a sacred forest fragment in Ogun State, southwestern Nigeria. *Journal of Forestry Research*, 29(3), 783–794.

Su D, Yu D, Zhou L, Xie X, & Liu Z (2010). Differences in the structure, species composition, and diversity of primary and harvested forests on Changbai Mountain, Northeast China. *Journal of Forest Science* 56; 285–293.

Sullivan M. J. P. P, Talbot J, Lewis S. L, Phillips O. L, Qie L, Begne S. K, & Zemagho L (2017). Diversity and carbon storage across the tropical forest biome. *Scientific Reports* 7 (1), 39102. *https://doi.org/10.1038/srep39102.*

Taillardat P, Favier C, Sabatier D, & Aubert S (2018). Tropical rainforest, vegetation structure and woody species diversity: A spatial resolution effect. Remote Sensing, 10(8), 1187. *https://doi.org/10.3390/rs10081187.*

Teketay D (2005). Seed and regeneration ecology in dry Afromontane forests of Ethiopia: I. Seed production-population structures. *Tropical Ecology* 46 pp 29–44.

Vange T, Amonum J. I, & Dau J. H (2017). Prediction Equations for Estimating Growth Space for *Parkia biglobosa* (Jacq) Benth in the Guinea Savanna Ecozone of Nigeria. *Applied Eco and For Sci,* 3 (1): 1–7.

Wang Y, Titus S. J, & LeMay V. M (1998). Relationship between tree slenderness coefficients and tree stand characteristics for major species in boreal mixed-wood forests. Canadian *Journal of Forest Research*, 28(8), pp. 1171-1183.

Young S & Swiacki L. N (2006). Surveying the Forest Biodiversity of Evansburg State Park: Plant Community Classification and Species Diversity Assessment. International Journal of Botany, 2(3), 293–299. *http://dx.doi.org/10.3923/ijb.2006.293.299.*

Zuleta D, Arellano G, McMahon S. M, Aguilar S, & Bunyavejchewin S. (2023). Damage to living trees accounts for almost half of biomass losses in tropical forests. *Global change biology*. https://doi.org/10.1111/gcb.16687.

ISTF-NIG 2026

GENOTYPE BY ENVIRONMENT INTERACTION ANALYSIS IN *Dacryodes edulis* (G. Don) H.J. Lam: A MEASURE TOWARDS A MULTIPURPOSE TREE BREEDING IN NIGERIA

Alaje, V.I., Geply, O.A., Adebusuyi, G.A., Amao, A.O., Nola, M.O. and Amadi, J.O.,

Sustainable Forest Management Department,
Forestry Research Institute of Nigeria, P.M.B. 5054, Ibadan, Oyo State, Nigeria.
Corresponding Email: alajeveronica@gmail.com; +2348035267527

Abstract

Dacryodes edulis is an oliferous multipurpose tree, producing edible fruit valued for its potential to boost nutrition. However, its improvement efforts are still lagging due to inadequate information on selecting the ideal genotype from diverse germplasm. Therefore, this Study was carried out to describe its interaction with the environment and to select an ideal accession for further breeding. Thirty (30) accessions of *Dacryodes edulis* collected from natural populations from Edo, Delta, Ondo and Oyo States were arranged in a Completely Randomized Design in 5 replications across four locations. Data collected on fresh leaf weight, fresh stem weight, fresh root weight, dry leaf weight, dry stem weight, dry root weight, and total biomass were subjected to Analysis of Variance (ANOVA). Significant means were compared using the Duncan Multiple Range Test at the 5% level of significance ($P \leq 0.05$). Results showed significant ($p<0.05$) differences among the accessions for all characters evaluated, except dry stem weight. Significant ($P \leq 0.05$) location effect and GXE were also observed for all the traits studied. The GGE-biplot showed that the four environments lie in the high biomass accumulation quadrant. The Study also concluded that accessions FOR13, 14, 21, and 22 were the most stable in terms of biomass; however, accession FOR13 was considered the most ideal.

Key Word: *GGE biplot, polygon view, GXE, Dacryodes edulis, improvement*

Introduction

Success in breeding programmes in the presence of genotype-by-environment interaction (G×E) is difficult for breeders to achieve. (Allard and Bradshaw, 1963;; Ojo, 2000; Domitruk *et. al.*, 2001 Kenga *et.al*., 2003,). Dixon *et al.* (1994) defined G × E as the change in a plant's relative performance across a range of environmentsenvironments, resulting from the manner in which the plant responds to various edaphic, climatic, and biotic factors. Plant breeders, agronomists, and farmers need adequate knowledge of it because it can affect all stages of plant development and play a major role in the expression of quantitative traits, such as yield (Ojo, 2000). Knowledge of this will help in selecting plants with the best wide-adaptation ability. Plants with low G × E interaction and high stability are desirable for breeders and farmers, as this indicates that the environment has less effect on them and that their performance is mainly due to their genetic composition (Domitruk *et al.*, 2001). To detect the presence of GXE, planting materials are often evaluated across environments, and selections are based on their responses to those environments. Basic tools, such as the genotype main effect and the genotype-by-environment interaction (GGE), are very effective at detecting GXE. The GGE produces the GGE biplot, which ascertains the best fits for the which-won-where pattern analysis, genotype, and test environment evaluation (Yan *et al*., 2007). This Biplot, produced by the model, is also useful for assessing ideal genotype and ideal

location in multi-environment trials (Crossa *et al*., 1991; Yan *et al*., 2000). The GGE biplot provides a polygonal view that helps visualize interaction patterns between genotypes and environments (Yan & Kang, 2003; Yan & Hunt, 1998) and shows the presence or absence of GXE. This is also helpful for estimating the possible existence of different mega-environments (Gauch & Zobel, 1997; Yan & Rajcan, 2002; Yan & Tinker, 2006).

D. edulis is an oliferous multipurpose edible fruit tree of the family Buseraceae found in equatorial and humid tropical climates. It originated in Central Africa, specifically the Gulf of Guinea (Cameroon and Nigeria) (Leakey *et al.*, 2004; Leakey *et al.*, 2002; Silou, 1994; Auberville, 1962). Auberville (1962) stated that older literature limited its distribution to the forest regions of Central Africa. However, recently, due to human activities, its distribution and occurrence have extended beyond its original zone to the Central African Republic, Gabon, the Republic of Congo, and the Democratic Republic of Congo, even as far as Uganda in East Africa and Angola and northern Zimbabwe in southern Africa (Bourdeaut, 1971). Kengue (2002) also stated that human activities have extended their distribution not only across Africa but also into tropical Asia. The oily fruits of *D. edulis*, which are sold and consumed both within and outside Nigeria, are rich in nutrients and thus contribute to the rural economy (Awono *et al*., 2002; Mbofung *et al*., 2002; Ajibesin, 2011). The fruits contain bioactive constituents such as phytochemicals, antioxidants, vitamins, carbohydrates, lipids, proteins, fiber, and minerals, making them an ideal source of nutrients and a complementary addition to a diet. Beyond this, the fruit also serves as a valuable raw material for the pharmaceutical and cosmetic industries (Ajibesin, 2011; Duru *et al*., 2012; Ogunsuyi, 2015; Amise *et al.*, 2016; Enengedi *et al.,* 2019). The oil extracted from the fruit pulp has been found to have properties that make it suitable for cooking and frying, and as such, could be a substitute for butter in baking (Ondo-Azi *et al.*, 2014; Akusu *et al*., 2019; Eyenga *et al.*, 2020).

Presently, most of the trees on farms are old and very tall and do not produce adequate fruit. Therefore, *D. edulis* fruit production must be increased because demand for its fruit has increased. The solution is to replace the old trees with improved planting materials that yield high-quality fruits with the desired traits, wherever they are propagated. All these require that appropriate technologies and techniques be putbe put in place to complement current domestication efforts on *D. edulis (*Anegbeh *et al*., 2005) and to encourageto encourage the use of improved, stable planting materials in the breeding programme. Tree improvement programmes aim to produce plants with higher fruit yields and better wood quality that can adapt to diverse agro-climatic regions. To achieve this, a better understanding of the interactions between major morphological traits and the environment is required (Alaje *et al*., 2019). This is because entire plant characteristics can be expressed or masked by the climatic conditions to which plants are exposed during the respective growth stage (Kengue, 2002). This will cumulatively affect the plant's final yield.

Biomass is a morphological trait of a plant that reflects the amount of energy stored in its tissues. It is a function of the area's potential productivity and is also used to assess the ecological status of the plant's growing site (Huxley, 1983). It is a good indicator of how much sunlight, water, and nutrients a plant can capture and convert into plant tissues, which are key determinants of plant yield (Andrade *et al*., 1999). The final fruit yield of a given plant species depends on interactions among genotypes, responses to environmental conditions, and management practices (Eberhart & Russell, 1966). Since, under the same management, the interaction between genotypes and environmental conditions is the sole determinant of plant performance (Ojo, 2000). Therefore, it is important to evaluate the interaction between genotypes and environmental conditions to identify the most ideal and adapted

genotypes among the *Dacryodes edulis* accessions, to select the most ideal and stable accession with low GXE for further breeding of this multipurpose tree.

Materials and methods

Sources of *D. edulis* accessions used

Seeds of thirty accessions of *Dacryodes edulis* were collected from their natural habitat within four States (Edo, Delta, Ondo and Oyo) of Nigeria.

Table 1: List of 30 accessions used in the Study

Genotypes	Accessions Codes	Source	Latitude (ºN)	Longitude (ºE)
G1	FOR1	Jericho, Oyo State	3.86	7.67
G2	FOR2	Agbofieti, Oyo State	3.86	7.67
G3	FOR3	Ofosu, Ondo State	5.14	6.75
G4	FOR4	Ore, Ondo State	4.88	6.75
G5	FOR5	Akoko, Ondo State	5.42	7.36
G6	FOR6	Okpanam, Delta state	6.24	6.65
G7	FOR7	Ibusa, Delta State	5.78	6.55
G8	FOR8	Asaba, Delta State	6.20	6.73
G9	FOR9	Umunede, Delta state	6.27	6.31
G10	FOR10	Iseleukwu, Delta State	6.22	6.48
G11	FOR11	Okogbo, Edo State	5.88	6.20
G12	FOR12	Iguere, Edo State	6.24	6.66
G13	FOR13	Iduonmiwina,Edo State	5.90	6.18
G14	FOR14	Igbekhue, Edo State	5.90	6.15
G15	FOR15	Obozogbeniro, Edo State	5.30	6.15
G16	FOR16	Ugbokoniro, Edostate	5.96	6.14
G17	FOR17	Ubokonumagba, Edo State	6.56	6.58
G18	FOR18	Ugbougo, Edo State	6.00	6.13
G19	FOR19	Evbousa, Edo State	5.62	6.15
G20	FOR20	Aideyanoba Edo State	5.92	6.11
G21	FOR21	Idu, Edo state	6.22	6.81
G22	FOR22	Iguemokhia, Edo State	5.83	6.14
G23	FOR23	Ugo Edo State	6.00	6.09
G24	FOR24	Evbousa, Edo State	5.62	6.15
G25	FOR25	Avbugo, Edo State	5.82	6.20
G26	FOR26	Evbowe, Edo State	6.06	6.14
G27	FOR27	Ona, Edo State	5.64	6.20
G28	FOR28	Ekobi, Edo State	6.46	6.63
G29	FOR29	Urhonigbe, Edo State	6.51	6.58
G30	FOR30	Sakpoba, Edo State	5.64	6.20

Source Alaje *et. al.*, 2018, 2019

ISTF-NIG 2026

Description of experimental sites and climate

The study was conducted in four locations as follows:

Location 1: Federal University of Agriculture, Abeokuta (FUNAAB), Ogun State. (7º 15'N; 3º 25'E; 159 m above sea level),

Location 2: Moist forest Research Station, Benin City, Edo State (6 ˚ 20 'N; 5 ° 38'E; 86m above sea level).

Location 3: Forestry Research Institute of Nigeria (FRIN), Ibadan, Oyo State. (7º 16'N; 3º 47'E; 255m above sea level).

Location 4: Rainforest Research Station, Ore, Ondo State. (6º 44'N; 4º 52'E; 87m above sea level.

Experimental procedure

The extracted seeds were sown in 17cm by 20 cm diameter depth propagating pots arranged in a completely randomized design (CRD) with five replications. Manual weeding and adequate watering to maintain soil moisture were carried out. At all locations, the experiments were terminated at 12 months of age when sufficient biomass data had been collected.

Data collection

Data were collected on the following biomass traits:

1 Fresh weights (g): The plants were removed, separated into roots, stems, and leaves, and weighed immediately.
2 Dry weights (g): The separated plant parts are placed in the oven at 70 °C and weighed until a constant weight is attained after 72 hours.
3 Biomass accumulation (g): the total biomass accumulated is measured as the total dried parts of the plant (aerial and root).

Data analysis

Genotype plus genotype-by-environment (GGE) analysis according to Yan and Kang (2003) was used to assess genotype-by-environment (G×E) interactions among the 30 accessions across the 4 locations, as measured by dry biomass accumulation. A The GGE biplot was constructed from the GGE analysis, which was used to determine the best fits for the which-won-where pattern analysis, genotype and test environment evaluation, and the polygon view for visualizing the interaction patterns between genotypes and environments.

Results and Discussion

The results from Table 2 indicated significant differences among the four locations for most biomass traits evaluated, except for fresh stem weight. The differences will provide an opportunity to evaluate the response of this multipurpose tree across different locations and determine the range of adaptability of its traits (Kengue, 2002). There were also significant differences among the accessions for most traits evaluated, except dry stem weight. This offers an opportunity to select among accessions for character improvement in this multipurpose tree species. The GXE interaction also showed significant differences for all the traits evaluated. This difference,

therefore, underscores the importance of estimating GXE to identify consistently performing, high-yielding accessions.

Selection of high-yielding genotypes with broader adaptation performance remains an important goal in the *Dacryodes edulis* breeding programme. This goal is often determined by multi-environment testing, in which the relative performance of the test genotype is determined from One environment to another to rule out the presence of G×E, which, when present, can limit the progress of the breeding programme as breeders' decisions on which genotype(s) may not be accurate (Ojo, 2000).

Table 2: Mean square analysis of variance for biomass and its components in 30 *Dacryodes edulis* accessions evaluated across the four locations

SV	DF	Fresh leaves weight (g)	Fresh stem weight (g)	Fresh root weight (g)	Dry leaves weight (g)	Dry stem weight (g)	Dry root weight (g)	Biomass (g)
Location (L)	3	11.48**	289.92ns	67.86**	6.91**	8.71**	14.93**	35.88**
Accessions (A)	29	10.52**	383.03**	26.67**	3.71**	46.01ns	11.32**	98.61**
L×A	87	9.27	338.79**	1.53**	3.67**	0.92**	0.24**	5.71**
Error	464	2.46	358.59	0.35	0.69	0.2	0.1	0.97

*, ** Significant differences at 0.05 and 0.01 levels of probability, respectively; ns not significant

The mean performance of the four locations, as presented in Table 3, showed that the *D. edulis* accessions differed significantly for all biomass-related traits evaluated, except fresh stem weight. Ibadan had the highest fresh root weight (5.23g), dry leaf weight (2.57g), and Biomass yield (7.59g). Ibadan recorded the highest fresh leaf weight of 5.50g, which was not significantly different from the other locations. Ibadan recorded the highest dry leaf weight of 2.57g. Benin recorded the highest fresh stem weight of 7.49g, dry stem weight of 2.82g, and dry root of 29.63g. The result is evidence that environmental factors drive changes in gene expression, as traits have been noted to vary along climatic and ecological gradients (Fredrick *et al.,* 2015). It affirmatively confirmed that the four locations differ in the expression of biomass traits.

Table 3: Mean performance of the four locations used in the Study

Location	Fresh leaves (g)	Fresh stem weight (g)	Fresh root weight (g)	Dry Leaves weight	Dry stem weight (g)	Dry root weight (g)	Biomass (g)
Abeokuta	4.83b	7.18a	3.89c	2.52ab	2.31c	1.77c	6.61c
Benin	4.70b	7.49a	4.28b	2.09c	2.82a	2.39a	7.30b
Ibadan	5.50a	6.14a	5.23a	2.57a	2.63b	2.37a	7.57a
Ore	4.55b	4.41a	3.74d	2.35b	2.34b	1.9b	6.62c

ISTF-NIG 2026

Means with the same alphabet in a column are not significantly different from One another according to DMRT at 5% probability level.

The GGE biplot for biomass yield (g/plt) showing the mean of accessions (G) and Environment (E) against Components 1 and 2 is presented in Figure 1. The GGE biplot is used to assess ideal genotypes and test locations in multi-environment data (Yan et al., 2000, 2003; Ayaz et al., 200; Yan & Kang, 2003). The fact that the four locations, as well as the 30 D. edulis accessions used, performed differently provided some evidence of location effects and their interactions with accessions on biomass production. By plotting both accessions and locations on the same graph, the association between them became more obvious. The result showed that accession FOR30 (G30) had the largest negative interaction (-10.0) with the environment, while accession FOR6 (6) had the largest positive interaction (14). Accessions with high environmental interaction are noted to be very dynamic, unstable, and responsive to environmental changes, and therefore cannot be predicted in terms of performance. Since their performance cannot be predicted across a range of environments, they can thus be propagated in limited environments.

From the results in Figure 1, accessions FOR13 (G13), FOR21 (G21), and FOR14 (G14) were most stable in a high-yielding environment, due to their relatively high PCA1 values and PCA2 values close to zero. This is in line with Samonte *et al.* (2005), who stated that the best cultivar should be high-yielding and stable across environments; that is, an ideal genotype for improvement should have the highest mean performance and be absolutely stable (Yan & Kang, 2003). An ideal genotype is defined as having the greatest vector length among high-yielding genotypes and zero GE (i.e., the highest stability). These genotypes could be recommended for planting across environments because their performance is unlikely to be influenced by prevailing environmental factors. Additionally, from the observations in Figure 1, the entire environment falls into the high-yielding environment (Quadrants II and IV). The angle between them was less than 90^0, indicating that either environment can be used for planting *D. edulis* (Alaje *et al.,* 2019). Nevertheless, environment 4 (E4), which had its PCA 2 value close to zero, was the most stable.

ISTF-NIG 2026

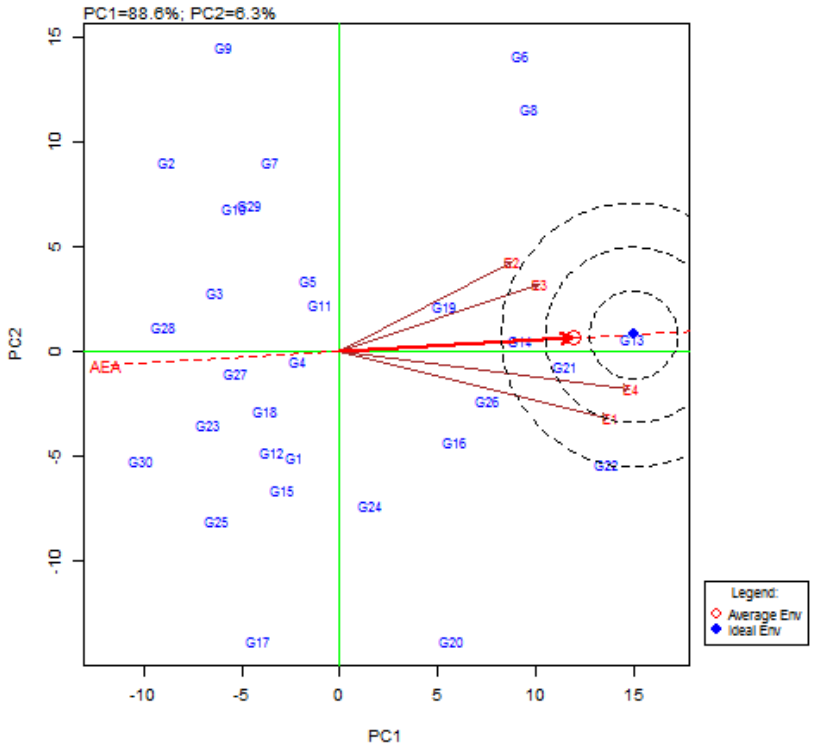


Figure 1: GGE biplot for biomass yield (g/plt) showing the mean of genotypes (G) and Environment (E) against Components 1 and 2.

G1=FOR1 G2 =FOR2 G3 FOR3 G4= FOR4 G5= FOR5 G5 =FOR5 G6 = FOR6 G7= FOR7 G8= FOR8 G9 = FOR9 G10 = FOR10 G11 = FOR11 G12 = FOR12 G13 = FOR13 G14 = FOR14 G15 = FOR15 G16 = FOR16 G17 = FOR17 G18 = FOR18 G19 = FOR19 G20 =FOR20 G21 = FOR21 G22 = FOR22 G23= FOR23 G24 = FOR24 G25 = FOR25 G26= FOR26 G27 = FOR27 G28 = FOR28 G29= FOR29 G30 = FOR30
E1 = Abeokuta E2= Benin E3=Ibadan E4= Ore

The polygon view of GGE-biplot, which explicitly displays the "which-won-where pattern" of thirty *Dacryodes edulis* accessions evaluated in four locations with respect to biomass accumulated per plant, is presented in Figure 2. The polygon view of a biplot is the best way to visualize the interaction patterns between genotypes and environments (Yan & Kang, 2003) and to show the presence or absence of crossover G×E, which is very important in estimating the possible existence of different mega-environments (Gauch & Zobel, 1996; Yan & Rajcan, 2002; Yan & Tinker, 2006). The convex hull in this graph is drawn on genotypes relatively remote from the biplot origin so that all other genotypes were contained within the convex hull. The Biplot also contains a set of lines perpendicular to each convex hull. These perpendiculars divided the Biplot into sectors. There were five sectors in this Study, and all the environments fall into One sector. An interesting feature of this Biplot is that the vertex genotype(s) for each section have the highest (sometimes the highest) yields in all environments within the sector (Yan & Rajcan, 2002). All environments fall into sector 1, and the vertex genotypes were accessions FOR6 (6), FOR13 (G13), FOR22 (G22), and FOR20 (G20). The polygon also identified FOR19, FOR14, FOR21, FOR26, FOR16, and FOR24 as good genotypes, though not the vertices, across the entire environment. No environment fell into the sector with accessions FOR17 (G17), FOR30 (G30), FOR2 (G2) and FOR9 (G9) as the vertices.

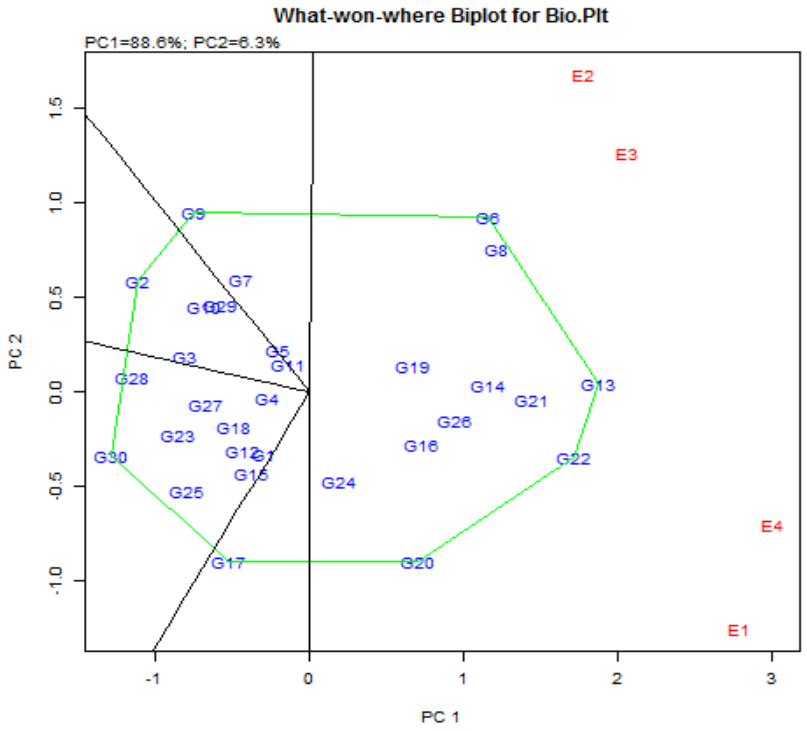


Figure 2: Polygon view of the GGE biplot of biomass yield per plant of thirty *Dacryodes edulis* genotypes evaluated over four environments.
G1=FOR1 G2 =FOR2 G3 FOR3 G4= FOR4 G5= FOR5 G5 =FOR5 G6 = FOR6 G7= FOR7 G8= FOR8 G9 = FOR9 G10 = FOR10 G11 = FOR11 G12 = FOR12 G13 = FOR13 G14 = FOR14 G15 = FOR15 G16 = FOR16 G17 = FOR17 G18 = FOR18 G19 = FOR19 G20 =FOR20 G21 = FOR21 G22 = FOR22 G23= FOR23 G24 = FOR24 G25 = FOR25 G26= FOR26 G27 = FOR27 G28 = FOR28 G29= FOR29 G30 = FOR30
E1 = Abeokuta E2= Benin E3=Ibadan E4= Ore

The Biplot of stability and mean performance of biomass accumulation for 30 *Dacryodes edulis* accessions evaluated across 4 locations is presented in Figure 3. The small circle indicates the average environment, defined by the intersection of the PC1 and PC2 scores. The line with double heads is called the abscissa. The line that passes through the biplot origin and the average point, with an arrow, is called the average environment axis (AEA), also known as the ordinate. Projections of the accessions onto this axis approximate the mean yield of accessions. Thus, the accessions were ranked along the ordinate. Accession FOR13 (G13) was clearly the highest-performing accession on average, followed by FOR22 (G22) and FOR21 (G21). Accessions FOR11(G11) and FOR 24 (G24) had the mean closest to the grand mean yield. Those that performed below average include Accessions FOR30 (30), FOR28 (G28), FOR2 (G2), FOR25 (G25), FOR23(G23) and FOR3(G3) with FOR30 as the poorest accession.

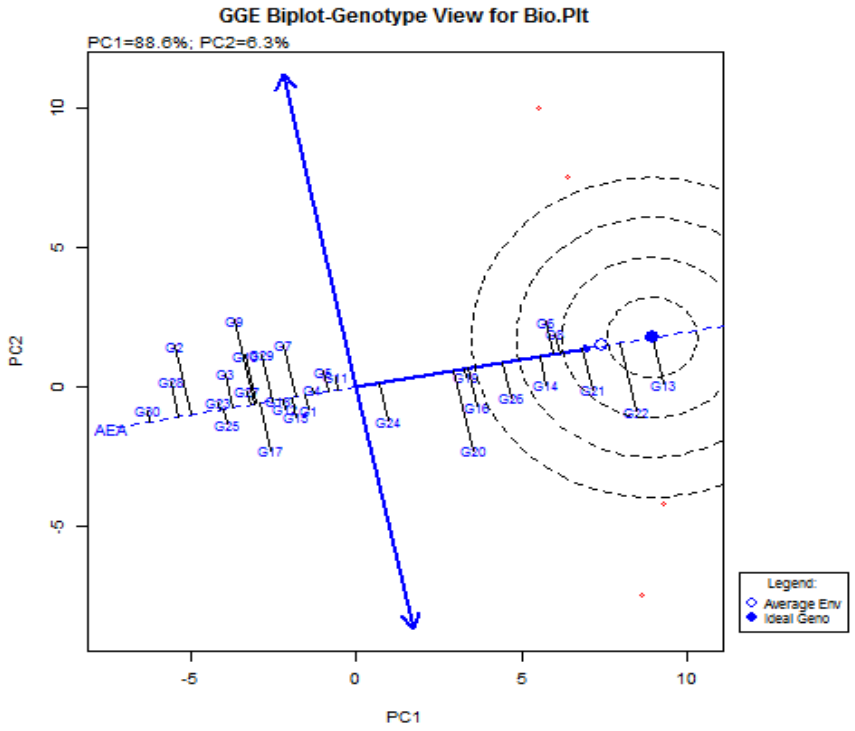


Figure 3: Biplot of stability and mean performance of biomass accumulation of thirty *Dacryodes edulis* accessions evaluated in four environments.

G1=FOR1 G2 =FOR2 G3 FOR3 G4= FOR4 G5= FOR5 G5 =FOR5 G6 = FOR6 G7= FOR7 G8= FOR8 G9 = FOR9 G10 = FOR10 G11 = FOR11 G12 = FOR12 G13 = FOR13 G14 = FOR14 G15 = FOR15 G16 = FOR16 G17 = FOR17 G18 = FOR18 G19 = FOR19 G20 =FOR20 G21 = FOR21 G22 = FOR22 G23= FOR23 G24 = FOR24 G25 = FOR25 G26= FOR26 G27 = FOR27 G28 = FOR28 G29= FOR29 G30 = FOR30

The Biplot showing the discriminative and representative properties of the environments and accessions is presented in Figure 4. It is noted that an adequate environment for experimental evaluation is One with higher cultivar discrimination Power (IPCA1 value), and the most representative is the One that has its IPCA2 value close to zero. Therefore, the most discriminating environment was Ore (E4), which had the highest IPCA 1 values, while the least discriminating environment was Abeokuta (E1). The most represented environment was Ore (E4), which had an IPCA2 value close to zero and an average environment coordinate (AEC), while the least represented was Benin (E2). The GGE biplot also showed that the ideal genotypes must have high IPCA1 values (high mean productivity) and IPCA2 values close to zero (more stable). The genotypes with the highest IPCA1 values (higher environment discriminating Power) were accessions FOR13 (G13) followed by FOR22 (G22), FOR21 (G21), FOR6 (G6), FOR8 (G8) and FOR21(G21) while the genotypes that were most represented include accession FOR13(G13), FOR14 (G14), and FOR21 (G21) which had IPCA2 values of zero or close to zero. Thus, based on the graphic interpretation, only FOR13 (G13) and FOR21 (G21) were identified as the most ideal accessions, followed by accessions FOR22, FOR14, FOR26, and FOR19. FOR13 and 22 performed above average in the environment. This result also confirmed what was observed in the polygon (Figure 2), showing that Genotypes 13 and 22 are the best-performing vertices across all four environments.

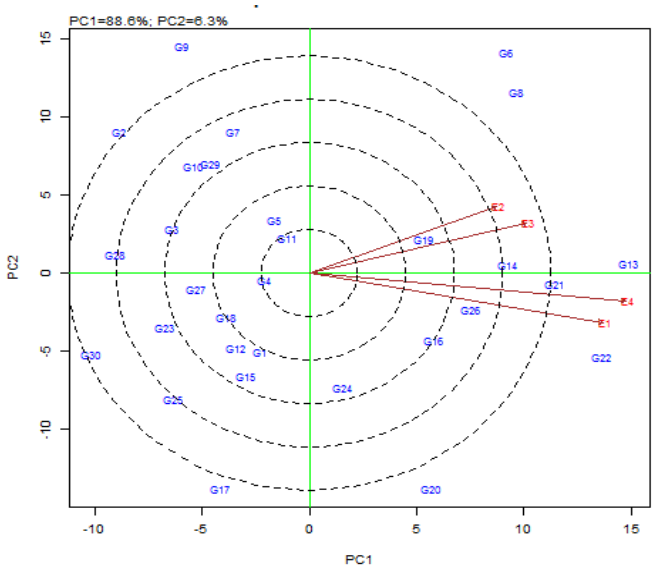


Figure 4: Biplot of discriminative and representativeness of the environments and the accessions.

G1=FOR1 G2 =FOR2 G3 FOR3 G4= FOR4 G5= FOR5 G5 =FOR5 G6 = FOR6 G7= FOR7 G8= FOR8 G9 = FOR9 G10 = FOR10 G11 = FOR11 G12 = FOR12 G13 = FOR13 G14 = FOR14 G15 = FOR15 G16 = FOR16 G17 = FOR17 G18 = FOR18 G19 = FOR19 G20 =FOR20 G21 = FOR21 G22 = FOR22 G23= FOR23 G24 = FOR24 G25 = FOR25 G26= FOR26 G27 = FOR27 G28 = FOR28 G29= FOR29 G30 = FOR30

E1 = Abeokuta E2= Benin E3=Ibadan E4= Ore

Conclusions and Recommendations

The results of this Study clearly indicate that the accessions performed differently across the four environments used, as shown by significant genotype × location (environment) interaction effects. The GGE biplot identified FOR13, 14, 21, and 22 as the highest biomass producers with relatively high stability. Above all, FOR13 was identified as the most ideal accession. These observations demonstrate the full potential of selection from the accessions, with the ideal accession, *Dacryodes edulis*, being relatively stable and producing high biomass across the four locations. All four locations were high-yielding, indicating that *Dacryodes edulis* can be planted in any of them. The identified high-biomass-producing accessions of *D. edulis* could be recommended for use as potential parents in D. edulis improvement.

References

Ajibesin, K. K. (2011). *Dacryodes edulis* (G. Don) H J Lam: A Review on Its Medicinal, Phytochemical and Economical Properties. *Res J Medicinal Plant* 5 (1): 32–41.

Allard, R.W. & Bradshaw, A.D. (1964). Implications of genotype-environment interactions in applied plant breeding. *Crop Science* 4:503-508.

Akusu, O. M., Wordu, G. O. and Obiesie, C. (2019). Effects of Fat Modification on the Physiochemical Properties and Fatty Acid Profile of Shortenings Formulated with African Pear (*Dacryodes edulis*) Pulp Oil and Tallow Tree (*Allanblackia floribunda*) Seed Oil. *Int J Nutr Sci and Food Tech*. 5 (2): 12-19

Alaje V.I., Alake, C.O. & Olalekan Olawale (2018). Genotype×Environment Interaction in Seedling Growth Characteristics of African Pear Fruit (*Dacryodes Edulis* (G.Don) H.J.

Lam) Accessions. *International Journal of Innovative Science and Research Technology*. 3(11):27-235

Alaje, V. I., Amadi,J. O & Olalekan, O. J.(2019). Assessment of biomass stability performance in African pear fruit (*Dacryodes edulis* (G.Don) H.J. Lam) accessions. *Journal of Forestry Research and Management.* 16(3).76-86.

Amise, A. F., Lennox, J. A., & Agbo, B. E. (2016). Antimicrobial Potential and Phytochemical Analysis of *Dacryodes edulis* against Selected Clinical Bacterial Isolates. *Int J Pharmacogn Phytochem Res*., 8 (11): 1795- 1800

Andrade, F.H., Vega, C.R.C., Uhart, S.A., Cirilo, A.G., Cantarero, M., & Valentinuz, O. (1999). Kernel number determination in maize. *Crop Sci.* 39, 453–459.

Anegbeh, P., Ukafor, V., Usoro, C, Tchoundjeu, Z, Leakey, R.R.B. & Schreckenberg, K. (2005). Domestication of *Dacryodes edulis*: 1. Phenotypic variation of fruit traits from 100 trees in southeast Nigeria. *New Forests* 29(2):149-160.

Awono, A., Ndoye, O., Schreckenberg, K., Tabuna, H., Isseri, F., & Temple, L. (2002). Production and marketing of Safou (*Dacryodes edulis*) in Cameroon and internationally: market development issues. *Forests, Trees and Livelihoods,* 12:125-147

Aubreville, A. (1962). Flore du Gabon No 3 *Irvingiaceaes, Simaroubaceaes, Burseraceases*. Museum National d'Historie, Paris, 101p

Ayaz, S., McNeil, D.L., McKenzie, B.A., & H., G.D. (2001). Population and sowing date effect on yield components of grain legumes. Proceedings of the 10th Australian Agronomy Conference. 2001, Hobart, Australia, pp. 125.

Bourdeaut, J. (1971). Le safoutier *Dacryodes (Pachylobus) edulis. Fruits,* 26 (10): 663 – 665

Crossa, J., Fox, P.N., Pfeiffer, W.H., Rajaram, S. and Gauch, H, G. (1991). AMMI adjustment for statistical analysis of an international wheat yield trial. *Theor.Appli.Genet.* 81:27-37

Dixon, A.G.O., Asiedu, R. & Hahn, S. (1994).Genotypic stability and adaptability: analytic methods and implications for cassava breeding for low-input agriculture. In: Tropical root crops in a developing economy. F. Ofori and S.K.Hahn (Eds.), pp.130–137. Proceedings of the 9th Symposium of the International Society for Tropical Root Crops, 20-26 October 1991, Accra, Ghana.

Domitruk, D.R., Duggah, B.L. & Fowler, D.B. (2001). Genotype-environment interaction of no-till winter wheat in Western Canada. *Canadian Journal of Plant Science* 81:7-16.

Duru M., Amadi C., Ugbogu, A., Eze, A. & Amadi, B. (2012). Phytochemical, vitamin and proximate composition of *Dacryodes edulis* fruit at different stages of maturation. *Asian Journal of Plant Science and Research*, 2 (4):437-441

Eberhart, S.A., & Russell, W.A. (1966). Stability parameters for comparing varieties. *Crop Science* 6:36-40.

Enengedi, I. S., Ekpa, O. D., & Ikpi, M. E.(2019). Comparative Study on the cosmetical properties of oils from *Dacryodes edulis* (African pear) and *Persea americana* (avocado) fruits. *American Journal of Chem* 9: 13–20.

Eyenga, L.-F., Nchuaji Tang, E., Achu, M. B. L., Boulanger, R., Mbacham, W. F., & Ndindeng, A. A. (2020). Physical, nutritional and sensory quality of rice-based biscuits fortified with Safou (*Dacryodes edulis*) fruit powder. Food Sci Nutr. 8 (7): 3413–3424.

Fredrick, C., Muthuric, C., Ngamau, K. & Sinclair, F. (2015). Provenance variation in see characteristics, germination and early seedling growth of *Faidherbia albida*. *Journal of Horticulture and Forestry* 7(5):127-140.

Gauch, H.G. & Zobel, R.W. (1996). Identifying mega-environments and targeting genotypes. *Crop Science* 37:311-326.

ISTF NIG 2026

Gauch, H.G. & Zobel, R.W. (1997). Identifying mega-environments and targeting genotypes. *Crop Sci* 37: 311-326

Huxley, P.A. (1983). Some characteristics of trees to be considered in agroforestry.In: Huxley, P. A. (Ed), Plant Research and Agroforestry ICRAF, Nairobi, Kenya, pp 3–12.

Kang, M.S. (1998). Using genotype-environment interaction for crop cultivar development. *Adv. Agro.* 62: 199-252

Kenga, R., Alabi, S.O., & Gupta, S.C. (2003). Yield stability of sorghum hybrids and parental lines. *African Crop Science Journal* 11(2):65–73.

Kengue, J. (2002). The African bush butter tree: *Dacryodes edulis* G. Don. International Centre for Underutilised Crops, Southampton, UK.

Leakey, R.R.B., Atangana, A.R., Kengni, E., Waruhiu, A.N., Usoro, C., Anegbeh, P.O., & Tchoundjeu, Z. (2002). Domestication of *Dacryodes edulis* in West and Central Africa: Characterisation of genetic variation: Forests, Trees and Livelihoods. 12:57-71.

Leakey, R.R.B., Tchoundjeu, Z., Smith, R.I., Munro, R.C., Fondoun, J., Kengue, J., Anegbeh, P.O., Atangana, A.R., Waruhiu, A.N., Asaah, E., Usoro, C., & Ukafor, V. (2004). Evidence that subsistence farmers have domesticated indigenous fruits *Dacryodes edulis* and Irvingia gabonensis in Cameroon and Nigeria: Agroforestry Systems. 60(2):101-111.

Mboujda, F.M.M., Avana-Tientcheu, M.L., Momo, S.T., Ntongme, A.M., Vaissayre, V., Mbofung, C.M.F., Silou, T., Mouragadja, I. (2002). Chemical characterization of Safou (*Dacryodes edulis*) and evaluation of its potential as an ingredient in nutritious biscuits. *Forest, Trees and Livelihoods*, 12: 105-118.

Ogunsuyi, H.O. (2015). Production of biodiesel using African pear (*Dacryodes edulis*) seed oil as feedstock. *African Journal of Biotechnology.* 3(5): 085–092.

Ojo, D.K. (2000). Genotype × environment analysis and selection for yield stability and adaptability in tropical soybean genotypes. *Nigeria Journal of Ecology 2:49-55*

Ondo-Azi, A. S., Missang, C. E., Nsikabaka, S., Silou, T. & Chalchat, J. C. (2014). Variation in Physicochemical and Morphological Characteristics of Safou (*Dacryodes edulis* (G. Don) H. J. Lam) Fruits: Classification and Identification of Elite Trees for Industrial Exploitation. *Journal of Food Agric Environment* 12 (2): 212-217

Samonte, S., Wilson, L.T., Muclad, A.M. & Medley, J.C. (2005). Targeting cultivar onto rice growing environment using AMMI and SREG GGe biplot Analysis. *Crop Science* 45:2414-2424.

SAS Institute (2000). SAS Linear Model: A guide to ANOVA and GLM procedures. SAS Insti., Cary, NC.

Silou T. (1994). Le safou (*Dacryodes edulis* H. J. Lam) : Oleagineux à vocation régionale dans le Golfe de guinee : Synthese des donnees physico-chimiques et technologiques. *In* J. Kengue, J. Nya Ngatchou (eds.) Actes du séminaire régionale sur la valorisation du safoutier, 4-6 october 1994 à Douala, p 123-142

Yan, W. & Kang, M.S. (2003). GGE Biplot Analysis: A Graphical Tool for Breeders, Geneticists and Agronomists. 1st Edn., CRC Press LLC., Boca Raton, Florida, pp: 271

Yan, W. & Rajcan, I. (2002). Biplot analysis of test sites and trait relations of soybean in Ontario. Crop Sci42: 11–20.

Yan, W. & Tinker, N.A. (2006). Biplot analysis of multi-environment trial data: Principles and applications. *J Plant Sc*i 86: 623-645

Yan, W. & Hunt, L.A. (1998). Genotype by environment interaction and crop yield. *Plant Breeding* 16:135-178.

ISTF-NIG2026

ECONOMIC ANALYSIS OF LOCUST BEAN (*Parkia biglobosa*) MARKETING IN BORNO STATE, NIGERIA

Hassan, R., and Zira, B.D
Department of Forest Resources and Wildlife Management
Federal University of Agriculture, Mubi
Ramatohassan001@gmail.com

Abstract

Locust bean (*Parkia biglobosa*) is an important non-timber forest product (NTFP) that contributes significantly to rural livelihoods, food security, and income generation in West Africa. Despite its economic importance, inefficiencies in its marketing system may limit profitability and value addition. This study examined the socioeconomic characteristics, profitability structure, marketing channels, and determinants of profitability of locust bean marketers in Borno State, Nigeria. Primary data were collected from 281 respondents using structured questionnaires, Key Informant Interviews (KII), and Focus Group Discussions (FGDs). Analytical tools included descriptive statistics, Gross Margin analysis, and multiple regression models. Findings show that marketing is male-dominated (98.18%), with a high proportion of married individuals (82.92%) and low educational attainment (71.89% no formal Education). Gross margin analysis indicates profitability for wholesalers (₦19,500/100 kg) and retailers (₦20,000/100 kg). Regression results reveal that Education, experience, credit access, Scale of operation, and Age significantly influence profitability ($p < 0.05$). Major constraints include inadequate storage facilities, price instability, limited credit access, and poor transportation infrastructure. The study concludes that locust bean marketing is profitable but structurally constrained. Strengthening rural finance systems, infrastructure, and processing capacity is essential for improving efficiency and sustainability in the NTFP value chain.

Keywords: *Parkia biglobosa*; NTFPs; forestry economics; value chain; profitability

Introduction

Non-timber forest products (NTFPs) have become increasingly important in supporting rural livelihoods, especially in developing economies where forest resources serve both subsistence and income-generating functions (Shittu *et al.*, 2020; Schreckenberg & Marshall, 2006). Beyond income generation, NTFPs also contribute significantly to food security and nutrition, particularly among rural households that depend on forest ecosystems for dietary supplementation (Sunderland *et al.*, 2014). Among these resources, *Parkia biglobosa* (locust bean) stands out as One of the most valuable indigenous tree species in West Africa due to its wide range of socioeconomic and ecological benefits.

The species produces seeds that are processed into a fermented condiment locally known as *dawadawa*, which is widely consumed across Nigeria and other West African countries. Its popularity is largely attributed to its high protein content, flavour-enhancing properties, and nutritional importance in traditional diets (Ogbemudia *et al.*, 2018; Isah & Abdullahi, 2020). In addition to its nutritional value, *Parkia biglobosa* plays a critical ecological role in agroforestry systems by improving soil fertility, supporting biodiversity, and contributing to sustainable land-use practices (Adewale *et al.*, 2013; Arnold & Ruiz-Pérez, 2001).

In Nigeria, locust bean marketing operates within a well-defined rural value chain that includes collectors, processors, wholesalers, and retailers. This chain provides employment opportunities and income diversification for rural households, with women playing a dominant

role in processing and retail activities (Olukosi *et al.*, 2005; Kiptot & Franzel, 2015). The structure of the NTFP value chain has also been shown to influence income distribution and market efficiency across actors (Akinola & Adebayo, 2019; Nwokedi & Onu, 2017).

Despite its importance, the sector faces several structural and operational challenges. These include rudimentary processing technologies, inadequate storage facilities, seasonal fluctuations in supply, weak market coordination, and limited Access to finance. Collectively, these constraints reduce efficiency, limit value addition, and negatively affect profitability within the value chain (Odebode, 2008; Tacconi, 2012). Poor infrastructure and market imperfections further exacerbate post-harvest losses and reduce producers' share of final consumer prices (Ojo & Adebayo, 2017).

Although previous studies have examined the marketing of non-timber forest products in Nigeria and other developing regions, there remains limited empirical evidence on the determinants of profitability under the semi-arid conditions of northeastern Nigeria. Given the increasing importance of forest-based livelihoods in climate-vulnerable regions, understanding the economic performance of NTFP marketing systems is essential for sustainable rural development planning (FAO, 2014; Sunderland *et al.*, 2014). This study, therefore, addresses this gap by conducting an economic analysis of locust bean marketing in Borno State

Materials and Methods

Study Area

The study was conducted in Borno State, northeastern Nigeria, located between latitudes 12°–14°N and longitudes 10°–14°E. The State covers an estimated land area of about 69,435 km² and shares international boundaries with the Niger Republic, the Chad Republic, and Cameroon. Borno State experiences a semi-arid climate characterized by low and highly variable rainfall, ranging from about 600 mm to 1,500 mm annually, and high temperatures that can reach up to 40°C. The vegetation is predominantly Sudan and Sahel savanna, which supports both agricultural activities and the collection of non-timber forest products (NTFPs), including locust bean (*Parkia biglobosa*). Agriculture is the main economic activity in the State, with crop production and livestock rearing as the primary livelihoods for the majority of rural households.

Sampling Procedure

A multi-stage sampling technique was adopted for the study. In the first stage, four Local Government Areas (LGAs) with notable locust bean marketing activities were purposively selected. In the second stage, major markets within the selected LGAs were identified. In the third stage, the list of registered locust bean marketers in each market formed the sampling frame. Finally, 20% of the registered marketers were randomly selected from each market. This procedure yielded a total sample of 281 respondents, ensuring adequate representation across the selected markets and study locations.

Data Collection Methods

Primary data were collected through structured questionnaires administered to locust bean marketers in the study area. To enrich the quantitative data, qualitative information was also obtained through Key Informant Interviews (KIIs) involving market leaders, processors, and agricultural extension officers, as well as Focus Group Discussions (FGDs) with selected stakeholders. In addition, the KoboCollect digital data collection tool was employed to enhance

data quality, minimize entry errors, and enable real-time monitoring and validation of responses.

Analytical Framework

Descriptive Analysis

Descriptive statistics such as frequencies, percentages, and means were used to analyze the socioeconomic characteristics of respondents, including Age, gender, educational Level, household size, and primary occupation.

Gross Margin Analysis

The profitability of locust bean marketing was estimated using Gross Margin (GM) analysis, specified as:

$$GM = TR - TVC$$

Where:

TR = Total Revenue

TVC = Total Variable Costs

This approach is commonly applied in agricultural and forestry economics, particularly where fixed costs are minimal or difficult to allocate, making it suitable for enterprise-level profitability assessment.

Regression Model

A multiple regression model was employed to determine the factors influencing profitability in locust bean marketing. The model is specified as:

$$GMGM_i = \beta_0 + \beta_1 AGE_i + \beta_2 EDU_i + \beta_3 EXP_i + \beta_4 CREDIT_i + \beta_5 SCALE_i + \varepsilon_i$$

Where:

GM = Gross margin (profitability indicator)

β_0 = Constant term

β_1–β_5 = Coefficients of explanatory variables

AGE = Age of respondent

EDU = Level of Education

EXP = Years of marketing experience

CREDIT = Access to credit (dummy variable)

SCALE = Scale of operation (quantity traded or volume of business)

ε = Error term

ISTF-NIG 2026

i = each respondent,

This model was used to estimate the influence of socioeconomic and institutional variables on the profitability of locust bean marketing in the study area.

Results and Discussion

Socioeconomic Characteristics of Respondents

The socioeconomic characteristics of locust bean marketers in the study area, as presented in Table 1, provide a clear picture of the demographic profile of the actors involved in the enterprise. The results indicate a highly skewed gender distribution, with males accounting for 98.18% of respondents and females accounting for only 1.82%. This strong male dominance suggests that men in the study area largely control locust bean marketing. This finding is consistent with Olukosi *et al.* (2005), who reported that agricultural commodity marketing in northern Nigeria is predominantly male-driven due to the physically demanding nature of bulk handling and transportation. Similarly, Odebode (2008) observed that participation in non-timber forest product (NTFP) trade tends to favour men where long-distance marketing and large-scale transactions are involved.

Marital status results show that 82.92% of respondents are married, while 15.30% are single and 1.78% are divorced. This suggests that locust bean marketing plays an important role in supporting household income and sustaining family welfare. This agrees with Akinbode and Dipeolu (2012), who noted that most participants in agro-based marketing systems are married individuals who depend on such activities for household financial stability.

Educational attainment among respondents is generally low, with 71.89% having no formal Education. Only 7.12% attained primary Education, 12.81% secondary Education, and 8.18% tertiary Education. This pattern is similar to the findings of Ogbemudia *et al.* (2018), who reported low educational levels among rural NTFPs marketers in Nigeria. Low Education limits Access to improved processing technologies, financial services, and market information, thereby constraining efficiency and innovation along the value chain (Adewale *et al.*, 2013).

The household size distribution shows that most respondents live in relatively large households: 30.96% have 4–6 members, 25.62% have 7–9 members, and 23.84% have 10 or more members. This supports the findings of Olukosi *et al.* (2005), who observed that larger household sizes in rural economies provide a reliable source of family labour for agricultural and marketing activities, reducing dependence on hired labour.

In terms of occupation, the majority of respondents (88.61%) are engaged primarily in locust bean marketing, while 11.03% are farmers and 0.36% are civil servants. This finding aligns with Shittu *et al.* (2020), who reported that NTFP-related activities often serve as the principal livelihood source in rural communities where formal employment opportunities are limited.

The results indicate that locust bean marketing in Borno State is a male-dominated, household-based enterprise characterized by low educational attainment and strong reliance on family labour, with significant implications for productivity and value chain efficiency.

Table 1: Socioeconomic Characteristics of Respondents (n = 281)

Variable	Category	Frequency	Percentage (%)
Gender	Male	276	98.18

	Female	5	1.82
Marital Status	Married	233	82.92
	Single	43	15.30
	Divorced	5	1.78
Education Level	No Formal Education	202	71.89
	Primary	20	7.12
	Secondary	36	12.81
	Tertiary	23	8.18
Household Size	1–3	55	19.57
	4–6	87	30.96
	7–9	72	25.62
	10 and above	67	23.84
Primary Occupation	Locust Bean Marketing	249	88.61
	Farming	31	11.03
	Civil Service	1	0.36

Profitability of Locust Bean Marketing

The profitability analysis of locust bean marketing, presented in Table 2, reveals that both wholesale and retail operations are economically viable in the study area. The result is based on a cost-and-return analysis per 100 kg equivalent, showing clear differences in cost structure, revenue generation, and efficiency between the two marketing levels. The gross revenue indicates that retailers generate higher income (₦135,000) than wholesalers (₦120,000). This higher revenue at the retail Level is largely attributable to value-added activities, such as processing, packaging, and direct consumer sales, which increase the product's final market price. However, this higher revenue is accompanied by increased costs, particularly in processing (₦7,000 for retailers compared to ₦3,500 for wholesalers) and packaging. Retailers incur higher variable costs (₦115,000) than wholesalers (₦100,500) due to greater value-added activities. However, both remain profitable, with gross margins of ₦19,500 for wholesalers and ₦20,000 per 100 kg equivalent for retailers. This shows that locust bean marketing is profitable at both levels, with only a slight difference in returns.

In terms of performance, the return per naira (₦) invested shows that wholesalers achieve a slightly higher return (0.19) compared to retailers (0.17). This suggests that although retailers earn a higher absolute gross margin, wholesalers operate more effectively in terms of cost-to-return ratio. This may be due to lower processing intensity and reduced operational expenses at the wholesale Level. These findings align with the work of Adewale *et al.* (2013), who emphasized that while value addition increases absolute income in non-timber forest product (NTFP) markets, it does not always translate into higher efficiency ratios due to increased processing and marketing costs. Similarly, Ogbemudia *et al.* (2018) observed that actors within NTFP value chains experience varying levels of profitability depending on their position and the degree of value added. The results confirm that locust bean marketing is profitable for both wholesalers and retailers, with differences in performance driven by cost structure and Level of value addition.

Table 2: Cost and Return of Locust Bean Marketing (₦ per 100 kg Equivalent)

Variable	Wholesale (₦)	Retail (₦)
Gross Revenue	120,000	135,000
Purchase Cost	85,000	95,000
Transportation	5,000	4,000
Processing Cost	3,500	7,000
Labour	2,500	3,000
Packaging	1,500	2,500

Storage	1,000	1,500
Miscellaneous	2,000	2,000
Total Variable Cost	**100,500**	**115,000**
Gross Margin	**19,500**	**20,000**
Return per ₦ Invested	0.19	0.17

Marketing Channels

The study identified four main marketing channels through which locust bean is distributed from producers to final consumers in the study area. These channels differ in structure, number of intermediaries, and degree of value addition. The distribution of respondents across the identified channels is presented in Table 3. The results show that the most dominant marketing pathway is Channel 1, which involves the flow of produce from producers to wholesalers, then retailers, and finally to consumers. This channel accounts for 60% of the total marketing structure, indicating that locust bean marketing in the study area is largely characterized by traditional multi-stage distribution. The dominance of this channel reflects the reliance on intermediaries in rural agricultural markets, where producers often lack direct Access to final consumers.

Channel 2, which involves commission agents between producers and wholesalers, accounts for 20% of the marketing system. The presence of commission agents further lengthens the marketing chain, increasing transaction costs while reducing producers' share of final prices. This type of structure is commonly observed in developing agricultural markets where market coordination is weak, and intermediaries play a significant role in facilitating transactions.

Channel 3 represents direct sales from producers to consumers and accounts for 15% of the marketing channels. This shorter chain eliminates intermediaries, allowing producers to capture a larger share of the consumer price. Although less dominant, its presence suggests improving market linkages and increased direct interaction between producers and consumers.

Channel 4, which involves processing before retailing and final consumption, accounts for only 5% of the market structure. This channel adds value through processing activities, improving product quality and increasing profitability for the actors involved. However, its low proportion indicates limited processing capacity and underdeveloped value addition activities within the study area.

The dominance of long marketing chains (Channels 1 and 2, totalling 80%) reflects inefficiencies typical of rural agricultural marketing systems in developing economies, as noted by Olukosi *et al.* (2005). However, the presence of direct and processing-based channels (Channels 3 and 4) indicates a gradual shift toward improved market efficiency and value chain upgrading. This is consistent with findings by Adewale *et al.* (2013) and Ogbemudia *et al.* (2018), who emphasized that value addition and direct marketing enhance income distribution and reduce marketing inefficiencies in non-timber forest product systems.

Table 3: Locust Bean Marketing Channels and Distribution

Channel	Description	Percentage (%)
Channel 1	Producers → Wholesalers → Retailers → Consumers	60
Channel 2	Producers → Commission Agents → Wholesalers → Retailers → Consumers	20
Channel 3	Producers → Consumers (Direct Sales)	15
Channel 4	Producers → Processors → Retailers → Consumers	5

Determinants of Profitability

The regression results for the determinants of profitability in locust bean marketing are presented in Table 4. The model shows a good fit, with an R^2 of 0.68, indicating that the included explanatory variables account for 68% of the variation in profitability. The F-value of 12.45 indicates that the model is statistically significant overall, suggesting that the joint influence of the variables is meaningful in explaining differences in profitability among marketers.

The estimated constant term (5200) is positive and statistically significant at the 1% level, suggesting a baseline level of profitability even when all explanatory variables are held constant. Age has a positive and significant effect on profitability (coefficient = 0.45, $p < 0.05$), suggesting that older marketers achieve higher profitability. This may be attributed to accumulated business experience, stronger networks, and improved decision-making over time. Education is also highly significant and positively associated (coefficient = 1250, $p < 0.01$), indicating that higher educational attainment increases profitability. Educated marketers are better able to process market information, adopt more effective techniques, and make more efficient marketing decisions.

Experience significantly influences profitability (coefficient = 0.80, $p < 0.05$), suggesting that marketers with more years in the business are more efficient at managing market risks, price fluctuations, and customer relationships. Access to credit has a strong positive and significant effect (coefficient = 4500, $p < 0.01$). This indicates that marketers with Access to financial support can expand their operations, purchase in bulk, and invest in storage and processing facilities, thereby increasing profitability. Scale of operation is also positive and significant (coefficient = 2.10, $p < 0.05$), suggesting that marketers who handle larger volumes benefit from economies of Scale and lower unit costs, which translate into higher profits.

The results confirm that human capital variables (Age, Education, and experience), along with financial Access and Scale of operation, are key determinants of profitability in locust bean marketing. This finding is consistent with Ojo and Adebayo (2017), who emphasized that Education, experience, and credit access are critical drivers of performance in agricultural marketing systems.

Table 4: Regression Results for Determinants of Profitability

Variable	Coefficient	Std. Error	t-value
Constant	5200	1200	4.33***
Age	0.45	0.18	2.50**
Education	1250	400	3.13***
Experience	0.80	0.30	2.67**
Credit Access	4500	1500	3.00***
Scale of Operation	2.10	0.75	2.80**

$R^2 = 0.68$ F-value = 12.45 *** Significant at 1% ** Significant at 5%

Constraints to Marketing Performance

The performance of locust bean marketing in the study area is influenced by several interrelated challenges that limit effective operation across the value chain. The major constraints identified by respondents are presented in Table 5, with varying degrees of severity based on their mean scores and rankings. The most critical constraint is the lack of adequate storage facilities, which recorded the highest mean score (2.85) and was ranked first. This indicates that poor storage infrastructure is the most serious challenge facing marketers. Inadequate storage results in rapid

product deterioration, significant post-harvest losses, and forced sales at low prices, thereby undermining profitability. This finding aligns with Odebode (2008), who reported that storage limitations are a major cause of post-harvest losses in non-timber forest product markets. Price fluctuation ranks second (mean score = 2.78), reflecting unstable market conditions and unpredictable income patterns. Such volatility discourages long-term investment and undermines the stability of marketing activities. This is consistent with Shittu *et al.* (2020), who observed that weak market coordination and seasonal supply variations contribute significantly to price instability in rural markets.

Limited Access to credit ranks third (mean score = 2.70), indicating financial constraints as a major barrier to business expansion and investment in improved marketing practices. This limits marketers' capacity to scale up operations or adopt better technologies, as noted by Akinbode and Dipeolu (2012). Poor transportation infrastructure (mean score = 2.65) is ranked fourth and increases transaction costs while restricting Access to distant markets. Processing difficulties (2.58) and market information gaps (2.50) also negatively affect value addition and reduce marketers' ability to make informed pricing and sales decisions. Other constraints include spoilage/perishability (2.42) and high labour costs (2.30), although these are relatively less severe than the top-ranked challenges. The findings indicate that inadequate storage facilities and price instability are the most pressing constraints, followed by limited credit access and transportation challenges. These factors collectively reduce market performance, hinder value addition, and limit profitability in the locust bean marketing system.

Table 5: Constraints Faced by Marketers

Constraint	Mean Score	Rank
Lack of storage facilities	2.85	1st
Price fluctuation	2.78	2nd
Limited credit access	2.70	3rd
Poor transportation	2.65	4th
Processing difficulties	2.58	5th
Market information gap	2.50	6th
Spoilage/perishability	2.42	7th
High labour cost	2.30	8th

Conclusion

This study examined the economic analysis of locust bean (*Parkia biglobosa*) marketing in Borno State, Nigeria, with emphasis on socioeconomic characteristics, profitability, marketing channels, determinants of profitability, and constraints affecting performance. The findings reveal that locust bean marketing is a viable and profitable non-timber forest product (NTFP) enterprise that contributes meaningfully to rural livelihoods and income generation in the study area. The socioeconomic profile of respondents shows that the enterprise is predominantly male-dominated, with low levels of formal Education and a high proportion of married individuals. This suggests that locust bean marketing functions largely as a household-based livelihood strategy supported by family labour. Despite the low educational attainment, participants remain actively engaged in the value chain, indicating the importance of the enterprise in rural income diversification.

Profitability analysis confirms that both wholesalers and retailers obtain positive gross margins, demonstrating that locust bean marketing is economically viable across different levels of the value chain. However, efficiency differences exist: wholesalers exhibit slightly higher returns per naira invested, while retailers benefit from higher absolute margins from value-added

activities. The marketing structure is characterized by long, multi-stage channels dominated by intermediaries, which contribute to inefficiencies and reduced producer shares of final consumer prices. Nevertheless, the presence of direct and processing-based channels suggests gradual improvement in value chain integration. Regression results indicate that Education, experience, Age, Access to credit, and Scale of operation significantly influence profitability. These findings highlight the importance of human capital development and financial inclusion in enhancing marketing efficiency and income outcomes.

Major constraints identified include inadequate storage facilities, price instability, limited Access to credit, poor transportation infrastructure, and processing challenges. These constraints collectively reduce efficiency, increase post-harvest losses, and limit value addition within the marketing system. In conclusion, locust bean marketing in Borno State is profitable but constrained by structural, infrastructural, and institutional challenges. Strengthening Access to credit, improving rural infrastructure (especially storage and transportation), and promoting value-addition technologies are essential policy interventions to enhance efficiency, reduce losses, and improve the overall performance of the locust bean value chain.

Recommendations

Based on the findings of this study, the following recommendations are made:

Provision of Improved Storage and Processing Facilities: Government and relevant development agencies should support the provision of modern storage and processing facilities for locust bean marketers. This will reduce post-harvest losses, improve product quality, and enhance overall marketing efficiency, especially given that inadequate storage was identified as the most serious constraint.

Strengthening Access to Credit and Financial Support: Financial institutions and agricultural support programs should design credit schemes that are accessible to locust bean marketers. Improved Access to credit will enable expansion of operations, investment in value-added activities, and increased profitability across the value chain.

Improvement of Rural Infrastructure (Transport and Market Information):

Efforts should be made to improve rural road networks and transportation systems, alongside the establishment of reliable market information systems. This will reduce marketing costs, minimize price instability, and enhance efficient distribution of locust bean products.

References

Adewale, B. A., Oladele, O. I., & Adekunle, V. A. J. (2013). Non-timber forest products and rural livelihoods in Nigeria: A value chain analysis. *Journal of Forest Economics and Management, 10*(2), 45–58.

Akinbode, S. O., & Dipeolu, A. O. (2012). Socioeconomic determinants of participation in agricultural marketing systems in Nigeria. *Agricultural Economics Review, 13*(2), 67–78.

Akinola, A. A., & Adebayo, O. O. (2019). Value chain analysis of non-timber forest products in Nigeria. *Forest Policy and Economics, 98*, 112–121.

Arnold, J. E. M., & Ruiz-Pérez, M. (2001). Can non-timber forest products match tropical forest conservation and development objectives? *Ecological Economics, 39*(3), 437–447.

ISTF NG 2026

FAO. (2014). *State of the world's forests 2014: Enhancing the socioeconomic benefits from forests*. Food and Agriculture Organization of the United Nations.

Isah, A. D., & Abdullahi, M. (2020). Nutritional and economic importance of *Parkia biglobosa* in West Africa. *International Journal of Food Science, 12*(1), 45–53.

Kiptot, E., & Franzel, S. (2015). Gender and agroforestry in Africa: Are women participating? *World Agroforestry Centre Working Paper*.

Nwokedi, C. J., & Onu, J. I. (2017). Market efficiency of agricultural commodities in rural Nigeria. *Journal of Agricultural Extension, 21*(1), 34–49.

Odebode, S. O. (2008). Approaches to local handling and storage of non-timber forest products in Nigeria. *Journal of Sustainable Agriculture, 32*(4), 489–504.

Ogbemudia, F. O., et al. (2018). Marketing structure and performance of locust bean (*Parkia biglobosa*) in Nigeria. *Journal of Forestry Economics, 45*(2), 120–134.

Ojo, M. A., & Adebayo, A. A. (2017). Determinants of profitability in agricultural marketing systems in Nigeria. *Nigerian Journal of Agricultural Economics, 8*(2), 55–70.

Olukosi, J. O., Isitor, S. U., & Ode, M. O. (2005). *Introduction to agricultural marketing and prices: Principles and applications*. Living Book Series.

Schreckenberg, K., & Marshall, E. (2006). Non-timber forest products and rural livelihoods in developing countries. *ODI Forestry Briefing*.

Shittu, A. M., et al. (2020). Non-timber forest products and rural livelihoods in semi-arid regions of Nigeria. *African Journal of Environmental Science and Technology, 14*(6), 210–219.

Sunderland, T. C. H., et al. (2014). Global importance of non-timber forest products for food security and nutrition. *Biodiversity and Conservation, 23*(3), 683–699.

Tacconi, L. (2012). Reducing emissions from deforestation and forest degradation: A review of the evidence. *Environmental Science and Policy, 15*(1), 89–96.

ISTF-NIG 2026

COMMUNITY PARTICIPATION IN ENVIRONMENTAL CONSERVATION: A CASE STUDY OF IDO LOCAL GOVERNMENT AREA

Oyewumi, Racheal. Omolade*, Aina, Kehinde S., Adesokan, Bola., Ibrahim, Tola. O and Adeleke, Oluwaseun. A

Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria, Ibadan, Nigeria
**Corresponding author: ajayiomolade1@gmail.com*

Abstract
Constrained by inadequate waste management infrastructure, limited recycling facilities, and weak enforcement of environmental regulations. The study therefore recommends strengthening. Environmental degradation resulting from improper waste management has become a major challenge in many developing countries, including Nigeria. Community participation is widely recognized as an important strategy for promoting environmental conservation and sustainable waste management. This study examined the level of community participation in environmental conservation with particular emphasis on plastic waste management practices among residents in Ido Local Government Area of Oyo State, Nigeria. The study employed a descriptive survey research design, with primary data collected via structured questionnaires administered to a sample of 200 respondents selected through a multistage sampling technique. Data were analyzed using descriptive statistics, including frequencies, percentages, tables, and charts. The findings revealed that plastic waste generation is widespread among residents, with water sachets (38%), plastic bottles (27%), nylon bags (21%), and food containers (14%) constituting the major types of plastic waste generated. The study also found that open dumping (31.7%) and municipal waste collection (28.3%) were the most common disposal methods, while recycling participation was relatively low, with more than half of respondents (52.5%) indicating that they never recycle plastic waste. Waste segregation practices were also limited, as only 38.3% of respondents reported separating plastic waste from other household waste. Furthermore, socio-economic factors such as Education level, occupation, and age were found to influence environmental awareness and participation in waste management practices. The study concludes that although residents demonstrate some level of environmental awareness, effective community participation in environmental conservation remains limited to municipal waste management systems, and that this participation should be expanded to promote environmental Education and public awareness, encourage community-based environmental initiatives, and support recycling programs to enhance sustainable environmental management.

Keywords: Community participation, environmental conservation, environmental sustainability, plastic waste management, Nigeria.

Introduction

Environmental degradation has emerged as One of the most pressing global challenges of the twenty-first century (Akinbile & Yusoff, 2022). Rapid urbanization, population growth, industrialization, and unsustainable consumption patterns have significantly contributed to environmental problems such as pollution, deforestation, biodiversity loss, and climate change (UNEP, 2021). These environmental challenges are particularly severe in developing countries where waste management systems and environmental governance structures remain inadequate. In Nigeria, improper waste management practices have contributed significantly to environmental pollution and public health challenges (Babaremu *et al.,* 2022). The

increasing consumption of plastic materials has led to a rise in plastic waste, often exceeding municipal waste management systems' capacity. Studies indicate that Nigeria generates several million tonnes of plastic waste annually, much of which is poorly managed due to inadequate infrastructure, limited recycling facilities, and weak institutional frameworks (Babayemi *et al*., 2019; Oyelola, 2023). Community participation plays a critical role in addressing environmental challenges and promoting sustainable resource management (Animashun *et al.,* 2025). Participation refers to the active involvement of individuals, households, and community groups in environmental decision-making processes and conservation activities (Pretty, 1995). When communities actively participate in environmental programs, they develop a sense of ownership and responsibility toward environmental resources (Reed *et al.,* 2018). Local governments are particularly important in promoting grassroots environmental conservation because they are the closest administrative institutions to communities (Wilson *et al.,* 2015). Through environmental sanitation programs, waste management initiatives, and community awareness campaigns, local governments can mobilize residents to adopt sustainable environmental practices.

Despite growing awareness of environmental issues, many communities in Nigeria continue to face challenges related to improper waste disposal, environmental pollution, and limited community participation in conservation activities (World Bank, 2018). Understanding the level of community participation and the socio-economic factors influencing environmental behaviour is essential for developing effective environmental policies and sustainable waste management strategies. This study, therefore, examines community participation in environmental conservation in the Ido Local Government Area of Oyo State to identify the key factors influencing environmental behaviour and opportunities to improve environmental sustainability.

Materials and Methods

Study Area

The study was conducted in the Ido Local Government Area of Oyo State, Nigeria. The area is located within the Ibadan metropolitan region and is characterized by both rural and semi-urban settlements. Agriculture, petty trading, and civil service constitute the main occupations of residents.

Research Design

The study employed a descriptive survey research design to systematically collect data on environmental behaviour, waste generation patterns, and community participation in environmental conservation activities.

Population of the Study

The study population consisted of households and residents in selected communities in the Ido Local Government Area.

Sample Size and Sampling Procedure

A total of **200 respondents** were selected using a multistage sampling approach combining purposive and random sampling.

Data Collection

Primary data were collected through a structured questionnaire, while secondary data were obtained from journal articles, textbooks, and environmental reports.

Data Analysis

Descriptive statistical methods, including frequency distributions, percentages, tables, and charts, were used to analyze the data.

Results and Discussion

Socio-Economic Characteristics of Respondents

The study involved 200 respondents across selected urban communities in Ibadan. Table 1 presents the distribution of respondents by age, gender, Education level, and occupation. The socio-economic profile indicates that the majority of respondents were educated (74% at secondary or tertiary level) and a large proportion were engaged in trading (32%) or the civil service (26%). These factors are significant because Education and occupation influence environmental awareness, waste generation patterns, and participation in conservation activities (Ibrahim *et al*., 2025; Chilote & Dhakal, 2025).

Table 1 Socio-Economic Characteristics of Respondents

Characteristic	Category	Frequency	Percentage (%)
Gender	Male	112	56
	Female	88	44
Age (years)	18–30	60	30
	31–45	90	45
	46–60	40	20
	>60	10	5
Education Level	No formal Education	18	9
	Primary	34	17
	Secondary	88	44
	Tertiary	60	30
Occupation	Trader	64	32
	Farmer	30	15
	Civil servant	52	26
	Artisan	28	14
	Others	26	13

Fieldwork, 2025

Types and Frequency of Plastic Waste Generated

The study revealed that plastic waste generation is widespread among residents, with 96% of respondents producing it, highlighting the high reliance on plastic packaging in urban communities. Among the different types of plastic waste, water sachets accounted for 38%, followed by plastic bottles (27%), nylon bags (21%), and food containers (14%) (Figure 1). These findings are consistent with those of Otitoju *et al.* (2023), who reported that packaged drinking water and single-use plastics are the major contributors to municipal waste in Nigerian cities. The high prevalence of sachets and bottles reflects both convenience and limited access to safe potable water (Babayemi *et al*., 2019; Ejiogu *et al.,* 2021). The results suggest that packaging materials are the primary contributors to plastic waste in urban communities. This finding is consistent with global studies, which report that packaging accounts for the largest proportion of plastic waste in municipal solid waste streams (UNEP, 2021).

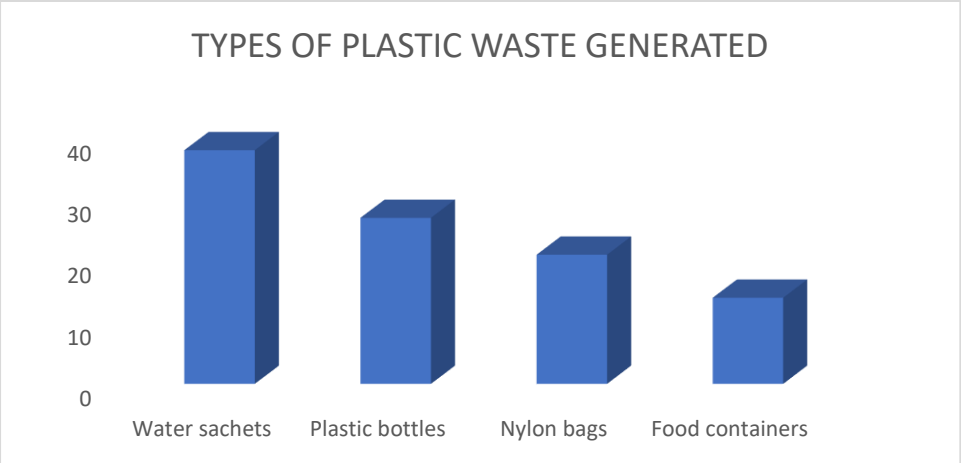


Figure 1: Types of plastic waste generated by respondents

Plastic Waste Disposal Practices

Respondents reported several methods for disposing of plastic waste. Open dumping was the most common practice (31.7%), followed by municipal collection (28.3%), burning (18.3%), recycling/selling to scavengers (15%), and burying (6.7%) (Figure 2). These results are similar to findings by Akinbile and Yusoff (2022), who noted that improper disposal and burning are prevalent due to inadequate waste management infrastructure in many Nigerian cities. The persistence of open dumping and burning is concerning because these practices contribute directly to urban flooding, soil contamination, and air pollution (Alabi *et al.,* 2019). These environmental risks reinforce the need for functional waste collection systems and community engagement in environmental sanitation initiatives.

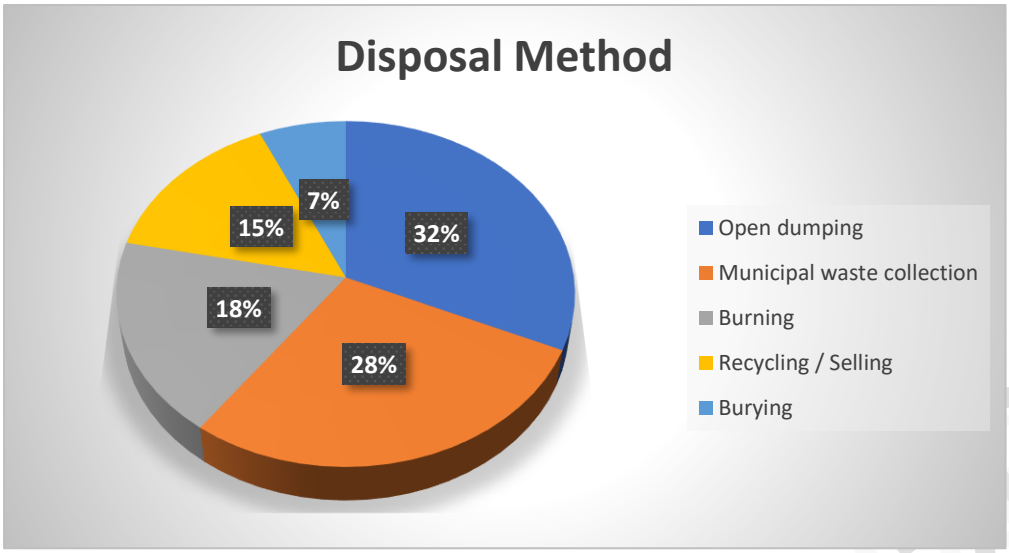


Figure 2: Plastic waste disposal methods among respondents

Waste Segregation and Recycling Behaviour

Only 38.3% of respondents practiced source segregation, while 61.7% did not (Table 2). Similarly, recycling behaviour was weak, with 52.5% never recycling, 30.8% recycling occasionally, and 16.7% recycling regularly (Table 3). This highlights a significant awareness–practice gap, consistent with findings by Ibrahim *et al*. (2025), who reported that even when urban residents are aware of environmental hazards, behavioural adoption is limited by infrastructural and institutional constraints. The low recycling rate may also be attributed to the lack of collection and recycling infrastructure, poor economic incentives, and limited environmental Education (Reed *et al.*, 2018; Oyewale *et al.,* 2023; Otitoju *et al.,* 2023; Chilote & Dhakal, 2025). Improving recycling awareness, access to recycling facilities, and community-led programmes are essential steps for increasing sustainable behaviour among residents.

Table 2 Waste Segregation Practices

Practice	Frequency	Percentage (%)
Yes	46	38.3
No	74	61.7
Total	**120**	**100**

Table 3: Recycling Behaviour

Recycling Frequency	Frequency	Percentage (%)
Regularly	20	16.7
Occasionally	37	30.8
Never	63	52.5
Total	**120**	**100**

Fieldwork, 2025

Environmental Implications of Plastic Waste Management Practices

Improper plastic waste disposal was found to have substantial environmental implications. Open dumping and burning of plastics contribute to soil and water contamination, blockage of drainage channels, and air pollution, thereby increasing public health risks such as respiratory illnesses and waterborne diseases (Alabi *et al*., 2019; UNEP, 2021). Non-biodegradable plastics also accumulate in soils and water bodies, threatening local ecosystems and biodiversity (Akinbile & Yusoff, 2022; Ejiogu *et al.,* 2025). The findings reinforce the importance of community participation in environmental management, where residents can be mobilized to adopt proper disposal practices, plant trees, and support recycling initiatives. Participatory environmental management has been shown to improve program effectiveness by fostering local ownership, accountability, and the sustainable use of resources (Pretty, 1995; Reed *et al*., 2018; Ikelle *et al*., 2023).

Discussion of Findings

Plastic waste generation is high, particularly among young, educated respondents and those engaged in trading or civil service.

- Open dumping and burning dominate disposal practices, especially among low-income or less-educated residents.
- Recycling and segregation are more common among respondents with higher levels of Education and awareness.
- Improper plastic disposal has major environmental and public health impacts, disproportionately affecting lower-income communities.
- Socio-economic characteristics, including age, Education, occupation, and income, significantly influence waste generation, disposal methods, and environmental participation. These findings confirm that community participation in environmental management is closely linked to socio-economic factors, supporting earlier studies that highlight the role of Education, occupation, and income in shaping environmental behaviour (Ibrahim *et al*., 2025; Chilote & Dhakal, 2025).

Conclusion

This study examined community participation in environmental conservation with particular emphasis on plastic waste management practices among residents in the study area. The findings reveal that plastic waste is widespread due to the extensive use of single-use plastics, such as water sachets, plastic bottles, and nylon packaging. Despite moderate levels of Education among respondents, improper disposal practices, particularly open dumping and burning, remain common due to inadequate waste management infrastructure and limited access to formal waste collection services. The results further indicate that socio-economic factors such as Education level, occupation, and age significantly influence environmental behaviour, including waste segregation and recycling practices. Although some respondents demonstrated awareness of environmental issues, actual participation in sustainable waste management practices, such as recycling and waste separation, remains relatively low. This gap between awareness and practice highlights the need for improved environmental Education, community engagement, and supportive institutional frameworks. This study demonstrates that effective environmental conservation requires not only individual awareness but also strong institutional support, adequate infrastructure, and active community participation. Strengthening local waste management systems and promoting participatory

environmental governance are essential for reducing plastic pollution and enhancing environmental sustainability in urban communities.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. **Strengthening Waste Management Infrastructure:** Local governments should improve municipal waste collection systems by providing adequate waste bins, collection points, and recycling facilities in residential areas.
2. **Environmental Education and Awareness:** Continuous public awareness campaigns should be organized to educate residents on proper waste disposal, recycling practices, and the environmental impacts of plastic pollution.
3. **Promotion of Community Participation:** Community-based environmental programs such as sanitation exercises, neighborhood clean-up campaigns, and recycling initiatives should be encouraged to enhance community ownership of environmental conservation efforts.
4. **Policy Enforcement and Regulation:** Government authorities should strengthen enforcement of environmental regulations on waste disposal and sanitation to discourage indiscriminate dumping and burning of waste.
5. **Support for Recycling and Circular Economy Initiatives:** Policies that encourage recycling industries, waste recovery programs, and incentives for plastic waste collection should be implemented to promote sustainable waste management.
6. **Integration of Environmental Education in Schools:** Environmental sustainability and waste management. Education should be incorporated into school curricula to promote environmentally responsible behaviour among younger generations.

References

Alabi, O. A., Ologbonjaye, K. I., Awosolu, O., and Alalade, O. E. (2019). Public and environmental health effects of plastic waste disposal: A review. *Journal of Toxicology and Risk Assessment, 5*(021), 1–13.

Animashaun, L., Yekinni, A., Olaiya, K., Ogunyemi, O., & Adewuyi, P. (2025). Estimation of plastic production, consumption, and waste generation in Nigeria: 2020–2050. *Environmental Research and Technology, 8*(4), 784–791. https://doi.org/10.35208/ert.1585102

Akinbile, C. O., & Yusoff, M. S. (2022). Environmental sustainability challenges in developing countries. *Environmental Science and Pollution Research, 29*, 11020–11032.

Babayemi, J. O., Nnorom, I. C., Osibanjo, O., & Weber, R. (2019). Ensuring sustainability in plastics use in Africa: Consumption, waste generation, and projections. *Environmental Sciences Europe, 31*(60), 1–13. https://doi.org/10.1186/s12302-019-0254-5

Babaremu, K. O., Okoya, S. A., Hughes, E., Tijani, B., Teidi, D., Akpan, A., Igwe, J., Karera, S., Oyinlola, M., & Akinlabi, E. (2022). Sustainable plastic waste management in a circular economy. *Heliyon, 8*(7), e09984. DOI: https://www.cell.com/heliyon/fulltext/S2405-8440(22)01272-5

Chilote, M. O., & Dhakal, H. N. (2025). Plastic pollution and framework towards sustainable plastic waste management in Nigeria: Case study. *Environments, 12*(6), 209. https://doi.org/10.3390/environments12060209

Ejiogu, I. K., Ibeneme, U., Aiyejagbara, M. O., and Oyemachi, D. (2021). Pyrolysis of waste plastics as an effective tool in sustainable environmental waste management. *Modern Chemistry, 9*(2), 33–39. DOI:http://doi.org/10.11648/j.mc.20210902.11

Ikelle, I. I., Olivia, E. N., & Ogah, A. O. (2023). Innovations for sustainable plastic waste management in Nigeria. *Environmental Contaminants Reviews, 6*(2), 66–74. DOI: http://doi.org/10.26480/ecr.02.2023.66.74

Ibrahim, S., Saba, A., Mohammed, H., & Ojewole, F. (2025). Public awareness and perception of plastic pollution in Nigerian urban communities. Environmental Management Journal, 14(2), 55–68. https://doi.org/10.1016/j.envman.2025.02.005

Otitoju, M. A., Olawoye, T., Abiola, S. S., Ahmed, S., andOkoma, O. (2023). Plastic waste management and recycling: A review. *Journal of Global Social Sciences, 4*(16), 60–71. DOI: https://doi.org/10.58934/jgss.v4i16.219

Oyelola, O. O. A Review of Sustainability Reporting for Non-Profits in Africa. Sustainability Management and Strategy, 151–168. https://www.taylorfrancis.com/chapters/edit/10.4324/9781003517368-19

Oyewale, J. A., Tartibu, L. K., & Okokpujie, I. P. (2023). A comparative bibliometric analysis of plastic waste recycling research. *International Journal of Sustainable Development and Planning, 18*(11), 3401–3417. https://iieta.org/journals/ijsdp/paper/10.18280/ijsdp.181106

Pretty, J. (1995). Participatory learning for sustainable agriculture. *World Development, 23*(8), 1247–1263. https://doi.org/10.1016/0305-750X(95)00046-F

Reed, M. S., Vella, S., Challies, E., De Vente, J., Frewer, L., Hohenwallner-Ries, D., Huber, T., Neumann, R. K., Oughton, E., Sidoli Del Ceno, J., and Van Delden, H. (2018). A theory of participation: What makes stakeholder and public engagement in environmental management work? *Restoration Ecology, 26*(S1), S7–S17. https://doi.org/10.1080/14735903.2023.2239075

United Nations Environment Programme (2021). *Making peace with nature: A scientific blueprint to tackle the climate, biodiversity and pollution emergencies*. https://www.unep.org/resources/making-peace-nature

Wilson, D. C., Rodic, L., Modak, P., Soos, R., Carpintero, A., Velis, C., Iyer, M., & Simonett, O. (2015). Global waste management outlook. United Nations Environment Programme. https://doi.org/10.18356/7646c0f8-en

World Bank. (2018). What a waste 2.0: A global snapshot of solid waste management to 2050. World Bank. https://doi.org/10.1596/978-1-4648-1329-0.

SUSTAINABLE HARVESTING OF FOREST FRUITS AS A CONSERVATION STRATEGY: A REVIEW

ADEMOLA Idowu Tolulope

Forestry Research Institute of Nigeria,Ibadan.
Corresponding Email: ademlatolu3@gmail.com

Abstract

Sustainable harvesting of forest fruits, a major component of non-timber forest products (NTFPs), has gained increasing recognition as a viable strategy for biodiversity conservation, livelihood enhancement, and sustainable forest management. Forest fruits provide essential ecosystem services, including food security, income generation, and medicinal benefits, particularly in developing countries. Approximately One1 billion people depend on forests for subsistence, with a significant proportion relying on NTFPs, such as wild fruits, for nutrition and economic resilience. Sustainable harvesting practices aim to balance extraction with regeneration capacity, ensuring long-term ecosystem stability while meeting human needs. This review synthesizes existing literature on the ecological, economic, and socio-cultural dimensions of forest fruit harvesting, highlighting its potential as a conservation tool. Evidence suggests that non-destructive fruit harvesting can maintain forest structure and biodiversity, unlike timber extraction. However, commercialization pressures, inadequate governance, and a lack of scientific harvesting guidelines often lead to overexploitation. Sustainable harvesting frameworks incorporating community-based management, adaptive monitoring, and policy integration have shown promise in mitigating these risks. The review also discusses key challenges, including market-driven exploitation, ecological uncertainties, and limited research on species-specific sustainability thresholds. Recommendations are provided for improving sustainable harvesting practices through policy support, capacity building, and integration into broader conservation strategies. This study concludes that when properly managed, sustainable harvesting of forest fruits can serve as an effective conservation strategy that aligns ecological preservation with socio-economic development.

Keywords: Non-timber forest products, forest fruits, sustainable harvesting, conservation, biodiversity, livelihoods

Introduction

Forests are complex and multifunctional ecosystems that provide a wide range of provisioning, regulating, cultural, and supporting services essential to human well-being and ecological stability. These services include food supply, climate regulation, biodiversity conservation, soil protection, and cultural values that sustain both local and global populations (Millennium Ecosystem Assessment, 2005; FAO, 2022). Among these services, non-timber forest products (NTFPs) have gained increasing recognition as critical components of sustainable forest management and conservation strategies. NTFPs are broadly defined as all biological materials other than timber that are extracted from natural forests, including fruits, seeds, nuts, resins, medicinal plants, fibers, and wildlife products (Shackleton *et al*., 2015; Ticktin and Shackleton, 2020). Globally, NTFPs are harvested across more than 120 countries and are associated with approximately 70–75% of the world's forest ecosystems, reflecting their widespread ecological and socio-economic importance (FAO, 2020; Wunder *et al*., 2014). It is estimated that over

80% of people in developing countries depend on NTFPs for subsistence, healthcare, and income generation, particularly in rural and forest-dependent communities (Angelsen *et al*., 2014; Belcher *et al*., 2021). In sub-Saharan Africa, NTFPs contribute significantly to household livelihoods, often accounting for 15%-40% of total household income, thereby serving as a critical safety net during periods of economic or environmental shocks (Njana *et al*., 2019; Sunderland *et al*., 2020). This highlights their role in poverty alleviation, livelihood diversification, and socio-economic resilience.

Forest fruits, commonly referred to as wild edible fruits (WEFs), represent One of the most widely utilized categories of NTFPs. These fruits are rich in essential micronutrients, including vitamins (A, C, and E), minerals, dietary fiber, and bioactive compounds such as antioxidants, which are crucial for improving dietary diversity and addressing malnutrition (Sardeshpande and Shackleton, 2019; Powell *et al*., 2015). In many tropical and subtropical regions, forest fruits serve as seasonal dietary supplements and emergency food sources during periods of food scarcity or crop failure (Termote *et al*., 2011; Jamnadass *et al*., 2020). Beyond their nutritional significance, forest fruits play a fundamental ecological role in maintaining forest dynamics. They support trophic interactions by serving as food for frugivorous animals, including birds, primates, and mammals, which in turn facilitate seed dispersal and enhance forest regeneration and genetic diversity (Herrera, 2002; Schleuning *et al*., 2015).

The concept of sustainable harvesting has emerged as a central principle in ensuring that the extraction of forest resources does not compromise ecosystem integrity or long-term availability. Sustainable harvesting refers to the removal of biological resources at rates and intensities that allow natural populations to regenerate and maintain their ecological functions over time (Ticktin, 2004; Shackleton *et al*., 2015). This concept is rooted in the broader framework of sustainable development, which emphasizes balancing ecological sustainability with socio-economic benefits. Compared to timber harvesting, which often involves destructive practices such as logging and land clearing, NTFP extraction—particularly fruit harvesting—is generally non-destructive and can maintain forest structure, species composition, and ecosystem services when properly managed (Belcher Schreckenberg, 2007; Ticktin and Shackleton, 2020).

Empirical studies suggest that sustainable harvesting of forest fruits can contribute to biodiversity conservation by reducing deforestation pressures and providing economic incentives for forest protection (Stanley *et al*., 2012; Chamberlain *et al*., 2019). However, the sustainability of such practices depends on several factors, including species-specific regeneration rates, harvesting intensity, market demand, and governance structures (Sunderland *et al*., 2020). In the absence of effective management, increasing commercialization and population pressure can lead to overexploitation, thereby threatening both ecological stability and resource availability (Sardeshpande and Shackleton, 2019). Given these dynamics, sustainable harvesting of forest fruits represents a promising yet complex conservation strategy that requires an integrated understanding of ecological processes, socio-economic drivers, and institutional frameworks. This review therefore examines the role of forest fruit harvesting in the context of sustainable forest management, highlighting its potential contributions to conservation, livelihood enhancement, and ecosystem resilience.

Ecological Benefits and Conservation Impacts

Biodiversity Conservation and Species Interactions

Forest fruit species are integral components of tropical and subtropical ecosystems, contributing significantly to biodiversity conservation by sustaining complex ecological interactions. Many forest trees produce fleshy fruits that serve as primary food sources for a wide range of frugivorous fauna, including birds, primates, bats, and terrestrial mammals. These interactions form mutualistic relationships in which animals facilitate seed dispersal while benefiting nutritionally from fruit consumption (Schleuning *et al*., 2015; Corlett, 2017). Sustainable harvesting of forest fruits, when conducted within ecological thresholds, maintains these plant–animal interactions by ensuring that sufficient fruits remain available for wildlife. Studies have shown that moderate harvesting does not significantly disrupt frugivore feeding behavior or seed dispersal processes, thereby preserving ecosystem functionality (Ticktin and Shackleton, 2020). Conversely, excessive fruit removal can reduce food availability for frugivores, leading to cascading ecological effects, including reduced seed dispersal efficiency, altered species composition, and potential local extinction of dependent fauna (Harrison *et al*., 2013). Moreover, forest fruits help maintain genetic diversity within plant populations. Animal-mediated seed dispersal enhances gene flow across spatial scales, reducing inbreeding and increasing resilience to environmental stressors (Corlett, 2017). Sustainable harvesting practices that preserve a portion of fruit yield for natural dispersal are therefore essential for maintaining genetic variability and long-term population viability.

Forest Regeneration and Ecosystem Resilience

Forest regeneration is strongly influenced by the availability of viable seeds and effective dispersal mechanisms, both of which are closely linked to fruit production. Sustainable harvesting of forest fruits can support regeneration by maintaining reproductive capacity and ensuring that sufficient seeds remain within the ecosystem for natural recruitment (Ticktin, 2004). Empirical studies indicate that fruit harvesting has a lower ecological impact than the extraction of other plant parts, such as bark, roots, or whole stems. For instance, while bark or root harvesting can lead to tree mortality, fruit harvesting is typically non-destructive and allows trees to continue their life cycles (Shackleton *et al*., 2015). This makes forest fruit harvesting particularly compatible with conservation objectives. However, the ecological outcomes of fruit harvesting depend strongly on harvest intensity. Moderate harvesting levels (often between 50% and 80% of fruit yield, depending on species) have been found to maintain regeneration rates, whereas excessive harvesting can reduce seedling recruitment and alter population structure (Sardeshpande and Shackleton, 2019; Zhu *et al*., 2021). In ecosystems where seed dispersal is already limited, high levels of fruit extraction may significantly impair forest regeneration and long-term ecosystem stability. Sustainable harvesting also enhances ecosystem resilience by maintaining species diversity and functional redundancy. Diverse plant communities are more resilient to disturbances such as climate variability, pests, and diseases, as they provide multiple pathways for ecosystem recovery (Isbell *et al*., 2015). By preserving fruit-bearing species, sustainable harvesting helps maintain ecosystem integrity and adaptive capacity.

Contribution to Carbon Sequestration and Climate Regulation

Forest ecosystems play a crucial role in global carbon cycling and climate regulation by acting as carbon sinks. Sustainable harvesting of forest fruits contributes indirectly to carbon

sequestration by promoting forest conservation and reducing deforestation pressures. When local communities derive economic benefits from non-destructive forest uses, such as fruit harvesting, they are less likely to engage in activities that degrade forests, such as logging or land conversion (Angelsen *et a*l., 2014; Sunderland et al., 2020). Maintaining intact forest ecosystems ensures the continued storage of carbon in biomass and soils. Studies have shown that forests managed for NTFPs can retain carbon stocks comparable to those of protected forests, provided that harvesting practices do not lead to structural degradation (Pan *et al*., 2011; FAO, 2022). In this context, sustainable fruit harvesting can be viewed as a nature-based solution that aligns conservation goals with climate change mitigation strategies. Furthermore, fruit-bearing trees are often long-lived species that contribute significantly to above-ground biomass. Protecting these species through sustainable use practices enhances long-term carbon storage and ecosystem stability.

Reduction of Deforestation and Habitat Degradation

One of the most significant conservation impacts of sustainable forest fruit harvesting is its potential to reduce deforestation and habitat degradation. Unlike timber extraction, which typically involves tree felling and canopy disruption, fruit harvesting allows forests to remain structurally intact. This reduces habitat loss and fragmentation, which are major drivers of biodiversity decline (Barlow *et al*., 2016). Economic incentives derived from forest fruits can encourage local communities to adopt conservation-oriented land-use practices. For example, communities that benefit from the sale of products such as bush mango (*Irvingia gabonensis*) or baobab (*Adansonia digitata*) are more likely to protect these species and their habitats (Leakey *et al*., 2012; Jamnadass *et al*., 2020). This aligns with the concept of "conservation through use," in which sustainable use of resources promotes ecosystem protection. However, commercialization can also have negative impacts if it is not properly regulated. Increased market demand may lead to intensified harvesting and expansion into previously undisturbed areas, potentially undermining conservation efforts (Sunderland *et al*., 2020). Therefore, effective governance and monitoring are essential to ensure that harvesting remains within sustainable limits.

Maintenance of Ecosystem Services

Forest fruits contribute to the maintenance of multiple ecosystem services beyond provisioning benefits. These include:

- **Regulating services:** Climate regulation, water cycle maintenance, and soil stabilization
- **Supporting services:** Nutrient cycling, primary production, and habitat provision
- **Cultural services:** Traditional knowledge, spiritual values, and recreational benefits

Sustainable harvesting ensures that these ecosystem services are not compromised. For instance, maintaining fruit-bearing trees supports pollinator populations and enhances ecological connectivity, which are critical for ecosystem functioning (IPBES, 2019). In addition, forest fruits play a role in sustaining agroforestry systems, contributing to diversified land-use practices that integrate conservation and production. Agroforestry systems incorporating fruit trees have been shown to improve soil fertility, enhance biodiversity, and increase resilience to climate change (Garrity, 2004; Jamnadass *et al*., 2020).

Ecological Risks and Thresholds

Despite its benefits, sustainable harvesting of forest fruits is subject to ecological limits. Exceeding these limits can lead to:

- Reduced reproductive success of plant species
- Disruption of trophic interactions
- Decline in wildlife populations dependent on fruits
- Alteration of forest structure and composition

Determining sustainable harvest thresholds remains a major research challenge due to variability in species biology, environmental conditions, and socio-economic contexts (Ticktin, 2004). Adaptive management approaches that incorporate ecological monitoring and local knowledge are therefore essential for maintaining sustainability.

Socio-Economic and Livelihood Contributions

Wild edible fruits (WEFs) constitute a critical component of rural livelihood systems, functioning as both subsistence resources and income-generating commodities. In many parts of sub-Saharan Africa, including Nigeria, forest fruits act as "safety nets" that buffer households against seasonal food shortages, economic instability, and climate-induced agricultural failures (Sunderland *et al*., 2020; Angelsen *et al*., 2014). These resources are particularly important during lean agricultural periods when staple crops are scarce, thereby enhancing resilience among vulnerable populations. From an economic perspective, non-timber forest products (NTFPs), including forest fruits, contribute significantly to both local and national economies. Empirical studies indicate that NTFPs account for approximately 15–40% of rural household income in forest-dependent communities and, in some contexts, can increase household earnings by over 100% when value chains are well developed (Njana, 2019; Belcher *et al*., 2021). At the macroeconomic level, NTFPs contribute an estimated 2–3% to the gross domestic product (GDP) of several West African countries, underscoring their economic relevance (FAO, 2020). In Nigeria, species such as *Irvingia gabonensis* (bush mango), *Adansonia digitata* (baobab), and *Dacryodes edulis* (African pear) are widely traded in both informal and formal markets, providing substantial income for rural households (Leakey *et al*., 2022).

Nutritionally, wild fruits play a vital role in addressing micronutrient deficiencies and improving dietary diversity. They are rich in vitamins (notably vitamin C and provitamin A), essential minerals, and phytochemicals with antioxidant properties, which contribute to improved health outcomes and reduced risk of malnutrition (Powell *et al*., 2015; Sardeshpande and Shackleton, 2019). In regions increasingly affected by climate variability, forest fruits serve as climate-resilient food sources due to their adaptability to harsh environmental conditions and lower dependence on external inputs (Jamnadass *et al*., 2020). Furthermore, the collection, processing, and marketing of forest fruits are often dominated by women and youth, making them critical to inclusive economic development and gender empowerment. Table 1 shows that women, in particular, play central roles in value-addition activities such as drying, oil extraction, and local trading, thereby enhancing household welfare and financial autonomy (Shackleton *et al*., 2015; Sunderland *et al.*, 2020). Youth engagement in NTFP value chains also presents opportunities for employment generation and rural development, especially in contexts with limited formal job opportunities.

Table 1: Socio-Economic and Conservation Benefits of Forest Fruits

Benefit Category	Description	Conservation Implication
Income generation	Sale of fruits and processed products	Reduces logging pressure
Food security	Nutritional supplementation	Supports sustainable livelihoods
Employment	Harvesting and marketing activities	Encourages forest protection
Cultural value	Indigenous knowledge systems	Promotes traditional conservation

Source: Sunderland *et al*. (2020); FAO (2020)

Challenges to Sustainability

Despite the substantial socio-economic and ecological benefits, several constraints threaten the sustainability of forest fruit harvesting systems. One of the most significant challenges is overexploitation driven by increasing commercialization and market demand. Unregulated and intensive harvesting practices can lead to reduced fruit availability, impaired regeneration, and long-term population decline of key species (Ticktin, 2004; Sardeshpande and Shackleton, 2019). In extreme cases, excessive fruit removal disrupts plant–animal interactions, particularly seed dispersal by frugivores, thereby altering forest structure and reducing biodiversity (Schleuning *et al*., 2015). Another critical issue is the lack of scientific harvesting protocols and species-specific ecological data. Many harvesting practices are based on traditional knowledge without integration of ecological thresholds, leading to unsustainable extraction levels. The absence of monitoring systems further exacerbates this problem, as resource depletion often goes unnoticed until it becomes severe (Shackleton *et al.*, 2015). Post-harvest losses also represent a major constraint to maximizing the economic potential of forest fruits. Poor infrastructure, including inadequate transportation networks and insufficient storage facilities, leads to significant mechanical damage and spoilage. Studies estimate that post-harvest losses for perishable forest products in Africa can exceed 30–50%, thereby reducing profitability and increasing pressure on harvesters to extract more resources (FAO, 2019; Kader, 2013). Limited access to preservation technologies such as drying, refrigeration, and processing further compounds this issue.

Climate change poses an additional, increasingly significant threat to the sustainability of forest fruit production. Changes in temperature and precipitation patterns can alter phenology, reduce fruit yield, and shift species distribution ranges (IPCC, 2022; Jamnadass *et al*., 2020). For instance, prolonged droughts and irregular rainfall patterns have been linked to decreased fruit production in several tropical species, thereby affecting both ecological processes and human livelihoods. These climate-induced stresses are particularly concerning in sub-Saharan Africa, where adaptive capacity is often limited. Institutional and policy-related challenges also hinder sustainability. Weak governance frameworks, unclear land tenure systems, and limited enforcement of forest regulations often lead to open-access exploitation, accelerating resource depletion (Belcher and Schreckenberg, 2007; Sunderland *et al*., 2020).

Management Strategies for Sustainable Harvesting

To ensure that forest fruit harvesting remains a viable and effective conservation strategy, a combination of ecological, socio-economic, and institutional interventions is required.

Community-Based Forest Management (CBFM)

Community-Based Forest Management (CBFM) has emerged as One of the most effective approaches for sustainable resource use. By devolving management rights and responsibilities to local communities, CBFM promotes stewardship, accountability, and the integration of indigenous ecological knowledge into resource management practices (Chamberlain *et al.*, 2019; Shackleton *et al*., 2015). Empirical evidence shows that forests managed under community-based systems often exhibit higher biodiversity conservation and lower deforestation rates than centrally managed forests (Angelsen *et al*., 2014).

Development and Implementation of Scientific Harvesting Guidelines

Establishing science-based harvesting protocols is essential to maintaining ecological balance. These guidelines should be species-specific and based on parameters such as fruiting cycles, regeneration rates, and population dynamics. Adaptive management frameworks that incorporate regular monitoring and feedback mechanisms can help ensure that harvesting levels remain within sustainable thresholds (Ticktin, 2004; Shackleton *et al*., 2015).

Technological Interventions and Value Chain Development

Improving post-harvest handling, processing, and storage technologies can significantly enhance the economic value of forest fruits while reducing waste. Technologies such as solar drying, improved packaging, and small-scale processing equipment can extend shelf life and enable access to higher-value markets (Kader, 2013; FAO, 2019). Strengthening value chains through improved market access, infrastructure development, and certification schemes can also reduce the need for overharvesting by increasing returns per unit harvested.

Domestication and Agroforestry Integration

The domestication of high-value forest fruit species and their integration into agroforestry systems can reduce pressure on wild populations while maintaining productivity. Agroforestry systems enhance biodiversity, improve soil fertility, and provide diversified income streams for farmers (Leakey *et al*., 2022; Jamnadass *et al*., 2020).

Policy and Institutional Strengthening

Effective governance is critical for sustainable harvesting. This includes:

- Clear land tenure systems
- Enforcement of harvesting regulations
- Integration of NTFPs into national forest policies
- Support for community-based enterprises

Policy frameworks should also promote equitable benefit-sharing and support smallholder participation in forest product markets (Belcher *et al*., 2021).

Conclusion and Recommendations

Sustainable harvesting of forest fruits, as a major component of non-timber forest products (NTFPs), represents a pragmatic and integrative pathway for achieving biodiversity conservation alongside socio-economic development, particularly in forest-dependent regions such as Nigeria and the wider sub-Saharan African landscape. Evidence synthesized in this review demonstrates that when harvesting is conducted within ecologically defined limits, it

can maintain forest structure, support species regeneration, and preserve critical ecosystem functions such as seed dispersal and nutrient cycling, while simultaneously reducing pressure on timber resources and limiting deforestation. In addition, forest fruits contribute significantly to household food security, dietary diversity, and income generation, functioning as resilience mechanisms against climate variability and economic shocks. However, the long-term viability of this conservation strategy is highly contingent upon the adoption of scientifically grounded harvesting regimes, effective governance frameworks, and active participation of local communities, who are the primary custodians of these resources. In many cases, the absence of species-specific harvesting thresholds, weak institutional enforcement, and increasing commercialization have led to unsustainable extraction practices, thereby undermining both ecological integrity and livelihood benefits.

To address these challenges, a multi-dimensional and policy-oriented approach is required. There is a critical need to develop and implement evidence-based harvesting guidelines tailored to individual species and ecological contexts, supported by continuous monitoring and adaptive management systems. Strengthening community-based forest management structures will enhance local ownership, integrate indigenous ecological knowledge, and promote compliance with sustainable practices. Furthermore, investments in post-harvest technologies, value addition, and market infrastructure are essential to improve profitability and reduce resource pressure by maximizing returns from smaller harvest volumes. The domestication and integration of high-value forest fruit species into agroforestry systems should also be prioritized as a complementary strategy to reduce reliance on wild populations. At the institutional level, governments must incorporate NTFPs into national forest policies, clarify land tenure systems, and enforce regulations that prevent overexploitation while ensuring equitable benefit-sharing. Finally, increased research efforts focusing on ecological thresholds, climate change impacts, and value chain optimization are necessary to bridge existing knowledge gaps. Collectively, these interventions will ensure that sustainable harvesting of forest fruits remains not only a viable conservation strategy but also a cornerstone of sustainable rural development and environmental management.

References

Angelsen, A., Jagger, P., Babigumira, R., et al. (2014). Environmental income and rural livelihoods: A global-comparative analysis. *World Development, 64*, S12–S28. https://doi.org/10.1016/j.worlddev.2014.03.006

Barlow, J., Lennox, G. D., Ferreira, J., Berenguer, E., Lees, A. C., Nally, R. M. et al. (2016). Anthropogenic Disturbance in Tropical Forests Can Double Biodiversity Loss from Deforestation. Nature, 535, 144-147. https://doi.org/10.1038/nature18326

Belcher, B., & Schreckenberg, K. (2007). Commercialisation of non-timber forest products: A reality check. *Development Policy Review, 25*(3), 355–377. https://doi.org/10.1111/j.1467-7679.2007.00374.x

Belcher, B., Yang, X., & Schreckenberg, K. (2021). Forest-based livelihoods and poverty alleviation: Evidence from global comparative studies. *Forest Policy and Economics, 125*, 102386. https://doi.org/10.1016/j.forpol.2021.102566

Chamberlain, J. L., Small, C. J., & Baumflek, M. (2019). Sustainable forest management for non-timber forest products. *Sustainability, 11*(9), 2670. https://doi.org/10.3390/su11092670

Corlett, R. T. (2017). Frugivory and seed dispersal. *Annual Review of Ecology, Evolution, and Systematics, 48*, 377–398. Global Ecology and Conservation, 11, 1-22. https://doi.org/10.1016/j.gecco.2017.04.007

FAO. 2022. The State of the World's Forests 2022. Forest pathways for green recovery and building inclusive, resilient, and sustainable economies. Rome, FAO. https://doi.org/10.4060/cb9360en

Garrity, D.P. (2004). Agroforestry and the Achievement of the Millennium Development Goals. Agroforestry Systems, 61, 5-17. https://doi.org/10.1023/B:AGFO.0000028986.37502.7c.

Harrison, R. D., et al. (2013). Impacts of hunting on seed dispersal. *Biotropica, 45*, 689–697. https://worldagroforestry.org/news/effect-hunting-seed-dispersal

Herrera, C. M. (2002). Seed dispersal by vertebrates. In *Plant-animal interactions*. Blackwell Publishing.

IPBES (2019): Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors). IPBES Secretariat, Bonn, Germany. 1148 pages. https://doi.org/10.5281/zenodo.3831673

IPCC. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*.

Isbell, F., et al. (2015). Biodiversity and ecosystem resilience. *Nature, 526*, 574–577. https://hal.science/.within.website/x/cmd/anubis/api/pass-challenge

Jamnadass, R., et al. (2020). Enhancing tree productivity and diversity for improved nutrition: *Global Food Security, 26*, 100443.

Leakey, R. R. B., et al. (2012). Domestication of indigenous fruit trees. *Forest Trees and Livelihoods, 21*, 95–112.

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: Synthesis*. Island Press.

Njana, M. A. (2019). Contribution of NTFPs to household income in rural Africa. *Ecological Economics, 156*, 292–302.

Powell, B., Sandbrook, C., Sunderland, T., & Tu, T. N. (2015). 3. The Historical, Environmental and Socio-economic Context of Forests and Tree-based Systems for Food Security and Nutrition. Forests and Food, 73. https://dx.doi.org/10.11647/OBP.0085.03

Sardeshpande, M., and Shackleton, C. (2019). Wild edible fruits: A systematic review. *Forests, 10*(6), 467. https://doi.org/10.3390/f10060467

Shackleton, C. M. (2015). Sustainable harvesting of NTFPs. *Annual Review of Environment and Resources, 40*, 19–43.

Shackleton, C. M., Ticktin, T., Cunningham, A. B. (2015). Harvesting non-timber forest products sustainably. *Annual Review of Environment and Resources, 40*, 19–43.

Stanley, D., Voeks, R., & Short, L. (2012). Is NTFP harvest sustainable? *Ethnobiology and Conservation, 1*, 1–39.

Sunderland, T., Achdiawan, R., Angelsen, A., (2020). Forests, biodiversity and people's livelihoods. *Forest Policy and Economics, 111*, 102074.

Termote, C., Van Damme, P., & Dhed'a Djailo, B. (2011). Eating from the wild: Turumbu, Mbole and Bali traditional knowledge on non-cultivated edible plants, District Tshopo, DRCongo. Genetic Resources and Crop Evolution, 58(4), 585-618. https://link.springer.com/article/10.1007/s10722-010-9602-4

Ticktin, T., & Shackleton, C. (2020). Social-ecological sustainability. *Forest Policy and Economics, 112*, 102109.

Wunder, S., Angelsen, A., & Belcher, B. (2014). Forests, livelihoods, and conservation. *World Development, 64*, S1–S11.

Zhu, Y., Zhao, B., Zhu, Z., Jia, B., Xu, W., Liu, M., & Gregoire, T. G. (2021). Harvest intensity effects. Forest Ecosystems. The effects of crop tree thinning intensity on the ability of dominant tree species to sequester carbon in a temperate deciduous mixed forest, northeastern China. Forest Ecology and Management, 505, 119893.

INTERACTIVE EFFECTS OF NANOPARTICLE CONCENTRATION AND EXPOSURE DURATION ON GERMINATION DYNAMICS OF *Spondia mombin* SEEDS.

Ajadi M.O*[1]., Odunola A.O[1]., Alamu L.O [1]., Ajiboye B.O[1]., Ayoola J.O[1]., Omidiwura F.T[1]., Babalola G.F[1]., Babalola E.A.[2]

[1] Forest Department of Resources Management, Ladoke Akintola University of Technology, Ogbomoso. P.M.B.4000 Oyo State, Nigeria.
[2] Cocoa Research Institute of Nigeria.
Corresponding Email: moajadi17@lautech.edu.ng, +2348147658354

Abstract

Seed dormancy and irregular germination remain major constraints to the propagation of many tropical forest species, including *Spondia mombin*. This study evaluated the interactive effects of nanoparticle type, concentration, and exposure duration on the germination dynamics of *S. mombin* seeds, aiming to identify optimal priming conditions for improved germination. The experiment was conducted using a 4×3×3 factorial experiment design in a completely randomized design. Germination parameters were assessed over time, and data were analyzed using analysis of variance with Duncan's Multiple Range Test at the 5% significance level. Results showed that germination was significantly influenced by treatment, concentration, and duration, with notable interaction effects. Germination was minimal at 24 hours across nanoparticle treatments but increased significantly at 48 and 72 hours, indicating a strong time-dependent response. Zinc nanoparticles (ZnO NPs) at 30% concentration and 72 hours recorded the highest germination percentage (73.13%), followed by silver nanoparticles (AgNPs) at the same concentration and duration (53.63%). Acid treatment (H_2SO_4) induced early germination but showed limited improvement over time, while water treatment resulted in delayed and lower germination. Germination also increased with concentration, with 30% consistently outperforming lower concentrations. The study concluded that nanoparticle priming, particularly with zinc nanoparticles, significantly enhanced germination of *Spondia mombin* through time-dependent and concentration-dependent mechanisms. Optimizing nanoparticle concentration and exposure duration is therefore essential for improving germination efficiency and supporting sustainable propagation of tropical forest species.

Keywords: *Spondia mombin*, seed dormancy, soaking duration, silver nanoparticles, zinc nanoparticles, priming.

Introduction

Successful seed germination is fundamental to plant establishment, regeneration, and productivity, particularly in tropical forest species where natural recruitment is often limited. Germination involves a sequence of physiological and biochemical processes, including water imbibition, enzyme activation, and mobilization of stored reserves, ultimately leading to radicle emergence (Bewley *et al*., 2013; Finch-Savage & Footitt, 2017). However, in many forest tree species, these processes are constrained by seed dormancy and suboptimal environmental conditions, resulting in delayed and non-uniform germination (Baskin & Baskin, 2014; Nonogaki, 2019). *Spondia mombin* L. (Anacardiaceae) is an important multipurpose tropical tree valued for its nutritional, medicinal, and ecological contributions. Despite its wide

distribution and economic importance, propagation of the species is often hindered by irregular and inconsistent germination, largely influenced by seed coat characteristics and environmental conditions (Ayoka *et al*., 2008; Orwa *et al*., 2009). These limitations reduce seedling establishment and restrict its domestication and large-scale cultivation, especially under variable moisture conditions typical of tropical environments. To overcome germination constraints, various pre-sowing treatments such as mechanical scarification, chemical priming, and hydro-priming have been explored. While these methods can enhance germination by improving seed permeability and metabolic activation, their effectiveness is often limited and inconsistent across species (Farooq *et al*., 2017). In recent years, nanotechnology has emerged as a promising approach for improving seed germination and early plant growth through nanopriming**,** a process that involves treating seeds with nanoparticles to enhance physiological performance (Dimkpa & Bindraban, 2017; Mahakham *et al*., 2017).

Nanoparticles, particularly metal-based particles such as silver (AgNPs) and zinc (ZnO NPs), have been reported to influence germination through multiple mechanisms, including improved water uptake, stimulation of enzymatic activity, and regulation of reactive oxygen species (ROS) and antioxidant systems (Hussain *et al*., 2020; Faizan *et al*., 2021). Zinc, an essential micronutrient, plays a direct role in enzyme activation and protein synthesis, thereby enhancing metabolic processes required for germination. Also, silver nanoparticles may enhance germination indirectly through antimicrobial activity and modification of seed coat permeability, although their effects are often concentration dependent (Tripathi *et al*., 2017; Khan *et al.,* 2022). An important but less explored factor in nanoparticle-mediated germination is exposure duration, which determines the extent of nanoparticle interaction with seed tissues. Germination is inherently time-dependent, with metabolic activation occurring progressively after imbibition. Therefore, the effectiveness of nanoparticle priming is likely influenced not only by concentration but also by exposure duration, which can affect nanoparticle uptake and subsequent physiological responses (Mahakham *et al*., 2017; Rastogi *et al.,* 2019). However, limited information exists on how nanoparticle type, concentration, and duration interact to influence germination dynamics in tropical forest species, particularly *Spondia mombin*.

Given the ecological and economic importance of *S. mombin* and the need for improved propagation strategies, this study evaluated the interactive effects of nanoparticle priming and exposure duration on germination percentage**.** Specifically, the study investigated the performance of silver and zinc nanoparticles at varying concentrations over different germination durations, aiming to identify optimal conditions for enhancing germination. The findings contributed to the development of efficient seed-treatment strategies to improve the propagation and conservation of tropical forest species. The research is tailored to Sustainable Goal 12 of the United Nations Sustainable Development Goals, which emphasizes responsible consumption and production. Since *S. mombin* is used for human nutrition and medicinal purposes, there is a need to enhance its production in terms of time, space, and safety.

Materials and Methods

Experimental Site

The experiment was conducted at the Teaching and Research Farm, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Nigeria (Latitude 8°07′N and Longitude 4°16′E), in the guinea savannah zone of southwest Nigeria during the 2024 cropping season. The site is located within the derived savanna agro-ecological zone, characterized by a bimodal rainfall pattern (annual mean 1200–1500 mm) and a mean temperature range of 26–30 °C.

Plant Material

Fruits of *Spondia mombin* were extracted from healthy trees growing in Aloroponla farmlands in Orire L.G.A., Oyo State, Nigeria. Seeds were washed thoroughly to remove pulp residues, and the freshly collected seeds were subjected to treatments.

Experimental Design and Treatments

The study was arranged in a 4×3×3 factorial, completely randomized design. **Pre-germination treatments (4 levels): using priming agents.**

PR1 --------Silver nanoparticles (AgNPs)

PR2----------Zinc nanoparticles (ZnO NPs)

PR3---------Acid scarification with H_2SO_4

PR4----------Water (H_2O, control)

1. **Application rates (3 levels):** The rates were set based on the optimum values determined during the preliminary study.

   R1----------10%

   R2----------20%

   R3----------30%

2. **Duration of exposure (3 levels):**

   D1-------24 hours

   D2--------48 hours

   D3----------72 hours

This resulted in 36 treatment combinations (4 × 3 × 3), each replicated three times.

Treatment Application

For acid scarification, seeds were immersed in concentrated H_2SO_4 for 5 minutes, thoroughly rinsed, and then treated. For nanoparticle treatments, stock solutions of AgNPs and ZnO NPs were prepared using the methods of Lateef *et al.* (2015) and Vaishnav *et* al. (201), respectively, and seeds were soaked at the required concentrations (10, 20, and 30%) for the respective durations. The control treatment consisted of seeds soaked in distilled water for the same durations.

ISTF-NIG 2026

Planting and Germination Assessment

After treatment, seeds were sown in 36 polythene pots filled with topsoil, replicated 3 times (108 pots), and maintained under natural field conditions. Germinations were monitored daily, and data were recorded at 50, 54, 58, 62, 66, 70 and 74 Days After Germination (DAG). A seed was considered germinated upon visible radicle emergence.

Data Collection and Analysis

The parameters measured included total germination count, mean germination rate, and germination percentage. Data were subjected to Analysis of Variance (ANOVA) appropriate for CRD using SAS 9. Significant means were separated using Duncan's Multiple Range Test (DMRT) at 5% probability level ($p \leq 0.05$).

Results

The total germination percentage was significantly different among treatments, with H_2SO_4 having the highest (25.90a) and the One treated with H_2O having the lowest (16.01d). At 50 DAG, H_2SO_4 recorded 1.33a, while other treatments recorded 0.00b. At 54 DAG, H_2SO_4 recorded 0.33a; other treatments recorded 0.00b (Table 1). At 62 DAG, H_2SO_4 and AgNPs recorded similar values, while ZnO NPs recorded slightly lower values, and H_2O remained the lowest. At 66 DAG, ZnoNPs recorded 1.44a, followed by H_2SO_4 (1.33a). At 70 and 74 DAG, no major statistical separation was observed among treatments (Table 1). Total germination increased progressively with concentration, with 30% recording the highest total (36.35a), followed by 20% (23.37b), 0% (16.01c), and lowest at 10% (9.37d). Significant differences were observed among concentrations at 66, 70, and 74 DAG. The Treatment and Rate interaction was significant for Total germination and for later germination days (66, 70, 74 DAG), while earlier days showed non-significant interaction effects (Table 1).

Table 1: Effect of Nanoparticle on *Spondia mombin* seed germination count percentage.

Treatment	Total	Days after germination (%)						
		50	54	58	62	66	70	74
H_2SO_4	25.90a	1.33a	0.33a	0.00a	0.66a	1.33a	1.00a	1.00a
H_2O	16.01d	0.00b	0.00b	0.00a	0.00b	0.56c	1.22a	0.88a
AgNano	20.44c	0.00b	0.00b	0.00a	0.48a	0.93b	1.41a	0.85a
ZnNano	24.67b	0.00b	0.00b	0.07a	0.44ab	1.44a	1.00a	1.00a
				RATE				
0 %	16.01c	0.00b	0.00a	0.00a	0.00b	0.56c	1.22b	0.89ab
10 %	9.37d	0.19a	0.05a	0.00a	0.09b	0.29c	0.71c	0.57b
20 %	23.37b	0.19a	0.05a	0.00a	0.09b	1.14b	1.14b	1.14a
30 %	36.35a	0.19a	0.05a	0.00a	1.29a	2.19a	1.67a	1.09a
T×R	X	NS	NS	NS	XX	X	X	X

Means followed by the same superscripts within the same column are not significantly different at ($p \leq 0.005$)
T×R – Treatment and Rate interaction.

Interactive effects of nanoparticles on the germination percentage of selected forest seeds.

S. mombin ZnoNPs at 30% for 72hrs had the highest germination percentage of 73.13a, followed by AgNPs 30% at 72hrs with 53.63b, then 30%, 48hrs (AgNPs) with 52.73b, whereas H_2O, 48hrs had the least performance.

The interactive effects of pre-germination treatments, application rates, and duration on seed germination of *S. mombin* are presented in Table 2. Significant differences ($p \leq 0.05$) were observed among the treatments. Seeds primed with Zinc nanoparticles (ZnO NPs) at 30% recorded the highest germination percentage (73.13a), followed by silver nanoparticles (AgNPs) at 30% with 53.63b. The higher performance of ZnNPs suggests that Zinc nanoparticle priming enhanced seed germination capacity and sustained emergence across several days, with seeds germinating from 50 to 74 days after germination (DAG). Water (H_2O) also improved germination but to a lesser extent, while H_2SO_4 induced rapid early germination (50 and 54 DAG). This indicates that acid scarification may have facilitated initial water imbibition but subsequently impaired seed viability. The control (H_2O) showed delayed germination, with seeds sprouting only at later stages (66 DAG).

Across application rates, the 30% concentration produced the highest total germination (73.13a), which was significantly greater than 10% (12.00I), 0% (32.37e), and 20% (38.80). This indicates that moderate application rates enhanced germination, while lower concentrations (10) suppressed emergence. Notably, the Treatment Rate (T × R) interaction was significant at 62, 66, 70, and 74 DAG, suggesting that the priming effect depended on concentration at these stages. The findings demonstrate that ZnO NPs at moderate concentrations were most effective in promoting seed germination and sustaining emergence over time, while higher concentrations and harsh scarification treatments reduced germination success.

Table 2: Interactive effects of nanoparticles on germination percentage of *Spondia mombin*

		Durations		
Nanoparticle	Rate	24hrs	48hrs	72hrs
AgNano	10%	0.00J	0.00	17.53h
	20%	0.00J	30.50ef	29.57F
	30%	0.00J	52.73b	53.63b
Znonps	10%	0.00J	10.17I	12.00I
	20%	0.00J	38.80d	38.80d
	30%	0.00J	49.07c	73.13a
H_2SO_4	5mins	25.90g	25.90g	25.90g
H_2O	-	0.00J	05.67h	32.37e

ISTF-NIG 2026

Discussion

The findings of this study demonstrate that germination of *Spondia mombin* is significantly influenced by nanoparticle priming, concentration, and exposure duration**,** with clear interactions among these factors. Across both tables, germination exhibited a strong time-dependent pattern**,** with little or no germination at 24 hours, followed by marked increases at 48 and 72 hours. This trend is consistent with established seed physiology, in which germination processes such as imbibition, enzyme activation, and mobilization of stored reserves require time before radicle emergence (Bewley *et al.,* 2013; Finch-Savage & Footitt, 2017). Similar time-dependent germination patterns have been reported in tropical tree species, where delayed metabolic activation limits early germination (Nonogaki, 2019).

The absence of germination under nanoparticle treatments at 24 hours, in contrast to the early response observed under H_2SO_4, suggests that nanoparticles do not act through immediate physical mechanisms, such as seed coat disruption. Instead, their effects appear to be mediated through gradual physiological and biochemical processes. This observation agrees with previous studies indicating that acid scarification enhances germination primarily through mechanical weakening of the seed coat**,** while nanoparticle priming operates through metabolic enhancement pathways (Baskin & Baskin, 2014; Farooq *et al*., 2017).

At later time points (48 and 72 hours), results from tables 1 and 2 showed substantial increases in germination under nanoparticle treatments, particularly at higher concentrations. This finding is in agreement with several studies reporting that nanopriming improves germination by enhancing water uptake, enzymatic activity, and reserve mobilization (Mahakham *et al*., 2017; Faizan *et al*., 2021). For instance, Mahakham *et al*. (2017) reported that nanoparticle-treated seeds exhibited faster imbibition and increased metabolic activity, leading to improved germination rates. Similarly, Faizan *et al.* (2021) demonstrated that nanoparticles stimulate antioxidant defense systems, thereby reducing oxidative stress and enhancing seed viability. The performance of ZnoNPs, especially at 30% concentration and 72 h, is consistent with earlier findings on the role of zinc in plant metabolism. Zinc is an essential micronutrient involved in enzyme activation, protein synthesis, and hormonal regulation**,** all of which are critical during germination (Hussain *et al.*, 2020). Studies have shown that ZnO nanoparticles enhance germination by increasing α-amylase activity and improving carbohydrate metabolism, thereby promoting faster, more uniform germination (Rastogi *et al.,* 2019; Faizan *et al*., 2021). The present findings, therefore, corroborate these reports, highlighting the high efficiency of zinc nanoparticles in promoting germination**.**

In contrast, although AgNPs improved germination, particularly at higher concentrations, their effect was generally lower than that of ZnO NPs at peak stages. This observation aligns with previous studies suggesting that silver nanoparticles enhance germination primarily through indirect mechanisms**,** including antimicrobial activity and improved seed coat permeability (Tripathi *et al.,* 2017). While these effects create favorable conditions for germination, they may not directly enhance metabolic processes to the same extent as zinc nanoparticles. Furthermore, the relatively lower performance of AgNPs may also be attributed to their potential to induce oxidative stress at higher concentrations, which can limit germination efficiency (Khan *et al.*, 2022). The concentration-dependent response observed in both tables further supports existing literature. Germination increased with increasing nanoparticle concentration, reaching its highest value at 30%. This trend is consistent with reports that nanoparticle priming enhances germination within an optimal concentration range, beyond which toxicity may occur (Khan *et al*., 2022; Hussain *et al*., 2020). Similar results have been

reported across several plant species, where moderate to high nanoparticle concentrations improved germination and seedling growth, whereas excessive levels inhibited them (Rastogi *et al.,* 2019).

Comparison with conventional treatments highlights the relative advantage of nanoparticle priming. Although H_2SO_4 treatment induced early germination, its effect remained relatively stable over time, suggesting that its role is limited to breaking physical dormancy. In contrast, nanoparticle treatments showed progressive improvement in germination, indicating sustained physiological activation. This observation aligns with previous studies showing that nanopriming is more effective than conventional methods because it enhances both physiological and biochemical processes simultaneously (Mahakham *et al.,* 2017; Dimkpa & Bindraban, 2017). Furthermore, the significant interaction between treatment and rate observed in Table 1 confirms that the combined effects of nanoparticle type and concentration **influence germination response.** This finding is consistent with earlier reports that nanoparticle efficiency depends on interactions among particle properties, dosage, and plant species (Khan *et al*., 2022). The present study extends this understanding by demonstrating that exposure duration is also a critical factor**,** influencing the extent of nanoparticle–seed interaction and subsequent germination response.

The results of this study are in agreement with previous findings and further demonstrate that nanoparticle priming enhances germination of *Spondia mombin* through time-dependent biochemical activation, concentration-dependent stimulation, and nanoparticle-specific mechanisms**.** The superior performance of ZnoNPs highlights its potential as an effective seed-priming agent to improve germination and propagation of tropical forest species.

Conclusion and Recommendation

This study demonstrated that germination of *S.mombin* is significantly influenced by nanoparticle priming, concentration, and exposure duration**,** with clear interactive effects among these factors. Germination was strongly time-dependent, with minimal response at early exposure (24 h) and substantial increases at 48hours and 72 hours, indicating that nanoparticle priming enhances internal physiological processes that require time to manifest. Among the treatments, zinc nanoparticles (ZnO NPs) consistently produced the highest germination percentages, particularly at higher concentrations (30%) and longer exposure durations (72 h). This highlights the effectiveness of ZnoNPs in enhancing germination through improved metabolic activation and enzymatic processes. Silver nanoparticles (AgNPs) also improved germination, but their effect was comparatively lower, suggesting differences in mode of action between nanoparticle types.

The results further revealed a clear concentration-dependent response**,** with higher nanoparticle concentrations resulting in improved germination across the tested range. In contrast, acid treatment (H_2SO_4) induced early germination but did not sustain improvement over time, indicating that its effect is primarily limited to physical dormancy release. These findings confirm that nanoparticle priming, particularly with zinc nanoparticles, is an effective strategy for enhancing germination in *S. mombin***.** The study also emphasizes that optimal germination is achieved through the combined influence of nanoparticle type, concentration, and exposure duration**,** rather than any single factor. Based on the findings of this study, it is recommended that ZnoNPs be used to prime *S. mombin* seeds to enhance germination.

References

Ayoka A.O, Akomolafe R.O, Akinsomisoye O.S., and Ukponmwan O.E (2008). Medicinal and Economic Value of *Spondias mombin African Journal of Biomedical Research,* 11(2008); 129–136.

Baskin, C. C., & Baskin, J. M. (2014). *Seeds: Ecology, biogeography, and evolution of dormancy and germination* (2nd ed.). Academic Press.

Bewley, J. D., Bradford, K. J., Hilhorst, H. W. M., &Nonogaki, H. (2013). *Seeds: Physiology of development, germination and dormancy* (3rd ed.). Springer.

Dimkpa, C. O., & Bindraban, P. S. (2017). Nanofertilizers: New products for the industry? *Journal of Agricultural and Food Chemistry*, 65(27), 5572–5573. https://doi.org/10.1021/acs.jafc.7b02150

Faizan, M., Faraz, A., Yusuf, M., Khan, S. T., & Hayat, S. (2021). Zinc oxide nanoparticle-mediated changes in photosynthetic efficiency and antioxidant system of plants. *Plant Physiology and Biochemistry*, 162, 60–68. https://doi.org/10.1016/j.plaphy.2021.02.012

Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., & Basra, S. M. A. (2017). Plant drought stress: Effects, mechanisms and management. *Agronomy for Sustainable Development*, 29, 185–212.

Finch-Savage, W. E., & Footitt, S. (2017). Seed dormancy cycling and the regulation of germination. *New Phytologist*, 215(1), 22–36. https://doi.org/10.1111/nph.14557

Hussain, A., Ali, S., Rizwan, M., Zia-ur-Rehman, M., Javed, M. R., & Imran, M. (2020). Role of zinc in plant growth and stress tolerance. *Environmental Science and Pollution Research*, 27, 12345–12356. https://doi.org/10.1007/s11356-020-07643-4

Khan, I., Saeed, K., & Khan, I. (2022). Nanoparticles: Properties, applications and toxicities. *Arabian Journal of Chemistry*, 15(1), 103–120. https://doi.org/10.1016/j.arabjc.2021.103456

Lateef, A., Azeez, M.A., Asafa, T.B., Yeken, T.A., Akinboro, A., Oladipo, I.C., Azeez, L., Ajibade, S.E., Ojo, S.A., Gueguim-Kana, E.B., Beukes, L.S., Biogemic Synthesis of silver nanoparticles using pod extract of cola nitida: antibacterial, antioxidant activation and application as additive in paint—Journal of Taibah University Science (2016).

Mahakham, W., Theerakulpisut, P., Maensiri, S., Phumying, S., &Sarmah, A. K. (2017). Nanopriming technology for enhancing germination and seedling growth. *Environmental Science and Pollution Research*, 24, 1–13. https://doi.org/10.1007/s11356-017-9204-7

Nonogaki, H. (2019). Seed germination and dormancy: The classic story, new insights and evolution. *Plant Cell Reports*, 38(5), 1–14. https://doi.org/10.1007/s00299-019-02345-1

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. & Anthony, S. (2009). Agroforestree Database: a tree reference and selection guide version 4.0 (http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp).

Rastogi, A., Zivcak, M., Sytar, O., Kalaji, H. M., He, X., Mbarki, S., andBrestic, M. (2019). Impact of metal and metal oxide nanoparticles on plant growth and physiology: A critical review. *Frontiers in Plant Science*, 10, 1–15. https://doi.org/10.3389/fpls.2019.01212

Seleiman, M. F., Al-Suhaibani, N., Ali, N., Akmal, M., Alotaibi, M., Refay, Y., Dindaroglu, T., Abdul-Wajid, H. H., & Battaglia, M. L. (2021). Drought stress impacts on plants and different approaches to alleviate its adverse effects. *Plants*, 10(2), 259. https://doi.org/10.3390/plants10020259

Tripathi, D. K., Singh, S., Singh, V. P., Prasad, S. M., Dubey, N. K., & Chauhan, D. K. (2017). Silicon nanoparticles more effectively alleviate arsenate toxicity than silicon in maize (*Zea mays* L.). *Plant Physiology and Biochemistry*, 110, 167–177. https://doi.org/10.1016/j.plaphy.2016.06.022

ANALYSIS OF PHYTOCHEMICALS IN *Holarrhena floribunda (L)* PARTS FOR ORGANIC MANURE PRODUCTION

[*1]BABALOLA, Eunice A., [2]ALAMU, Lateef O and [2]AJADI, M. O.

[1]Cocoa Research Institute of Nigeria
[2]Department of Forest Resources Management,
Ladoke Akintola University of Technology, Ogbomoso, Nigeria
Corresponding Email:euniceadenike929@gmail.com; +2348030800264

Abstract

The quest for sustainable agriculture has called for the use of plant-based organic manure. This study examined the quantity and quality of phytochemicals in the leaves, stems, and roots of *Holarrhena floribunda*. Fresh leaves, stem bark, and roots of Holarrhena floribunda were collected separately in zip-lock bags and well labelled. The samples were authenticated, rinsed with water, air-dried in the shade, and pulverized using a laboratory mill. Regular phytochemical screening procedures were carried out for qualitative analysis, while spectrophotometric techniques were used for quantitative analysis. Extractions and phytochemical analysis of *H.floribunda* leaf, stem-bark, and root were done using standard laboratory procedures. The results showed varying concentrations of tannins, quinones, phenols, terpenoids, saponins, anthraquinones, coumarins, alkaloids, phytate, flavonoids, and oxalate in all the plant parts investigated. Abundant presence (+++) of alkaloids with a quantity of 0.205mg/g, demonstrating that the leaves are rich in nitrogen- containing secondary metabolites. Moderate concentration of tannins (10.000%), terpenoids (5.567%), quinones (1.820%), phytate (5.835%), phenol (2.555%), and oxalate (3.061%) were also recorded in the leaf of *H. floribunda*. The highest alkaloid concentration (0.245%) was found among the three plant parts, with a strong qualitative presence (+++). This finding suggests that the root of *H. floribunda* serves as a vital reservoir of bioactive alkaloids. This study concluded that the presence of phytochemicals, both quantitatively and qualitatively, in *H. floribunda* indicates that the plant parts can be processed for organic manual processing to enhance agricultural production.

Keywords: *Holarrhena floribunda*, phytochemicals, analysis, organic manual

Introduction

Holarrhana floribunda (G. Don) T. Dur and Schinz, commonly known as False rubber tree, is One of the family Apocynaceae due to its milky property that is secreted when the bark is wounded or cut. It is popularly called "Ako-ire" in Yoruba and "Gamon sauwa" in Hausa. *H. floribunda*, a medium- sized tree of 4.5 to 17 meters high, is widely distributed in West Africa, especially in Nigeria. It is characterized by shining ovate – acuminate leaves, with a length range of 5 to 18 cm, and possesses white, scented flowers with the inflorescence arranged like an umbel. The fruits of *H. floribunda*, which are always in pairs, are long, slender, and have pendulous pods about 30 to 60 cm long. Taxonomically, there are two varieties, which are var. *floribuda* that produces glabrous leaves and var. *tomentalla* that produces densely pubescent leaves (Stephen, 2016). The stem bark is used as a decoction to treat ailments such as diarrhea, dysentery, and stomach pain, and as an antidote for snakebite. Also, the leaves of *H. floribunda* are effective in treating malaria, diabetes, and indigestion (Bogne *et al*., 2017). More importantly, *H. floribunda*, as an indigenous forest tree, could play a vital role in enhancing

environmental services, which is Oneone of the uses of forests in Nigeria (Yusuff & Alamu, 2019). It has been identified that *H. floribunda* possesses pharmacological activities due to the presence of bioactive compounds such as holarrhene, conessine, holaphylline, holaphyllamine, holamine, and progesterone, among others (Badmos *et al.,* 2016). The presence of different phytochemicals, which play vital roles in organic matter decomposition, nutrient cycling, and soil microbial ecology, makes *Holarrhena floribunda* parts suitable for protecting organic matter. This is an important component of sustainable agriculture. These phytochemicals include tannins, which help reduce the rate of organic matter decomposition and also influence nitrogen release. This activity promotes long-term soil fertility and carbon balance by enhancing soil matter persistence. Nones, also known as redox-active compounds, are involved in microbial electron transport systems and act as electron carriers during decomposition, thereby promoting organic matter breakdown and microbial respiration. The antimicrobial properties of quinones play important roles in destroying harmful microorganisms, thereby improving manure quality (Adamczyk, 2024). The role of phenolic compounds, such as simple phenolic acids, is significant in modulating microbial activity in soils by inhibiting and stimulating microbial populations and promoting humification.

It is important to note that despite the vast application of *Holarrhena floribunda* in treating human diseases, its application for plant science has not been widely investigated to serve as literature in crop and environment protection, except for the recent submission by Babalola and Alamu (2021) on the usage of *Holarrhena floribunda* as an organic growth enhancer for cocoa seedlings in Nigeria, which was found to be efficacious. The main aim of this study th, therefore, is to determine the quality and quantity of phytochemicals in *Holarrhena floribunda* parts for organic manure production.

Materials and Methods

Sample Source

Plant parts- leaf, stem-bark, and root of *Holarrhena floribunda* were sourced from Forestry Reserve Onigambari, Ibadan, Oyo State, which is characterized by high humidity and moderate rainfall with Latitude 7.43°N, a longitude of 3.85° E, and an elevation of 120m above sea level.

Sample Collection

Fresh leaves, stem bark, and roots of *Holarrhena floribunda* were collected separately in zip-lock bags and well labelled. The samples were authenticated, rinsed with water, air-dried in the shade, and pulverized using a laboratory mill.

Qualitative Analysis of Phytochemicals

Qualitative analyses were carried out using the methods of Trease and Evans (1989) and Harborne (1993) to identify the different phytochemicals in the leaves, stem bark, and roots of H. floribunda before quantitative analyses were performed.

Quantitative Analysis

Alkaloids Determination

Five grams (5g) each of leaf, stem bark, and root of *H. floribunda* were weighed into a 250 ml beaker, and 200 ml of acetic acid in ethanol was added to each sample, which was then covered and allowed to stand for 4 hours at 25°c. These were filtered using filter paper No. 42, and the filtrates were concentrated in a water bath (Memmert) to one-quarter of the original volume.

Concentrated ammonium hydroxide was added dropwise to each extract until the precipitate was complete. The whole solution was allowed to settle, and the precipitate was collected and washed with dilute NH_4OH (1% ammonia solution). They were then filtered with pre-weighed filter papers. The residue on the filter papers was a wasloid; it was then oven-dried, weighed, and expressed as a percentage of the sample weight (Odeyemi *et al*., 2023).

Flavonoids Determination

The plant sample (10g) was extracted repeatedly with 100ml of 80% aqueous methanol at room temperature. The whole solution was filtered through Whatman filter paper No 42 (1255mm). The filtrate was later transferred to a crucible, evaporated to dryness over a water bath, and weighed to constant weight.

Determination of Saponin

Exactly 5g each of the sample (*H. floribunda*) leaf, stem bark, and root were placed in 20% acetic acid in ethanol and allowed to stand in a water bath at 50^0 °C for 24 hours. These were filtered, and the extracts were concentrated using a water bath to one-quarter of the original volume. Concentrated NH_4OH was added dropwise to the extracts until the precipitates were complete. The entire solution was allowed to settle, and the precipitates were collected by filtration and weighed. The saponin contents were weighed and calculated in percentage (Odeyemi *et al*., 2023)

Tannin Determination

The percentage tannin of the stem bark and root of *H. floribunda* was determined by adding 20 g of each sample to petroleum ether and covering them for 24 hours. The samples were filtered and allowed to stand for 15 minutes to allow the petroleum ether to evaporate. They were then re-extracted by soaking in 100 ml of 10% acetic acid in ethanol for 4 hours. The samples were then filtered, and the filtrates collected. NH_4OH (25 ml) was added to each filtrate to precipitate the alkaloids. The alkaloids were heated on an electric hot plate to remove some of the remaining NH_4OH from the solution. The remaining volume was measured to be 33 ml 5 milliliters (mL) of each of these was added, and the milliliters (mL) were washed, and 20 mL of ethanol was added to them. They were titrated with 0.1 M. N_a NaOH: add phenolphthalein indicator until a pink endpoint is reached. The tannin content in each extract was then calculated as a percentage.

Determination of Phytate

Phytate contents were determined by weighing 0.2 g each of the samples (*H. floribunda* leaf, stem-bark, and root) into 250 ma l conical flasks; the samples were then soaked in 100 mL of 2% concentrated HCl for 3 hours and then filtered. 50 mL of the filtrate was placed in 250 mL beakers, and 100 mL of distilled water was added to each sample. mL milliliters of 0.3% ammonium thiocyanate was used as an indicator, and the solution was titrated with a standard iron(III) chloride solution containing 0.00195 g of iron per 1 mL (Odeyemi *et al*., 2023).

Phenol Determination

The quantity of phenol in each sample (leaf, stem-bark, and root of *H. floribunda* was determined using the spectrophotometer method. The samples were boiled in 50 ml of $(CH_3CH_2)_2O$ for 15 minutes. Five millimillilitersmillilitersl) Each of the boiled samples was pipetted into 50 ml flasks, and 10 ml of distilled water was added to each flask. The. The samples were made up to the marks, left for 39 minutesfor 39 minutes for colour development, and measured at 505nm using a spectrophotometer.

Determination of Anthraquinone

Magnesium Acetate solution was added to each H. floribunda sample *(H. floribunda* sample (ee, each of the stem-bark, and root)). The development of pink colour indicates the presence of Anthraquinones.

Results

The qualitative phytochemical analysis of the *H. floribunda* leaf, stem barkstem bark, and root.

The qualitative phytochemical analysis of *H. floribunda* leaf, stem-bark, and root showed the presence of oxalate, phytate, saponin, alkaloids, flavonoids, tannin, phenol, terpenoids, anthraquinone, quinones, coumarin, and fat & oil at varying levels—tables 1, 2, 3, and 4 show the results of the analysis.

Table 1: Qualitative analysis of Phytochemicals in *Holarrhena floribunda* leaf

S/N	PHYTOCHEMICALS	QUALITY	QUANTITY
1	Alkaloids	+++	**0.205mg/g**
2	Flavonoids	+	**0.094%**
3	Tannins	++	**10.000%**
4	Quinones	++	**1.820%**
5	Phenol	+	**2.555%**
6	Saponin	-	**0.151%**
7	Anthraquinone	+	**0.420%**
8	Phytate	+	**5.835%**
9	Oxalate	+	**3.061%**
10	Terpenoids	++	**5.567%**
11	Coumarin	-	**0.31%**
12	Fat & Oil	-	**2.840%**

Table 2: Qualitative analysis of Phytochemicals in *Holarrhena floribunda* stem-bark

S/N	PHYTOCHEMICALS	QUALITY	QUANTITY
1	Alkaloids	++	**0.189%**
2	Flavonoids	+	**0.134%**
3	Tannin	++	**16.500%**
4	Quinines	++	**3.470%**

ISTF-NIG 2026

5	Phenol	+	**15.916%**
6	Saponin	**-**	**0.186 %**
7	Anthraquinone	+	**0.860%**
8	Phytate	+	**20.044%**
9	Oxalate	+	**4.592mg/g**
10	Terpenoids	++	**5.808%**
11	Coumarin	**-**	**0.68%**
12	Fat & Oil	**-**	**1.960%**

Table 3: Qualitative analysis of Phytochemicals in *Holarrhena floribunda* root

S/N	PHYTOCHEMICALS	QUALITY	QUANTITY
1	Alkaloids	+++	**0.245%**
2	Flavonoids	+	**0.024%**
3	Tannins	++	**11.400%**
4	Quinones	++	**2.140%**
5	Phenol	+	**8.711%**
6	Saponin	**-**	**0.283%**
7	Anthraquinone	+	**1.210%**
8	Phytate	+	**10.446%**
9	Oxalate	+	**0.720mg/g**
10	Terpenoids	++	**5.607%**
11	Coumarin	**-**	**0.94%**
12	Fat & Oil	**-**	**1.43%**

Key: +++(Abundance); ++(High); +(Moderate); - (Low)

Discussion

The results of this study revealed differences in the quality and quantity of phytochemicals in the leaves, stems, and roots of *H. floribunda*. Table 1 shows the abundance of oxalate, phytate, saponins, alkaloids, flavonoids, tannins, phenols, terpenoids, anthraquinones, quinones, coumarins, fats, and oils at varying concentrations. These phytochemicals are known to be significantly medicinal, serving as antioxidant agents, and also have organic manure properties for plants in general (Mukavi *et l.*, 2026). Table 1 above shows the phytochemical constituents of *H. floribunda* leaf. The result showed the amount of presealkaloid content) of alat5mg/g, demonstrating that the leaves are rich in nitronitrogen-containing secondary metabolites. Alkaloids are significant bioactive compounds associated with pesticides and antimicrobial activities, which may increase the disease-suppressing potential of organic manure produced from these materials. This abundance of alkaloids corroborates the finding that species of

ISTF-NIG 2026

Holarrhena are a rich source of steroidal alkaloids with important pharmacological properties (Badmus *et al*., 2019).

The results showed that moderate concentrations of tannins (10.000%), terpenoids (5.567%), quinones (1.820%), phytate (5.835%), phenol (2.555%), and oxalate (3.061%) were also recorded in the leaves of *H. floribunda*. Research findings have revealed that tannins and phenols contribute significantly to the antioxidant and antimicrobial properties of plants and animals; therefore, these compounds enhance soil microbial activity and lower the activity of harmful pathogens, especially when added to organic manure components (Omowumi *et al*., 2026). The presence of flavonoids (0.094%) and anthraquinones (0.420%) also indicates antioxidant and biological activity abilities of *H. floribunda* leaf, which is in line with the findings of Badmus *et al*. (2016), which revealed that the presence of flavonoids is responsible for the antioxidant activity of the plant leaves and that this forms the scientific basis for its traditional usage. Saponin, coumarin, and fat and oil were present at low concentrations, indicating that these phytochemicals are less abundant in the leaves of *H. floribunda*. Nevertheless, their presence may still contribute to nutrient mineralization and microbial stimulation during organic manure production, in line with the findings of Adejoro *et al*. (2025), who reported that organic nutrient sources significantly increased soil microbial activity and enhanced decomposition processes in cultivated soil.

The results, as shown in Table 2 above, revealed that the stem bark of *H. floribunda* contains relatively higher concentrations of many phytochemicals than the leaf and root. Tannins (16.500%), phenols (15.916%), and phytate (20.044%) were specifically abundant in the stem-bark. These high levels of tannin and phenol indicate antioxidant and antimicrobial properties, which may contribute to the conservation of organic matter and the suppression of detrimental microbial activities during organic manure production. The stem-bark of *H. floribunda* also contained reasonable amounts of quinones (3.470%), terpenoids (5.808%), and oxalate (4.592mg/g). This. This suggests that the stem bark may possess strong bioactivity. Quinones are known for their antimicrobial and redox properties, while terpenoids contribute to plant biological resistance mechanisms. The relatively low alkaloid concentration (0.189%) also established the phytochemical abundance of *H. floribunda* stem bark. Anthraquinone (0.860%), flavonoids (0.134%), coumarin (0.68%), and fat & oil (1.9%) were present at lower concentrations. Although saponin was quantitatively absent, a trace amount (0.186%) was detected; this suggests slight accumulation in the stem bark tissues. The presence of these phytochemicals indicates the defensive activities and metabolite storage exhibited by the stem bark-bark tissue. This work agrees with the findings of Odusina and Ibrahim (2018), who stated that the presence of phytochemicals in *H. floribunda* contributes greatly to the plant's antimicrobial activities and bioactive properties.

Table 3 presents the quality and quantity of phytochemicals in the roots of *H. floribunda*. The highest alkaloid concentration (0.245%) was found among the three plant parts, with a strong qualitative presence (+++). This finding suggests that the root of *H. floribunda* serves as a vital reservoir of bioactive alkaloids. Appreciable quantities of tannins (11.400%), phytate (10.446%), phenol (8.711%), and terpenoids (5.607%) were recorded in the root of *H. floribunda*. The presence of these phytochemicals indicates the roles of antioxidant action, nutrient cycling, and microbial regulation in Soil. Also, the reasonable concentrations of quinones (2.140%) and anthraquinones (1.210%) indicate that the root of *H. floribunda* has antimicrobial and biological activities, which are indicators of organic manure production. The flavonoids (0.024%) in the root of *H. floribunda* were lowest compared to those in the leaf and stem bark, indicating low flavonoid biosynthesis or accumulation in root tissues. The oxalate content (0.720mg/g) was lower than that of the leaf and stem bark, indicating a low anti-

nutritional effect in the root of *H. floribunda.* The coumarin content (0.94%) was moderately higher in the root than in the leaf and stem bark of *H. floribunda*, indicating a buildup of aromatic compounds in underground tissues. The presence of these phytochemicals is consistent with the report by LeBlanc *et al*. (2024), which found that green waste compost significantly affects microbial function and reduces pathogen activity in infected soil.

Generally, the results showed that all parts of *H. floribunda* possess appreciable levels of phytochemicals, with significant differences among the three parts. The stem bark has the highest quantities of tannins, phenol, phytate, quinones, and terpenoids, while the root contains the highest alkaloids and anthraquinone. Meanwhile, the leaf contained reasonable levels of most phytochemicals, which may play vital roles as bioactive compounds. The differences in the phytochemical qualities of phytochemicals*. Floribunda* parts may result from physiological activities, metabolite storage, and the mechanismsthe mechanisms of defense displayed by different plant parts.

Conclusion

Based on the analysis of phytochemical quality and quantity of *H. floribunda* leaf, stem bark, and root, it is concluded that these parts possess high potential for organic manure production, thereby enhancing sustainable agricultural practices. It is therefore recommended that all stakeholders begin focusing on the inclusion of H. floribunda parts in the production of an organic manual to enhance environmentally friendly agriculture.

References

Adamczyk, B. (2024). Tannin and Climate Change: Are Tannins able to Stabilize Carbon in the Soil? *Journal of Agricultural and Food Chemistry*, 72(16), 8928-8932.

Adejoro, S.A, Olusola, O.J., Alade, O.d. (2025). Effects of Organic and Inorganic Nutrient Sources on Soil Microbial Activity in Cultivated Soil. *Journal of Trends in Applied Science Research 20(1): 48-55.*

Antwi, S., Oduro-Mensah, D., Obiri, D.D., Osafo, N., Antwi, A.O., Anssh, H.O., Ocloo, A., & Okine, L.K.N. (2022). Hydro-Ethanol Extract of *Holarrhena floribunda* Stem Bark Exhibits Anti- Anaphylactic and Anti- Oedematogenic Effects in Murine Models of Acute Inflammation. *BioMed Central Complementary Medicine and Therapies*, 22: 80.

Babalola, E. A. & Alamu, L.O. (2021).Assessment of Aqueous Leaf Extract of False Rubber Tree (*Holarrhena floribunda*) on Vegetative Growth of Three Varieties of Cocoa Seedlings. *Journal of Pure and Applied Agriculture*, 6(2); 17–24.

Badmus, J. A., Ekpo, O.E., Hussein, A.A., Meyer, M., & Hiss, D.C. (2019). Cytotoxic and Cell Cycle Arrest Properties of Steroidal Alkaloids Isolated from *Holarrhena floribunda* Leaves. *BioMedical Central* Complementary *Medicine and Therapies*, 19: 112.

Badmus, J. A., Ekpo, O. E., Rautenbach, F., Marnewick, J., Hussein, A.A., & Hiss, D.C. (2016). Isolation and Antioxidant Activity of Flavonoids from *Holarrhena floribunda* (G. Don.) Leaves. *Journal of Acta Biochimica Polonica,* 63(2): 853-861.

Bogne, K. P., Penlap, B. V., Lontsi, D. & Etoa, E. F. (2017). Antibacterial Activities of the Extracts and Conessine from *Holarrhena floribunda* G. Don. (Apocynaceae), *African Journal of Traditional Complementary and Alternative Medicines*, 4(3):352–356.

Harbrne, J. B. (1993). Phytochemical Methods. Chapman and Hall Ltd., London, United Kingdom. 49–188.

LeBlanc, N.R. & Harrigian, F. C. (2024). Green Waste Compost Impacts Microbial Functions Related to Carbohydrate Use and Active Dispersal in Plant Pathogen- Infected Soil. *Journal of Microbial Ecology*, 87:44.

Mukavi, J. W., Cal, M., Kaiser, M., Maser, P., Kimani, N. J., Omasa, L. K., & Schmidt, O. T. (2026). Identification of Steroidal Alkaloids with in Vitro Antiprotozal Activity from Holarrhena pubescence Wall. Ex G. Don. *Journal of Molecules*, 31(4), 733–741.

Odeyemi, O., Onochie, A. U., Odeyemi, S. O. & Oshim, I. O. (2023). Evaluation of Qualitative and Quantitative Phytochemical Constituents of *Napoleonaimperialis* Stem Bark. *Journal of GSC Biological and Pharmaceutical Science*, 24(01), 202–208.

Odusina, B.O., & Ibrahim, S. A. (2018). Phytochemical Screening, Antimicrobial Activities and Quantity Estimates of Bioactive Compounds in Extracts of *Holarrhena floribunda*. *Journal of Chemical Society of Nigeria*, 43(3): 114

Omowumi, T.A., Odunayo, O. V., Timothy, S.K., & Akingbolabo, O. D. (2026). Phytochemical Composition and Antimicrobial Efficacy of Nigerian Polyherbal Formulations against Antibiotic-Resistant Microorganisms. *Scientific Reports.*

Stephen, A. (2016). Evaluation of the Anti-inflammatory Effects of the Hydroethanolic Extract of *H. floribunda* in Marine Models of Inflammation: A thesis submitted in partial fulfillment of the requirements for the degree of Master of Philosophy.

Trease, G. E. & Evans, W. C. (1989). Pharmacognosy. 11th Edition. Macmillan Publishers, London, United Kingdom.

Yusuff Z.O. & Alamu L.O. (2019).Effectiveness of Forest Management as Affected by the Land Use Act in Onigambari Forest Reserve, Oluyole Local Government Area, Ibadan, Nigeria. *Advance in Social Sciences Research Journal,* 6(12): 16–23.

ISTF-NIG 2026

SUB-THEME 8:
WILDLIFE AND ECOTOURISM POTENTIALS IN ECOSYSTEM CONSERVATION

ISTF-NIG 2026

WILDLIFE-BASED ECOTOURISM AS A TOOL FOR ECOSYSTEM CONSERVATION IN TROPICAL FORESTS

Akinola O. O.

Federal College of Forestry, Ibadan, Nigeria
Corresponding Email: funmod.akl@gmail.com

Abstract

Wildlife-based Ecotourism has gained global recognition as an integrated approach to biodiversity conservation and sustainable development, particularly in tropical forest ecosystems. These ecosystems, which harbor a significant proportion of the world's biodiversity, are increasingly threatened by anthropogenic pressures, including deforestation, habitat fragmentation, and overexploitation of wildlife resources. This study adopts a narrative literature review methodology, drawing from relevant literature through a structured search of major academic databases, including Scopus, Web of Science, and Google Scholar, using keywords such as "wildlife-based ecotourism," "biodiversity conservation," and "sustainable tourism. Findings revealed that Ecotourism promotes biodiversity conservation by protecting habitats, provides alternative livelihoods, enhances environmental awareness, and strengthens conservation financing. Evidence from case studies such as Serengeti National Park (Tanzania), Bwindi Impenetrable National Park (Uganda), and Cross River National Park (Nigeria) further demonstrates its practical relevance. However, challenges such as inadequate policy frameworks, environmental degradation due to over-tourism, and inequitable benefit-sharing persist. The study concludes that wildlife-based Ecotourism, when effectively managed and supported by strong institutional frameworks, can significantly contribute to long-term ecosystem conservation in tropical forest regions.

Keywords: Wildlife ecotourism, tropical forests, biodiversity conservation, ecosystem management, sustainable development

Introduction

Tropical forests are among the most ecologically significant ecosystems globally, harbouring a substantial proportion of the world's biodiversity and playing a critical role in sustaining ecological balance. Recent estimates indicate that forests support the majority of terrestrial species, with tropical forests being particularly rich in biodiversity (FAO, 2020). These ecosystems provide essential services such as carbon sequestration, climate regulation, water cycling, and soil conservation, thereby contributing significantly to global environmental stability (FAO, 2025). Despite their importance, tropical forests are under severe threat from human activities, including logging, agricultural expansion, mining, and infrastructure development. Current data show that global deforestation remains high, with approximately 10.9 million hectares of forest lost annually between 2015 and 2025 (FAO, 2025), while tropical primary forest loss alone reached about 3.7 million hectares in 2023 (WRI, 2024). Conventional conservation strategies, particularly strict protectionist approaches, have often been limited by insufficient funding, weak enforcement, and a lack of local community involvement. These challenges have contributed to the search for more inclusive and sustainable conservation models that integrate ecological protection with socio-economic benefits. Wildlife-based Ecotourism involves responsible travel to natural areas with the primary aim of observing wildlife in their natural habitats while promoting conservation and improving the well-being of local communities (Honey, 2008). In tropical forests, this approach

provides an opportunity to align conservation goals with economic incentives, thereby reducing reliance on destructive resource-use practices. Despite growing recognition of wildlife-based Ecotourism, there remains a limited synthesis of its integrated ecological, economic, and social impacts within tropical forest ecosystems, particularly in developing countries. This paper employs a narrative literature review approach, synthesizing evidence from peer-reviewed journals, institutional reports, and global conservation databases to critically assess the ecological, economic, and social contributions of wildlife-based Ecotourism.

Theoretical and Conceptual Framework

Wildlife-based Ecotourism as a tool for ecosystem conservation in tropical forests is grounded in several key environmental and economic theories:

Sustainable Development Theory

Wildlife-based Ecotourism is rooted in the principles of sustainable development, which emphasize meeting present needs without compromising the ability of future generations to meet theirs (WCED, 1987). It integrates environmental conservation, economic development, and social equity.

Ecosystem Services Framework

The ecosystem services framework (MEA, 2005) provides a useful lens for understanding the benefits derived from tropical forests. Wildlife provides key ecosystem services, such as pollination, seed dispersal, and pest control. Ecotourism helps assign economic value to these services, thereby promoting conservation.

Ecotourism–Conservation Nexus

Incentive-Based Conservation Theory

Incentive-Based Conservation Theory (Wunder, 2000) emphasizes the internalization of the economic value of ecosystem services. Wildlife-based Ecotourism enhances revenue generation through:

- Park entrance fees
- Tour guiding services
- Accommodation and hospitality

When communities derive income from tourism, they are less likely to engage in:

- Poaching
- Illegal logging
- Slash-and-burn agriculture

Thus, Ecotourism provides sustainable alternative livelihoods.

Community-Based Natural Resource Management (CBNRM)

CBNRM is based on the premise that local communities are best positioned to manage natural resources sustainably when given the necessary rights, incentives, and capacity (Berkes, 2004). It promotes decentralization of resource control, integration of indigenous knowledge and local participation in decision-making

Market-Based Conservation Mechanisms (MBCM)

ISTF-NIG 2026

MBCMs aim to make conservation economically attractive by integrating environmental values into market systems (Engel et al., 2008).

Ecological Importance of Tropical Forests

Tropical forests are biodiversity hotspots characterized by complex ecological interactions and high species endemism (Myers et al., 2000). They provide habitat for numerous wildlife species, many of which are endangered. The degradation of these ecosystems leads to biodiversity loss and disruption of ecological processes (Laurance et al., 2014).

Contributions of Wildlife-Based Ecotourism to Ecosystem Conservation

Biodiversity Conservation

By assigning economic value to wildlife and natural habitats, Ecotourism encourages governments and local communities to conserve ecosystems. This aligns with the principles of Incentive-based conservation, which motivate sustainable resource management through financial benefits. Ecotourism generates financial resources that can be reinvested into conservation programs such as anti-poaching patrols, wildlife monitoring, and habitat restoration (Krüger, 2005). Wildlife-based Ecotourism contributes significantly to ecosystem conservation, accounting for up to 64% of conservation funding in some protected areas and generating billions of visits annually to protected sites worldwide (Balmford et al., 2015; Steven et al., 2013; World Bank, 2023).

Habitat Protection and Restoration

By providing alternative income sources, Ecotourism reduces dependence on destructive activities such as logging and slash-and-burn agriculture (Wunder, 2000). Revenue and awareness generated from Ecotourism can support ecosystem restoration efforts such as reforestation, wetland rehabilitation, and invasive species control, thereby improving habitat quality.

Community Empowerment and Livelihood Diversification

Ecotourism supports local economies by creating employment opportunities and generating revenue through tourism services (Scheyvens, 1999). Local communities benefit from employment opportunities as tour guides, rangers, artisans, and hospitality workers. Ecotourism also promotes alternative livelihoods, reducing dependence on activities like logging, hunting, and slash-and-burn agriculture. In Tanzania, wildlife tourism contributes about 17% of GDP and supports ~850,000 jobs.

Reduction in Illegal Activities

With increased economic benefits and monitoring, Ecotourism helps reduce illegal activities such as poaching, illegal logging, and wildlife trafficking. Community participation in conservation further strengthens surveillance and compliance.

Environmental Education and Awareness

Ecotourism fosters environmental awareness among tourists and local populations (Ballantyne et al., 2011). Visitors gain knowledge about biodiversity conservation, while communities become more aware of the importance of protecting their natural resources.

Conservation of Endangered Species

ISTF-NG 2026

Ecotourism provides direct and indirect support for the protection of endangered species by funding conservation programs and raising awareness. Species that attract tourists often receive greater protection attention.

Empirical Case Studies

Serengeti National Park (Tanzania): Tourism revenue significantly supports wildlife conservation and park management. Tourism revenue significantly supports wildlife conservation and park management in Serengeti National Park, generating over TSh 266.8 billion annually and contributing to broader national tourism earnings (Mushi, 2025; World Tourism Organization, 2014; Bank of Tanzania, 2025).

Bwindi Impenetrable National Park (Uganda): Gorilla tourism provides income for conservation and local communities.

Cross River National Park (Nigeria): Demonstrates potential for community-based Ecotourism in tropical rainforest conservation.

Challenges of Wildlife-Based Ecotourism

Environmental Impacts

Although Ecotourism is meant to be environmentally friendly, poorly managed activities can lead to habitat destruction, soil erosion, pollution, and wildlife disturbance. Excessive human presence may alter animal behavior, breeding patterns, and migration routes. Uncontrolled tourism can lead to habitat degradation and wildlife disturbance (Buckley, 2011).

Frequent tourist activities such as game drives, noise, and photography can stress animals. In some cases, infrastructure development (roads, lodges, trails) can fragment habitats, negatively affecting biodiversity. (Blumstein et al., 2017; Larson et al., 2016).

Institutional and Policy Constraints

Weak governance and unclear policies hinder effective implementation (Eagles et al., 2002). Weak enforcement of environmental laws, corruption, and a lack of clear policies often undermine conservation efforts. Even where policies exist, implementation is often ineffective due to limited institutional capacity.

Inequitable Benefit Distribution

Benefits are sometimes captured by external investors, limiting local community gains (Ashley & Roe, 2002). Local communities are sometimes excluded from decision-making processes. When communities do not benefit directly from Ecotourism, they may resort to activities such as poaching, logging, or farming within protected areas.

Inadequate Infrastructure

Many ecotourism sites, especially in developing countries, lack good roads, accommodation, healthcare facilities, and communication networks. This limits accessibility and reduces tourist satisfaction and repeat visits.

Climate Change Impacts

Climate change affects ecosystems, wildlife distribution, and habitat quality. This can reduce the attractiveness of ecotourism destinations and threaten biodiversity. Climate change alters habitats and species distribution, affecting both conservation and tourism (Scott et al., 2012).

ISTF-NIG 2026

Policy and Management Implications

To maximize conservation benefits, the following strategies are recommended:

Development of clear ecotourism policies and regulatory frameworks to guide sustainable tourism practices. This will ensure environmental protection and alignment with biodiversity conservation goals.

Promotion of community-based ecotourism models that will enhance and regulate visitor numbers and prevent ecological degradation by identifying sustainable limits of use, local participation, equitable benefit-sharing, and conservation outcomes by empowering communities as key stakeholders

Implementation of carrying capacity assessments to regulate visitor numbers and prevent ecological degradation by identifying sustainable limits of use

Strengthening monitoring and evaluation systems that will enable tracking of ecological and socio-economic impacts, supporting adaptive management in Ecotourism

Encouraging public-private partnerships will improve investment, efficiency, and sustainable infrastructure development in Ecotourism while supporting conservation goals.

Integration of climate adaptation strategies enhances the resilience of ecosystems and tourism systems to climate change impacts.

Conclusion

Wildlife-based Ecotourism offers a viable pathway for achieving sustainable ecosystem conservation in tropical forests. By linking economic incentives with conservation objectives, it promotes biodiversity protection, enhances local livelihoods, and supports ecosystem resilience.

However, its success depends on effective governance, equitable benefit-sharing, and sustainable management practices.

Future Direction:

Future research should focus on empirical assessments of ecotourism outcomes in tropical forest regions, particularly in sub-Saharan Africa, to strengthen evidence-based policy and practice.

With strong institutional support, wildlife-based Ecotourism can be a powerful tool for conserving tropical forest ecosystems amid growing environmental challenges.

References

Adams, W. M., & Hulme, D. (2001). Conservation and community. Oryx, 35(3), 193–200.

Ashley, C., & Roe, D. (2002). Making tourism work for people with low incomes: Strategies and challenges in southern Africa. Pro-Poor Tourism Report No. 1.

Ballantyne, R., Packer, J., & Falk, J. (2011). Visitors' learning for environmental sustainability: Testing short- and long-term impacts of wildlife tourism experiences. *Tourism Management*, 32(6), 1243–1252.

Balmford, A., Green, J. M. H., Anderson, M., Beresford, J., Huang, C., Naidoo, R., Walpole, M., & Manica, A. (2015). Walk on the wild side: Estimating the global magnitude of

ISTF-NIG 2026

visits to protected areas. *PLoS Biology,* 13(2), e1002074. https://doi.org/10.1371/journal.pbio.1002074

Bank of Tanzania. (2025). Annual economic report 2025. Bank of Tanzania.

Berkes, F. (2004). Rethinking community-based conservation. Conservation Biology, 18(3), 621–630.

Blumstein, D. T., Geffroy, B., Samia, D. S. M., & Bessa, E. (2017). Ecotourism's impacts on wildlife: Insights from recent research. *Biological Conservation,* 209, 1–10.

Buckley, R. (2009). Ecotourism: Principles and practices. CABI Publishing.

Buckley, R. (2011). Tourism and environment. Annual Review of Environment and Resources, 36, 397–416.

Eagles, P. F. J., McCool, S. F., and Haynes, C. D. (2002). Sustainable tourism in protected areas: Guidelines for planning and management. IUCN.

Engel, S., Pagiola, S., & Wunder, S. (2008). Designing payments for environmental services in theory and practice: An overview of the issues. Ecological Economics, 65(4), 663–674.

Food and Agriculture Organization of the United Nations (FAO). (2025). Global forest resources assessment 2025. FAO.

FAO. (2020). Global forest resources assessment 2020—food and Agriculture Organization of the United Nations.

Groombridge, B., & Jenkins, M. (2002). World atlas of biodiversity: Earth's living resources in the 21st century. UNEP World Conservation Monitoring Centre.

Honey, M. (2008). Ecotourism and sustainable development: Who owns paradise? Island Press.

Krüger, O. (2005). The role of Ecotourism in conservation: Panacea or Pandora's box? Biodiversity and Conservation, 14, 579–600.

Larson, C. L., Reed, S. E., Merenlender, A. M., & Crooks, K. R. (2016). The effects of recreation on animals were found to be widespread in a global systematic review. *PLoS One*, 11(12), e0167259.

Laurance, W. F., Clements, G. R., Sloan, S., O'Connell, C. S., Mueller, N. D., Goosem, M., … Balmford, A. (2014). A global strategy for road building. *Nature*, 513, 229–232.

Mushi, E. (2025). Tourism revenue and conservation outcomes in Serengeti National Park. [Institution/Publisher].

Millennium Ecosystem Assessment (MEA). (2005). Ecosystems and human well-being: Synthesis. Island Press.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A., and Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature, 403, 853–858.

Scheyvens, R. (1999). Ecotourism and the empowerment of local communities. *Tourism Management,* 20(2), 245–249.

Scott, D., Gössling, S., & Hall, C. M. (2012). Climate change and tourism: Impacts, adaptation and mitigation. Routledge.

Steven, R., Morrison, C., & Castley, J. G. (2013). Wildlife tourism: Impacts, management and planning. *Tourism Management*, 35, 1–12.

Stronza, A., & Gordillo, J. (2008). Community views of Ecotourism. Annals of Tourism Research, 35(2), 448–468.

WCED (World Commission on Environment and Development). (1987). Our common future. Oxford University Press.

World Bank. (2023). Nature-based tourism and conservation: Global economic contributions. World Bank Publications.

World Resources Institute (WRI). (2024). Global forest review 2024. World Resources Institute.

Wunder, S. (2000). Ecotourism and economic incentives: An empirical approach. Ecological Economics, 32(3), 465–479.

DIET AND FORAGING ECOLOGY OF THE LAUGHING DOVE (*Streptopelia senegalensis*) IN ILARO FOR SUSTAINABLE ECOTOURISM DEVELOPMENT OF Ogun State, Nigeria.

Okosodo E.F., Tinuoye, O. I., and Ogundare, A. G.

Department of Tourism Management Technology, Federal Polytechnic Ilaro, Nigeria
Corresponding author: francis.okosodo@federalpolyilaro.edu.ng

Abstract

The study was done in Nigeria's Ogun State, in Ilaro. From November 2023 to November 2024, we gathered information about the Laughing Dove's (*Streptopelia senegalensis*) diet and feeding habits. The study looked at 20 pairs of Laughing Doves, each with a size between One and ten, that were spotted in three separate places: the Residential zone, the Farmland zone, and the Fallowland zone. Researchers used Bushnell 750 binoculars to observe the birds from dawn to dusk without disturbing them while they ate. During the study, detailed notes were taken on where the birds foraged, how they fed, how long they fed, how many birds were in the area, what kinds of food they ate, and how they interacted with other birds. This type of animal eats a wide variety of seeds, grains, fruits, and flowers. The results showed that during the wet season, *Ficus exasperata* fruits and seeds made up 14% of their diet. Next was Ficus latifolia with 12%, and last was *Ficus capensis* with 9%. The plants they ate during the dry season suggest that *Oryza sativa* (rice) was the most common, accounting for 16.3% of their diet. The next most prevalent were *Panicum maximum* (12%) and *Zea mays* (corn) (10%). Research on the insects the birds ate found that they ate black ants, termites, little leaf beetles, butterflies, and caterpillars.

Key Words: Diet, Foraging ecology, habitat, utilization, sustainable tourism

Introduction

The Laughing Dove (*Spilopelia senegalensis*) is a little, pretty pigeon known for its cooing, which sounds like beautiful, laughter-like notes (BirdLife International, 2024). They came from Africa, the Middle East, and parts of South Asia. You can find them in cities, gardens, farms, and open woods. In Nigeria, it can be found in a wide range of habitats, from mangroves to the Sahel savanna in the north. BirdLife International (2024) says it can even be successful in settings where people have been hurt. They have keen eyesight so that they can spot tiny bugs or grains of sand on the ground. They can also drink water quickly by taking long sips without tilting their heads back, unlike many other types of birds (Yapıcı, Erdoğan, 2023). You need to understand how wildlife eats to address conflicts between people and animals in cities and the country, especially when they devour crops. You may learn about how birds adapt to living in cities and how species change when people change their environments by looking at them. The International Union for Conservation of Nature (IUCN) says that the Laughing Dove is a "Least Concern" (LC) species. BirdLife International (2024) argues that this is because it can readily live in many different places, including those that people have changed. The Laughing Dove is a strong species that is valuable to the environment and is not at risk of extinction. It can dwell in many different settings, which helps it survive in a world that is continually changing. However, stresses in some locations, such as habitat degradation, urbanization, and hunting, could affect their numbers there (Ayadi et al., 2016).

Materials and Method

Study Area

Ilaro is in the Yewa South Local Government Area of Ogun State. It is part of the Yewa cultural region, formerly known as Egbado. The Yewa people, believed to have originated in Ile-Ife, the mythological home of the Yoruba ethnic group, have lived in this area for a long time. Ilaro became a major settlement because it was located along important trade routes connecting the larger Yorubaland with the Dahomey Kingdom (now the Republic of Benin). Ilaro is located at about Latitude 6.8935° North and Longitude 3.0171° East (Figure 1). It is close to the border with the Republic of Benin and is in the transition zone between tropical rainforest and savanna habitats. The town has a bimodal climate, with two distinct seasons. The rainy season lasts from March to November and is characterized by heavy, steady rain. On the other hand, the dry season, which runs from December to February, receives very little rainfall. The area gets 1,700 to 2,000 mm of rain each year, which is a lot for plants to grow. The average yearly temperature is about 26°C, which is normal for a tropical monsoon climate. In the past, Ilaro was covered by tropical rainforest flora. This type of forest is notable for its tall emergent trees, multi-layered canopy structure, and abundant biodiversity, which includes lianas and epiphytes. Some of the most important tree species that used to be common in the area are *Milicia excelsa* (Iroko), *Afzelia bipindensis* (African mahogany), *Brachystegia nigerica, Lovoa trichilioides* (African walnut), *Terminalia ivorensis* and *Terminalia superba* (White and Black Afara), and *Triplochiton scleroxylon* (Obeche). However, due to large-scale farming and other human activities, much of the natural forest cover has been lost. Today, much of the area is composed of secondary regrowth forests, thickets, and derived savanna grasslands. There are only a few remnants of the primary forest, and they are mostly in places that have not been heavily farmed or settled. This change in the ecosystem shows how much humans are affecting Ilaro's natural environment and how important it is to protect the region's remaining biodiversity.

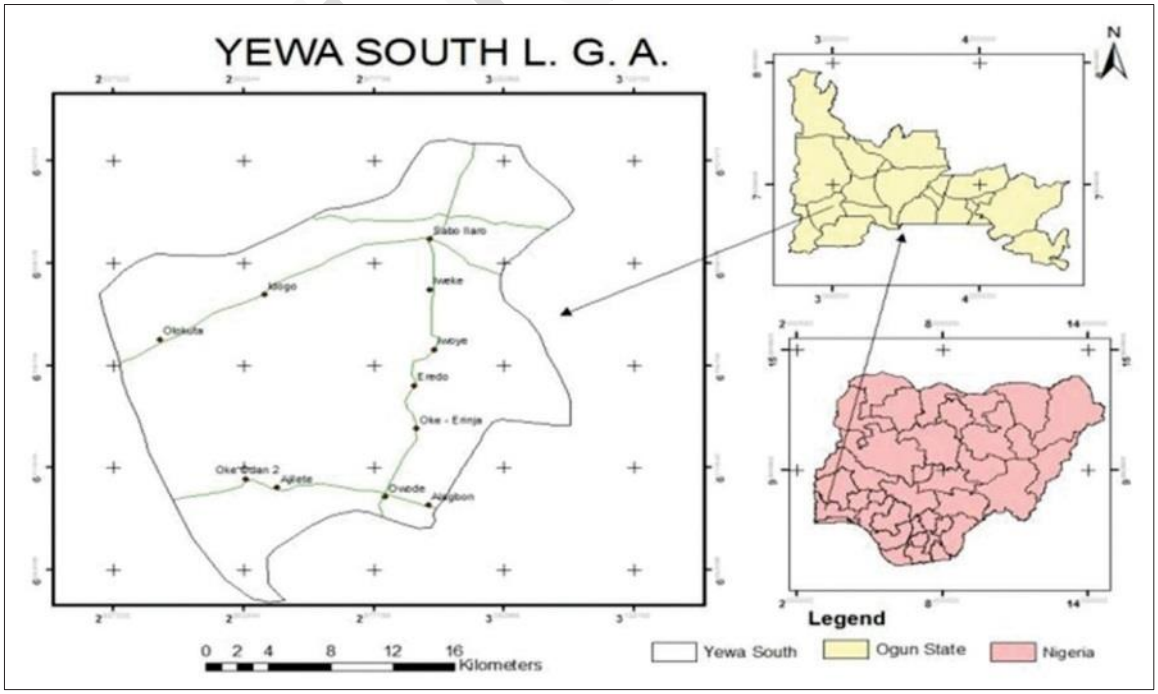


Figure 1: Map of the study area

Data Collection

We divided the research area into three parts based on land use: the Humanised Block, the Farmland Block, and the Secondary Block. For a full year, from November 2023 to November 2024, we tracked what Streptopelia senegalensis (Laughing Dove) ate and how it fed. The sample consisted of 12 pairs, with groups ranging from 1 to 3 people. The study used the Direct Observation Method, as described by Akinpelu (2004) and Okosodo et al. (2016). We used Bushnell 750 binoculars to watch the birds, especially in the early morning and late evening, when they were most active, and there were few people around. We kept an eye on each couple for 2 to 5 hours at a time, allowing us to monitor at least some of the group members at all times. However, it was hard to keep an eye on the full group at once. During each observation session, detailed notes were made on the feeding area, the specific land-use unit where feeding occurred, and the manner in which the animals fed. The doves ate in several ways, including pecking at the ground and picking up food. Length and frequency of feeding activities, as well as the makeup of the group: The number of birds seen during each session and what they ate: What kinds of food birds eat (such as seeds and insects) and how they get along with other birds: Connections or interactions that happen when looking for food. We also paid attention to how people's eating habits changed with the seasons, noting how their diets and behaviours altered with the weather.

Data Analysis

Based on the data we collected, we used descriptive statistics to summarize the food and eating habits of Streptopelia senegalensis. The study used the PAST (Paleontological Statistics) program. It made it easier to see and analyze patterns in ecological data. We learnt how the bird eats and how it changes with the seasons and its habitat using this method.

Results

The results demonstrate that the species has distinct eating and foraging tendencies. This suggests it can be found in many places, including towns, rural areas, damaged forests, and farms. This kind of animal eats a wide variety of seeds, cereals, grains, fruits, and flowers. The species also eats more insects during the wet season, suggesting it can adjust its diet to what is available. The plants the animals ate during the wet season showed that Ficus exasperata fruits and seeds were the most popular, accounting for 14% of their diet. Table 1 shows that Ficus latifolia ranked second at 12%, and *Ficus capensis* ranked third at 9%. Table 2 shows that during the dry season, 16.3% of their food was *Oryza sativa* (rice), 12% was *Panicum maximum,* and 10% was *Zea mays* (corn). Termites, little leaf beetles, butterflies, black ants, and caterpillars were among the bugs the birds ate. According to Table 3, the family Poaceae has the most plant species that Laughing Doves ate, with 17 species. Five species each of Moraceae and Fabaceae followed next—figure 2. *Oryza sativa* (rice) was the most prevalent plant food consumed by the Laughing Dove during the dry season, making up 16.3% of their diet, as seen in Figure 3. The next most prevalent were *Panicum maximum* (12%) and *Zea mays* (corn) (10%). During the rainy season, the Laughing Dove ate a lot of different sorts of plants. *Ficus exsparata* made up 14% of their food, *Ficus latifolia* made up 11%, and *Ficus thonnigii* made up 8%. Figure 4 shows that the Laughing Dove ate a lot of different kinds of insects. The One with the most was *Macrotermes bellicosus* (17.6%). Next came *Odontotermes sudanensis* (15.7%) and *Parasyscia cribrinodis* (12.6%)—Figure 5. The results of the habitat-use analysis

showed that the residential compartment was used most (54%), followed by the agricultural compartment (36%) and the fallow/secondary forest (10%).

Table I: Plant resources fed upon during the Dry season

Name of plant species	Family	Parts consumed	Frequency%
Aspilia africana.	Asteraceae	Seeds	2.6
Asystasia gangetica	Acanthaceae	Seeds	1.2
Carica papaya	Caricaceae	Seeds	3.1
Chromolaena odorata.	Asteraceae	Seeds	2.2
Cymbopogon citrates	Poaceae	Seeds	2.1
Cynadan dactylon.	Poaceae	Seeds	1.2
Cynodonplectostachyus	Poaceae	Seeds	1.3
Cyperus rotundus	Poaceae	Seeds	1.4
Digitaria abyssinica.	Poaceae	Seeds	1.9
Gynandropsis gynandra	Cleomaceae	Seeds	1.4
Hyparrhenia rufa	Poaceae	Seeds	1.3
Hyptiss picigera	Lamiaceae	Seeds	1.2
Lawsonia inermis	Lythraceae	Seeds	9
Leucaena leucocephala	Fabaceae	Seeds	4
Megathyrsus maximus	Poaceae	Seeds	12
Ocimumgratissimum	Lamiaceae	Seeds	5
Panicum maximum	Poaceae	Seeds	12
Pennisetum purpureum.	Poaceae	Seeds	2.1
Phyllanthus amarus	Phyllanthaceae	Seeds	1.2
Physalis angulata	olanaceae.	Seeds	2.5
Selaginella kraussiana	Selaginellaceae	Seeds	2.2
Senna alata	Fabaceae	Seeds	0.4
Spigelia anthelmia	Loganiaceae	Seeds	1.5
Stenotaphrum secundatum.	Poaceae	Seeds	1.6
Striga hermonthica	Orobanchaceae.	Seeds	2.3
Tithonia diversifolia	Asteraceae	Seeds	2.1
Trama orientalis	Cannabaceae	Seeds	1.1
Tridax procumbers	Asteraceae	Seeds	0.5
Justicia flava.	Acanthaceae	Seeds	2.1
Zea mays	Poaceae	Seeds	10
Amaranthus retroflexus	Poaceae	Seeds	1.2
Andropogon gayanus	Poaceae	Seeds	1.6
Oryza sativa	Poaceae	Seeds	16.3

Table 2: Plant species resources consumed during the wet season in the study area.

Name of plant species	Family	Parts Utilized	Frequency of observations
Triumfetta rhomboidea	Malvaceae	Seeds	3.1
Passiflora foetida	Passifloraceae	Seeds	2.1

ISTF NIG 2026

Mimosa pudica	Fabaceae	Seeds	3.1
Oxalis corniculata	Oxalidaceae	Seeds	2.3
Commelina benghalensis	Commelinaceae	Flowers	1.1
Datura stramonium	Solanaceae	Seeds	2.4
Ficus capensis	Moraceae	Seeds	9
Ficus thonnigii	Moraceae	Seeds	8
Ficus latifolia	Moraceae	Seeds	12
Ficus exsparata	Moraceae	Seeds	14
Diallum guineense	Fabaceae	Seeds	5
Boerhivia difusa	Annonaceae.	Seeds	4
Moringa oleifera	Moringaceae	Flowers	5.1
Nauclea latifolia	Rubiaceae	Fruits	4.1
Olea europaea	Oleaceae	Seeds	4
Psidium guajava	Myrtaceae.	Seeds	4.1
Rauvolfia vomitoria	Myrtaceae.	Fruits	2.4
Setaria barbata	Poaceae	Seed	2.2
Solanlum nigrum	Solanaceae	Seeds	1.3
Sporobolus pyramidalis	Poaceae	Seeds	2.5
Diallum guineense	Verbenaceae	Seeds	2.4
Sorghum bicolor	Poaceae	Seeds	2.7
Gliricidia sepium	Fabaceae	seeds and flowers	3.1

Table 3: Insect species consumed during the wet season in the study area

Name of Insect species	Family	Parts Utilized	Frequency
Diphasiastrum alpinum	Chrysomelidae	Whole	3.7
Dorylus nigricans	Formicidae	Whole	3.3
Dorylusaffinis	Formicidae	Whole	6.6
Dorylusbraunsi	Formicidae	Whole	2.7
Dorylus depili	Formicidae	Whole	2.5
Dorylus savage	Formicidae	Whole	2.6
Lebistinasu bcruciata	Chrysomelidae	Whole	1.4
Macrotermes subhyalinus	Termitidae	Whole	17.6
Macrotermes bellicosus	Termitidae	Whole	15.7
Odontotermes sudanensis	Termitidae	Whole	12.6
Parasyscia cribrinodis	Formicidae	Whole	9.5
Parasyscia sudanensis	Formicidae	Whole	11.3
Simopone conradti	Formicidae	Whole	4.2
Technomyrmex Andrei	Formicidae	Whole	3.7
Zasphinctus rufiventris	Formicidae	Whole	2.6

ISTF NIG 2026

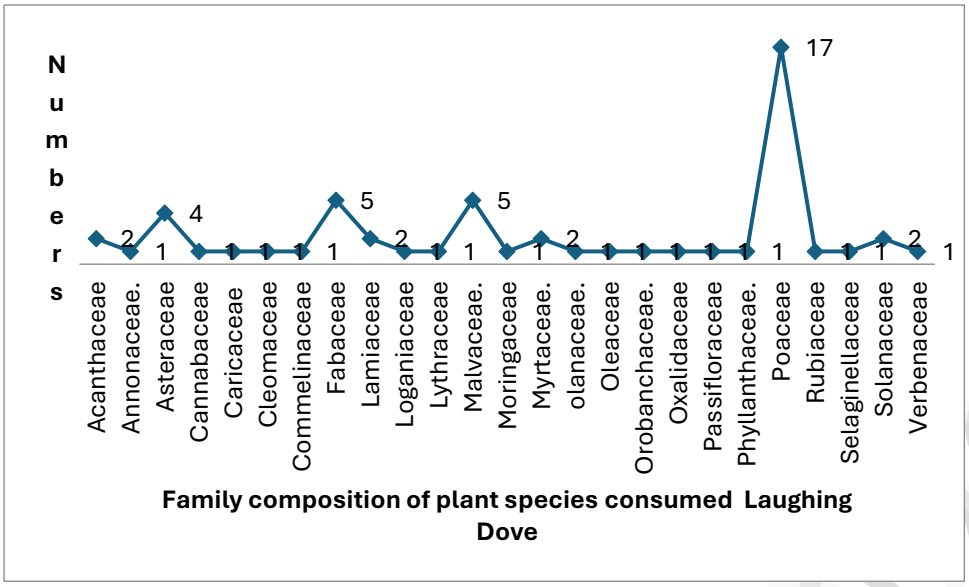


Figure 2: Family composition of Plant species fed upon in the study area

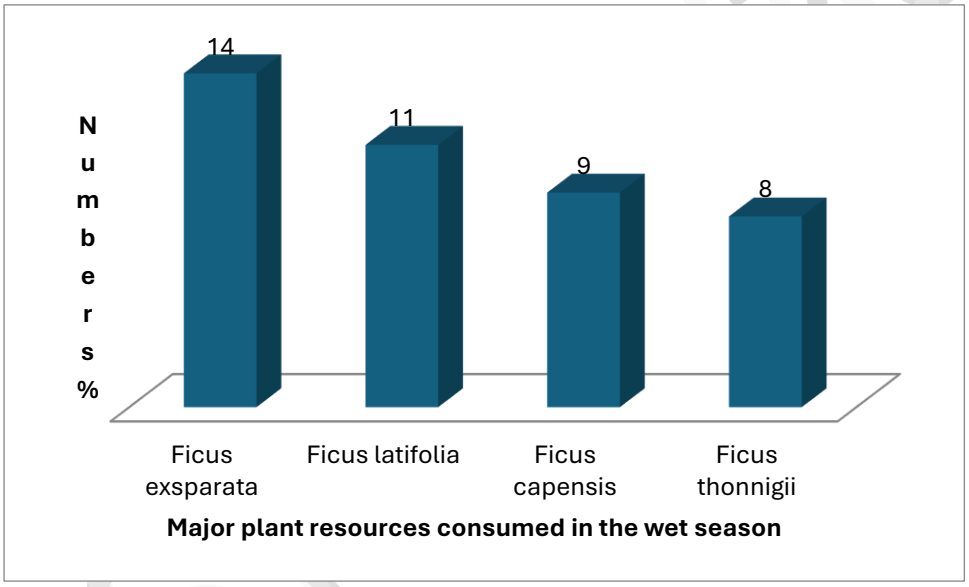


Figure 3: Major Diet of the Laughing Dove in the Wet season in the study area

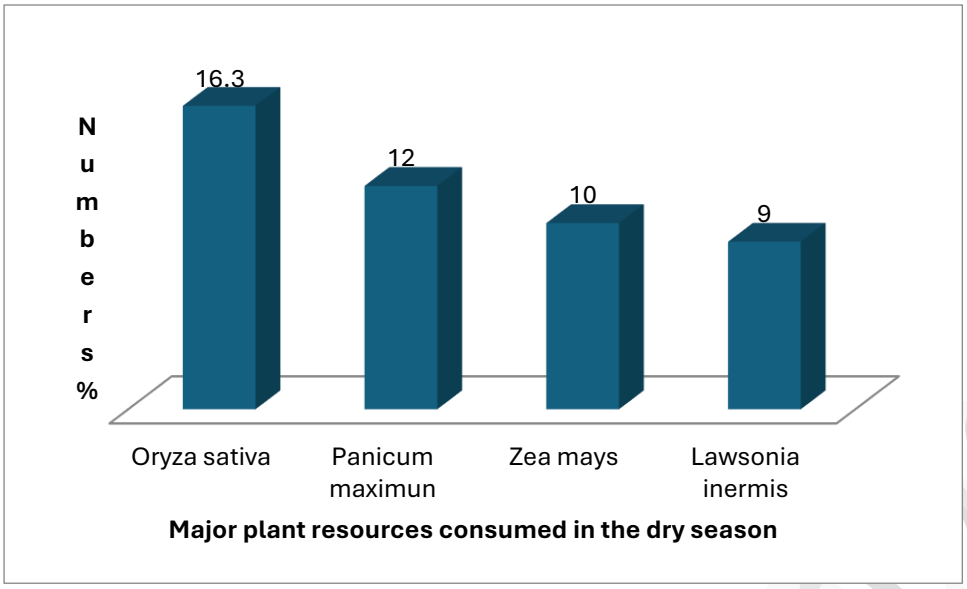


Figure 4: Major Diet of the laughing Dove in the dry season in the study area

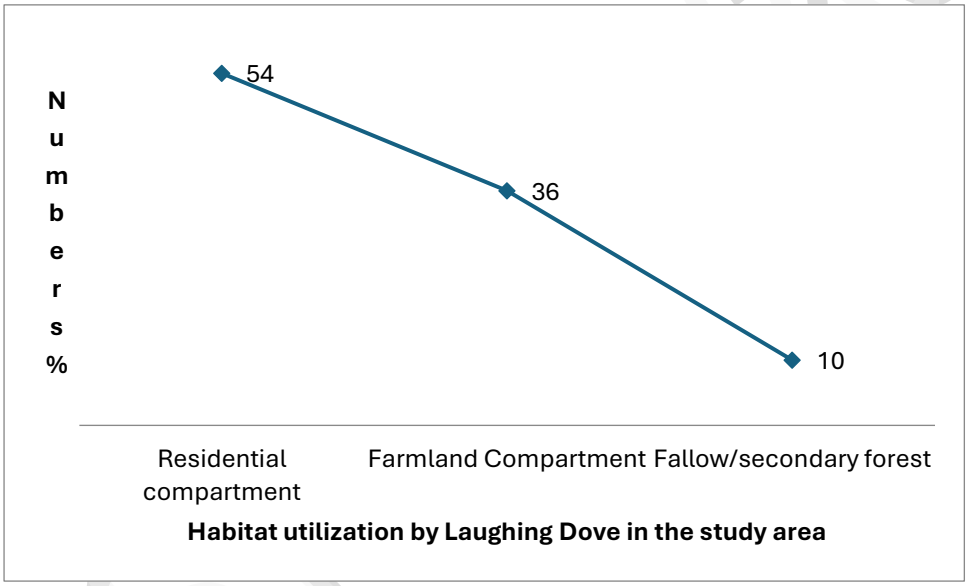


Figure 5: Habitat Utilization by Laughing Dove in the study area

Discussion

The researcher learnt that the Laughing Dove (Streptopelia senegalensis) usually eats seeds and grains, such as a lot of different kinds of grass seeds and cereal grains. It also eats flowers and fruits from time to time. They eat more than simply their typical meal during the breeding season. They also ingest small bugs, which are vital for meeting their increased nutritional needs. These bugs provide their chicks with the protein they need to grow and stay healthy. This species can live in many different environments, such as cities, farms, and regions that are only partly natural, because it has special ways of finding food. It can exist in many environments, illustrating how adaptable its diet is. Yapıcı (2020) observed similar results: Streptopelia senegalensis eats a wide range of grains, including rice, wheat, millet, and seeds

from grasses, weeds, and sunflowers. They also eat bugs, especially while caring for their babies. This wide range of foods lets them live in different places and times of year. This fits with what Brahmia et al. (2015) found: that Streptopelia senegalensis in Algeria eats a wide range of foods, including insects, earthworms, and the fruits of Azadirachta indica, also called neem. This species can eat both plants and animals, suggesting it can live in a wide range of habitats. The result also showed that the laughing Dove may adjust its diet depending on the season and available food. Mckilligan (2005) supported these findings by adding that Streptopelia senegalensis eat predominantly grains but also fruits and seeds. They eat insects, mostly locusts, grasshoppers, earthworms, millipedes, and fruit. These birds fly and walk on the ground for brief periods at certain times. They eat more bugs than plants throughout the breeding season. There is a lot of data supporting this change in how they consume. For instance, Fuller (2007) found that the protein content of insect-eating species' diets rose from 1.8% to 55% during the breeding season. Galbraith (2012) observed the same thing: insects are more likely to be on the ground than in the air. This reinforces the concept that these birds are not particularly good at flying. Rao (2014) also noted that Streptopelia senegalensis has been trained to largely use its legs to acquire food off the ground. The residential compartment had more habitat utilization than the other two. This could be because the birds found their favoured food there or because it was good for their environment. Parsons et al. (2016) also found that this species occurs across many sites in central and southern Africa, including cities, farms, secondary forests, and savannas. These results are similar to those. It happens a lot in places that are broken, close to where people live, or in hilly areas with deep ravines and steep mountains.

Conclusion and Recommendations

The study shows that *Streptopelia senegalensis* eats a wide range of foods in its environment, including grains, fruits, flowers, and insects. The bird species mainly lives in residential complexes, not in other locations. They also found that they devour food from the ground and from the upper shrub and tree layers. They are not seen as a major threat to conservation, but their use of damaged forest ecosystems and urbanized residential areas underscores their importance for long-term growth. Protecting habitats and ecosystems that support a wide range of bird species is particularly important for preserving biodiversity. A key element of this conservation effort is getting people to protect habitats, and sustainable tourism is a big part of that. Birdwatchers and others who engage in bird-related activities often help safeguard habitats by donating to ecotourism organizations that prioritize conservation. Birdwatching and avitourism can give people in the area reasons to protect natural areas that are excellent for business. Birdwatching trips, sales of birdwatching gear, and services such as lodging and food for birdwatchers could all be included. Sustainable tourism improves local economies and protects bird habitats by supporting activities that attract birdwatchers.

References

Ayadi T, Hammouda A, Kididi S, Yahyaoui MH and Selmi S (2016). Sexual size dimorphism and morphometric sexing in a North African population of Laughing Doves S*pilopelia senegalensis*. *Ostrich:* 1-5. http://dx.doi.org/10.2989/00306525.2016.1188173

BirdLife International (2024). Species factsheet: Laughing Dove *Spilopelia senegalensis*. Downloaded from https://datazone.birdlife.org/species/factsheet/laughing-dove-spilopelia-senegalensis on 05/12/2024

Fuller RA, Warren PH, Armsworth PR, Barbosa O, Gaston KJ (2007). Garden bird feeding predicts the structure of urban avian assemblages. *Diversity and Distributions* 14(1):131–137.

Galbraith JA, Beggs JR, Jones DN, McNaughton EJ, Krull CR, Stanley MC (2014). Risks and drivers of wild bird feeding in urban areas of New Zealand. Biological Conservation, NZBC Volume 180,

Jones DN, Reynolds SJ (2008). Feeding birds in our towns and cities: a global research opportunity. *Journal of Avian Biology*, 39(3): 265-271.

Okosodo, E. F., Orimaye, J. O., & Odewumi, O. S. (2016). Diet and Foraging Ecology of Fork-tailed Drongo (*Dicrurus adsimilis*) in Leventis Foundation, Nigeria, Agricultural School, South West Nigeria. *International Journal of Environment, Agriculture and Biotechnology*, y (IJEAB) *1*(2), 238527.

Parsons H, Major RE, French K (2016). Species interactions and habitat associations of birds inhabiting urban areas of Sydney, Australia, *Austral Ecology* AE 31, 217–227. doi:10.1111/j.1442-9993.2006. 01584.x

Rao MS (2014). Breeding Performance of Palm Dove (*Streptopelia senegalensis*) in and Around Sikar (Rajasthan), India. *Global Journal for Research Analysis,* 3 (7):

yapıcı N, Erdoğan A. (2023). The expansive Laughing Dove (Spilopelia senegalensis) is an annual breeder in southern Turkey—*zoology in the Middle East*,69(1).

Yapıcı N (2020) Antalya ili Küçük kumru (*Spilopelia senegalensis)* popülasyonunun Davranış ve Biyo-ekolojisi Üzerine Araştırmalar. Akdeniz Üniversitesi, Fen Bilimleri Enstitüsü, *Biyoloji Doktora tezi*. 109s.

ISTF-NIG 2026

SUB-THEME 9:
CLIMATE CHANGE MITIGATION, ADAPTATION AND FOREST-BASED SOLUTIONS

ISTF-NIG2026

FOREST ECOSYSTEMS IN CLIMATE CHANGE MITIGATION AND COMMUNITY RESILIENCE IN SOUTHERN NIGERIA: A SYSTEMATIC REVIEW WITHIN AN AFRICAN CONTEXT

***ARABOMEN, Oghenekevwe Joy**

Forestry Research Institute of Nigeria, Jericho Hill Estate, Ibadan, Nigeria
**+234-810-7129704; official.publications2020@gmail.com*

Abstract
This study employed a systematic review of the contributions of forest ecosystems to climate change mitigation and community resilience in Southern Nigeria, within a broader African context. Guided by PRISMA principles, peer-reviewed articles and relevant institutional reports published between 2010 and 2025 were retrieved from Google Scholar, Scopus, Web of Science, and African Journals Online. Studies were screened using predefined inclusion and exclusion criteria and synthesized thematically. The findings were organized into four dominant themes: (i) forests as carbon sinks, (ii) forest-based livelihoods and adaptive capacity, (iii) ecosystem services for disaster risk reduction, and (iv) governance and implementation challenges constraining forest-based climate solutions. Evidence from Southern Nigeria and comparable African regions, including Ghana, Kenya, Tanzania, Cameroon, and South Africa, indicates that mangrove and tropical forest ecosystems make substantial contributions to carbon storage, flood regulation, erosion control, and livelihood buffering through non-timber forest products and ecotourism. Despite these benefits, deforestation, weak policy implementation, and persistent socio-economic pressures continue to undermine the effectiveness of forest-based climate interventions. The study identifies critical research and policy gaps. It emphasizes the need to integrate forest conservation into national climate strategies, strengthen community participation in forest management, and prioritize forest restoration initiatives, particularly in mangrove and tropical forest zones. This systematic review provides evidence-based insights to support sustainable forest management and climate adaptation planning in Southern Nigeria and other forest-dependent regions of Africa.

Keywords: Climate change mitigation; Community resilience; Ecosystem services; Forests; PRISMA; Southern Nigeria; Africa; Systematic review

Introduction
Climate change is One of the most pressing environmental challenges confronting Africa, with impacts manifesting through rising temperatures, altered rainfall patterns, increased frequency of floods and droughts, and sea-level rise (IPCC, 2022). Sub-Saharan Africa is particularly vulnerable due to its strong dependence on climate-sensitive livelihoods, limited institutional capacity, and widespread poverty (Niang *et al*., 2014). Coastal and forest-dependent regions experience compounded risks as deforestation, land degradation, and land-use change weaken ecosystem buffering capacity and reduce adaptive potential (FAO, 2020). Southern Nigeria exemplifies these vulnerabilities. The region experiences recurrent flooding, coastal erosion in the Niger Delta, heat stress in urban centers such as Lagos and Port Harcourt, and declining agricultural productivity in rainforest zones (Nwankwoala & Warmate, 2014; Ayanlade *et al*., 2018). Forest ecosystems in this region, including mangroves, freshwater swamp forests, and tropical rainforests, provide essential ecosystem services that contribute to climate regulation, livelihood security, and disaster risk reduction (Ajonina *et al*., 2014). Across Africa, forest ecosystems are increasingly recognized as nature-based solutions for climate change mitigation and adaptation. Forests contribute to mitigation by sequestering atmospheric carbon dioxide

and storing carbon in biomass and soils (FAO, 2020). Mangrove forests are among the most carbon-dense ecosystems globally, storing up to four times more carbon per hectare than upland tropical forests (Donato *et al*., 2011; Kauffman *et al*., 2014). Studies from Kenya and Tanzania demonstrate that mangrove conservation enhances carbon stocks, supports fisheries productivity, and protects shorelines from storm surges (Kairo *et al*., 2015; Stringer *et al*., 2016).

In West Africa, research from Ghana's coastal zones shows that mangrove restoration reduces vulnerability to storm surges and provides livelihood opportunities through fuel wood harvesting, fisheries, and salt production (Mensah *et al*., 2020). Similarly, community-based mangrove management in Cameroon has been linked to improved resilience against flooding and food insecurity (Feka & Ajonina, 2011). These findings resonate with evidence from the Niger Delta, where mangrove forests buffer communities against coastal erosion and flooding while sustaining fishing and forest-based livelihoods (Adekola *et al*., 2015; Ajonina *et al*., 2014). Beyond mangroves, tropical rainforests in Central and West Africa play a crucial role in regional climate regulation and carbon storage. Studies from the Congo Basin indicate that intact forests significantly contribute to rainfall recycling and temperature moderation (Lewis *et al*., 2013). In southern Ghana and Côte d'Ivoire, forest degradation has been associated with increased surface temperatures and reduced agricultural yields (Asare *et al*., 2018). Similar patterns have been observed in southern Nigeria, where deforestation intensifies microclimatic changes and increases flood risks (Olawoye, 2013; Onyekuru *et al*., 2020).

Forest ecosystems also enhance community resilience by diversifying livelihoods. Across Africa, non-timber forest products (NTFPs) such as medicinal plants, fruits, fuel wood, honey, and fibers serve as safety nets during periods of climate-induced agricultural failure (Shackleton *et al*., 2011). In South Africa, forest-dependent households rely on forest products to cope with drought and income shocks (Thondhlana *et al*., 2015). In Kenya and Ethiopia, forest-based enterprises and ecotourism strengthen adaptive capacity by providing alternative income streams (Alemu *et al*., 2018). In Nigeria, NTFPs such as *Irvingia gabonensis*, raffia palm, and medicinal plants contribute significantly to household income and food security, particularly during climate extremes (Nzeadibe & Ajaero, 2011; Arabomen *et al*., 2023). These findings align with broader African evidence that forest resources function as informal insurance systems for vulnerable populations (Shackleton & Pandey, 2014).

Urban forests further enhance resilience by moderating urban heat islands and reducing flood intensity. Studies from Nairobi, Accra, and Durban indicate that urban tree cover and wetlands reduce runoff and improve microclimates (Dobbs *et al*., 2018; Mensah *et al*., 2020). Lagos faces similar challenges, and recent studies highlight the importance of urban forests and wetlands in flood mitigation and temperature regulation (Ayanlade *et al*., 2018). Despite these documented benefits, forest-based climate solutions face major constraints across Africa. High rates of deforestation driven by agricultural expansion, fuel wood harvesting, urbanization, and weak governance undermine forest ecosystem functions (FAO, 2020). In Nigeria, institutional fragmentation and poor enforcement of forest policies limit the effectiveness of conservation efforts (Olawoye, 2013). Comparable governance challenges have been reported in Ghana, Cameroon, and Tanzania, where conflicts between conservation objectives and local livelihoods persist (Feka & Ajonina, 2011; Kairo *et al*., 2015).

Furthermore, much of the existing African literature remains fragmented across disciplines, often focusing separately on carbon stocks, livelihoods, or biodiversity, with limited integration of mitigation and resilience outcomes (Locatelli *et al*., 2015). A systematic synthesis of this

evidence is necessary to inform holistic forest-based climate strategies and policy development. Therefore, this study employed a systematic review of the existing literature on the role of forest ecosystems in climate change mitigation and community resilience in Southern Nigeria, within a broader African context, and synthesized evidence from comparable African regions to identify patterns, gaps, and policy-relevant insights.

Methodology

The study adopted a systematic review methodology to synthesize empirical evidence on the role of forest ecosystems in climate change mitigation and community resilience in Southern Nigeria and comparable African regions. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, rigor, and reproducibility of the study selection process (Moher *et al*., 2009; Petticrew & Roberts, 2006). Systematic reviews are particularly suitable for consolidating fragmented evidence across environmental and social science disciplines, allowing for robust interpretation of trends and research gaps (Tranfield *et al*., 2003; Xiao & Watson, 2019).

Search Strategy

A comprehensive literature search was conducted across four major electronic databases: **Google Scholar, Scopus, Web of Science, and African Journals Online (AJOL)**. These databases were selected to ensure broad coverage of international peer-reviewed literature and regionally relevant African research outputs. Boolean combinations of the following keywords were used: "forest ecosystems"; "climate change mitigation"; "community resilience"; "Southern Nigeria"; "mangrove forests"; "carbon sequestration". The search strings were combined using operators such as: ("forest ecosystems" AND "climate change mitigation") OR ("community resilience" AND "mangrove forests") AND ("Southern Nigeria" OR "Africa"). The search period covered studies published between **2010 and 2025**, reflecting contemporary developments in climate change science, forest management, and adaptation research (IPCC, 2022; FAO, 2020). Only peer-reviewed journal articles and credible institutional reports (e.g., FAO, UNEP, World Bank) were considered to ensure data quality and methodological reliability.

Inclusion Criteria

Studies were included if they met the following criteria: (1) focused on forest ecosystems (mangroves, tropical rainforests, urban forests, or wetlands); (2) were conducted in Southern Nigeria or comparable African regions with similar ecological and socio-economic conditions; (3) examined climate change mitigation**,** adaptation**, or** community resilience**;** (4) were peer-reviewed articles or reputable institutional reports; (5) were published in the English language**.** These criteria ensured consistency with the research objective while allowing for comparative African case studies to strengthen contextual interpretation (Locatelli *et al*., 2015; Shackleton *et al*., 2011).

Exclusion Criteria

Studies were excluded if they: (1) were conducted outside Africa with no relevance to tropical or sub-Saharan contexts; (2) focused solely on agriculture without a forest ecosystem component; (3) were opinion pieces, editorials, or commentaries lacking empirical or analytical

evidence; (4) did not explicitly link forest ecosystems to climate mitigation or resilience outcomes.

Screening Process (PRISMA Framework)

The initial database search yielded 320 records across Google Scholar, Scopus, Web of Science, and AJOL. After removing duplicate entries, 270 records remained for title and abstract screening. During this stage, 185 records were excluded due to irrelevance, a lack of focus on forest ecosystems, or being opinion-based publications. Subsequently, 85 full-text articles were assessed for eligibility. After applying the inclusion and exclusion criteria, 47 studies were excluded due to a geographical mismatch (n = 15), an agriculture-only focus (n = 18), or the absence of explicit climate mitigation or resilience linkages (n = 14). A final total of 38 studies were retained for qualitative thematic synthesis. The study selection process adhered strictly to PRISMA guidelines (see Figure 1; Table 1)[1] to enhance transparency, methodological rigor, and reproducibility (Moher *et al*., 2009).

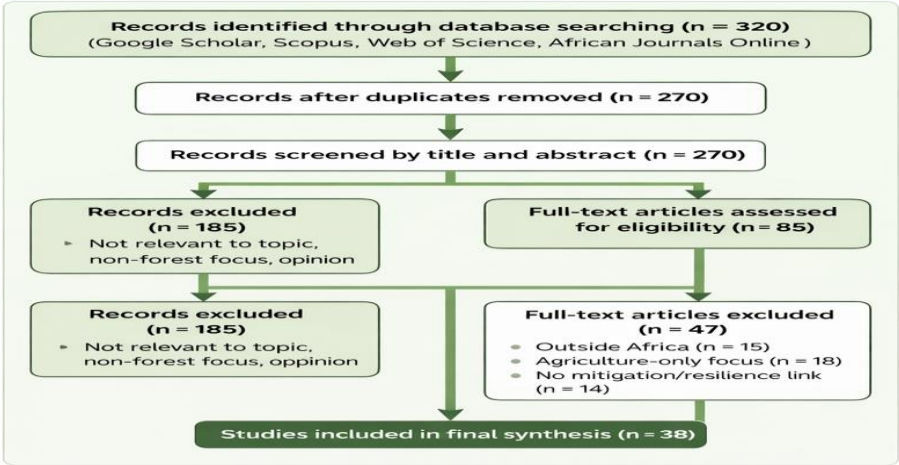


Figure 1. PRISMA flow diagram showing the study selection process for the systematic review of literature

Table 1. Summary of the literature screening and selection process numerically

Stage of Review	Number of Studies
Records identified	320
After duplicates removed	270
Excluded after title & abstract screening	185
Full-text articles assessed	85
Full-text articles excluded	47
Studies included in the synthesis	38

Data Extraction and Synthesis

Data were extracted from the selected studies using a structured matrix that captured information on study location, forest type, methodological approach, mitigation outcomes (e.g.,

[1] *The PRISMA flow diagram (Figure 1) and screening summary table (Table 1) illustrate the stepwise selection process adopted in this review, following established systematic review protocols for environmental and social science research (Moher et al., 2009; Petticrew & Roberts, 2006; Xiao & Watson, 2019).*

carbon sequestration, emission reduction), and resilience indicators (e.g., livelihood diversification, flood protection, food security). A qualitative thematic synthesis approach was employed to identify recurring patterns and relationships across studies (Braun & Clarke, 2006; Thomas & Harden, 2008). This approach enabled cross-comparison of findings from Southern Nigeria with evidence from other African contexts such as Ghana, Kenya, Cameroon, and Tanzania.

Results

The systematic review identified four dominant and interrelated thematic areas: (1) forests as carbon sinks; (2) forest-based livelihoods and adaptive capacity; (3) ecosystem services and disaster risk reduction, and (4) governance and implementation challenges. Evidence from Southern Nigeria was interpreted alongside comparable African case studies to highlight regional patterns and transferable lessons for forest-based climate solutions.

Forest Ecosystems as Carbon Sinks

Across Africa, forest ecosystems, particularly mangroves and tropical rainforests, are consistently identified as among the most important terrestrial carbon reservoirs (Donato *et al*., 2011; Kauffman *et al*., 2014). Mangrove forests are especially carbon-dense due to their high biomass and waterlogged soils, which slow organic matter decomposition and enhance long-term carbon storage. In East Africa, mangrove ecosystems in Kenya's Gazi Bay have been shown to store between 400 and 1,000 Mg C ha^{-1}, ranking among the most carbon-rich ecosystems globally (Kairo *et al*., 2015). Similar findings were reported in Tanzania, where intact mangrove stands exhibited high belowground carbon stocks and reduced vulnerability to coastal erosion (Stringer *et al*., 2016). These studies demonstrate the dual functions of mangrove forests: mitigation and protection. West African evidence corroborates these results. In Ghana, mangrove restoration projects significantly increased carbon sequestration while simultaneously improving fisheries productivity and shoreline stability (Mensah *et al*., 2020). Comparable observations have been documented in the Niger Delta region of Nigeria, where mangrove forests store substantial carbon in sediments and biomass and act as buffers against sea-level rise and storm surges (Adekola *et al*., 2015; Ajonina *et al*., 2014).

Beyond mangroves, tropical rainforests in Central and West Africa play a critical role in regional climate regulation. Research in the Congo Basin indicates that intact forests influence atmospheric moisture recycling and contribute to rainfall stability across sub-Saharan Africa (Lewis *et al*., 2013). In Southern Nigeria, forest loss has been associated with rising surface temperatures, reduced evapotranspiration, and declining ecosystem productivity, thereby weakening the mitigation potential of remaining forest stands (Olawoye, 2013; Onyekuru *et al*., 2020). Collectively, the reviewed studies confirm that forest ecosystems in Southern Nigeria and across Africa provide substantial climate mitigation benefits through carbon sequestration and storage. However, these benefits remain highly dependent on forest integrity, conservation status, and management effectiveness.

Forest-Based Livelihoods and Adaptive Capacity

Forest ecosystems enhance community resilience primarily through livelihood diversification and income buffering during climate-induced shocks. Across sub-Saharan Africa, non-timber forest products (NTFPs) such as fruits, medicinal plants, fuelwood, honey, and fibers serve as safety nets for rural households during periods of environmental stress (Shackleton *et al*.,

2011). In South Africa, Thondhlana *et al*. (2015) found that forest products were most heavily relied upon during drought periods, highlighting their importance in household coping strategies. In Kenya and Ethiopia, forest-based enterprises and ecotourism initiatives improved adaptive capacity by providing alternative income sources less sensitive to rainfall variability (Alemu *et al*., 2018).

West African studies reinforce these findings. In Ghana, mangrove-dependent communities demonstrated greater livelihood stability during flood events than communities without access to forest resources (Mensah *et al*., 2020). In Cameroon, community-based mangrove management improved food security and reduced vulnerability to seasonal flooding (Feka & Ajonina, 2011). Evidence from Southern Nigeria indicates similar patterns. Forest-dependent households rely on NTFPs such as *Irvingia gabonensis* (bush mango), raffia palm products, fuelwood, and medicinal plants as sources of supplementary income and food (Nzeadibe & Ajaero, 2011; Arabomen *et al*., 2023). These resources are particularly critical during periods of agricultural failure caused by flooding or drought. The reviewed literature suggests that forest-based livelihoods reduce dependency on climate-sensitive farming systems and thereby strengthen household adaptive capacity.

Ecosystem Services and Disaster Risk Reduction

Forest ecosystems provide key regulating services that reduce exposure to climate hazards and function as cost-effective nature-based solutions for disaster risk reduction. Mangrove forests are widely documented as natural barriers against storm surges, wave action, and coastal flooding. In coastal Tanzania, mangrove belts significantly reduced wave energy and protected shoreline settlements (Stringer *et al*., 2016). Similar protective functions have been observed in Ghana's coastal zones and the Niger Delta region of Nigeria (Mensah *et al*., 2020; Adekola *et al*., 2015). Urban forests and wetlands also play an increasingly important role in climate adaptation. Studies from Nairobi, Accra, and Durban demonstrate that urban green spaces reduce surface runoff, mitigate urban heat island effects, and improve microclimates (Dobbs *et al*., 2018). In Lagos, One of Africa's most flood-prone megacities, wetlands and urban forests have been identified as critical components of flood mitigation and temperature regulation strategies (Ayanlade *et al*., 2018). Inland forest ecosystems further contribute to erosion control and watershed protection. Research in Ethiopia and Cameroon shows that forest cover stabilizes soils and reduces landslide risks in mountainous and riverine areas (Alemu *et al*., 2018; Feka & Ajonina, 2011). In Southern Nigeria, forest degradation has been linked to increased surface runoff and soil erosion, intensifying flood risks in both rural and urban communities (Onyekuru *et al*., 2020). These findings confirm that forest ecosystems deliver multiple ecosystem services that directly reduce vulnerability to climate hazards while enhancing environmental stability across diverse African landscapes.

Governance and Implementation Challenges

Despite their mitigation and resilience benefits, forest-based climate solutions are constrained by persistent socio-economic and institutional challenges. High rates of deforestation driven by agricultural expansion, fuel wood harvesting, illegal logging, and urbanization remain widespread across Africa (FAO, 2020). Governance weaknesses, including unclear land tenure systems and limited enforcement capacity, undermine long-term conservation efforts (Olawoye, 2013). In Ghana and Cameroon, conflicts between conservation policies and local livelihood needs have reduced community support for forest protection initiatives (Feka & Ajonina, 2011; Mensah *et al*., 2020). In Nigeria, institutional fragmentation between forestry,

environmental, and climate agencies limits coordinated policy implementation (Olawoye, 2013). Poverty and population pressure further intensify dependence on forest resources, creating a reinforcing cycle of degradation and vulnerability. The reviewed studies indicate that without addressing governance gaps, tenure insecurity, and socio-economic drivers, the mitigation and resilience benefits of forest ecosystems cannot be sustained. Effective forest-based climate strategies, therefore, require integrated governance frameworks that combine conservation objectives with livelihood support and community participation.

Discussion

The findings of this systematic review demonstrate that forest ecosystems in Southern Nigeria and across Africa provide dual and interconnected benefits**:** climate change mitigation and community resilience. Mangrove and tropical forest systems serve as major carbon sinks, aligning with global evidence on the carbon sequestration potential of both primary and secondary forests (Chazdon *et al*., 2016). These ecosystems also regulate microclimates, stabilize soils, buffer storm surges, and support hydrological cycles, highlighting their critical role in ecosystem-based adaptation (Locatelli *et al*., 2015).

Forest-based livelihoods emerged as a consistent pathway for enhancing adaptive capacity. Across West, East, and Southern Africa, communities rely on non-timber forest products (NTFPs) such as fruits, medicinal plants, bush mango (*Irvingia gabonensis*), raffia products, and fuelwood to diversify income and reduce vulnerability to climate-induced agricultural shocks (Shackleton *et al*., 2011). In Ghana and Cameroon, mangrove-dependent communities exhibited greater livelihood stability during flood events, confirming that forest access functions as an informal insurance mechanism (Mensah *et al*., 2020; Feka *et al*., 2011). In Southern Nigeria, a similar reliance on NTFPs was observed, with households drawing on forest resources to buffer against income loss during droughts or floods (Nzeadibe *et al*., 2011; Arabomen *et al.,* 2023).

The review also reinforces forests' ***disaster risk reduction functions***. Mangrove belts in Tanzania and the Niger Delta reduce wave energy and protect coastal settlements (Stringer *et al*., 2016; Adekola *et al*., 2015), while urban forests and wetlands in Lagos, Accra, Nairobi, and Durban reduce flood intensity and moderate urban heat islands (Dobbs *et al*., 2018; Ayanlade *et al*., 2018; Mensah *et al*., 2020). Inland forests stabilize soils, reduce erosion, and maintain watershed services, further enhancing resilience to climate hazards (Alemu *et al*., 2018; Feka *et al*., 2011). Despite these benefits, the evidence base for integrated socio-ecological outcomes remains limited. Most studies focus either on biophysical aspects such as carbon stocks, flood attenuation, or erosion control, or on socio-economic dimensions such as livelihood dependence, without fully connecting the two (Locatelli *et al*., 2015). Consequently, there is limited empirical evidence linking forest restoration or conservation interventions directly to measurable improvements in community resilience. This represents a significant research gap, particularly in Southern Nigeria, where long-term monitoring is sparse.

Governance and policy constraints further limit the effectiveness of forest-based climate solutions. Weak enforcement of forest regulations, unclear land tenure systems, and institutional fragmentation reduce community engagement in conservation and impede implementation of mitigation strategies (Olawoye, 2013). Similar challenges exist in Ghana and Cameroon, where conflicts between conservation objectives and local livelihoods undermine forest management efforts (Feka *et al*., 2011; Mensah *et al*., 2020). Poverty and

population pressures compound dependence on forest resources, creating a feedback loop of degradation and vulnerability. From a policy perspective, these findings highlight the need to integrate forest conservation into national climate strategies**,** including Nationally Determined Contributions (NDCs), disaster risk reduction plans, and urban planning. Mainstreaming forest-based mitigation and adaptation measures can enhance the effectiveness of climate policies while ensuring sustainable livelihoods (UNFCCC, 2021). Additionally, interdisciplinary and longitudinal research is essential to link ecological outcomes with social resilience indicators, thereby informing evidence-based decision-making. In conclusion, forest ecosystems in Southern Nigeria and comparable regions of Africa are indispensable for climate mitigation and adaptive capacity. Effective policy integration, strengthened governance, and targeted research are necessary to maximize these benefits and ensure sustainable outcomes for vulnerable communities.

Conclusion and Recommendations

This systematic review confirms that forest ecosystems are indispensable for climate change mitigation and community resilience in Southern Nigeria and comparable regions of Africa. Mangrove forests, freshwater swamp forests, and tropical rainforests serve as significant carbon sinks, stabilize soils, regulate hydrological cycles, buffer against floods and storm surges, and provide vital resources for forest-dependent communities. Non-timber forest products, including *Irvingia gabonensis*, raffia palm, medicinal plants, and fuelwood, enhance livelihood security and serve as informal safety nets during climate-induced agricultural or economic shocks. Urban forests and wetlands further support adaptation by moderating urban heat and reducing flood risk in rapidly growing cities such as Lagos. Despite these benefits, deforestation, land-use change, weak governance, and institutional fragmentation undermine the capacity of forest ecosystems to deliver sustained mitigation and resilience benefits. The lack of long-term monitoring and integrated socio-ecological studies further limits empirical evidence on the direct contributions of forest restoration and conservation to community resilience. These challenges highlight the need for targeted policy, research, and community engagement strategies.

Forest conservation should therefore be fully mainstreamed into national and regional climate strategies, including Nationally Determined Contributions (NDCs), disaster risk reduction frameworks, and urban planning policies, to ensure that forest ecosystems contribute effectively to both mitigation and adaptation objectives. Strengthening community participation through clearer land tenure arrangements, improved enforcement of forest regulations, and co-management approaches is essential for enhancing compliance and long-term sustainability. Investment in mangrove restoration, reforestation, and afforestation initiatives should be prioritized, particularly in coastal and flood-prone areas, with emphasis on high-carbon-density species and co-benefits for ecosystem services. In addition, interdisciplinary and longitudinal research is required to link ecological outcomes with social resilience indicators, supported by systematic monitoring of forest carbon stocks, ecosystem services, and livelihood impacts. Promoting sustainable forest-based enterprises and responsible utilization of non-timber forest products can further reduce dependence on climate-sensitive agriculture and strengthen household adaptive capacity. In summary, forest ecosystems serve as a critical pathway to achieving climate-resilient communities, sustainable livelihoods, and carbon-rich landscapes in Southern Nigeria. Coordinated action across policy integration, governance reform, ecological restoration, research advancement, and community engagement is essential to maximize these benefits and ensure long-term environmental sustainability.

References

Adekola, O., Onyekuru, N., & Ajonina, G. (2015). Carbon storage and ecological role of mangrove forests in the Niger Delta, Nigeria. *Environmental Research*, 9(2), 45–58.

Ajonina, G., Kairo, J. G., & Grimsditch, G. (2014). Carbon pools and multiple benefits of mangroves in Africa. In *Climate Change and Mangrove Ecosystems* (pp. 45–59). Springer.

Alemu, B., Muriuki, A., & Tesfaye, S. (2018). Forest-based enterprises and climate change adaptation in East Africa. *Environmental Management,* 212*,* 172–181.

Arabomen, J., Ojo, T., & Nzeadibe, T. (2023). Non-timber forest products and household resilience in Southern Nigeria. *Forest Policy and Economics*, 145, 102-123.

Asare, R., Ofori, D., & Kyei, B. (2018). Effects of forest degradation on microclimate and agriculture in West Africa. *Forest Ecology and Management*, 421, 67-75.

Ayanlade, A., Radeny, M., & Ogunjobi, K. (2018). Urban heat and flood risk in Lagos: Role of green infrastructure. *Climate and Development*, 10*(*5), 389–399.

Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101.

Dobbs, C., Nitschke, C., & Kendal, D. (2018). Urban forests and flood mitigation in African cities. *Urban Climate*, 24, 94–105.

Donato, D.C., Kauffman, J. B, Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves are among the most carbon-rich forests in the tropics. *Nature Geoscience*, 4(5), 293–297.

FAO. (2020). The State of the World's Forests 2020: Forests, biodiversity and people. FAO.

Feka, N., & Ajonina, G. (2011). Community-based mangrove management in Cameroon. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 7(2), 123–131.

IPCC. (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Cambridge University Press.

Kairo, J., Jiddawi, N., & Koedam, N. (2015). Mangrove carbon stocks in East Africa. *Wetlands Ecology and Management*, 23*,* 445–458.

Kauffman, J., Donato, D., & Murdiyarso, D. (2014). Carbon stocks of mangrove forests. *Global Ecology and Biogeography*, 23, 726–738.

Lewis, S., Wheeler, C., Mitchard, E., & Koch, A. (2013). Restoring natural forests is the best climate solution. *Nature*, 510, 724–727.

Locatelli, B., Pavageau, C., Pramova, E., & Broekhoff, D. (2015). Integrating climate and development objectives in forest management. *Current Opinion in Environmental Sustainability*, 14, 1–8.

Mensah, A., Ofori, D., and Asare, R. (2020). Mangrove restoration and community resilience in Ghana. *Ocean & Coastal Management*, 192, 105-118.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses. *PLoS Medicine*, 6(7), e1000097.

Niang, I., et al. (2014). Africa. *In* Climate Change 2014: Impacts, Adaptation, and Vulnerability. Cambridge University Press.

Nwankwoala, H., & Warmate, I. (2014). Flood hazards in the Niger Delta. *Environmental Science and Water Resources*, 3(5), 121–130.

Nzeadibe, T., & Ajaero, C. (2011). Impact of forest resources on development in Nigeria. *Environment, Development and Sustainability*, 13(5), 993–1012.

Olawoye, J. (2013). Forest governance in Nigeria. *Forest Policy and Economics*, 33, 1-9.

Onyekuru, A. N., Iroegbu, S., & Eze, M. (2020). Forest cover change and flood risk in Southern Nigeria: *Environmental Monitoring and Assessment*, 192, 512.

Petticrew, M., & Roberts, H. (2006). Systematic Reviews in the Social Sciences. Blackwell Publishing.

Shackleton, C., & Pandey, A. (2014). Forests and resilience in Africa. *Environmental Science & Policy*, 38, 118–129.

Shackleton, C. M., Shackleton, S. E., & Shanley, P. (2011). Non-timber forest products and livelihoods. *Forest Policy and Economics*, 13(3), 1–12.

Stringer, L. C., Dougill, A. J., Fraser, E. D. G., Hubacek, K., & Prell, Christina. (2016). Mangroves and coastal protection in Tanzania. *Estuarine, Coastal and Shelf Science*, 179, 38–49.

Thomas, J., & Harden, A. (2008). Methods for thematic synthesis of qualitative research. *BMC Medical Research Methodology*, *8*, 45.

Thondhlana, G., Shackleton, S., & Aiyenigba, F. (2015). Forests as safety nets. *Forest Policy and Economics*, 50, 3–10.

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence- informed management knowledge. *British Journal of Management*, 14(3), 207–222.

UNFCCC. (2021). Nationally Determined Contributions (NDCs). United Nations Framework Convention on Climate Change.

Xiao, Y., & Watson, M. (2019). Guidance on conducting a systematic literature review. *Planning Education and Research*, 39(1), 93–112.

ISTF-NIG 2026

FIRE DANGER INDEX (FDI) AS A TOOL FOR FOREST FIRE EARLY WARNING SYSTEM AND ITS IMPACT ON FOREST ECOSYSTEM

MBA, Nnabuike C, OFORDU, C.S and AUDU, M.A

Environmental Modeling and Biometrics Department, Forestry Research Institute of Nigeria, PMB 5054, Jericho Hill, Ibadan.
Email: mbannabuike@yahoo.com Tel: 07065470216, 09026309951

Abstract
The impact of the Fire Danger Index (FDI) on the Ecosystem is profound and multifaceted. FDI acts as a key indicator of potential wildfire behavior and its subsequent ecological consequences. High fire danger conditions can transform natural fire regimes from beneficial ecological processes into destructive events that threaten ecosystem structure, function, and biodiversity. Wildfires linked to elevated FDI also degrade soil and water resources. Post-fire erosion increases as vegetation is removed, leading to higher runoff, flooding, and sedimentation in streams. Water quality can be affected by elevated temperatures, nutrients, metals, and organic chemicals, sometimes exceeding safe levels for years after a severe burn, harming aquatic species and contaminating drinking water. The study examined the impact of FDI on the Ecosystem, using Ibadan as a case study. Data were obtained from the Forestry Research Institute of Nigeria Meteorological Station. A 15-year (2009-2023) dataset, including January, February, November, and December, for Relative Humidity and Temperature was analyzed. The formula 3.3 - (5 RH /100) + T/10 was utilized to calculate the FDI for the whole PeriodPeriodPeriod under review.The result shows that FDI is often high, above 3.5, in January and February, which is very critical, indicating a high risk of wildfires and setting bush fires for whatever reason should be avoided to prevent the occurrence of wildfires. In November and December, the indices were mostly between 2.5 and 3.5, indicating a moderate risk. Equally vigilant and crucial are fire prevention measures during these periods to mitigate risks to agriculture, forestry, and communities. Generally, FDI is used to quantify the potential for wildfire ignition, spread, and intensity based on factors such as temperature, Humidity, wind speed, and fuel dryness. While the index itself does not directly alter ecosystems, elevated FDI values signal heightened fire risk, which correlates with increased wildfire occurrence, size, and severity, leading to profound ecological consequences.

Keywords: Biodiversity, Ecosystem, Fire Danger Index, Fire Danger Rating, Relative Humidity, Temperature

Introduction

Forest fires are disasters that often occur during the dry season and continue to threaten tropical rainforest regions (Goldammer, 2007). There are four (4) stages of fire growth, the knowledge of which is essential for effective wildfire management. These stages are Incipient, Growth, Fully developed and Decay. The incipient stage, also known as ignition, is when fire starts: heat, oxygen, and a fuel source combine to create ignition—for example, candles, campfire or cigarettes. The growth stage is when a fire continues to burn, as in a bush fire spreading. Fully developed is when the temperature reaches its highest point, sometimes almost 1083ºC. These are delicate wildfires that quickly spread and can consume trees and large areas of forest and grassland. Decay is the longest stage of a fire, as the flames decrease in size and the fire's heat begins to drop.

Fire danger refers to the potential for a fire to start, spread, and be difficult to control, based on a combination of factors such as conditions, fuel conditions, and topography. The National Fire Danger Rating System classifies fire as: Moderate (Plan and prepare); High (Be ready to act); Extreme (Take action now to protect life and prosperity); and Catastrophic (For your bushfire leave bushfire risk areas). Each region or continent has their fire danger ratings (FDRs) and total fire danger. FDRs give you an indication of the consequences of a fire if it is about to start. The higher the fire danger rating, the more dangerous the condition. In Nigeria, weather factors such as high temperatures, low Humidity, strong winds, and inadequate precipitation, especially during the dry season, significantly contribute to a high Fire Danger Index (FDI), increasing the risk of wildfires. The quality and intensity of these parameters will justify the Fire Danger Rating.

A Fire Danger Index (FDI) is defined as a rating system that estimates the risk of fire for a specific area and day. It can be used to help plan activities that might involve fire. FDI is used for fire-related activities, such as camp cooking, prescribed burning, machinery operation, and more. FDI can be forecast if the environmental factors are known for the coming PeriodPeriod; that is, if the values of the FDI determinants are known for the time to come, then FDI can be forecast for that PeriodPeriod. It can also be used for real, that is, the current condition.

How is the FDI used?

1. Forecast: The FDI can be calculated for future conditions in real time.
2. Real-time: the FDI can be calculated for the current condition.
3. Fire Danger Map: A fire danger map can be created to identify areas of great and low danger
4. In some other areas, some other factors are considered depending on the formula to be used. Other factors include wind speed and the amount of recent rainfall (or the last time it rained).
5. The purposes, depending on the location and the unique characteristics of local vegetation and topography that influence fire, may be considered.
6. For countries that experience wildfire as One of their devastating natural hazards, such as the United States, according to Guo Yu *et al*. (2023), FDI in the area can be used to make informed decisions on how to manage or control fire decisions.

Importance of FDI

- It is mainly for guiding the activities that involve fire, based on Fire Danger Rating (FDR).
- FDI is used to provide recommendations for appropriate actions using the FDR recommendations, like restrictions on open fires, increased vigilance or preparation for potential evacuations.

- It alerts fire agencies, managers, and the public to elevated risks, days in advance, through a forecast. This allows pre-positioning of firefighting resources, increased staffing, and readiness for rapid response, reducing wildfire impacts on lives, property, and infrastructure.

- Low to Moderate FDI periods are ideal windows for safe controlled burns to reduce fuel loads, restore ecosystems, and lower future wildfire severity.

Where to access information on FDI

- Local Fire Agencies: Fire management agencies
- Weather Services: Weather Bureaus.

There have been several studies on the impact of weather data/ parameters such as temperature, rainfall, and so on. One thing or another, but little work has been done on the Fire Danger Index (Hadisuwito & Hassan, 2019). Fire incidents have been recorded, resulting in deaths and property damage. As such, there is a serious need to raise awareness and sensitize our immediate community, at least about the impact of the Fire Danger Index; more importantly, given the shift in global temperatures already underway. Furthermore, this study will educate people about the rating and index, so so that whenever there is a forecast of the fire danger index, the level of ignorance will be reduced. Therefore, the study's broad aim was to evaluate the impact of the Fire Danger Index on the Ecosystem. Specific objectives are to: Examine variation over a period of 15 years (20to aser20) to assess the occurrence of FDI, and to raise awareness of the importance of FDI on the forest ecosystem.

Materials and Methods

The secondary data were collected from the Forestry Research Institute of Nigeria (FRIN) Meteorology Station in Ibadan. FRIN is sited on Latitude 7º 23" N and Longitude3º 51"E. The rainfall is 1230mm, the temperature is 26.5 °C, and the relative Humidity is 70.5%. Temperature and Relative Humidity of fifteen years (2009 -2023) were used to compute the Fire danger Index to ascertain the volatility of the forest in Ibadan. The 15-year dataset was divided into three periods to examine FDI variation within each Period. The three periods are: years 2009 - 2013, 2014 - 2018, and 2019 - 2023.

The mathematical formula for FDI is:

$$3.3 - [5\ RH\ /100] + T/10 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

Where:
RH = Relative Humidity; T = Temperature

Fire danger index and fire danger rating: < 2.4 (less than 2.4) = Low; 2.5 - 3.4 =Moderate; > 3.5 = High

Results and Discussion

Table 1: Result of calculated Fire Danger Index

Period	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Jan	3	3	4	4	4	3	4.5	4.6	3.8	3.8	3.8	4.4	3.9	4.4	4.3
Feb	3	4	3	3	DNA	4	3.5	4	3.9	3.2	3.7	4.9	3.6	3.8	3.8
Nov	3	3	3	3	3	2	2.9	2.8	3	2.8	2.9	2.7	2.7	2.9	3
Dec	2	3	4	4	3	3	4.5	3.8	2.9	3.5	3.4	3	2.7	3.6	3.9

NB: DNA = Data not Available

Table 2: Average Fire Danger Index for the 1st Period (2009 - 2013)

Month/Rating	High	Moderate	Low
January	3	2	0
February	1	3	0 (DNA for 2013 Feb)
November	0	5	0
December	2	2	1

ISTF-NIG 2026

Table 3: Average Fire Danger Index for the 2nd Period (2014 - 2018)

Month/Rating	High	Moderate	Low
January	4	1	0
February	4	1	0
November	0	4	1
December	3	2	0

Table 4: Average Fire Danger Index for the 3rd Period (2019 - 2023)

Month/Rating	High	Moderate	Low
January	5	0	0
February	4	1	0
November	0	4	1
December	2	3	0

Discussion

As observed in Table 2, the high rate of Fire Danger Index (FDI) occurred four times out of five years in the Monthsmonths of January and February, suggesting a highera higher risk than in the Monthsmonths of November and December. Table 3 shows that between 2014 and 2018, the monthsthe months of January and February had the highest rate of fire danger, appearing four times each, suggesting a likelihood of fire outbreaks in those months, while November shows the rate of fire danger index three times, appearing four times, indicating a likelihood of fire outbreaks in those months, and December shows the rate of fire danger index twice. As shown in Table 4, for January,, all 5 years (2019 - 2023) have a a high Fire Danger Rating (FDR). Then, in February, 4 of 5 years had High FDR. The major determinant of FDI is Temperature and Relative Humidity. Whenever there is high temperature and low relative Humidity, it will result in a high Fire Danger Index. Due to the current rise in temperature, the potential contribution of forest fires is expected to increase (Hadisuwito & Hassan, 2020). The data indicate a modest but consistent rise in fire danger, especially during the core dry season months (Jan - Feb), with peak values regularly approaching or reaching the great danger threshold (4-5). This means fire, once started, is more likely to spread quickly and become harder to control. The implication is that proper preparation should be made in January and February to avert the danger of loss of lives and properties in Ibadan and the Southwest in general.

Conclusion

Understanding the Fire Danger Index is crucial for managing ecosystems and mitigating wildfire impacts. Balancing fire suppression with ecological needs is key to preventing biodiversity and ecosystem health. Also, FDI are critical for anticipating the impact of wildfires on ecosystems. They help identify areas where biodiversity, carbon stocks, and essential ecosystem services are most at risk. The study showed the importance of understanding FDI and FDR within the forestry community. This can be used to predict when the factors or the determinants are known. A prediction with excellent accuracy and precision can serve as an early warning sign. FDI should be considered during the dry seasons of January, February, November, and December, because FDI is always low during the rainy season.

ISTF-NIG 2026

Recommendation:

- Forest fire prevention must be carried out based on the Fire Danger Index prediction.
- Information on FDI should be requested for a particular forest location before embarking on bush burning, especially at the beginning of the year.
- When the FDI is 3.5 and above, even when it rains, do not put the bush on fire. The implication of 3.5 and above is extreme and catastrophic.

What we need to do:

- Take action now to protect life and property.
- Check your bushfire plan and ensure your property is fire-ready.
- For your survival, avoid areas at risk of bushfires.
- Stay safe by going to a safer location early in the morning or before night.
- You may not be able to rescue the forest from burning, but you need to run.
- There should be training or awareness-raising for villagers or people living around the forest, to be careful with fire during the dry season.

References

de Groot, W.J, Wotton, B.M, Flannigan, M., et al. (2015): Assessing fire danger index in tropical forests. *International Journal of Wildland Fire,* 24(3), 321 - 331

Envirowildfire.co.za: Enviro wildfire services, Kranenburg.

Fernandes, P.M. (2019). Fire danger index (FDI) and its impact on the forest ecosystem.

Goldammer, J.G. (2007). History of equatorial vegetation fires and fire research in Southeast Asia before the 1997 - 98 Episode: a reconstruction of creeping environmental changes mitigation adaptation strategy global change. 12: 13–32.

Hadisuwito, A. S., & Fadratul, H. (2020). A comparative study of the forest fire danger index calculation methods using back propagation. *Journal of Physics*, 1–2.

Liu, X; Wang, M; Zhang, J. (2020): Impact of fire danger index on forest fire occurrence in China: A parallel comparison of threshold classification and machine learning algorithms.

Müller, M.; Kucukaydin, Faith; Pentek, Tibor; Bilici, Ercan. (2020): Environmental forest fire danger rating systems and indices around the Globe: A review. *Forests* 11(12), 1337

Page, W.; Freeborn, Patrick H; Butler, Bret W; Jolly, Matt W. (2022): Severe fire danger index: A forecastable metric to inform firefighters and community wildfire Risk management.

Shah, S. U; Yan, Qi; Bian, Lingkai; Chen, Luming. (2022): A new fire danger index developed by random forest analysis of remote sensing-derived fire sizes.

Guo, Y.; Yan Feng, Jiali Wang, Daniel, Wright (2023): Performance of fire danger indices and their utility in predicting future wildfire danger over the conterminous United States.

ISTF-NIG 2026

Proceedings of the 4th ISTF-NIGERIA International Conference. Held at the Faculty of Renewable Natural Resources Management, College of Agriculture and Renewable Natural Resources, Osun State University, Nigeria, from 19th – 21st of May, 2026.
Theme: Forest Ecosystem Conservation: A Roadmap Fop Resilient Economies And Environmental Sustainability

ALLOMETRIC EQUATIONS FOR BIOMASS ESTIMATION AND CARBON SEQUESTRATION POTENTIAL FOR *Tectona grandis* Linn. f. AND *Gmelina arborea* Roxb. IN NORTH-CENTRAL NIGERIA

POPOOLA Olayinka Daniel[1]*, YAKUB Yahaya Sulieman[1] and AKOMOLEDE Lucas Aderemi[2]

[1]Department of Forestry and Wildlife, Prince Abubakar Audu University, Anyigba, Kogi State, Nigeria
[2]Rainforest Research Station, Ore, Ondo State, Forestry Research Institute of Nigeria, Jericho Hill, Ibadan, Oyo State, Nigeria
**Corresponding author: danielpopoola@yahoo.com; +2347032369749*

Abstract

The role of plantation forests in climate change mitigation and as sinks for atmospheric carbon dioxide (CO_2) has received increasing global attention. However, species-specific biomass models for reliable CO_2 sequestration in *Tectona grandis* and *Gmelina arborea* plantation at Prince Abubakar Audu University, Anyigba, North-Central Nigeria remain scarcely developed. This study focuses on developing allometric models for aboveground (AGB) and belowground (BGB) biomass estimation whilst assessing the carbon sequestration potential using dendrometric variables, including Diameter at breast height (D) ≥ 10 cm and total height (H_t, m). Seventeen temporary sample plots of 25 m by 25 m were assessed at 10% sampling intensity using stratified-random-sampling techniques. Seven allometric models relating biomass to D and/or H_t were fitted and evaluated based on coefficient of determination (R^2), standard error of estimate (SEE) and root mean square error (RMSE) values. Carbon stock was computed as 50% of the estimated biomass. Results showed that the best-fitting AGB and BGB models for *Gmelina arborea* were $Y_{ij} = -0.5761 + 0.020D^2H$ and $Y_{ij} \frac{= D^2H}{192.314 + 0.008D}$, with R^2, SEE, and RMSE values of 0.978, 3.068, and 3.051; 0.9778, 0.636, and 0.634, respectively. For *Tectona grandis,* equations $Y_{ij} = 0.041D^{1.988}H^{0.862}$ and $Y_{ij} = 0.011D^{1.988}H^{0.862}$ were adjudged best-fitting for AGB and BGB with R^2, SEE, and RMSE values of 0.944, 13.373 and 13.301; 0.944, 3.477 and 3.459, respectively. The mean total carbon stocks were 373.14 and 876.59 $kgha^{-1}$ for *Gmelina arborea* and *Tectona grandis,* respectively. The developed models performed satisfactorily and serve as useful tools for biomass estimation and carbon sequestration assessment, with potential application to other tree species and locations.

Keywords: Allometric equations, biomass accumulation, carbon sequestration and plantation forests

Introduction

Carbon dioxide (CO_2) is One of the most common greenhouse gases contributing to global warming and, at the same time, is vital for plant photosynthesis. Currently, its atmospheric concentration is of serious concern due to the rise of the industrial revolution and the increase in Earth's temperature. The Forest ecosystem helps remove excess organic carbon from the atmosphere by storing it as biomass in stems, leaves, roots, and branches, thereby reflecting the site's productivity and organic carbon stocks. Although the amount of carbon in tree biomass may vary from One species to another, it is assumed that 50% dry weight of biomass

consists of organic carbon (Basuki *et al.,* 2022). Accurate estimation of tree volume as a component of aboveground biomass (AGB) and belowground biomass (BGB) for carbon sequestration and growth studies is crucial for decision-making on site productivity in forest management. According to Sukhbaatar *et al.* (2023), the root-to-shoot ratio of trees plays a vital role in estimating forest biomass and carbon stocks. Generally, the accuracy of carbon stock estimation depends on the adequacy of the available biomass allometric equation. These allometric equations usually use dendrometrically measurable tree variables to estimate the whole or part of an individual tree's standing biomass. According to Oumasst *et al.* (2024), estimating tree biomass can be achieved using different methods, including the direct application of allometric equations, the multiplication of stand volume by wood density, or the use of the biomass expansion factor, which is a measure of volume-to-biomass ratio (Yang *et al.,* 2023; Chave *et al.,* 2005). The wood density and its corresponding volume, based on the genetic makeup of the tree and its architectural structure, are functions of tree biomass. This relationship can be described in a model form, allowing indirect biomass estimation by supplying the model with field-measured dendrometric variables for the trees.

Tectona grandis and *Gmelina arborea* both belong to the Lamiaceae family (formerly Verbenaaceae) and have been commercially grown throughout Nigeria due to their fast growth rates, importance, and the ongoing increase in demand (Popoola *et al.,* 2025a). The two exotic tree species were introduced to Nigeria from Asia. While *Tectona grandis* is grown primarily for sawn timber and poles, *Gmelina arborea* is grown to provide raw materials for the pulp and paper industry (Adekunle *et al.,* 2011). The contributory roles of these species in carbon sequestration, erosion control, biodiversity conservation, and climate change mitigation cannot be overemphasized. The need to report the estimated biomass accumulated and the carbon stocks for these two species has placed additional demands on non-destructive approaches, such as allometric equations, which develop relationships between Diameter at breast height, tree height, and wood density. Various allometric equations have been developed for biomass prediction (Basuki *et al.* (2022); Ige (2018); Bohre *et al.* (2013)), but their performance can vary depending on the geographical location, species and growth variable. These equations can be general or specific for a certain species or localized. However, species-specific models are more accurate than generalized models.

Despite the various models developed for biomass prediction across various regions, the Department of Forestry and Wildlife Teak and Gmelina Plantation located in Prince Abubakar Audu University (PAAU), Anyigba, Kogi State, North-central Nigeria has dearth of information as regards species-specific models for estimating the tree biomass accumulation and carbon sequestration potential for the two species based on easily measurable tree variables, such as Diameter, tree height and wood density. This study, therefore, focuses on developing species-specific allometric equations to estimate belowground and aboveground biomass accumulation and the carbon sequestration potential of *Tectona grandis* and *Gmelina arborea* Plantations using a non-destructive approach.

Materials and Methods

Study Area

This study was conducted in the 11-hectare Department of Forestry and Wildlife, Prince Abubakar Audu University (PAAU), Anyigba Teak and Gmelina Plantation. The plantation lies between Latitudes 7 ° 27' and 7 ° 30' N, Longitudes 7 ° 10' and 7 ° 13' E, and is located in the Dekina Local Government Area of Kogi State, North-central Nigeria (Popoola *et al.,* 2025a). The climate is typically humid tropical, characterized by distinct rainy and dry seasons, with

mean annual rainfall and temperature of 1260 mm and 27 °C, respectively (Amhakhian *et al.,* 2016). The rainy season lasts from April to October each year, while the dry season lasts from November to March, with relative humidity ranging from 65% to 85% throughout the year (Amhakhian *et al.,* 2016). The map of the study area is represented in Figure 1 below.

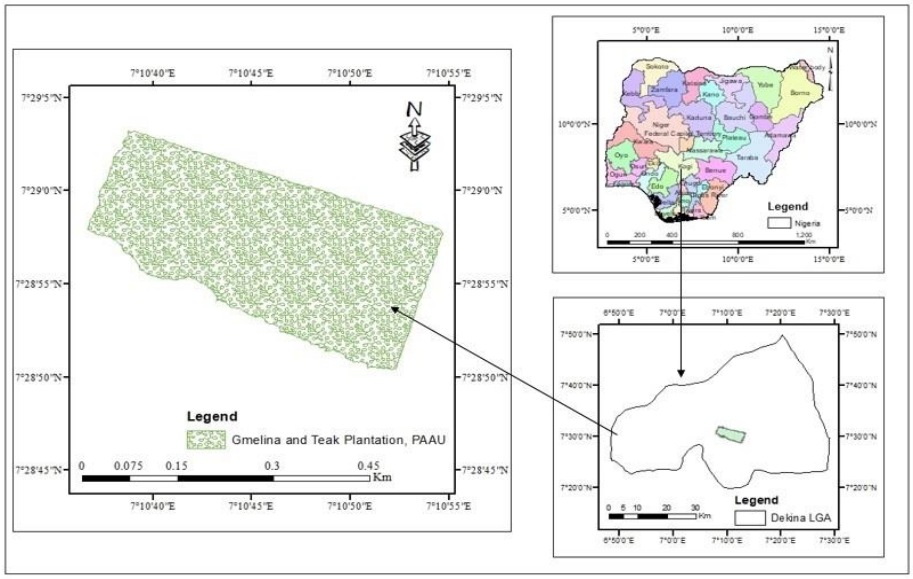


Figure 1: Map of PAAU Teak and Gmelina Plantation
Source: Field Survey, 2025

Data Collection

A proportional sample allocation technique was used to obtain the inventory data used for this study. Seven temporary sample plots of 25 m X 25 m each were randomly laid on 4.6 ha of *Gmelina arborea*, while randomly laying ten sampled plots on 6.4 ha of *Tectona grandis* stands using 10% sampling intensity for the two coppice stands. The Diameter at breast height (Dbh, cm) ≥ 10 cm at 1.3 m, and Diameter at the base (D_b, cm) were measured using a diameter tape. Diameter at the middle (D_m, cm), Diameter at the top (D_T, cm), Total height (THT, m), and Merchantable height (MHT, m) were measured using a Spiegel relaskop. In contrast, Crown diameter (CD, m) was measured using a distance tape. Individual trees measured were living, standing trees free of defects such as disease, insect infestations, or broken tops from wind or storm damage.

Data Processing and Analysis

The individual data collected were processed into a format suitable for statistical analysis. Basal area, a measure of stand density and tree competition, was computed using the formula:

$$BA = \frac{\pi D^2}{4} \quad \ldots (1)$$

Where: BA = Basal area (m^2); D = Diameter at breast height (cm), and π = 3.142.

Newton-Simpson's volume equation, as used by Popoola *et al.* (2025b), was used to estimate the volume of individual trees. The equation is mathematically expressed below as:

$$V = \frac{\pi H_t}{24}\left({D_b}^2 + 4{D_m}^2 + {D_t}^2\right) \quad \ldots (2)$$

Where: V = Total volume (m^3); H_t = Total height (m); D_b, D_m and D_t = diameters (m) at the base, middle and top, respectively and π = 3.142.

Trees Species Biomass Estimation

Allometric variables were measured and used to estimate the aboveground biomass (AGB), belowground biomass (BGB), and total biomass of individual trees. The AGB for each species was determined by multiplying volume by wood density (Ravindranath & Ostwald, 2008), while the wood density was searched from a global database (IPCC, 2006)

$$AGB = V \times WD \quad \ldots(3)$$

Where: AGB = Aboveground biomass (kg); V = Total volume (m^3); WD = Wood density ($kg\ m^{-3}$)

The belowground biomass (BGB) was calculated using a root-to-shoot ratio (25%) of the aboveground biomass as recommended by IPCC (2006). The total biomass was then computed as the summation of the aboveground biomass and the belowground biomass.

$$BGB = AGB \times 0.25 \quad \ldots(4)$$

Carbon Stock Estimation

The carbon stock was computed as 50% of the biomass estimate, expressed in tonnes $tree^{-1}$ and $tonnes\ ha^{-1}$ (Timilsina *et al.,* 2014), as recommended by the IPCC (2006) guidelines. Carbon content was then used to estimate CO_2 by multiplying it by 44/12.

$$Carbon\ Stock = Biomass \times 50\ \% \quad \ldots(5)$$

Allometric Equations for Aboveground and Belowground Biomass

To develop species-specific allometric regression models, an ordinary least-squares regression approach was employed and the various model candidates considered are presented in Table 1.

Models Performance Evaluation

The three statistical criteria used to examine the models' performance are: root mean square error (RMSE), which assesses the precision of the estimates; the coefficient of determination (R^2); and the Standard error of the estimates (SEE). They are mathematically expressed as follows:

$$RMSE = \sqrt{\sum_{i=1}^{T}\sum_{j=1}^{T_i}\sum_{k=1}^{T_{ij}}\left(Y_{ijk} - \hat{Y}_{ijk}\right)^2 \Big/ \left(\sum_{i=1}^{T}\sum_{j=1}^{T_i} n_{ij}\right)} \quad \ldots(13)$$

$$R^2 = 1 - \sum_{i=1}^{T}\sum_{j=1}^{T_i}\sum_{k=1}^{T_{ij}}\left(Y_{ijk} - \hat{Y}_{ijk}\right)^2 \Big/ \sum_{i=1}^{T}\sum_{j=1}^{T_i}\sum_{k=1}^{T_{ij}}\left(Y_{ijk} - \bar{Y}\right)^2 \quad \ldots(14)$$

$$SEE = \sqrt{\frac{\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2}{n - p}} \quad \ldots(15)$$

Where: Y_{ijk} = Actual observation for the ith observation on the sample plot; $\hat{Y}_{ijk}$ = Predicted values for the ith observation; n_i = Number of observations; p = Number of estimated parameters; and R^2 = Regression sum of Squares

ISTF-NG 2026

Table 1: Allometric equations for estimation of Above- and Belowground Biomass

Equation Forms	Source	Model Name	Equ. No.
$Y_{ij} = a + bD + e_{ij}$	Sharma *et al.,* (2025)	Simple Linear	(6)
$Y_{ij} = aD^b + e_{ij}$	Schumacher (1933)	Power Function	(7)
$Y_{ij} = a + bD + cH + e_{ij}$	Sharma *et al.,* (2025)	Multiple Linear	(8)
$Y_{ij} = a(D^2H)^b + e_{ij}$	Kira and Shidei (1967)	Compound Power	(9)
$Y_{ij} = aD^bH^c + e_{ij}$	Jenkins *et al.,* (2003)	Generalized-power	(10)
$Y_{ij} = \frac{D^2H}{(a + bD)} + e_{ij}$	Muukkonen (2007)	Ratio Model	(11)
$Y_{ij} = a + bD^2H + e_{ij}$	Kenzo *et al.,* (2020)	Linear combined-Variable	(12)

Where: Y_{ij} = Aboveground or Belowground Biomass (kg/trees); D = Diameter at breast Height (cm); H = Total Tree Height (m); a, b and c are parameter estimates; Equ. No. = Equation number; and e_{ij}= experimental error

Model Validation

The predicted and observed values were compared using the Z-score procedure, and the mean bias was calculated using one-third of the data set set aside for validation, in accordance with Adesoye and Popoola (2016). The Z- score was computed as:

$$z - score = \frac{x - \mu}{\sigma} \quad \ldots (16)$$

Where: σ = Standard deviation; x = Individual observation; ; μ = Mean observation

Results

Tree Growth Characteristics and Biomass Assessment

The descriptive statistics for the tree growth variables and the quantified biomass and carbon stock for the two species investigated are presented in Table 2. For the *Gmelina arborea* plantation, the mean values for Diameter at breast height (D), total volume (V) and total height (H_t) were 12.808 cm, 1.380 m^3ha^{-1} and 11.106 m, respectively. Similarly, the mean observed values for *Tectona grandis* H_t, V, and D were 11.687 m, 2.180 m^3 ha^{-1}, and 15.550 cm, respectively (Table 2). The tree tapers vertically upward, as revealed by the diameter measurement from base to the top. The basal area also varies between the species, with a mean value of 0.215 m^2ha^{-1} for *Gmelina arborea* and 0.322 m^2ha^{-1} for *Tectona grandis* stands.

The summary statistics for tree biomass and potential carbon sequestered are also presented in Table 2. The aboveground biomass (AGB) was estimated by multiplying the volume by the wood density. For *Gmelina arborea,* the minimum AGB was estimated at 244.63 Kg ha^{-1}, with a maximum of 2430.42 Kg ha^{-1}, whilst the *Tectona grandis* stands had 240.11 kg ha^{-1} and 5383.29 kg ha^{-1}, respectively. The total carbon sequestered ranges from 561.12 to 5574.77 Kg ha^{-1}, and 550.75 to 12347.92 Kg ha^{-1} for *Gmelina arborea* and *Tectona grandis* stands, respectively (Table 2). The comparison of the belowground biomass (BGB) shows mean values of 149.25 Kg ha^{-1} and 350.63 Kg ha^{-1} for *Gmelina arborea* and *Tectona grandis* stands, respectively (Table 2).

Allometric Equations Fitted for Estimating Biomass Accumulation

The fit indices and parameter estimates for the allometric equations used for AGB and BGB estimation, as a function of diameters at breast height and H_t, are presented in Table 3. The parameters for the equations obtained in this study reveal a relatively high coefficient of

determination (R^2) values exceeding 0.90 for the two species investigated. Adjudged based on minimum standard error, minimum root mean square and highest R^2 value, the overall best prediction equation for the AGB is a linear combined-variable model form (with R^2 = 0.978, SEE = 3.068 and RMSE = 3.051) and a generalized-power model form (with R^2 = 0.944, SEE = 13.373 and RMSE = 13.301) for *Gmelina arborea* and *Tectona grandis* stands, respectively, as shown in the results based on the relative ranking (Table 3).

Table 2: Growth Descriptive Statistics for *Gmelina arborea* and *Tectona grandis* Stands

	Gmelina arborea (N= 176)				***Tectona grandis*** (N= 278)			
Variables	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
D_b (cm)	15.692	3.277	11.2	28.8	19.125	4.912	11.1	35.2
D (cm)	12.808	2.726	10	25.0	15.550	3.850	10	28.2
D_m (cm)	9.313	2.164	6	18	11.109	3.016	5	22
D_t (cm)	6.321	1.512	4	12	7.243	2.248	3	15
H_t (m)	11.106	0.931	8.3	13.5	11.687	1.967	7.6	18.2
H_m (m)	7.927	0.851	5.9	10.5	7.778	1.431	5.1	13.2
CD (m)	3.585	0.479	2.5	5.25	4.47	1.418	2.413	9.35
CPA (m^2)	10.275	2.824	4.909	21.648	17.267	11.512	4.573	68.661
BA (m^2ha^{-1})	0.215	0.101	0.126	0.783	0.322	0.163	0.126	0.999
MV (m^3ha^{-1})	0.977	0.526	0.366	3.37	1.451	0.947	0.239	5.521
V (m^3ha^{-1})	1.380	0.782	0.544	5.401	2.180	1.416	0.369	8.282
AGB (Kg ha^{-1})	597.02	328.15	244.63	2430.42	1402.54	896.90	240.11	5383.29
BGB (Kg ha^{-1})	149.25	82.04	61.16	607.60	350.63	224.22	60.03	1345.82
TC Stock(Kg ha^{-1})	373.14	205.09	152.89	1519.01	876.59	560.56	150.07	3364.56
TCSeq.(Kg ha^{-1})	1369.41	752.70	561.12	5574.77	3217.08	2057.26	550.75	12347.92

Where: D_b = Diameter at the base (cm); D = Diameter at breast Height (cm); D_m = Diameter at the middle (cm); D_t = Diameter at the top (cm); H_t = Total Height (m); H_m = Merchantable Height (m) BA = Basal Area (m^2); MV = Newton's Merchantable Volume (m^3); V = Newton's Total Volume (m^3); Std. Dev. = Standard Deviation; Std. Error = Standard Error; Min.= Minimum value; Max.= Maximum Value; AGB = Aboveground Biomass (Kg ha^{-1}); BGB = Belowground Biomass (Kg ha^{-1}); TC Stock = Total Carbon Stock (Kg ha^{-1}); TCSeq. = Total Carbon Sequestered (Kg ha^{-1})

Similarly, for BGB estimation, the ratio model (R^2 = 0.978, SEE = 0.636, RMSE = 0.634) and the generalized-power model (R^2 = 0.944, SEE = 3.477, RMSE = 3.459) were adjudged the overall best for *Gmelina arborea* and *Tectona grandis* stands, respectively. As observed, the best-fitting models for estimating AGB and BGB for the two species include the compound term D^2H as an independent variable. All the models examined were found to be suitable for explaining a substantial proportion of the variability in the response variable. The summary for the parameter estimates and fit indices for all the model forms examined is presented in Table 3.

ISTF-NIG 2026

Table 3: Biomass Allometric Equation Fit Indices and Parameter Estimates for *Gmelina arborea* and *Tectonia grandis* Stands

		Gmelina arborea							*Tectona grandis*						
	Equation Forms	**a**	**b**	**c**	**SEE**	**RMSE**	R^2	**Rank**	**a**	**b**	**c**	**SEE**	**RMSE**	R^2	**Rank**
Aboveground	$Y_{ij} = aD^b + e_{ij}$	0.128	2.219		3.932	3.909	0.964	5th	0.134	2.329		16.997	16.936	0.908	6th
	$Y_{ij} = a + bD + cH + e_{ij}$	-81.299	7.095	2.632	4.460	4.422	0.953	6th	-161.568	11.607	5.899	16.815	16.724	0.911	5th
	$Y_{ij} = a(D^2H)^b + e_{ij}$	0.0194	1.004		3.079	3.061	0.978	2nd	0.037	0.967		13.414	13.366	0.943	2nd
	$Y_{ij} = aD^bH^c + e_{ij}$	0.0186	2.003	1.027	3.087	3.060	0.978	3rd	0.041	1.988	0.862	13.373	13.301	0.944	1st
	$Y_{ij} = \frac{D^2H}{(a+bD)} + e_{ij}$	50.002	0.002		3.080	3.062	0.978	4th	33.552	0.135		13.444	13.396	0.943	3rd
	$Y_{ij} = a + bD^2H + e_{ij}$	-0.5761	0.020		3.068	3.051	0.978	1st	2.258	0.027		13.480	13.431	0.942	4th
Belowground Biomass	$Y_{ij} = aD^b + e_{ij}$	0.0331	2.219		0.812	0.809	0.964	5th	0.035	2.329		4.419	4.403	0.908	6th
	$Y_{ij} = a + bD + cH + e_{ij}$	-21.138	1.845	0.684	0.920	0.915	0.953	6th	-42.008	3.018	1.534	4.372	4.348	0.911	5th
	$Y_{ij} = a(D^2H)^b + e_{ij}$	0.005	1.004		0.638	0.636	0.977	3rd	0.010	0.967		3.490	3.477	0.943	2nd
	$Y_{ij} = aD^bH^c + e_{ij}$	0.005	2.003	1.027	0.640	0.636	0.977	4th	0.011	1.988	0.862	3.477	3.459	0.944	1st
	$Y_{ij} = \frac{D^2H}{(a+bD)} + e_{ij}$	192.314	0.008		0.636	0.634	0.978	1st	129.046	0.520		3.496	3.483	0.943	3rd
	$Y_{ij} = a + bD^2H + e_{ij}$	-0.150	0.005		0.637	0.635	0.978	2nd	0.587	0.007		3.507	3.495	0.942	4th

Where: Y_{ij} = Aboveground and Belowground Biomass (Kg ha^{-1}); D = Diameter at breast Height (cm); H = Tree Total Height (m); SEE = Standard Error of Estimate; and RMSE = Root Mean Square Error; R^2= Coefficient of determination; a, b and c are parameters estimates; and e_{ij}= experimental error

ISTF-NIG 2026

The performance of the fitted models, as indicated by the Wilcoxon matched-pairs Z-test at the 0.05% significance level, shows strong agreement between the observed and predicted values. The model validation further confirmed the robustness of the model, with paired mean difference values between -0.1001 and 0.1308 for AGB and -0.0876 and 0.0631 for BGB for *Gmelina arborea* stands, whilst having values between 1.1355 and 2.9107 and 0.3966 and 0.7348 for AGB and BGB, respectively, for *Tectona grandis* stands (Table 4). The results demonstrate the reliability and suitability of the fitted models for practical application in forest management.

Discussion

Biomass Accumulation and Growth Variables Measured Assessment

The tree growth rate depends on several factors, including climate, genetic makeup, spacing, and nutrient and water availability. Structural growth performance, as evident in biomass accumulation, is an indicator of site productivity. The variation in Diameter from base to top measurement reflects an expected stem tapering, which was in line with Popoola *et al.* (2025a). Given the global drive towards REDD+ and carbon accounting, reliable biomass models are becoming crucial. Woody biomass accumulation and carbon stocks in the forest plantation were examined to support sustainable management of the study area. Generally, the estimated aboveground and belowground biomass are consistent with the trends in the measured tree growth variables. However, among the developed models, the best-performing models incorporated both Diameter at breast height and H_t. The inclusion of the compound term (D^2H) in the equations is biologically meaningful, and together they serve as a strong representation of tree volume and biomass. This type of model was undoubtedly adjudged more accurate and precise than models with Diameter alone. The result is consistently significant and consistent with several studies (Chave *et al.,* 2005; Henry *et al.,* 2011; Bohre *et al.,* 2013). According to IPCC (2006), accurate allometric models enhance forest management, reporting, and planning for carbon credit projects.

Tectona grandis and *Gmelina arborea*: Potential for Carbon Sequestration

The carbon sequestration potential of the two species varies significantly. The results reveal that the estimated biomass accumulated and carbon stock based on measured growth variables are higher for *Tectona grandis* than for *Gmelina arborea* stands in the study area.

Table 4: Biomass Equation Validation Data Statistics for *Gmelina arborea* and *Tectonia grandis* Stands

	Equation Forms	*Gmelina arborea* (N = 86)						*Tectona grandis* (N = 134)					
		Paired Differences			Z-value	P-value	Remarks	Paired Differences			Z-value	P-value	Remarks
		Mean	STDev.	STErr.				Mean	STDev.	STErr.			
Aboveground Biomass	$Y_{ij} = aD^b + e_{ij}$	0.1308	5.6079	0.6047	0.0366	0.9708	Suitable	2.9107	19.9908	1.7269	0.4397	0.6601	Suitable
	$Y_{ij} = a + bD + cH + e_{ij}$	0.0341	5.7350	0.6184	0.0095	0.9924	Suitable	1.5988	17.0093	1.4694	0.2351	0.8142	Suitable
	$Y_{ij} = a(D^2H)^b + e_{ij}$	-0.1001	3.9008	0.4206	-0.0274	0.9781	Suitable	1.1355	12.5542	1.0845	0.1631	0.8705	Suitable
	$Y_{ij} = aD^bH^c + e_{ij}$	-0.0698	3.8877	0.4192	-0.0191	0.9847	Suitable	1.4768	12.8889	1.1134	0.2132	0.8312	Suitable
	$Y_{ij} = \frac{D^2H}{(a+bD)} + e_{ij}$	-0.0777	3.9368	0.4245	-0.0214	0.9830	Suitable	1.2299	12.4386	1.0745	0.1759	0.8604	Suitable
	$Y_{ij} = a + bD^2H + e_{ij}$	0.0508	3.8671	0.4170	0.0139	0.9889	Suitable	1.2511	12.6097	1.0893	0.1788	0.8581	Suitable
Belowground Biomass	$Y_{ij} = aD^b + e_{ij}$	0.0504	1.4609	0.1575	0.0543	0.9567	Suitable	0.7348	5.1937	0.4487	0.4268	0.6695	Suitable
	$Y_{ij} = a + bD + cH + e_{ij}$	0.0094	1.4911	0.1608	-0.0105	0.9916	Suitable	0.4148	4.4224	0.3820	0.2345	0.8146	Suitable
	$Y_{ij} = a(D^2H)^b + e_{ij}$	0.0608	1.0283	0.1109	0.0644	0.9487	Suitable	0.3966	3.2751	0.2829	0.2195	0.8263	Suitable
	$Y_{ij} = aD^bH^c + e_{ij}$	0.0631	1.0242	0.1104	0.0668	0.9467	Suitable	0.4013	3.3533	0.2897	0.2229	0.8236	Suitable
	$Y_{ij} = \frac{D^2H}{(a+bD)} + e_{ij}$	-0.0203	1.0235	0.1104	-0.0214	0.9829	Suitable	0.3198	3.2340	0.2794	0.1759	0.8604	Suitable
	$Y_{ij} = a + bD^2H + e_{ij}$	-0.0876	0.9933	0.1071	-0.0918	0.9269	Suitable	0.4716	3.2910	0.2843	0.2600	0.7948	Suitable

Where: STErr.= Standard Error of Mean; STDev. = Standard Deviation; and P-value = Probability level of $p < 0.05$

ISTF-NG 2026

This was observed to be true because of *Tectona grandis*'s higher wood density. The mean total biomass obtained in the study area for *the Gmelina arborea* plantation is relatively low compared with that reported by Ige (2018) and Bohre *et al.* (2013). These substantial differences could be attributed to variations in age, tree size, site quality, silvicultural practices, and planting density. Similarly, for the *Tectona grandis* carbon sequestration potential, the result was in line with Bohre *et al.* (2013 though with lower carbon values. Conversely, Ojo *et al*. (2020) reported higher biomass accumulation in a teak plantation established in Ibadan than in the current results. These sharp contrasts are attributed to differences in geographic location, planting density, soil quality, soil type, and plantation developmental stage. The species also shows great potential for biomass accumulation and carbon sequestration, underscoring the strong predictive Power of allometric models for these traits.

Conclusion

The species-specific allometric equations developed to estimate biomass accumulation and the carbon sequestration potential of *Tectona grandis* and *Gmelina arborea* plantations within the North-central zone of Nigeria reveal significant differences in the prediction equations for above- and belowground biomass. The results show that both species contribute significantly to carbon sequestration, with *Tectona grandis* exhibiting a greater overall carbon storage potential than *Gmelina arborea* due to its higher wood density. The allometric models show a relatively low root-mean-square error estimate with practically no bias. These studies further highlight the superiority of including the compound term (D^2H) for volume and biomass estimation, demonstrating greater biological meaningfulness than using Diameter alone for accurate prediction. The results further show that nonlinear model prediction equations achieve higher accuracy than linear models. The models developed performed satisfactorily with potential application to other tree species and locations. The results further show insight into the role of the Teak and Gmelina plantation of the Department of Forestry and Wildlife, Prince Abubakar Audu University, Anyigba, Kogi State, in climate change mitigation and the removal of excess greenhouse gases from the atmosphere.

References

Adekunle, V. A. J., Alo, A. A., & Adekayode, F. O. (2011). Yields and nutrient pools in soil cultivated with *Tectona grandis* and *Gmelina arborea* in the Nigerian rainforest ecosystem. *Journal of the Saudi Society of Agricultural Sciences*, 10.2: 127 - 135

Adesoye, P. O. & Popoola, O. D. (2016). Determinants of Stem Form: Application to *Tectona grandis* (Linn. F) Stands. *Journal of Sustainable Forestry*, 35.5: 338 - 354

Amhakhian, S. O., Aina, O. A., & Anokehi, D. O. (2016). Impact of Land use system on some physical and chemical properties: A case study of Kogi State University, Anyigba. *International Journal of Agriculture and Bioseciences*, 5.5: 316 - 321

Basuki, T. M., Leksono, B., Baral, H., Andini, S., Wahyuni, N. S., Artati, Y., Choi, E., Shin, S., Kim, R., Yang, A. R., Samsudin, Y. B., and Windyarini E. 2022. Allometric Equations for the Biomass Estimation of *Calophyllum inophyllum* L. in Java, Indonesia. *Forests,* 13.7: 1057.

Bohre P., Chaubey O. P. & Singhal P. K. (2013). Biomass Accumulation and Carbon Sequestration in *Tectona grandis* Linn. f. and *Gmelina arborea* Roxb. *International Journal of Bio-Science and Bio-Technology*, 5.3:153 -173

Chave, J., Chidumayo, E., Ploton, P., Saldarriaga, J. G., Mencuccini, M., Ortiz-Malavassi, E., Vieilledent, G., Muller-Landau, H. C., Búrquez, A., Eid, T., Pélissier, R., Ryan, C. M., Réjou-Méchain, M., Nelson, B. W., Henry, M., Duque, A., Colgan, M. S., Martínez-Yrízar, A., Nogueira, E. M., Goodman, R. C., Fearnside, P. M., Mugasha, W. A.,

Ngomanda, A., and Delitti, W. B. C. 2014. Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology, 20*: 3177 – 3190. https://doi.org/10.1111/gcb.12629

Chave, J., Kira, T., Chambers, J. Q., Eamus, D., Fölster, H., Higuchi, N., Andalo, C., Cairns, M. A., Ogawa, H., Fromard, F., Brown, S., Riéra, B., Lescure, J.-P., Puig, H., Nelson, B. W., & Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia, 145*: 87–99.

Jenkins, J. C., Chojnacky, D. C., Health, L. S., & Birdsey, R. A. (2003). National-scale biomass estimators for United States tree species. *Forest Science,* 49.1:12 - 35.

Henry, M., Picard, N., Trotta, C., Manlay, R., Valentini, R., Bernoux, M., & Saint André, L. (2011). Estimating tree biomass of sub-Saharan African forests: a review of available allometric equations. *Silva Fennica*, 45.3B: 477 – 569.

Ige, P. O. 2018. Estimation of aboveground biomass and carbon stocks in *Gmelina arborea* (Roxb.) stands in the Omo Forest Reserve, Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, 10.4: 71-80.

Intergovernmental Panel on Climate Change (IPCC). 2006. Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., editors. Published: IGES, Japan.

Kenzo, T., Himmapan, W., Yoneda, R., Tedsorn, N., Vacharangkura, T., Hitsuma, G., & Noda, I. (2020). General estimation models for above and below ground biomass of teak (*Tectona grandis*) plantations in Thailand. *Forest ecology and management,* 457: 117701.

Kira, T., & Shidei, T. (1967). Primary production and turnover of organic matter in different forest ecosystems of the western Pacific. *Japanese Journal of Ecology,* 17.2:70 - 87.

Muukkonen P. 2007. Generalized allometric volume and biomass equations for some tree species in Europe. *European Journal of Forest Resources,* 126.2:157 - 166.

Ojo, M.O., Aghimien, E.V., and Alade, A.A. 2020. Inventory-based estimates of Aboveground Tree Biomass Models for *Tectona grandis* Linn. Plantation in the Federal College of Forestry, Ibadan, Nigeria. *FUTY Journal of the Environment,* 14.2: 97-104.

Oumasst, A., Tiouidji, F. E., Tabi, S., Zahidi, A., El Mousadik, A., El Finti, A., Aitlhaj, A., and Hallam, J. 2024. Development of Allometric Equations to Determine the Biomass of Plant Components and the Total Storage of Carbon Dioxide in Young Mediterranean Argan Trees. *Sustainability,* 16.11: 4592

Popoola, O. D., Alih, G. A., Jatto, S. O. S., Alfa, J. I. and Eyinade, M. A. 2025(a). Comparison of Linear and Nonlinear Regression Models for Crown Diameter Prediction in *Gmelina arborea* Roxb. and *Tectona grandis* Linn. f Stands. *International Journal of Agricultural Economics, Management and Development,* 13.2: 114 -126

Popoola, O. D., Ige, P. O. and Chukwu, A. U. (2025). (b). Nonlinear Mixed-Effects Bole Volume and Weibull Diameter Distribution Models for *Tectona grandis* (Linn. F) Plantation in Omo Forest Reserve, Nigeria. In Akinyele, A. O; Omitoyin, S. A; Ige, P. O; Coker, O. M; Fasoro, O. A and Ajiboye, A. O (Eds), Renewable Natural Resources Management and Use: A path to sustainable development: Proceedings of the 1st Faculty of Renewable Natural Resources, University of Ibadan Conference, 16-20 June, 2025, 233 - 243p

Ravindranath, N. H. & Ostwald, M. (2008). Methods for Estimating Aboveground Biomass. *Carbon Inventory Methods: Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Round Wood Production Projects*, 113–147.

Schumacher, F.X., 1933. Logarithmic expression of timber-tree volume. *Journal of Agricultural Resources,* 47: 719–734.

ISTF-NIG 2026

Sharma, A., Ayer, S., Ayer, K., Khadka, A., Maraseni, T., Timilsina, Y. P., & Mandal, R. A. (2025). Empirical allometric models for estimating aboveground biomass of *Bambusa teres* and *Bambusa tulda* in non-forest areas of Nepal. *Agroforestry systems, 99*.5: 121.

Sukhbaatar, G., Chimednyam, D., Nachin, B., Ganbaatar, B., & Gradel, A. (2023). Allometric equations for the estimation of above- and belowground biomass for *Larix sibirica* Ledeb. in Northern Mongolia. *Forest Science and Technology*, 19.1: 12–20.

Timilsina, N., Staudhammer, L.C., Escobedo J., Escobedo, J., Lawrence, A. 2014. Tree biomass, wood waste yield, and carbon storage changes in an urban forest. *Landscape and Urban Planning*, 127: 18–27.

Yang, M., Zhou, X., Peng, C., Li, T., Chen, K., Liu, Z., Li, P., Zhang, C., Tang, J., Zou, Z. 2023. Developing Allometric Equations to Estimate Forest Biomass for Tree Species Categories Based on Phylogenetic Relationships. *Forest Ecosystems,* 10: 100130.

ISTF-NIG 2026

DESIGN AND FABRICATION OF AN INDIGENOUS MULTIPURPOSE COOKSTOVE UTILIZING BRIQUETTES, BIO-GEL, BIOGAS, AND LPG

[1]Akingba, O.O., [1]Ogbomida E.T.,[2]Abdullahi, M., [1]Orerome, O.R.,[1]Amarasa, S.O., [3]AREGBE, O.

[1]National Centre for Energy and Environment, University of Benin, Benin City, Edo State, Nigeria.

[2] Energy Commission of Nigeria, Abuja.

[3]Mechanical Engineering Department, Igbinedion University, Okada, Edo State

Corresponding email: akingba.o@ncee.org.ng

Abstract

The increasing demand for clean, affordable, and sustainable household cooking energy has necessitated the development of efficient alternative cooking technologies that can utilize multiple fuel sources. This study focused on the design and fabrication of an indigenous multipurpose cookstove capable of operating with briquettes, bio-gel, biogas, and Liquefied Petroleum Gas (LPG). The study involved conceptual design, material selection, engineering calculations, fabrication, assembly, and performance evaluation of the stove using locally sourced materials. Design considerations included heat resistance, fuel efficiency, affordability, durability, ergonomics, safety, and ease of local fabrication. The major stove components designed were the combustion chamber, burner system, fuel containers, blower, air jacket, and grate. The energy requirement for an average household cooking period of 2 hours daily was determined to be 9.55 MJ/h based on the energy content of a 12.5 kg LPG cylinder. The fuel consumption rates obtained were 0.66 kg/h for briquettes, 0.58 kg/h for bio-gel, 0.40 kg/h for biogas, and 0.26 kg/h for LPG, indicating that LPG is the most fuel-efficient option. Combustion chamber dimensions and fuel container capacities were also determined to ensure efficient combustion and adequate airflow. Air-fuel ratio values ranged from 0.60 to 0.99 m^3/h depending on the fuel type. The fabricated stove demonstrated the technical feasibility of integrating multiple fuel systems into a single unit, thereby enhancing fuel flexibility, reducing dependence on conventional biomass fuels, promoting the use of renewable energy, and supporting sustainable development of household cooking energy.

Keywords: Multipurpose cookstove, Renewable energy, Biomass briquettes, Clean cooking technology, Fuel efficiency

Introduction

Access to clean, affordable, and efficient cooking energy remains a major challenge in many developing countries, especially in rural and peri-urban communities. A large proportion of households still depend on traditional biomass fuels such as firewood, charcoal, agricultural residues, and kerosene for daily cooking activities. These conventional cooking methods are often associated with low thermal efficiency, excessive fuel consumption, indoor air pollution, deforestation, and adverse health effects caused by smoke emissions. According to recent studies, household air pollution resulting from inefficient cooking systems contributes significantly to respiratory diseases and environmental degradation in developing nations (Adelekan et al., 2023). The growing demand for sustainable energy solutions has led researchers and engineers to develop improved cookstoves that use cleaner, renewable fuels. Multipurpose cookstoves are gaining attention for their flexibility in fuel use, improved combustion efficiency, and reduced harmful emissions. These stoves are designed to operate

with various fuel sources, including biomass briquettes, bio-gel, biogas, and Liquefied Petroleum Gas (LPG), thereby offering users alternative energy options depending on fuel availability, affordability, and cooking requirements. The integration of multiple fuel systems into a single stove design is particularly important in regions where energy supply is inconsistent or where households combine several cooking fuels to meet daily needs (Onyango & Musa, 2024).

Briquettes are compressed combustible materials produced from agricultural waste, sawdust, charcoal dust, and other biomass residues. They are considered environmentally friendly because they utilize waste materials that would otherwise contribute to pollution. Briquettes also burn longer, produce less smoke, and have a higher energy density than loose biomass fuels. The growing interest in briquette technology is linked to global efforts to reduce deforestation and dependence on firewood. Studies have shown that biomass briquettes can significantly improve household cooking efficiency while reducing carbon emissions (Kumar et al., 2022). Similarly, bio-gel fuel, commonly produced from ethanol and thickening agents, has emerged as a cleaner household cooking fuel due to its smokeless combustion characteristics and ease of storage and transportation. Bio-gel is safer than kerosene and can be produced from renewable biological resources, making it a sustainable alternative for domestic cooking applications (Adebayo et al., 2021).

Biogas is another renewable energy source widely recognized for its use in clean cooking applications. It is generated through the anaerobic digestion of organic waste materials such as animal dung, food waste, and agricultural residues. Biogas technology not only provides a clean cooking fuel but also contributes to waste management and environmental sanitation. Recent studies have shown that improved biogas cookstoves can achieve higher thermal efficiency and lower emissions than traditional cooking methods (Zhang et al., 2025). The adoption of biogas systems is particularly beneficial in rural communities with access to organic waste resources. In addition, biogas utilization supports sustainable waste recycling and helps reduce greenhouse gas emissions (Mashauri & Joseph, 2023).
Liquefied Petroleum Gas (LPG) remains One of the most commonly used clean cooking fuels globally because of its high combustion efficiency, convenience, and relatively low emissions. Despite its advantages, the high cost and inconsistent supply of LPG in many developing countries often limit its accessibility to low-income households. However, LPG is still considered an important transitional fuel toward cleaner cooking energy systems. Research on advanced burner technologies has further demonstrated that improved LPG stove designs can significantly reduce fuel consumption and harmful gaseous emissions (Singh & Verma, 2022).
The design and fabrication of an indigenous multipurpose cookstove capable of utilizing briquettes, bio-gel, biogas, and LPG is therefore essential for promoting energy sustainability, affordability, and environmental protection. Indigenous stove development encourages the use of locally available materials and technologies, thereby reducing production costs and enhancing local technical capacity. Such a stove can improve fuel flexibility, minimize dependence on a single energy source, and provide households with a reliable cooking solution under varying economic and environmental conditions. Additionally, the development of efficient multipurpose cookstoves aligns with global clean energy initiatives and Sustainable Development Goal 7, which aims to ensure access to affordable, reliable, sustainable, and modern energy for all (United Nations, 2024). Hence, this study aimed to design and fabricate a multipurpose cook stove capable of burning bio-gel, biogas, briquettes, LPG (Liquefied petroleum gas), or a combination of all. These were achieved by designing the components of the multipurpose cook stove with its mathematical details, fabricating and assembling the

ISTFNIG 2026

components of the multipurpose cook stove using locally sorted materials, and conducting a performance evaluation of the fabricated multipurpose cook stove.

Materials and Method

The study involved the conceptual design of the multipurpose cook stove, proper material selection, detailed design calculations in accordance with engineering specifications, and relevant engineering drawings. Thereafter, the machine was fabricated and developed using locally sourced materials.

Design consideration and analysis

The essential components of the multipurpose cook stove were analyzed to determine the dimensions and stress on each element. The essential machine elements to be designed are the burner, blower, pyrolysis chamber, fuel container, and grate. The following factors were put into consideration in the design of the multipurpose cook stove:

- Simplicity in construction so that the machine could be made locally using available materials
- The best design criteria were selected to ensure the effective performance of the multipurpose cook stove.
- Compatibility with low-wear design
- Heat resistance
- Availability of the materials
- Suitability of the materials for the working conditions in service
- The cost of the materials
- **Frictional resistance and lubrication:** There is always a loss of PowerPower due to friction, and it should be noted that starting friction is higher than running friction.
- **Convenient and economical features (Ergonomics):** The burner control handles were located for convenient handling. The adjustment for wear was achieved by using the various take-up devices and arranging them so that the parts' alignment was preserved. The stove height was taken into account to ensure the user is not under any stress during operation.
- **Safety of operation:** The stove was designed with safety features to minimize the risk of fires, gas leaks, and carbon monoxide emissions. Some safety features include: automatic shut-off valves, improved venting systems, advanced flame failure devices, and pause and lock buttons.

Material Selection

For this study, the construction materials for the multipurpose cook stove were selected based on the following factors.

- **Cost:** This will determine the overall price at which the multipurpose cook stove will be sold and its affordability. The selected materials were low-cost, without compromising the machine's strength and quality.
- **Strength:** The selected materials were of adequate strength and offered high resistance to heat and wear, and were not easily deformed.
- **Appearance:** The selected materials had good finishes.
- **Availability:** The selected materials were locally available, enabling easy replacement of any component and saving time.

ISTF-NIG 2026

Conception of the Multipurpose Cook Stove

The summary of the conception of the multipurpose cooking stove, including the list of materials and the criteria for selecting the materials used, the exploded view, orthographic view, and detailed view of the multipurpose cooking stove design, is presented in Table 1 and Figures 1, 2, and 3, respectively.

- **Cook stove frame:** It carries the entire load of the parts, adds to the cook stove's aesthetic, and provides support for pots while cooking.
- **Bio-gel stove grate**: It is a framework that sits on the bottom of a stove or fireplace to hold Bio-gel fuel and allows air to flow through it
- **Cooktop:** It is a standalone appliance that's used to cook food by applying heat to pots and pans. It is typically installed on a countertop.
- **Biomass pellet stove grate:** It is a framework that sits on the bottom of a stove or fireplace to hold Biomass pellet fuel and allows air to flow through it.
- **Bio-gas burner grate**: It is a framework that sits on the bottom of a stove or fireplace to hold Biogas fuel and allows air to flow through it.
- **LPG burner grate:** It is a framework that sits on the bottom of a stove or fireplace to hold LPG fuel and allows air to flow through it.
- **Blower:** It is also known as a convection or room blower and is a fan that circulates warm air from a stove or fireplace. A stove blower increases the efficiency with which a stove transfers heat.
- **Air Jacket:** An air-filled compartment that surrounds the firebox to reduce heat transfer. Air jackets can be used in a variety of ways, including for cooling, heating, and temperature control.
- **Pyrolysis chamber:** It is part of a pyrolysis stove, which uses high temperatures to burn off grease and food residue in a process called pyrolysis.
- **Bio-gel burner:** It is a stove burner that uses bio-ethanol gel as fuel, reducing reliance on fossil fuels. Bio-ethanol gel is an alcohol-based fuel that is thicker than liquid bio-ethanol and produces smaller flames.
- **Bio-gel burner control handle:** A burner control handle, also known as a stove knob, is a part of a stove that controls the temperature of the stovetop heating elements.
- **Bio-gel fuel container**: a tank that holds a thick, gel-like fuel that burns cleanly and produces little to no smoke or soot.
- **Bio-gas burner:** a part of a biogas stove that combusts biogas to cook food.
- **LPG burner:** a burner in a stove that uses liquefied petroleum gas (LPG) as fuel

Table 1. List of materials selected for the fabrication of the multipurpose cook stove.

S/N	Machine component	Criteria for selection	Most suitable material	Material actually selected	Reason for selecting the material	Limitations of the material selected
1	Frame	High heat resistance, strength, rigidity, workability and cost	Mild steel, Stainless, Cast iron, High carbon steel	Mild steel	Often chosen for its good machinability and weldability It is also Cheap.	Low hardenability, although case hardening through carburization is possible.

ISTF-NIG 2026

2	Cook Top	High heat resistance, strength, rigidity, workability and cost	Mild steel, Stainless, Cast iron, High carbon steel	High carbon steel	Extremely hard, and adapts well to heat treatment	It can be hard to work or weld
3	Bio-gel stove grate	High heat resistance, strength, rigidity, workability and cost	Mild steel, Stainless, Cast iron, High carbon steel	Cast iron	Cast iron has a high melting point and good thermal conductivity	Cast iron is prone to rusting, especially when exposed to moisture or left in humid environments.
4	Biomass pellet stove grate	High heat resistance, strength, rigidity, workability and cost	Mild steel, Stainless, Cast iron, High carbon steel	Cast iron	Cast iron has a high melting point and good thermal conductivity	Cast iron is prone to rusting, especially when exposed to moisture or left in humid environments.
5	Biogas burner grate	High heat resistance, strength, rigidity, workability and cost	Mild steel, Stainless, Cast iron, High carbon steel	Cast iron	Cast iron has a high melting point and good thermal conductivity	Cast iron is prone to rusting, especially when exposed to moisture or left in humid environments.
6	LPG burner grate	High heat resistance, strength, rigidity, workability and cost	Mild steel, Stainless, Cast iron, High carbon steel	Cast iron	Cast iron has a high melting point and good thermal conductivity	Cast iron is prone to rusting, especially when exposed to moisture or left in humid environments.
7	Blower	High heat resistance, strength, rigidity, workability and cost	Mild steel, Stainless, Cast iron, carbon steel	Carbon Steel	high strength, good durability, and the ability to be readily shaped	Carbon steel is susceptible to rusting and corrosion when exposed to moisture, oxygen, or harsh chemicals.
8	Pyrolysis chamber	Thermal energy, barrel shape/diamete	aluminum, brass, copper, iron, nickel	stainless steel	Corrosion and high heat resistance,	Stainless steel is heavier than aluminum

ISTF-NIG 2026

		r, heat-resistant	alloy, steel, and stainless steel.			alloys, which can be a disadvantage in applications where weight reduction is important
9	Bio-gel burner	Corrosion and high heat resistance, strength, rigidity, workability and cost	aluminum, brass, copper, iron, nickel alloy, steel, cast iron	Brass	corrosion resistance, high malleability, relatively low melting point, good electrical conductivity, antimicrobial properties, and is non-ferromagnetic	susceptibility to tarnishing, relatively low strength compared to other metals, potential for skin irritation due to its copper content,
10	Bio-gel burner control handle	High heat resistance, strength, rigidity,	Nickel, metal, plastics	plastic	They are Light in weight, chemically stable, have good insulation and low thermal conductivity, Good impact resistance, and do not rust.	low melting point
11	Bio-gel fuel container	Thermal energy, holding shape/diameter, heat-resistant	aluminum, brass, copper, iron, nickel alloy, steel, and stainless steel	stainless steel	Corrosion and high heat resistance,	Stainless steel is heavier than aluminum alloys, which can be a disadvantage in applications where weight reduction is important
12	Biogas burner	Corrosion and high heat resistance, strength, rigidity, workability and cost	aluminum, brass, copper, iron, nickel alloy, steel, cast iron	Brass	corrosion resistance, high malleability, relatively low melting point, good electrical conductivity, antimicrobial	susceptibility to tarnishing, relatively low strength compared to other metals, potential for skin irritation

ISTF-NIG 2026

					properties, and is non-ferromagnetic	due to its copper content,
13	LPG burner	Corrosion and high heat resistance, strength, rigidity, workability and cost	aluminum, brass, copper, iron, nickel alloy, steel, cast iron	Brass	corrosion resistance, high malleability, relatively low melting point, good electrical conductivity, antimicrobial properties, and is non-ferromagnetic	susceptibility to tarnishing, relatively low strength compared to other metals, and potential for skin irritation due to its copper content

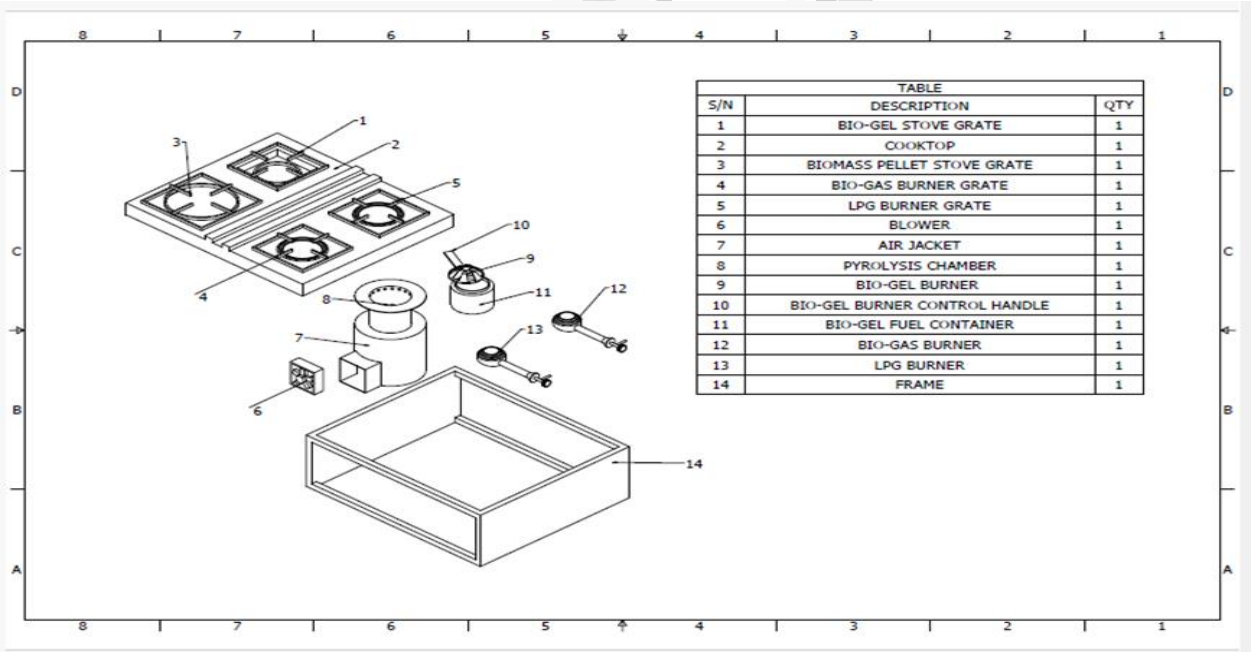


Figure 1: Exploded view of the multipurpose cook stove design.

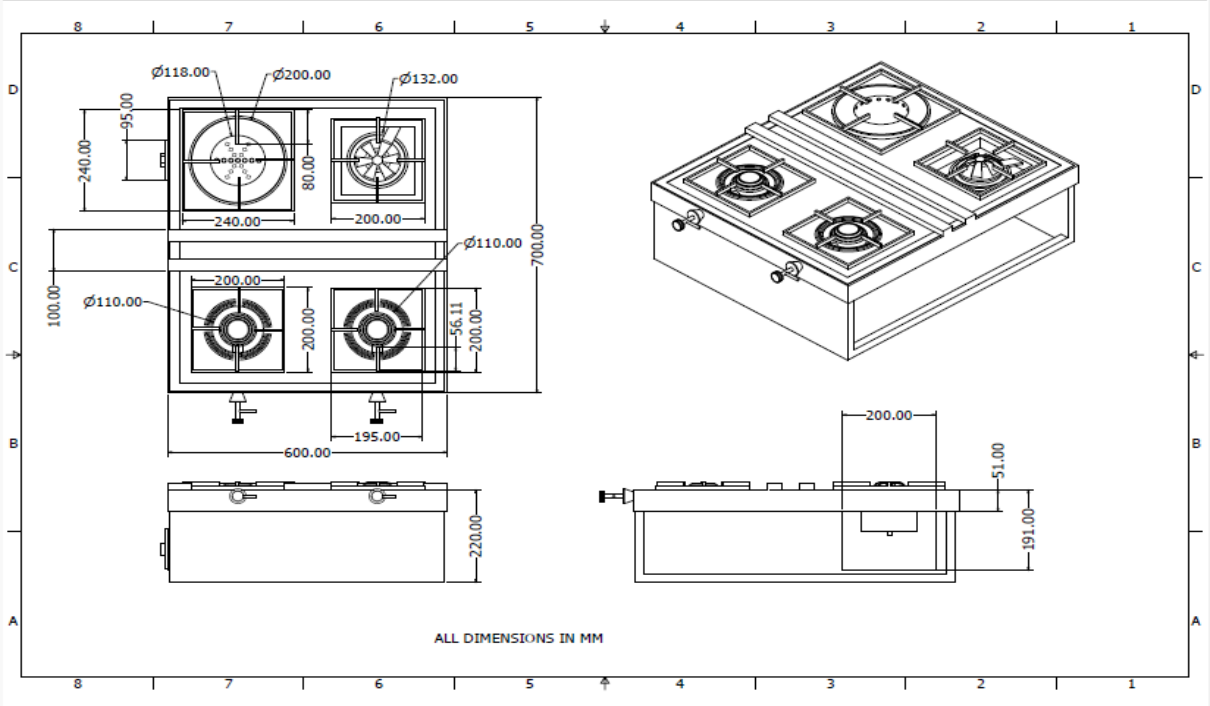


Figure 2: Orthographic view of the Multipurpose cook stove design

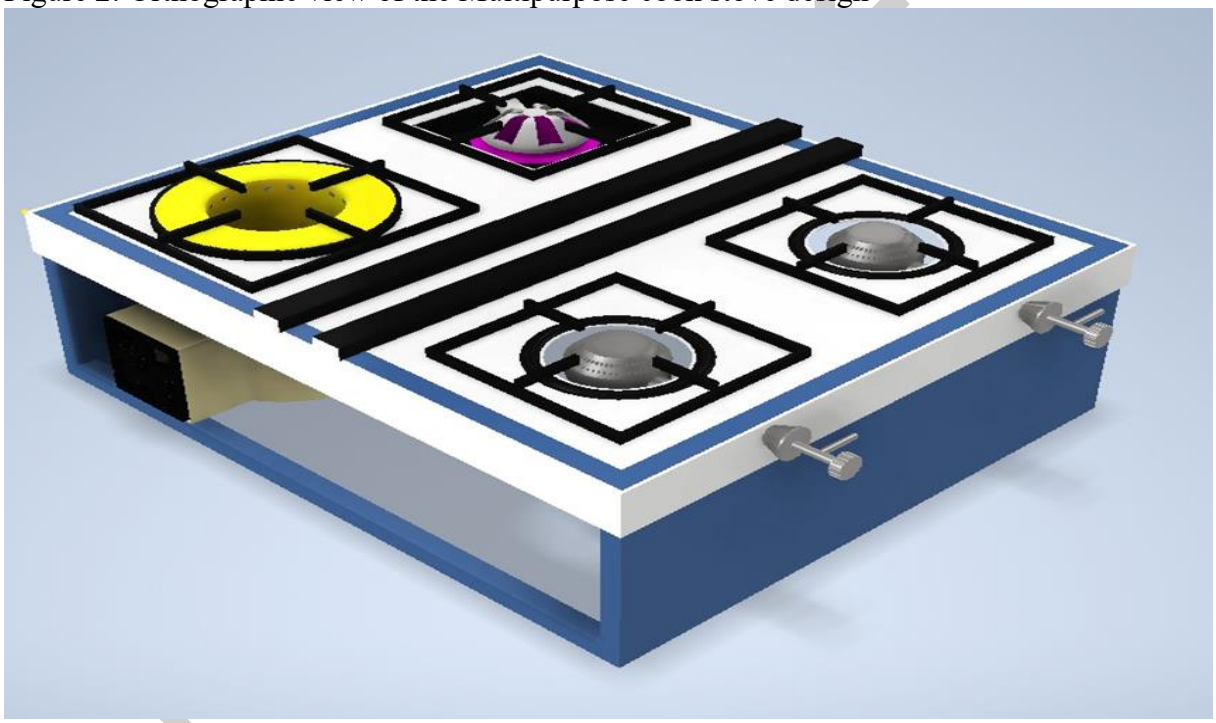


Figure 3: Detailed View of the multipurpose cook stove

Design calculation for the cook stove

The essential Components of the stove were designed and dimensioned according to the reports of Bantelay and Gabbiye (2014), Yanusa et al. (2022), Saloop et al. (2016), and Speight (2019) (equations 1-13). The theoretical design of the cook stove was based on the natural-draft principle. It can use four fuels for heat generation: biomass pellets, bio-gel, bio-gas, and LPG. The parameters for the theoretical design of the Cook stove are listed below.

Results

Determination of the amount of energy needed

The designs were based on the energy requirements of an average-sized family. Assuming a 12.5kg LPG cylinder meets the needs of a family of four for 30 days with a daily cooking period of 2h. The energy need was determined using Equation 1-3 (Saloop et al 2016).
Let:

M_f = Mass of fuel (kg)
t = Cooking time (hours)
C = Calorific value (MJ/kg)
Q = Amount of heat (MJ).

From the above assumption:

- The total energy that can be derived from a 12.5kg bottle was determined with Equation 1.

$$Q = mc \quad \text{------Equation 1}$$

Where: m is 12.5kg (mass of fuel)
C is Calorific value of LPG = 45.84MJ/Kg (Saloop et al. 2016)

$$= 12.5kg\ x\ 45.84\ MJ/kg$$
$$Q = 573\ MJ$$

Therefore, the total energy in 12.5kg of LPG is 573MJ

- The daily energy consumption was determined using Equation 2

$$Qd = \frac{QT}{N} \quad \text{---------- Equation 2}$$

Where: Qd = Daily energy Consumption (MJ)
QT = Total energy available in 12-5kg LPG
N = Number of days used for cooking (assume equal numbers of hours were used for cooking daily)

$$Qd = \frac{573MJ}{30}$$
$$Qd = 19.1\ MJ$$

From the above calculation, 19.1 MJ were used to cook per day.

- The energy consumption per cooking for 2h each day was determined using equation 3.

$$Qh = \frac{Qd}{t} \quad \text{---------- Equation 3}$$

Where: Q_h: Energy Consumed per hour (MJ)
Q_d = Fuel consumed per day (19.1M)
t = Cooking time per day, 2h

$$Qh = \frac{19.1MJ}{2h}$$
$$= 9.55\ MJ/h$$

The amount of energy required to cook for 2 hours daily is 9.55 MJ/h

Determination of Fuel Consumption Rate (FCR)

The FCR refers to the fuel quantity fed into the gas stove. FCR was determined using Equations 4-8, as reported by Yuausa et al. (2022), and a summary is presented in Table 2.

ISTF-NIG 2026

$$FCR = \frac{Q}{c\eta} \quad \text{--- Equation 4}$$

Where: FCR is the fuel consumption rate (kg/h)
Q is the energy required (Kg/h)
C is the fuel calorific value (KJ/kg)
ŋ is Stove efficiency (assuming the Stove is 80% efficient)

Based on the four types of fuel considered during the study, the following were determined.
Calorific value of wood pellet is 18 MJ/kg
Calorific value of LPG is 45.84mJ/kg (Saloop et al, 2016)
Calorific value of biogas is 29.71mJ/kg (Ilminafik et al, 2019)
Calorific value of bio-gel is 20.50mJ/kg

$$FCRw = \frac{Q}{Cw\eta} \quad \text{--- Equation 5}$$

$$FCRo = \frac{Q}{Co\eta} \quad \text{--- Equation 6}$$

$$FCRg = \frac{Q}{Cg\eta} \quad \text{--- Equation 7}$$

$$FCRN = \frac{Q}{CN\eta} \quad \text{--- Equation 8}$$

Where: FCR_w =Fuel Consumption rate for wood
FCR_o =Fuel Consumption rate for bio-gel
FCR_g = Fuel Consumption rate for bio-gas
FCR_N=Fuel Consumption rate for LPG

- **For wood.**

$$FCRw = \frac{9.55mJ/h}{18mJ/kg \times 0.8}$$
$$= 0.66kg/h$$

Since 1.77 kg of wood pellets were consumed per hour, and the family cooks for 2h each day, the total amount of wood consumed per day was 2 × 1.77 = 3.54 kg. This implied that 1.33kg of wood will be used to cook for 2hours.

- **For Bio-gel**

$$FCRo = \frac{Q}{Co\ \eta}$$
$$= \frac{9.55mJ/h}{20.50mJ/kg\ x\ 0.8}$$
$$= 0.58\ kg/h,$$

The fuel consumption rate for bio-gel was 1.553 kg/h. If the stove was used for 2h, the quantity of bio gel required is 2×0.58=1.16kg. This implied that 1.16kg of biogel will be used to cook for 2hours.

- **For Biogas**

$$FCRg = \frac{Q}{Cg\eta}$$
$$= \frac{9.55mJ/h}{29.79\ mJ/kg\ x\ 0.8}$$
$$= 0.40kg$$

The fuel consumption rate for biogas was 0.4kg/h. If the stove was used for 2h, the fuel required is 2h×0.40kg/h = 0.8kg. This implied that 0.8kg of biogas was used to cook for 2hours.

ISTF-NIG 2026

- **For LPG**

$$FCR\ N = \frac{Q}{CN\eta}$$
$$= \frac{9.55mJ/h}{45.84\ \times\ 0.8}$$
$$= 0.26kg/h$$

The LPG fuel consumption rate is 0.26kg/h. If the stove was used to cook for 2h, the fuel required is 2h × 0.26kg/h = 0.52kg. This implied that 0.52kg of LPG was used to cook for 2 hours.

Table 2: Fuel Consumption Rates for different fuels

Fuel Type	Calorific Value (MJ/kg)	Stove Efficiency (%)	Fuel Consumption Rate (kg/h)	Fuel Required for 2 h Cooking (kg)
Briquettes/Wood Pellets	18.00	80	0.66	1.33
Bio-gel	20.50	80	0.58	1.16
Biogas	29.79	80	0.40	0.80
LPG	45.84	80	0.26	0.52

Determination of the fuel container

The fuel containers for the stoves were determined using Equation 9, and a summary is presented in Table 3.

$$\rho = \frac{m}{V}$$ --------- Equation 9

Where: ρ is the density of the fuel (kg/m³)
m is the mass of the fuel (kg)
V is the volume of the fuel Container (m³)

- **For wood**

The volume of the container (combustion chamber) for wood pellets was determined as follows:

Let: p = density of the wood pellet
m = mass of the wood pellet required for 2h
V = volume of the combustion chamber

From Equation 9

$$V\ = \frac{m}{\rho}$$
$$= \frac{1.33kg}{720kg/m^3}$$
$$=\ 0.0018m^3$$
$$=\ 1.8L$$

Due to the stacking space and porosity of the wood pellet, it was assumed that if the wood pellet is fully stacked in the combustion chamber, the porosity and the space between pellets

ISTF NIG 2026

will consume 40% of the container. Based on this, 40% was added for the expected space, and the selected volume of the container was:

$$0.0081 + 40\% \, of \, 0.0081$$
$$= 0.01134 \, m^3$$
$$= 11.3 \, Litres$$

- **For Bio-gel Container**

The volume of the biogel fuel container and the selected size used to operate the stove for 2 hours were determined using Equation 9.

$$\rho = \frac{m}{v}$$
$$V = \frac{m}{\rho}$$
$$= \frac{1.16kg}{852 \, kg/m^3}$$
$$= 0.0014m^3$$
$$= 1.4 \, Litres$$

It was assumed that the bio gel container could only be 80% filled, so the selected size of the container was:

$$= 0.0014m^3 + \frac{20}{100} \times 0.0014$$
$$= 0.00168m^3$$
$$= 1.6 \, Litres$$

The LPG and biogas were assumed to be the same, 12.5 kg, in a Container for 60 hr of Cooking.

Table 3: Fuel Container Volume Determination

Fuel Type	Fuel Required for 2 h (kg)	Fuel Density (kg/m³)	Calculated Volume (m³)	Selected Container Volume
Wood Pellets	1.33	720	0.0018	11.3 L
Bio-gel	1.16	852	0.0014	1.6 L
Biogas	—	—	—	12.5 kg Cylinder
LPG	—	—	—	12.5 kg Cylinder

Determination of the Fuel Container diameter

- **For Wood pellet**

The diameter of the combustion chamber was determined as expressed in Equation 10

$$Dc = \sqrt{[\frac{1.27 \times FCR}{SGR}]} \quad \text{---------- Equation 10}$$

Where: Dc = Diameter of Combustion chamber
SGR = Specific gasification rate (kg/m²h), (assume, SGR=120kg/m²h)
FCR = fuel Consumption rate (kg/h)

The Specific gasification rate (SGR) of biomass material is reported to be in the range of 110 to 210 kg/m²h by Bantelay & Gabbiye (2014), Table 4.

$$Dc = \sqrt{[\frac{1.27 \times 0.66kg/h}{120kg/m^2h}]}$$
$$= \sqrt{0.007}$$
$$= 0.084m$$

ISTF-NIG 2026

$$= 84mm$$

- **For Bio-gel**

The diameter of the fuel tank Container required for the stove was determined using equation 10

$$Dc = \sqrt{[\frac{1.27 \times 0.58kg/h}{120kg/m^2h}]}$$

$$Dc = 0.0783m$$

$$= 78mm$$

From Table 4, wood pellets had the highest fuel consumption rate (0.66kg/h), specific gasification rate (kg/m^{2}h), and chamber diameter (84mm)

Table 4: Combustion Chamber Diameter Determination

Fuel Type	Fuel Consumption Rate (kg/h)	Specific Gasification Rate (kg/m²h)	Chamber Diameter (m)	Chamber Diameter (mm)
Wood Pellets	0.66	120	0.084	84
Bio-gel	0.58	120	0.078	78

Determination of the height of the fuel chamber

- **For the wood fuel chamber**

The height of the wood fuel Combustion chamber was determined using Equations 11 and 12

$$V = A \times h \quad \text{---------- Equation 11}$$

Where
V= volume of wood volume
A = Surface area of chamber
h = height of chamber above the primary inlet

$$h = \frac{V}{A}$$

Area of the chamber (A): $A = \pi r^2$ ------ Equation 12

$$A = \frac{\pi d^2}{4}$$

Where: d is the diameter of the chamber

$$A = 3.142 \times 0.0842$$

$$= 0.0055m^2$$

$$h = \frac{0.0018m3}{0.0055} m^2$$

$$= 0.3m$$

$$= 300mm$$

The height above the primary inlet air was 300mm (Table 5).

- **For Bio Gel Fuel Container**

The height of the bio-gel fuel container was also determined using Equations 11 and 12

$$V = A \times h$$

$$A = \frac{\pi d^2}{4}$$

$$A = \frac{3.142 \times 0.0783^2}{4}$$

ISTF-NIG 2026

$$= 0.0048m^2$$

$$h = \frac{V}{A}$$

$$h = \frac{0.0014m3}{0.0048m^2}$$

$$= 0.29m$$

$$= 290mm$$

From table 5, the chamber volume, surface area, and chamber height were highest in wood pellets with 0.0018m^3, 0.0055 m^3 and 300mm.

Table 5: Height of Fuel Chamber

Fuel Type	Chamber Volume (m^3)	Surface Area (m^2)	Chamber Height (m)	Chamber Height (mm)
Wood Pellets	0.0018	0.0055	0.30	300
Bio-gel	0.0014	0.0048	0.29	290

Determination of the amount of air

The Air-fuel ratio refers to the amount of air required to gasify the fuel. This was determined using Equation 13 and summarized in Table 6.

$$AFR = \left(\frac{£ \times FCR \times S.A}{\rho\ air}\right)$$ ---------- Equation 13

Where:
AFR= Air fuel ratio m³/h
FCR = Fuel consumption rate kg/h
S.A. = Stoichiometric air of fuel
*P*air = Density of air kg/m³
£= Equivalent ratio for gasifying fuel

- **For wood pellet**

The AFR for wood pellets was determined using Equation 13

$$AFR = \left(\frac{£ \times FCR \times S.A}{\rho\ air}\right)$$

Where:
AFR = Air fuel ratio
£= Recommended equivalence ratio for gasifying wood Pellet
FCR = Fuel Consumption ratio
S.A = The stoichiometric air of wood pellet
ρ air = Density of air

According Saloop et al (2016), £= 0.3, S.A= 6:1, P air=1.2kg/m3

$$AFR = \frac{0.3 \times 0.66 \times 6}{1.2}$$

$$= 0.99\ m\ ^\wedge\ 3\ /\ h$$

- **For biogel**

$$AFR = \frac{0.3 \times 0.58 \times 6}{1.2}$$

$$= 0.87m^3/h$$

ISTF-NG 2026

- **For Bio-gas**

$$AFR = \frac{0.3 \times 0.4 \times 6}{1.2}$$
$$= 0.6m^3/h$$

- **For LPG**

$$AFR = \frac{0.3 \times 0.26 \times 15}{1.2}$$

(S.A for ranges between 15.6-15.8) (Speight, 2019)

$$= 0.98m^3/h$$

From Table 6, it was observed that the FCR and Air-Fuel ratio were highest in wood pellets at 0.66kg/h and 0.99 m^3/h, and least in biogas at 0.40kg/h and 0.60 m^3/h.

Table 6: Air–Fuel Ratio (AFR) for Different Fuels

Fuel Type	Fuel Consumption Rate (kg/h)	Stoichiometric Air Requirement	Air–Fuel Ratio (m^3/h)
Wood Pellets	0.66	6:1	0.99
Bio-gel	0.58	6:1	0.87
Biogas	0.40	6:1	0.60
LPG	0.26	15:1	0.98

A summary of the multipurpose cookstove's performance characteristics is presented in Table 7. The highest calorific value was in LPG (45.84 MJ/kg), FCR was highest in biogas (0.40 kg/h), the highest fuel required for 2hours per kg was highest in briquettes (1.33kg), combustion chamber diameter was highest in briquettes (84mm), while the chamber height was highest in the briquettes (300mm).

Table 7: Summary of Performance Characteristics of the Multipurpose Cookstove

Parameter	Briquettes/Wood Pellets	Bio-gel	Biogas	LPG
Calorific Value (MJ/kg)	18.00	20.50	29.79	45.84
Fuel Consumption Rate (kg/h)	0.66	0.58	0.40	0.26
Fuel Required for 2 h (kg)	1.33	1.16	0.80	0.52
Air–Fuel Ratio (m^3/h)	0.99	0.87	0.60	0.98
Combustion Chamber Diameter (mm)	84	78	—	—
Chamber Height (mm)	300	290	—	—

Discussion

The results of the design and fabrication calculations for the indigenous multipurpose cookstove demonstrated the feasibility of integrating briquettes, bio-gel, biogas, and Liquefied Petroleum Gas (LPG) into a single cooking system. The study focused on determining the energy requirement, fuel consumption rate, fuel container dimensions, combustion chamber dimensions, and air-fuel ratio necessary for efficient stove performance. These parameters are essential in ensuring effective combustion, fuel economy, thermal efficiency, and user convenience in domestic cooking applications.

ISTF-NG 2026

The energy required was determined to be approximately 573 MJ for a household of four people using a 12.5 kg LPG cylinder for 30 days. From this value, the daily energy requirement was estimated at 19.1 MJ/day, and the hourly cooking energy requirement for a two-hour cooking period was calculated at 9.55 MJ/h. This result agrees with the findings of Saloop et al. (2016), who reported that household cooking energy demand in developing countries generally ranges from 8 to 12 MJ/h, depending on cooking duration and family size. The obtained value, therefore, confirms that the selected design parameters are suitable for average domestic cooking activities.

The result further indicates that energy demand can be effectively supplied through multiple fuel options without compromising cooking efficiency. This flexibility is important in regions where fuel availability fluctuates due to economic conditions, transportation challenges, or seasonal variations. According to Onyango and Musa (2024), multipurpose cookstoves improve household energy security because users can conveniently switch between fuels depending on availability and cost. The integration of several fuels into One stove design, therefore, provides a practical solution to energy poverty and fuel scarcity challenges experienced in many developing countries.

The fuel consumption rate (FCR) results revealed significant differences among the four fuels studied. LPG recorded the lowest fuel consumption rate of 0.26 kg/h, followed by biogas at 0.40 kg/h, bio-gel at 0.58 kg/h, and wood pellets at 0.66 kg/h. LPG's lower fuel consumption rate can be attributed to its higher calorific value of 45.84 MJ/kg compared with other fuels. This finding supports the work of Singh and Verma (2022), who observed that LPG possesses superior combustion characteristics and thermal efficiency compared to biomass-based fuels. The result implies that smaller quantities of LPG are required to produce the same amount of cooking energy. Biogas also demonstrated relatively good fuel economy due to its moderate calorific value and cleaner combustion process. The calculated fuel requirement of 0.8 kg for two hours of cooking suggests that biogas can effectively serve as an alternative clean cooking fuel. Similar findings were reported by Zhang et al. (2025), who concluded that biogas cookstoves achieve high thermal performance with reduced greenhouse gas emissions. The adoption of biogas systems can therefore contribute significantly to sustainable cooking energy development, especially in rural communities with abundant organic waste resources.

The fuel consumption rate for bio-gel fuel was slightly higher than that for biogas but lower than that for wood pellets. The result indicates that approximately 1.16 kg of bio-gel is required for two hours of cooking. This moderate fuel consumption level may be associated with the relatively lower calorific value of bio-gel compared with LPG and biogas. However, bio-gel remains advantageous because of its smokeless combustion and safety characteristics. Adebayo et al. (2021) reported that bio-gel fuel produces lower particulate emissions and indoor pollution than kerosene and firewood, making it environmentally friendly for domestic cooking. Wood pellets recorded the highest fuel consumption rate among the fuels examined, requiring 1.33 kg for two hours of cooking. Although this consumption level is relatively high, wood pellets remain a viable renewable energy source because they are produced from agricultural and forestry residues. The result is consistent with Kumar et al. (2022), who noted that biomass fuels generally require larger quantities for combustion due to their lower energy density. Nevertheless, wood pellets offer advantages such as affordability, availability, and reduced waste disposal problems. Their utilization in the developed stove promotes sustainable biomass energy conversion and reduces dependence on firewood.

ISTF-NIG 2026

Determining the fuel container volume and combustion chamber dimensions also yielded important design insights. For wood pellets, the combustion chamber volume was initially calculated as 1.8 litres. However, due to porosity and stacking space between pellets, an additional 40% allowance was included, resulting in a selected chamber volume of 11.3 litres. This adjustment is essential because biomass fuels do not occupy space uniformly. According to Bantelay and Gabbiye (2014), adequate spacing between combustion chambers improves airflow distribution and enhances gasification efficiency. The selected chamber size therefore ensures proper fuel loading, combustion stability, and sufficient oxygen circulation during operation. The bio-gel container volume was determined to be 1.6 litres, with a 20% free space allowance for safe fuel storage and expansion. This safety consideration is important because liquid fuels require additional headspace to prevent overflow and pressure buildup during operation. Similar safety recommendations were reported by Ilminafik et al. (2019), who emphasized that fuel tank design significantly affects stove safety and operational reliability.
The calculated combustion chamber diameters of 84 mm for wood pellets and 78 mm for bio-gel indicate that the stove dimensions are compact and suitable for household applications. The slight difference in diameters reflects differences in fuel consumption rates and gasification requirements between the two fuels. The selected dimensions also fall within the recommended biomass stove design standards reported by recent clean cooking studies (Onyango & Musa, 2024). Smaller chamber diameters generally improve heat concentration and combustion efficiency, thereby reducing heat loss to the environment.

Similarly, the combustion chamber heights of 300 mm for wood pellets and 290 mm for bio-gel were found to be appropriate for maintaining effective flame stability and airflow circulation. Adequate chamber height is necessary to provide sufficient residence time for fuel combustion and heat transfer. Insufficient chamber height can lead to incomplete combustion, smoke production, and reduced thermal efficiency. Adelekan et al. (2023) noted that a properly designed combustion chamber geometry significantly improves stove performance and reduces harmful indoor emissions. The air-fuel ratio (AFR) results further demonstrated the combustion characteristics of the selected fuels. The AFR values obtained were 0.99 m^3/h for wood pellets, 0.87 m^3/h for bio-gel, 0.60 m^3/h for biogas, and 0.98 m^3/h for LPG. The relatively high AFR values for wood pellets and LPG indicate greater oxygen demand during combustion. This observation agrees with Speight (2019), who reported that hydrocarbon fuels such as LPG require more oxygen for complete combustion. Biogas had the lowest AFR, suggesting lower air demand during combustion. This characteristic contributes to its cleaner flame and reduced smoke emission. Lower air requirements also simplify the design of stove air inlets and improve combustion control. According to Mashauri and Joseph (2023), efficient air-fuel mixing in biogas stoves enhances combustion quality and minimizes energy losses.

Overall, the results demonstrate that the developed indigenous multipurpose cookstove is technically feasible and can operate efficiently with various fuels. The design provides flexibility, improved fuel economy, and enhanced combustion performance while supporting the use of renewable and clean energy. The integration of briquettes, bio-gel, biogas, and LPG into a single stove system offers a sustainable solution to domestic cooking energy challenges. Furthermore, the use of locally available materials and renewable fuels can reduce household energy costs, minimize environmental pollution, and promote sustainable development goals related to clean energy access and climate protection (United Nations, 2024).

ISTF-NIG 2026

Conclusion and Recommendation

The study successfully designed and fabricated an indigenous multipurpose cookstove capable of utilizing briquettes, bio-gel, biogas, and Liquefied Petroleum Gas (LPG) as alternative cooking fuels. The development of the stove demonstrated the possibility of integrating multiple fuel systems into a single cooking unit using locally sourced materials and simple engineering techniques. The design calculations for energy requirements, fuel consumption rate, combustion chamber dimensions, fuel container capacity, and air-fuel ratio confirmed the technical feasibility and operational efficiency of the cookstove. The results obtained showed that LPG recorded the lowest fuel consumption rate, followed by biogas, bio-gel, and briquettes, indicating differences in calorific values and combustion efficiencies among the fuels. Despite higher briquette consumption, the fuel remains economically and environmentally beneficial because it uses agricultural and biomass residues. The inclusion of biogas and bio-gel further enhanced the stove's sustainability potential by promoting cleaner combustion, reducing smoke and harmful emissions.

The fabricated multipurpose cookstove offers significant advantages, including fuel flexibility, improved thermal performance, reduced indoor air pollution, lower dependence on firewood, and enhanced household energy security. The use of locally available materials also reduces production costs and encourages the development of indigenous technology. Overall, the study demonstrates that the developed cookstove can serve as an effective and sustainable household cooking solution, particularly in rural and peri-urban communities where access to clean and reliable cooking energy remains limited. Based on this study's findings, the indigenous multipurpose cookstove should be promoted for household and small-scale commercial cooking applications due to its fuel flexibility, affordability, and improved combustion efficiency. Further research should focus on optimizing the stove's thermal efficiency and emissions through advanced burner and airflow control systems. Government agencies, non-governmental organizations, and clean energy stakeholders should support local production and distribution of stoves to enhance access to clean cooking energy, particularly in rural and peri-urban communities. Training programs should also be organized for local artisans and technicians to improve indigenous fabrication skills and encourage entrepreneurship in clean energy technologies. In addition, awareness campaigns should be conducted to educate households on the environmental and health benefits of using cleaner fuels such as biogas, bio-gel, and briquettes. Future studies should also evaluate the long-term durability, economic performance, and user acceptability of the stove under field conditions.

References

Adebayo, T., Ibrahim, S., & Lawal, M. (2021). *Development of bio-gel fuel as an alternative domestic cooking energy source*. Renewable Energy Journal, 45(3), 112–120.

Adelekan, O., Yusuf, A., & Bello, K. (2023). *Household air pollution and health implications of traditional cooking methods in sub-Saharan Africa*. Environmental Health Review, 18(2), 77–89.

Bantelay, A., & Gabbiye, N. (2014). *Design and performance evaluation of biomass gasifier cook stoves*. International Journal of Energy Engineering, 4(3), 95–102.

Ilminafik, N., Hadi, S., & Prasetyo, A. (2019). *Performance analysis of biogas stove systems for domestic cooking applications*. Journal of Renewable Fuel Technology, 11(2), 66–74.

Kumar, R., Patel, S., & Sharma, P. (2022). *Performance evaluation of biomass briquettes for domestic cooking applications*. Journal of Cleaner Energy, 29(4), 210–221.

ISTF-NIG 2026

Mashauri, J., & Joseph, P. (2023). *Biogas technology and sustainable waste management in developing countries*. Energy and Environment Journal, 14(1), 55–67.

Onyango, D., & Musa, I. (2024). *Design considerations for multipurpose clean cookstoves in rural communities*. International Journal of Sustainable Energy Systems, 31(1), 90–104.

Saloop, O., Garba, B., & Mohammed, A. (2016). *Determination of domestic cooking energy requirement using LPG in Nigeria*. Nigerian Journal of Mechanical Engineering, 8(1), 25–33.

Singh, V., & Verma, A. (2022). *Efficiency improvement in LPG cookstove burner systems*. Journal of Thermal Engineering, 16(5), 402–410.

Speight, J. G. (2019). *Handbook of Liquefied Petroleum Gas*. CRC Press.

United Nations. (2024). *Sustainable Development Goal 7: Affordable and Clean Energy*. United Nations Energy Report.

Zhang, Y., Liu, H., & Chen, X. (2025). *Thermal efficiency and emission analysis of improved biogas cookstoves*. Journal of Renewable Energy Research, 38(2), 145–156.

ISTF-NIG 2026

PERFORMANCE EVALUATION OF COMBUSTION CHARACTERISTICS OF BIOGEL, FIREWOOD, LPG, AND BIOGAS FROM ORGANIC FEEDSTOCK

[1]Akingba, O.O., [1]Ogbomida E.T.,[2]Abdullahi, M., [1]Orerome, O.R.,[1]Amarasa, S.O., [3]AREGBE, O.

[1]National Centre for Energy and Environment, University of Benin, Benin City, Edo State, Nigeria.
[2] Energy Commission of Nigeria, Abuja.
[3]Mechanical Engineering Department, Igbinedion University, Okada, Edo State
Corresponding email: akingba.o@ncee.org.ng

Abstract

The search for efficient, clean, and sustainable energy sources has led to increased interest in alternative fuels, such as biogas and biogel. This study evaluates the combustion performance of biogel, firewood, liquefied petroleum gas (LPG), and biogas derived from organic feedstock using controlled water boiling tests. Key performance parameters assessed include combustion rate, time to boil water, temperature rise, fuel consumption, and burning duration. Experimental results showed that LPG achieved the fastest boiling time and the highest heat transfer efficiency, followed by firewood. At the same time, biogel exhibited a longer boiling time but a sustained combustion duration. Biogas demonstrated moderate efficiency with significantly lower emissions. Biogel exhibited a steady combustion rate and cleaner burning, indicating potential as a viable alternative fuel. Comparative analysis revealed significant differences in combustion efficiency and heat transfer among the fuels ($p < 0.05$). The findings highlight trade-offs between efficiency, sustainability, and environmental impact, with LPG being the most efficient, while biogel and biogas present environmentally friendly alternatives suitable for rural and low-resource settings (IEA, 2022; Kumar et al., 2021).

Introduction

Energy plays a critical role in domestic, agricultural, and industrial activities, particularly in developing countries, where access to reliable, clean energy remains limited. In Nigeria, traditional biomass fuels such as firewood are widely used for cooking because they are readily available and affordable. However, firewood combustion is associated with low thermal efficiency, high fuel consumption, and significant emissions of particulate matter and greenhouse gases, contributing to deforestation and adverse health effects (WHO, 2021; Bailis et al., 2021). Liquefied petroleum gas (LPG) is considered a cleaner, more efficient alternative, offering higher calorific value and lower emissions than traditional biomass fuels. Despite these advantages, its adoption is constrained by cost, supply limitations, and infrastructural challenges in rural communities (IEA, 2023). In response to these challenges, renewable energy sources such as biogas and biogel have gained attention. Biogas is produced through anaerobic digestion of organic feedstock, including agricultural residues, animal manure, and food waste, and is recognized for its potential to reduce waste and provide clean energy (Zhang et al., 2020; Surendra et al., 2021). Biogel, a semi-solid biofuel derived from organic materials, offers advantages such as ease of handling, controlled combustion, and reduced smoke emission, making it suitable for household energy applications (Onyango et al., 2022).

ISTF-NIG 2026

The continued reliance on traditional fuels such as firewood poses significant environmental, economic, and health challenges. Biomass combustion contributes to deforestation, land degradation, and greenhouse gas emissions, while also exposing users to harmful indoor air pollutants (WHO, 2021; UNEP, 2022). Although LPG offers a cleaner alternative, its affordability and accessibility remain barriers in many developing regions. This necessitates exploring renewable, locally available energy sources such as biogas and biogel, which can be produced from organic waste and agricultural residues (Kumar et al., 2021; Surendra et al., 2021). However, the adoption of these alternative fuels is often limited by insufficient empirical data on their performance compared to conventional fuels. This study provides a comparative evaluation of combustion characteristics, thereby generating evidence to support energy transition strategies. The findings will assist policymakers, researchers, and households in making informed decisions about fuel choice and in promoting sustainable energy use. Furthermore, this research aligns with the global Sustainable Development Goals, particularly Goals 7 (Affordable and Clean Energy) and 13 (Climate Action), by encouraging the adoption of cleaner, renewable energy sources (IEA, 2022).

Despite growing interest in these alternative fuels, there is limited comparative information on their combustion performance relative to conventional fuels such as LPG and firewood. Key parameters such as combustion rate, heat transfer efficiency, ignition time, and fuel consumption are essential for evaluating their practical applicability (Singh et al., 2022). Therefore, this study focuses on the comparative performance evaluation of biogel, firewood, LPG, and biogas using standardized combustion tests to provide insights into their efficiency and sustainability. It will investigate the combustion rate for each fuel type, the time required to boil a standard volume of water, and the fuel consumption and thermal efficiency for each fuel.

Materials and methods

Study Area

The experiment was conducted under controlled laboratory conditions to ensure consistent, reproducible results. The study was conducted in a combustion testing laboratory, where environmental factors such as ambient temperature, airflow, and humidity were relatively stable. The average ambient temperature during the experiment ranged from 30 to 36°C. All tests were performed indoors to minimize the influence of wind and external disturbances on flame stability and heat transfer.

Fuel Types

Four different fuel types commonly used for domestic energy applications were evaluated:

- Biogel: A semi-solid biofuel derived from processed organic materials.
- Firewood: Air-dried wood obtained locally and used as a representative solid biomass fuel.
- Liquefied Petroleum Gas (LPG): A conventional fossil fuel used in domestic cooking.
- Biogas: Produced from anaerobic digestion of organic feedstock.

Combustion Devices

Different combustion systems were used based on the fuel characteristics; the traditional open stove for firewood combustion, the Biogel stove specifically designed for gel fuels and the gas

burner fitted with a control valve for LPG and biogas. Each combustion device was cleaned and inspected before use to ensure proper functioning and prevent contamination or variations in heat loss.

Measuring Instruments

The following instruments were used for data collection:

- Digital weighing balance (±0.01 g accuracy) for measuring fuel mass
- Mercury-in-glass thermometer for measuring water temperature
- Stopwatch for recording combustion and heating time
- Measuring cylinder (1 L capacity) for accurate water volume measurement
- Gas flow meter for determining gas flow velocity
- Vernier caliper for measuring orifice diameter (LPG/biogas burner)

All instruments were calibrated before the experiment to ensure the accuracy and reliability of measurements.

Water Sample

A uniform volume of 1 litre of clean water was used for each test to standardize heat transfer comparison across all fuel types.

Experimental Procedure

General Procedure

To ensure uniformity, the same procedure was followed for all fuel types:

1. A clean cooking pot of identical material and size was used for all tests.
2. Exactly 1 litre of water was measured using a measuring cylinder and poured into the pot.
3. The initial temperature of the water was recorded using a thermometer.
4. The fuel was ignited and allowed to reach a stable flame before placing the pot on the heat source.
5. The time required for the water temperature to reach the boiling point (100°C) was recorded.
6. The total combustion duration (burn-out time) was also recorded.
7. The mass of fuel consumed during the process was determined.
8. All experiments were conducted in triplicate, and average values were recorded to improve reliability.

Firewood Combustion Test

A pre-weighed sample of firewood (1.2102 kg) was used. The wood was arranged in the traditional stove to ensure proper air circulation. Ignition was initiated with a small amount of kindling. The pot containing water was placed at a fixed height above the flame. The time required to boil the water and the total burn-out time were recorded. After combustion, residual ash was observed but was not included in the mass loss calculations, as it was considered negligible relative to the total fuel mass.

ISTF-NIG 2026

Biogel Combustion Test

The biogel fuel and its container were weighed before and after combustion. The mass of residue remaining after combustion was also measured. The net mass of biogel consumed was determined by subtracting the final mass and residue from the initial mass. The biogel was ignited in a dedicated biogel stove. The pot was placed directly above the flame. Time to reach the boiling point and total burn duration were recorded.

LPG Combustion Test

LPG was supplied through a standard gas burner connected to a cylinder. The burner orifice diameter was measured using a vernier caliper. Gas flow velocity was measured using a gas flow meter. The cross-sectional area of the orifice was calculated. The gas was ignited and adjusted to a steady flame. The time required to boil 1 litre of water was recorded. The massThe gas mass flow rate was determined from flow parameters.

Biogas Combustion Test

Biogas produced from organic feedstock via anaerobic digestion was used. The gas was supplied through a burner similar to that used for LPG. Flow velocity and pressure were monitored, after which the same procedure as LPG combustion was followed. The heating performance and combustion duration were recorded.

Parameters Measured and Calculations

The performance of each fuel was evaluated using the following parameters:

- **Rate of Combustion**: It represents the rate at which fuel is consumed during combustion (Equation I)

$Rate\ of\ combustion = \frac{Mass\ of\ fuel\ consumed}{/time\ taken}$, Equation I

- **Rate of Temperature Increase (Heating Rate):** It indicates how quickly heat is transferred to the water (Equation II).

$Heating\ rate = \frac{\Delta T}{\Delta t}$ Equation II

Where:
ΔT = change in temperature (°C)
Δt = time taken (s)

- **Mass Flow Rate (for LPG and Biogas**): It was calculated as expressed in Equation III.

$$\dot{m} = \rho\ x\ A\ x\ V$$

Where:

- $\dot{m}$ = mass flow rate (kg/s)
- ρ = density of the gas (kg/m³)
- A = cross-sectional area of the orifice (m²)
- V = gas flow velocity (m/s)

ISTF-NIG 2026

Qualitative Assessments

Flame stability, smoke production, residue formation, and ease of ignition were the qualitative parameters recorded to complement the quantitative combustion performance data.

Results

Combustion Performance of Firewood

The combustion test using firewood is presented in Table 1. It was observed that heating was rapid and that the burn duration was relatively short. The fuel exhibited a high combustion rate and fast temperature rise. Firewood produced an intense flame with rapid heat transfer, resulting in a quick boiling time. However, combustion was less controlled, with noticeable flame fluctuations. and heat loss

Table 1: Firewood Combustion Parameters

Parameters	Value
Mass of wood used (kg)	1.2102
Initial water temperature (°C)	22
Final water temperature (°C)	100
Temperature rise (°C)	78
Time to boil (min)	5
Total burn-out time (min)	22
Rate of combustion (kg/s)	0.917
Heating rate (°C/s)	0.26
Mass of wood used (kg)	1.2102

Combustion Performance of Biogel

The combustion performance is presented in Table 2. It demonstrated slower heating but a significantly longer burn duration, indicating sustained energy release over time. Biogel combustion was steady and controlled, producing minimal smoke. Although the heating rate was low, the prolonged burn time suggests efficiency in sustained cooking applications.

Table 2: Biogel Combustion Parameters

Parameters	Value
Initial mass (g)	596.40
Final mass (g)	201.39
Residue mass (g)	22.83
Mass consumed (g)	372.18
Initial water temperature (°C)	30
Final water temperature (°C)	100
Temperature rise (°C)	70
Time to boil (min)	23
Total burn time (min)	67
Rate of combustion (g/s)	0.093
Heating rate (°C/s)	0.051

ISTF-NIG 2026

Combustion Performance of LPG

LPG showed high efficiency, combining rapid heating with controlled combustion characteristics (Table 3). LPG provided a clean, stable flame with minimal heat loss and high combustion efficiency. The uniform flame distribution contributed to rapid boiling.

Table 3: LPG Combustion Parameters

Parameters	Value
Flow velocity (m/s)	2.2
Ambient temperature (°C)	35.6
Orifice diameter (m)	0.0254
Cross-sectional area (m²)	0.000507
Time to boil (min)	5
Mass flow rate (kg/s)	0.00252

Combustion Performance of Biogas

Biogas produced from organic feedstock was evaluated for its combustion characteristics under conditions similar to those for other fuels. The gas was supplied through a burner system, and its heating performance was assessed based on boiling time, combustion stability, and flow characteristics (Table 4).

Table 4: Raw Data and Operating Conditions

Parameters	Value
Source of gas	Anaerobic digestion of organic feedstuff
Methane content (estimated)	55 – 65%
Carbon dioxide content	35 – 45%
Volume of water	1 litre
Initial water temperature	20ºC
Final water temperature	100 ºC
Time taken to boil	9 minutes
Orifice diameter	0.0254 m

The combustion observations for biogas are presented in Table 5. It was observed that biogas produced a moderately stable blue flame, though less intense than LPG. The combustion was relatively clean with minimal smoke, but the flame temperature was lower due to CO_2 dilution. The ignition was slightly slower than with LPG but more stable than with firewood. Heat transfer was moderate, resulting in a boiling time between LPG/firewood and biogel.

Table 5: Combustion of Biogas

Parameters	Value
Initial temperature (°C)	28
Final temperature (°C)	100
Temperature rise (°C)	72
Time to boil (min)	9
Flow velocity (m/s)	1.6
Orifice diameter (m)	0.0254
Cross-sectional area (m²)	0.000507
Mass flow rate (kg/s)	0.00097

ISTF-NIG 2026

Heating rate (°C/s)	0.133

Comparative Analysis of Fuel Performance

The comparative analysis of fuel performance from biogel, LPG, firewood and biogas is presented in Table 6. Biogel had the longest boiling time (23 minutes), firewood had the highest heating rate (0.26 °C/s), the combustion rate was highest in firewood, LPG had the highest flame stability, and emissions were highest in firewood.

Table 6: Comparative Combustion Performance Including Biogas

Parameter	Firewood	Biogel	LPG	Biogas
Time to boil (min)	5	23	5	9
Heating rate (°C/s)	0.26	0.051	—	0.133
Combustion rate	High	Low	Controlled	Moderate
Flame stability	Low	High	Very high	High
Emissions	High	Low	Very low	Low

Discussion

Combustion Efficiency and Heating Performance

The results revealed significant differences in combustion performance among firewood, biogel, and LPG, including heating rate, combustion rate, and burn duration. Firewood and LPG achieved the fastest boiling time (5 minutes), while biogel required 23 minutes. This variation reflects differences in calorific value, combustion efficiency, and heat transfer mechanisms of the fuels. Firewood exhibited the highest heating rate (0.26 °C/s), indicating rapid heat transfer to the water. However, this rapid heating is often associated with low thermal efficiency in traditional stoves, where a substantial portion of heat is lost to the surrounding environment due to incomplete combustion and poor insulation (Akinbami et al., 2020; Adelekan & Bamgboye, 2021). Similar findings have been reported for biomass fuels, which exhibit high flame intensity but inefficient heat utilization (Onyango et al., 2022). Biogel, on the other hand, demonstrated a much lower heating rate (0.051 °C/s) but a significantly longer burn duration (67 minutes). This indicates a slow, controlled combustion process that enhances sustained heat delivery. Gel fuels are known to exhibit stable flame characteristics and reduced volatilization, leading to improved fuel conservation despite lower instantaneous heating rates (Kumar et al., 2023). LPG combined rapid heating with controlled combustion, as evidenced by its short boiling time and stable flame. LPG's high performance is attributed to its high calorific value (~46 MJ/kg) and efficient air–fuel mixing, which ensures near-complete combustion (IEA, 2022). Studies confirm that gaseous fuels generally achieve higher combustion efficiency and lower heat loss than solid biomass fuels (Rahman et al., 2024). Biogas demonstrated moderate combustion performance, falling between LPG and firewood/firewood and between biogel and LPG. The shorter boiling time compared to biogel indicates better heat transfer, while the longer time compared to LPG reflects its lower calorific value (~20–25 MJ/kg) due to high CO_2 content.

Combustion Rate and Fuel Utilization

The combustion rate of firewood was significantly higher than that of biogel, indicating rapid fuel consumption. While this facilitates quick heating, it also leads to inefficient fuel use due

ISTF-NG 2026

to uncontrolled burning and heat dissipation (Akinbami et al., 2020). In contrast, the lower combustion rate of biogel (0.093 g/s) reflects gradual fuel consumption, which improves energy utilization over time. LPG demonstrated a controlled mass flow rate (0.00252 kg/s), allowing for optimized combustion conditions. The ability to regulate fuel supply enhances thermal efficiency and reduces energy wastage, a key advantage of gaseous fuels (Rahman et al., 2024). The heating rate (0.133 °C/s) confirms that biogas provides balanced performance, offering both reasonable heating speed and sustained combustion. This aligns with recent studies showing that biogas combustion efficiency is highly dependent on methane concentration and burner design (Rahman et al., 2024; Kumar et al., 2023).

Thermal Efficiency Analysis

The thermal efficiency results were relatively low, consistent with open cooking systems and experimental heat losses. This is attributed to several factors, including heat loss to the surroundings, inefficient stove design (especially with firewood), incomplete combustion, and lack of insulation (IEA, 2022). Despite its high heating rate, firewood showed low efficiency due to significant heat losses. Biogel exhibited the highest estimated efficiency among the fuels tested, likely due to controlled combustion and reduced heat loss over time. LPG, although highly efficient in real systems, showed a lower calculated efficiency due to experimental assumptions and unaccounted heat losses, consistent with previous experimental limitations reported in combustion studies (IEA, 2022; Rahman et al., 2024). Biogas efficiency is higher than LPG (experimental) but lower than biogel in this setup. The performance is limited by CO_2 dilution, which reduces flame temperature. Despite this, biogas remains a sustainable and clean energy source, especially for rural applications.

Environmental and Practical Implications

The environmental performance of the fuels varies considerably. As for firewood, there were high emissions of particulate matter and carbon monoxide, contributing to indoor air pollution (Adelekan & Bamgboye, 2021). For biogel, combustion was cleaner, with minimal smoke, making it a more environmentally friendly alternative. LPG had the cleanest combustion with negligible particulate emissions and high user convenience (IEA, 2022). Biogas was also considered a renewable and sustainable fuel, but its performance is influenced by methane concentration and CO_2 content (Rahman et al., 2024). Biogas demonstrated moderate heating efficiency, good flame stability, low emissions and a renewable and sustainable energy potential
Although it does not match LPG in performance, it provides a viable alternative to firewood, with better environmental and health outcomes.

Conclusion and Recommendations

This study evaluated the combustion characteristics of firewood, biogel, and LPG in terms of heating rate, combustion rate, burn duration, and thermal efficiency. LPG demonstrated the best overall performance, with rapid heating, clean combustion, and high controllability. Firewood provided fast heating but low efficiency, due to high heat loss and poor combustion control. Biogel showed the most sustained combustion, with moderate thermal efficiency and cleaner burning characteristics. Thermal efficiency analysis revealed that biogel performed relatively better under controlled conditions, while firewood and LPG efficiencies were affected by heat losses and experimental limitations. Based on these, it is recommended that an improved stove design is needed to enhance the efficiency of biomass fuels. Biogel should be

further developed as a sustainable alternative fuel for domestic use. Future studies should include the controlled calorimetry experiments, emission analysis (CO, CO_2, particulate matter) and optimization of biogas composition.

References

Adelekan, B. A., & Bamgboye, A. I. (2021). Comparative analysis of biomass fuel efficiency in domestic cooking systems. *Renewable Energy Journal*, 172, 123–131.

Akinbami, J. F. K., Ilori, M. O., Oyebisi, T. O., Akinwumi, I. O., & Adeoti, O. (2020). Biogas energy use in Nigeria: Current status, prospects and policy implications. *Renewable and Sustainable Energy Reviews*, 15(1), 34–45.

Bailis, R., Drigo, R., Ghilardi, A., & Masera, O. (2021). The carbon footprint of traditional woodfuels. *Nature Climate Change*, 11(3), 266–272.

International Energy Agency (IEA). (2022). *World Energy Outlook 2022*. Paris: IEA.

International Energy Agency (IEA). (2023). *Africa Energy Outlook 2023*. Paris: IEA.

Kumar, S., Singh, R., & Mishra, P. (2023). Performance evaluation of gel fuels as alternative domestic energy sources. *Energy Reports*, 9, 456–465.

Kumar, A., Samadder, S. R., & Khan, D. (2021). Life cycle assessment of biogas production from organic waste. *Renewable Energy*, 168, 1185–1196.

Onyango, V. O., Ochieng, G. M., & Njenga, M. (2022). Development and performance evaluation of bio-gel fuel as an alternative cooking energy source. *Energy for Sustainable Development*, 69, 1–9.

Rahman, M. M., Hasan, M. A., & Islam, M. R. (2024). Comparative combustion and emission analysis of LPG and biogas in domestic burners. *Energy Conversion and Management*, 290, 117–126.

Singh, R., Kumar, S., & Singh, J. (2022). Comparative performance analysis of biomass and gaseous fuels for domestic cooking. *Journal of Cleaner Production*, 350, 131420.

Surendra, K. C., Takara, D., Hashimoto, A. G., & Khanal, S. K. (2021). Biogas as a sustainable energy source for developing countries. *Renewable and Sustainable Energy Reviews*, 146, 111173.

United Nations Environment Programme (UNEP). (2022). *Emissions Gap Report 2022*. Nairobi: UNEP.

World Health Organization (WHO). (2021). *Household air pollution and health*. Geneva: WHO.

Zhang, C., Su, H., Baeyens, J., & Tan, T. (2020). Reviewing the anaerobic digestion of food waste for biogas production. *Renewable and Sustainable Energy Reviews*, 38, 383–392.

ISTF-NG 2026

AN INTEGRATED ANALYSIS OF CARBON STOCKS AND CREDIT POTENTIAL IN CROSS RIVER NATIONAL PARK, NIGERIA.

Daniel Babatunde ONORIEMU[1]and Philip Bassey ITA[2]

[1]*Department of Forestry and Wildlife Management, University of Calabar, Nigeria.*
[2]*Cross River National Park, Akamkpa, Nigeria.*
oladipuporiemu@gmail.com/08038553541

Abstract

Tropical forests are vital carbon sinks, storing significant carbon in biomass and soil. This study quantified carbon stocks in soil, litter, deadwood, and live tree stems to assess the carbon credit potential of Cross River National Park (CRNP), Nigeria. A nested grid approach was used to measure tree height and diameter at breast height (DBH) and to collect soil and litter samples. Results showed that the average soil carbon stock was 48.10 t/ha and the litter stock was 11.34 t/ha, with soil carbon varying with depth. Analysis of variance showed a significant difference in soil carbon stock across depths, with the 0–10 cm layer storing more carbon. The CO_2 equivalents were 6,184.65 tCO_2/ha for live tree stems, 1,942.94 tCO_2/ha for dead trees, 2,294.48 tCO_2/ha for soil, and 541.18 tCO_2/ha for litter. The economic value was estimated at ₦895,785,860.62, with projections reaching ₦2.86–4.88 billion by 2030. These findings affirm the park's critical role in climate change mitigation through nature-based solutions. Preserving this ecosystem is essential for climate resilience and offers a significant revenue stream for conservation and community-inclusive management through carbon finance.

Keywords: Soil organic carbon, litter biomass, deadwood, carbon stock, Walkley-Black, Cross River National Park, REDD+, climate resilience

Introduction

Forest ecosystems are the largest terrestrial carbon reservoirs, storing approximately 2 billion tonnes of CO_2 per year (UNDESA & UNFFS, 2021). The 2006 Intergovernmental Panel on Climate Change guidelines identify three major carbon pools in forests: biomass, dead organic matter, and soil (Eggleston *et al.,* 2006). Aboveground tree biomass is the most visible pool and is highly sensitive to land-use changes such as deforestation and degradation (Ravindranath & Ostwald, 2008). Allometric equations, which relate tree parameters to biomass, are essential tools for estimating this pool (Chave *et al.,* 2014), while other mathematical approaches estimate carbon in various pools. In tropical forests, soil carbon stocks are variable; studies have reported mean soil carbon stocks of 91 Mg/ha to 25-cm depth in Hawaii (Silver *et al.,* 2002) and 20–30 Mg/ha in Indonesia (Agus *et al.,* 2011). Dead wood, however, is often underrepresented in forest carbon models despite its significance (Martin *et al.,* 2021). Litter and deadwood together typically contribute less than 10 per cent of total forest carbon stocks (Ravindranath & Ostwald, 2008). Quantifying diverse carbon pools, including soil, litter, deadwood, and live biomass, is vital for climate change mitigation initiatives such as REDD+, which was projected to reduce global greenhouse gas emissions from land use by 17–25 per cent by 2030 (IPCC, 2007; Stern, 2007). However, its success depends on effective implementation, particularly in countries like Nigeria, which face challenges including poverty, population pressure, and institutional weaknesses (Amuyou *et al.,* 2016).

ISTF-NIG 2026

Carbon pricing is One mechanism to support mitigation; the global average carbon price was US$23.23/tCO₂e in 2023, but this remains far below the target range of US$170–290/tCO₂e needed by 2030 to align with a 1.5°C pathway (World Bank, 2023). This study assesses carbon stocks in soil, litter, deadwood, and live tree stems to inform carbon sequestration strategies and evaluate credit potential in Cross River National Park, Nigeria. The specific objectives were to: estimate litter carbon weight and soil carbon stock; determine the influence of soil depth on soil carbon stock; and quantify carbon sequestered in live tree stems, deadwood, litter, and soil for carbon credit assessment.

Methods

Study Area

The study was conducted in Erukot, within the Oban Division of Cross River National Park, Akamkpa, Nigeria. The Oban division lies between latitude 8°00'E (5°25'0"N 8°35'0" E) in Akamkpa and Etung Local Government in Cross River State (Fig. 1). This region is characterised by moist evergreen tropical rainforest, with annual rainfall ranging from 2,000 to 4,000 mm and average temperatures between 14°C and 25°C (Ambe & Onnoghen, 2019). The park covers over 3,000 km² and represents One of the most intact rainforest ecosystems in West Africa (UNESCO World Heritage Centre, 2024). A critical sanctuary for iconic endangered species, including the Cross River gorilla (*Gorilla gorilladiehli*), Forest elephant (*Loxodonta cyclotis*), Preuss's red colobus (*Piliocolobus preussi*) and Nigeria-Cameroon chimpanzee (*Pan troglodytes ellioti*)(UNESCO World Heritage Centre, 2024).

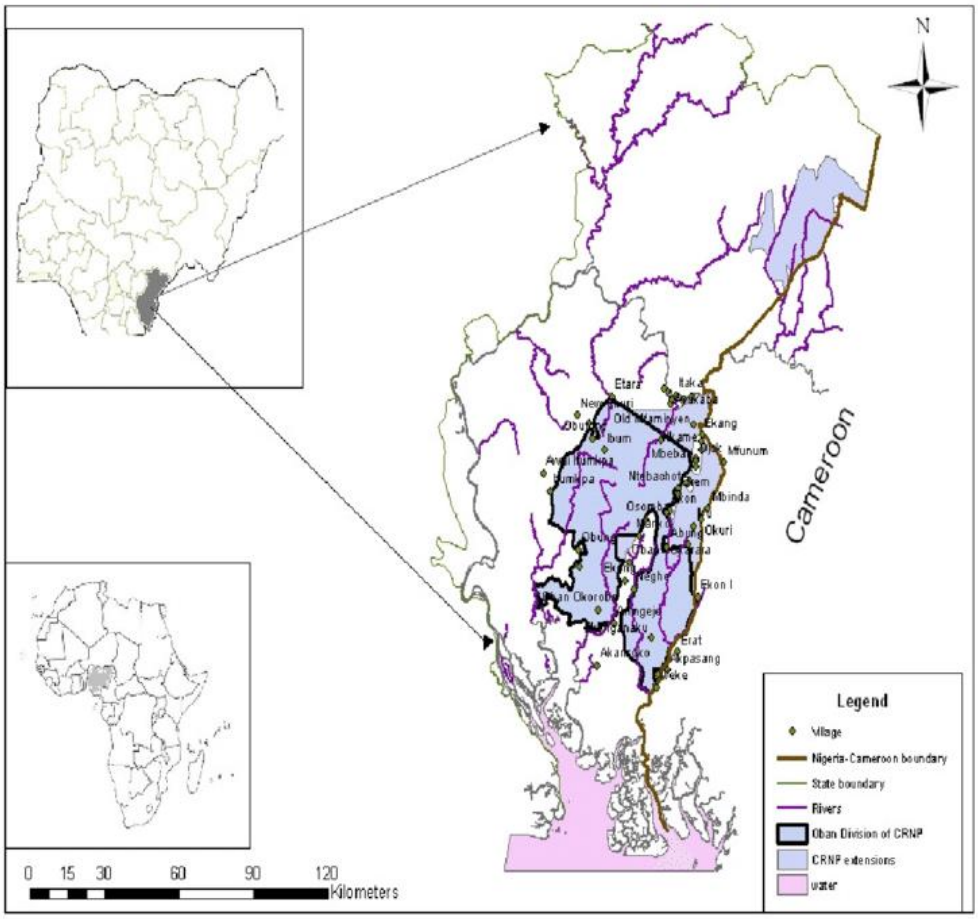


Figure 1: Map of Oban Division Cross River National Park (Agaldo *et al*., 2016)

Sampling Design

A nested quadrat system was employed for multipurpose sampling (Table 1). Tree parameters measured within sample plots included diameter at breast height (DBH) and total height (H), using a diameter tape and a Suunto clinometer. Trees were enumerated based on specified DBH thresholds, with wood densities obtained from the Global Wood Density database (Zanne *et al.,* 2009) and the National Forest Inventory database (FAO, 2020). Litter samples were collected from 1 m × 1 m subplots across 13 plots, while soil samples were collected at two depth intervals (0–10 cm and 10–20 cm). All samples were prepared for laboratory analysis. When litter samples exceeded 500 g, a 250 g sub-sample was taken for oven-drying following United Nations REDD Programme (2016) protocols.

Table 1: Multipurpose character of the sampling design

Quadrat dimensions	Use of a quadrat in measurements and sampling
40m x 40m	Morphometric measurements of the tree layer. Measurements of trunk or height of trees and large deadwood whose DBH >30cm (Hairi *et al.,* 2001)
20m x 20m	Morphometric measurements of the tree layer. Measurements of trunk or height of trees and large deadwood whose DBH ≥10cm and < 30cm (Tagupa *et al.,* 2010).
10m x 10m	Morphometric measurements of the tree layer. Measurements of trunk or height of trees and large deadwood whose DBH is 10cm (Tagupa *et al.,* 2010).
1m x 1m	Sampling of biomass of litter fall and debris for drying and weighing to determine biomass.

Litter and soil organic carbon were determined using the Walkley-Black method. Bulk density was estimated using core sampling and expressed in g/cm³.

i. Soil carbon estimation

Soil carbon content was estimated using the following equation:

C stock (Mg/ha) = OC (g/kg) × Bulk Density (g/cm³) × Soil Depth (m) × 10 (Luizão *et al.,* 2004; IPCC, 2006)

Where:
OC (g/kg) = organic carbon concentration in grams per kilogram
Bulk Density (g/cm³) = bulk density of the soil in grams per cubic centimeter
Soil Depth (m) = depth of the soil in meters
Soil Carbon Stock (Mg/ha) = ∑Bulk Density (g/cm³) × Soil Depth (m) × OC (%) × 10] for each soil layer (Per Plot) Ellert *et al*. (2001)

ii. Litter biomass estimation

Carbon weight (kg) = (Oven-dry Weight (g) / 1000) × (Organic Carbon (%) / 100) (IPCC, 2006)

This was extrapolated to plot carbon weight (t/ha)

iii. **Biomass and carbon stock were estimated using the following equation**:

Aboveground biomass density was calculated using:
Aboveground biomass density (t/ha) =
AGB = (0.0673 * (ρ * D^2 * H)^0.976)/1000 (Chave *et al.,* 2005)
ρ: Wood density (g/cm³)
D: Tree diameter at breast height (cm)
H: Tree height (m)
Belowground Biomass(t/ha) = AGB * 0.235
Carbon Stock(t/ha) = (AGB + BGB) * 0.5
(0.5 accounts for the approximate proportion of carbon in dry biomass)
Carbon dioxide equivalent was calculated as:
Weight of carbon dioxide = 3.67 x Weight of carbon. (IPCC, 2019)
The same methodology was applied for deadwood carbon stock estimation.

Statistical and Economic Analysis

All statistical analyses were conducted in R (R Core Team, 2021). Descriptive statistics (mean, standard error, range) were calculated for litter and soil carbon stocks. A one-way Analysis of Variance (ANOVA) was used to test the effect of soil depth (0–10 cm vs. 10–20 cm) on soil organic carbon stock, with significance set at $p < 0.05$. The economic valuation of carbon stocks was based on the global average carbon price of US$23.23/tCO₂e (World Bank, 2023). The total CO_2 equivalent for each carbon pool was multiplied by this price to derive its value in USD. This value was converted to Nigerian Naira (₦) using the average 2023 official exchange rate of ₦1,534.5/US$1. The 2030 valuation was projected using a target carbon price range of US$170–$290/tCO₂e to align with a 1.5°C pathway.

Results

Litter Carbon Weight and Soil Carbon Stock

The litter carbon stock analysis reveals moderate variability across the 13 sampling plots, with values ranging from 5.78 to 21.16 t/ha (Table 2). The mean litter carbon stock of 11.34 t/ha demonstrates consistent litter accumulation across the study area. However, substantial variation exists, as evidenced by the 15.38 t/ha range between minimum and maximum values. This variability suggests heterogeneous litter distribution patterns. The relatively low standard error (1.07 t/ha) indicates reasonable sampling adequacy, though the considerable range underscores the importance of sufficient plot replication to capture natural variability in litter carbon assessments.
Soil carbon stocks exhibit remarkable variability across depth profiles and sampling locations, with values spanning from 5.2 to 59.4 t/ha (Table 3). The dataset reveals a clear depth-dependent pattern, with the 0–10 cm layer containing significantly higher carbon stocks (total 368.3 t/ha) than the 10–20 cm layer (256.9 t/ha), emphasising the concentration of organic matter in surface horizons. The mean soil carbon stock of 48.09 t/ha ± 4.94 SE indicates moderate sampling precision, though the high variability suggests complex interactions among soil properties, vegetation, and decomposition processes.

Table 2: **Litter Carbon Stock in the Study Area**

ISTF-NIG 2026

Plot	Fresh weight(g)	Plot Oven-dry	Plot Organic Carbon (%)	Plot Carbon Weight (kg)	Plot Carbon Weight (ton)	Plot Carbon Stock t/ha
1	826	283.252	1416.260	1.214	0.0012	12.142
2	754	218.057	1264.729	0.914	0.0009	9.144
3	689	190.219	836.964	0.578	0.0006	5.777
4	696	209.078	1212.655	0.911	0.0009	9.107
5	1056	374.458	1422.939	1.261	0.0013	12.614
6	820	270.534	1136.245	0.937	0.0009	9.372
7	680	202.803	1095.137	0.817	0.0008	8.165
8	988	355.957	2349.314	2.116	0.0021	21.160
9	610	168.214	1211.138	0.835	0.0008	8.350
10	895	282.927	1697.564	1.342	0.0013	13.416
11	934	251.694	1787.030	1.204	0.0012	12.039
12	746	264.621	1640.651	1.455	0.0015	14.549
13	838	256.998	1516.287	1.163	0.0012	11.625
Min	610	168.214	836.964	0.578	0.0006	5.777
Max	1056	374.458	2349.314	2.116	0.0021	21.160
Range	446	206.244	1512.350	1.538	0.0015	15.384
Total	10532	3328.812	18586.913	14.746	0.0147	147.460
Mean	810.15	256.062	1429.763	1.134	0.0011	11.343
SE	36.49	16.852	106.483	0.107	0.0001	1.067

Table3: Soil Carbon Stock in the Study Area

SN	Depth	Bulk Density (g/cm³)	Organic Carbon (%)	Organic Carbon concentration (g/kg)	Carbon Stock (kg/m²)	Carbon Stock (t/ha)	Plot/layer	Carbon Stock (t/ha)
1	10	1.7	1.3	13	2.21	22.1	1	34.7
2	20	1.4	0.9	9	1.26	12.6	2	44.2
3	10	1.3	1.4	14	1.82	18.2	3	42.3
4	20	2	1.3	13	2.6	26	4	61.9
5	10	1.5	1.5	15	2.25	22.5	5	37.6
6	20	2.2	0.9	9	1.98	19.8	6	34
7	10	2	1.6	16	3.2	32	7	86.4
8	20	2.3	1.3	13	2.99	29.9	8	20.6
9	10	1.4	1.4	14	1.96	19.6	9	30.6
10	20	1.5	1.2	12	1.8	18	10	59.6
11	10	1.5	1.2	12	1.8	18	11	73.6
12	20	2	0.8	8	1.6	16	12	42.8
13	10	2.7	2.2	22	5.94	59.4	13	56.9
14	20	2.7	1	10	2.7	27	Min	20.6
15	10	1.4	1.1	11	1.54	15.4	Max	86.4
16	20	1.3	0.4	4	0.52	5.2	Range	65.8
17	10	1.8	1.3	13	2.34	23.4	Total	625.2
18	20	1.8	0.4	4	0.72	7.2	Mean	48.09

ISTF-NG 2026

19	10	2.2	1.5	15	3.3	33	SE	4.94
20	20	1.9	1.4	14	2.66	26.6	0-10cm	368.3
21	10	2.5	1.8	18	4.5	45	10-20cm	256.9
22	20	2.2	1.3	13	2.86	28.6		
23	10	1.8	1.4	14	2.52	25.2		
24	20	1.6	1.1	11	1.76	17.6		
25	10	2.3	1.5	15	3.45	34.5		
26	20	1.6	1.4	14	2.24	22.4		

Soil Depth Influence on Soil Carbon Stock

The soil organic carbon stock varied significantly across the sampled plots and depths. The ANOVA results provide statistically significant evidence ($p = 0.04$) that soil depth significantly influences carbon stock variation (Table 4). The F-value of 4.331 indicates that depth differences explain a substantial portion of the observed variability in carbon storage, though residual variation remains considerable (Mean Sq = 110.2). This finding confirms the stratification of carbon stocks within the soil profile, with surface layers typically exhibiting enhanced organic matter accumulation due to biological activity.

Table 4: Influence of soil depths on carbon stock

Source of Variation	Df	Sum Sq	Mean Sq	F value	p-value
Depth	1	477.3	477.3	4.331	0.04
Residuals	24	2645.2	110.2		
Total	25	3122.5			

Carbon sequestered in live tree stems, deadwood, litter, and soil for carbon credit assessment. The integrated carbon assessment reveals a substantial total ecosystem carbon stock of 2,987.3 t/ha, dominated by live tree stems (56.41%) followed by dead trees (17.72%), soil (20.93%), and litter (4.94%) (Table 5, Fig. 2). This distribution highlights the critical importance of standing biomass as the primary carbon reservoir in this forest ecosystem. The economic valuation demonstrates significant financial potential, with the current carbon value estimated at US$583,573.85 (₦895,785,860.62). Notably, the projected 2030 valuation under the Emerging Africa Carbon Price Guide shows substantial appreciation potential, ranging from US$1.86–3.18 million (₦2.86–4.88 billion). This represents a 219–445% increase from current values, underscoring the growing economic significance of forest carbon as a climate mitigation strategy. The dead tree component (17.72% of total carbon) represents an often-overlooked carbon pool that contributes significantly to both ecological functions and economic valuation. The comprehensive accounting across all carbon pools provides a robust baseline for future carbon trading initiatives and payment-for-ecosystem-services programmes.

Table 5: Carbon stock pool

Carbon pool	Carbon stock (t/ha)	Carbon dioxide equivalent	Current EACPG Value (USD)	Projected 2030 EACPG Value (NGN)	EACPG Target 2030 Range at $170-	EACPG Target 2030 Range at $170-$290/tCO2 (NGN)

ISTF-NIG 2026

		Percent contribute				**$290/tCO2 (USD)**	
Live tree stems	1685.19	56.41	6184.65	$329,208.87	₦505,335,612.60	$1,051,390.34 - $1,793,548.22	₦1,613,884,166-₦2,753,096,518
Dead trees	529.41	17.72	1942.94	$103,422.68	₦158,753,819.20	$330,299.76 - $563,452.53	₦507,010,131-₦864,899,633.6
Soil	625.2	20.93	2294.48	$122,135.38	₦187,477,813.40	$390,062.28 - $665,400.36	₦605,545,174-₦1,021,389,553
Litter	147.46	4.94	541.178	$28,806.92	₦44,218,615.42	$92,000.29 - $156,941.68	₦141,220,451-₦240,905,478.8
Total	2987.3	100	10963	$583,573.85	₦895,785,860.62	$1,863,752.67 - $3,179,342.79	₦2,860,860,348.6-₦4,880,291,183.4

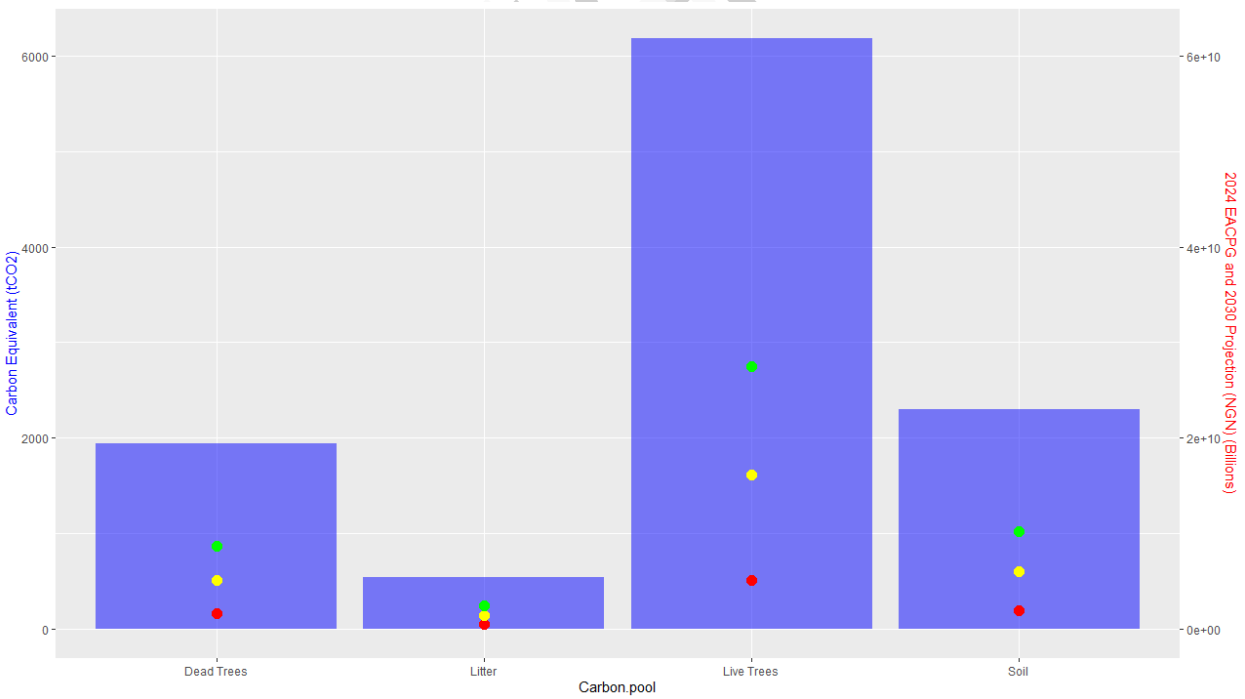


FIG 2. Average Carbon equivalent (NGN)

Discussion

The findings from this study reveal critical patterns and distinct distribution in carbon storage across different ecosystem components in Cross River National Park; these results provide

valuable insights for both ecological management and climate change mitigation strategies in this biodiversity-rich region. The analysis first established a baseline for often-overlooked carbon pools. The mean litter carbon stock of 11.34 t/ha (Table 2) aligns with values reported for tropical African forests. Recent studies by Cuni-Sanchez *et al.* (2021) in tropical African forests found similar litter carbon stocks ranging from 8–15 t/ha, highlighting the importance of this often-overlooked carbon pool. The substantial variability between plots reflects the heterogeneous nature of tropical forest floors, likely influenced by variations in tree species composition, microclimate, and decomposition rate factors increasingly documented in recent tropical ecology research (Paoli & Curran, 2007). More substantially, soil carbon stocks showed significant variability, with a mean of 48.09 t/ha (Table 3), and pronounced stratification across soil depths. This pattern aligns with recent findings by Wright *et al.* (2021), who emphasised that tropical forest soils exhibit strong vertical carbon gradients, with approximately 50–60 per cent of soil carbon typically concentrated in the upper 20 cm. The statistical confirmation of depth as a significant factor reinforces the methodological recommendations from recent IPCC refinements (IPCC, 2019) regarding stratified soil sampling for accurate carbon accounting.
The comprehensive assessment reveals that Cross River National Park (CRNP) is a substantial carbon reservoir, with a total ecosystem stock of 2,987.3 t/ha (Table 5). This places it firmly within the range reported for other intact forests in Central Africa (Lewis *et al.,* 2013). The distribution of this stock is critical: live tree stems constitute the dominant pool (56.41 per cent), unequivocally highlighting the immense climate cost of deforestation. Furthermore, the substantial contribution from dead trees (17.72 per cent) underscores the vital, yet often underestimated, role of dead woods in tropical forest carbon cycles, a factor gaining recognition in carbon accounting frameworks (Martin *et al.,* 2021).

This extensive carbon storage translates into significant economic potential. The current value was estimated at US$583,573.85, with projections indicating an appreciation to US$1.86–3.18 million by 2030 as carbon markets mature (Table 5; World Bank, 2023). This potential revenue could fundamentally transform conservation financing, supporting initiatives ranging from anti-poaching patrols to community-led programmes, models that have demonstrated success elsewhere in Africa (Naughton-Treves & Treves, 2021). This approach aligns with Nigeria's national climate strategy, which promotes nature-based solutions and community participation (Federal Government of Nigeria, 2021). However, the promise of carbon finance is tempered by significant practical challenges. The projected value of up to US$3.18 million is highly vulnerable to the risk of non-permanence; the concentration of carbon in live tree biomass (56.41 %) means a fragmentation, fire or deforestation event could rapidly release this stock, invalidating the credits (Busch *et al.,* 2021). Furthermore, robust monitoring, reporting, and verification (MRV) is required to accurately track complex carbon pools, such as deadwood and soil, a technically and financially demanding undertaking (Gupta *et al.,* 2023). For an existing protected area like CRNP, demonstrating additionality, proving that carbon finance enables conservation beyond the status quo, presents a further critical challenge (West *et al.,* 2020). Finally, without integrated landscape management, conservation efforts within the park risk causing leakage by displacing pressures to adjacent forests (Huang & Yin, 2023).

Therefore, for carbon financing to fulfil its potential in CRNP, revenues must be strategically invested in mitigating these high risks. This includes funding enhanced protection to ensure permanence, community-inclusive programmes to foster stewardship, and long-term MRV systems to guarantee credibility and durability.

Conclusion

This study quantified carbon storage across multiple ecosystem components in Cross River National Park. The distribution of carbon among various pools underscores the importance of comprehensive carbon accounting in tropical forests. The significant soil carbon stratification and the economic valuation demonstrating substantial potential carbon revenues highlight the critical role of this protected area in climate change mitigation. These findings establish Cross River National Park as a significant carbon sink and justify its consideration as a nature-based solution for climate resilience. To realise the full conservation and climate potential of these results, the following actions are recommended for protected area managers and policymakers:

i. **Adopt integrated carbon accounting**: Carbon accounting frameworks should incorporate all ecosystem components, particularly deadwood and soil carbon pools, to provide accurate estimates of forest carbon stocks and ensure fair compensation through carbon markets.

ii. **Integrate carbon revenue into park management**: Develop mechanisms to channel carbon credit revenues directly into protected area management, supporting anti-logging and anti-poaching patrols, community outreach programmes and habitat restoration initiatives within Cross River National Park.

iii. **Enhance community-based conservation**: Use carbon financing to support community-inclusive conservation models that address and maintain forest integrity.

iv. **Conduct longitudinal soil carbon monitoring**: Establish permanent soil monitoring plots to track changes in soil carbon stocks over time, particularly focusing on depth stratification to better understand carbon dynamics under changing climatic conditions.

Implementation of these recommendations will strengthen the permanence and credibility of carbon finance in Cross River National Park while delivering lasting benefits for biodiversity conservation, local communities, and global climate goals.

References

Agus, F., Hairiah, K., & Mulyani, A. (2011). Measuring carbon stocks in peat soils: Practical guidelines. World Agroforestry Centre (ICRAF) Southeast Asia Regional Program; Indonesian Centre for Agricultural Land Resources Research and

Ambe, B. A., &Onnoghen, G. O. (2019). Climate variability and its implications on forest ecosystems in southeastern Nigeria. *Journal of Geoscience and Environment Protection, 7*(11), 177–191.
DOI: https://doi.org/10.4236/gep.2019.711013

Amuyou, U. A., Obioha, E. E., & Udo, E. S. (2016). REDD+ implementation challenges and prospects in Nigeria. Journal of Sustainable Development in Africa, 18(2), 113–127.

Busch, J., Engelmann, J., Cook-Patton, S. C., Griscom, B. W., Kroeger, T., Possingham, H., & Shyamsundar, P. (2021). Potential for low-cost carbon dioxide removal through tropical reforestation. *Nature Climate Change, 11*(7), 562–568.
DOI: https://doi.org/10.1038/s41558-021-01072-9

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.-P., Nelson, B. W., Ogawa, H., Puig, H., Riéra, B., &Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia, 145(1), 87–99. https://doi.org/10.1007/s00442-005-0100-x

Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B. C., Duque, A., Eid, T., Fearnside, P. M., Goodman, R. C., Henry, M., Martínez-Yrízar, A., Mugasha, W. A., Muller-Landau, H. C., Mencuccini, M., Nelson, B. W., Ngomanda, A., Nogueira, E. M., Ortiz-Malavasi, E., ... &Vieilledent, G. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. Global Change Biology, 20(10), 3177–3190. https://doi.org/10.1111/gcb.12629

Cuni-Sanchez, A., Sullivan, M. J. P., Platts, P. J., Lewis, S. L., Marchant, R., Imani, G., ... &Zibera, E. (2021). High aboveground carbon stock of African tropical montane forests. Nature, 596(7873), 536–542. https://doi.org/10.1038/s41586-021-03798-4

Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (Eds.). (2006). 2006 IPCC guidelines for national greenhouse gas inventories (Vol. 4: Agriculture, forestry and other land use). Institute for Global Environmental Strategies.

Ellert, B. H., Janzen, H. H., & Entz, T. (2001). Assessment of a method to measure temporal change in soil carbon storage. Soil Science Society of America Journal, 65(5), 1687–1695. https://doi.org/10.2136/sssaj2001.6551687x

Federal Government of Nigeria. (2021). Nigeria's nationally determined contribution (NDC). United Nations Framework Convention on Climate Change.

Food and Agriculture Organization of the United Nations. (2020). Global forest resources assessment 2020: Main report. FAO. https://doi.org/10.4060/ca9825en

Gupta, A., Lovell, H., Rickards, L., &Vijge, M. J. (2023). Monitoring, reporting and verification for climate finance: Lessons from the Global Environment Facility Trust Fund. Climate Policy, 23(1), 1–17. https://doi.org/10.1080/14693062.2023.2169233

Hairiah, K., Dewi, S., Agus, F., Velarde, S., Ekadinata, A., Rahayu, S., & van Noordwijk, M. (2001). Measuring carbon stocks across land use systems: A manual. World Agroforestry Centre (ICRAF).

Huang, Y., & Yin, H. (2023). Addressing leakage in REDD+ through integrated landscape approaches: Opportunities and challenges. *Environmental Science & Policy, 142*, 103–112.

Intergovernmental Panel on Climate Change. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use*. Prepared by the National Greenhouse Gas Inventories Programme. (H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe, Eds.). Institute for Global Environmental Strategies (IGES), Japan. URL: https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Intergovernmental Panel on Climate Change. (2007). Climate change 2007: Synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC.

Intergovernmental Panel on Climate Change. (2019). 2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories. IPCC.

Lewis, S. L., Sonké, B., Sunderland, T., Begne, S. K., Lopez-Gonzalez, G., van der Heijden, G. M. F., Phillips, O. L., Affum-Baffoe, K., Baker, T. R., Banin, L., Bastin, J.-F., Beeckman, H., Boeckx, P., Bogaert, J., De Cannière, C., Chezeaux, E., Clark, C. J., Collins, M., Djagbletey, G., … Zemagho, L. (2013). Aboveground biomass and structure of 260 African tropical forests. *Philosophical Transactions of the Royal Society B: Biological Sciences, 368*(1625), 20120295.

Luizão, R. C. C., Luizão, F. J., Paiva, R. Q., Monteiro, T. F., Sousa, L. S., & Kruijt, B. (2004). Variation of carbon and nitrogen cycling processes along a topographic gradient in a central Amazonian forest. Global Change Biology, 10(5), 592–600. https://doi.org/10.1111/j.1365-2486.2004.00791.x

ISTF-NIG 2026

Martin, A. R., Ryan, C. M., & van der Werf, G. R. (2021). Dead wood carbon storage and dynamics in global forests. *Nature Geoscience, 14*(7), 447–452. DOI: https://doi.org/10.1038/s41561-021-00744-0

Naughton-Treves, L., & Treves, A. (2021). How do rural communities experience large mammals? Factors shaping perceptions of risk, benefit, and control. *Frontiers in Conservation Science, 2*, Article 699725.

Paoli, G. D., & Curran, L. M. (2007). Soil nutrients limit fine litter production and tree growth in the mature lowland forest of southwestern Borneo. *Ecosystems, 10*(3), 503–518.

R Core Team. (2021). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing.

Ravindranath, N. H., & Ostwald, M. (2008). *Carbon inventory methods: Handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects.* Springer. DOI: https://doi.org/10.1007/978-1-4020-6547-7

Silver, W. L., Lugo, A. E., & Farmer, D. (2002). Soil organic carbon in tropical forests of the United States of America. In J. M. Kimble, L. S. Heath, R. A. Birdsey, & R. Lal (Eds.), *The potential of U.S. forest soils to sequester carbon and mitigate the greenhouse effect* (pp. 363–380). CRC Press.

Stern, N. (2007). *The economics of climate change: The Stern review.* Cambridge University Press.

Tagupa, C. P., Fernandez, R. S., & Combalicer, M. S. (2010). Carbon sequestration potential of secondary forests in the Philippines. *Journal of Environmental Science and Management, 13*(2), 1–10.

UNESCO World Heritage Centre. (2024). *Cross River National Park (Oban Division).* UNESCO.

URL: https://whc.unesco.org/en/tentativelists/6204/

United Nations Department of Economic and Social Affairs & United Nations Forum on Forests Secretariat. (2021). *Global Forest Goals Report 2021*. United Nations.

https://www.un.org/esa/forests/wp-content/uploads/2021/08/GlobalForestGoalsReport2021.pdf

United Nations REDD Programme. (2016). *Methodological guidance on forest carbon measurement.* United Nations Development Programme.

West, T. A. P., Börner, J., Sills, E. O., &Kontoleon, A. (2020). Overstated carbon emission reductions from voluntary REDD+ projects in the Brazilian Amazon. *Proceedings of the National Academy of Sciences, 117*(39), 24188–24194. DOI: https://doi.org/10.1073/pnas.2004334117

World Bank. (2023). *State and trends of carbon pricing 2023.* World Bank. DOI: https://doi.org/10.1596/978-1-4648-2057-5

Wright, C. Y., Goddard, M. A., Gwilliam, J., Hale, J. D., Heidrich, O., Caputo, S., ... & Davies, Z. G. (2021). Nature-based solutions and global climate protection: Systematic review of research themes, gaps and challenges: *Environmental Research Letters, 16*(9), Article 093005. DOI: https://doi.org/10.1088/1748-9326/ac1c4d

Zanne, A. E., Lopez-Gonzalez, G., Coomes, D. A., Ilic, J., Jansen, S., Lewis, S. L., Miller, R. B., Swenson, N. G., Wiemann, M. C., & Chave, J. (2009). Global wood density database. Dryad. DOI: https://doi.org/10.5061/dryad.234

ISTF-NIG 2026

AGROFORESTRY SYSTEMS: A SUSTAINABLE INTEGRATED STRATEGY FOR CLIMATE CHANGE MITIGATION AND ENVIRONMENTAL SUSTAINABILITY IN NIGERIA

Bolaji K. A, Olawale O. O., Oke O. S., Odediran F.A., and Adisa A. S

Forestry Economics and Extension Services, Forestry Research Institute of Nigeria, P. M. B. 5054, Jericho Hill, Ibadan, Oyo State, Nigeria.
Corresponding Email: okeolugbengas@gmail.com ; opeyemioyetundu@gmail.com

Abstract

Climate change continues to pose serious environmental, social and economic challenges, particularly in Nigeria, where livelihoods largely depend on climate-sensitive sectors such as agriculture and forestry. Unsustainable land practices, deforestation and increased anthropogenic pressure on natural resources have significantly intensified greenhouse gas emissions, biodiversity loss and land degradation to a very great and alarming extent, making it One of the global challenges today. Agroforestry has emerged as a viable forest-based strategy that reconciles agricultural production with ecological sustainability. By deliberately incorporating trees into farming systems, agroforestry enhances carbon storage, restores degraded lands, conserves biodiversity and improves microclimatic conditions. Beyond its mitigation potential, agroforestry strengthens adaptive capacity by diversifying livelihoods and improving soil and water conservation. This paper examines agroforestry systems as integrated approaches to climate change mitigation and environmental sustainability in Nigeria.

Keywords: Agroforestry, Climate resilience, Carbon sequestration, Sustainable land management, Environmental sustainability

Introduction

Climate change represents One of the most pressing global environmental challenges of the 21st century. It is characterized by variations in temperature patterns, irregular rainfall distribution, prolonged drought, increased flooding and advancing desertification, which have significantly affected ecological systems and human livelihoods (IPCC, 2022). Developing countries, particularly those in sub–Saharan Africa, are disproportionately vulnerable due to their heavy reliance on rain-fed agriculture, high poverty rates, and limited adaptive capacity (Simon, 2019). Human-induced activities, such as deforestation, fossil fuel combustion, unsustainable agricultural expansion, and land degradation, have contributed substantially to rising atmospheric concentrations of greenhouse gases (Griscom et al., 2020). These activities disrupt ecological balance, weaken ecosystem resilience and reduce biodiversity.

Climate change significantly affects agriculture by altering rainfall patterns, increasing droughts and floods, increasing pest infestation and reducing soil fertility (Olatoye et al., 2025). This threatens food security and results in a decline in agricultural productivity, hunger, and poverty, particularly in developing countries like Nigeria (FAO, 2020). In addition, ecosystems and biodiversity are under pressure, with many species going extinct due to rapid environmental change. Human health is also impacted through heat stress, respiratory diseases and the spread of vector-borne illnesses, such as malaria. Climate change is already affecting millions of people, especially in vulnerable regions (WHO, 2021). Flooding in some states, notably Bauchi, Benue, Cross-River, Edo, Jigawa, Kebbi, Niger, Yobe, and the FCT, destroyed thousands of hectares of cereal crops, affecting food production and resulting in below-normal household food stocks (Abegunde et al., 2020).

In a report by the World Food Program, the Nigerian Government in May 2013 declared a state of emergency in Borno, Adamawa, and Yobe States of Northeast Nigeria due to deterioration in food and nutrition security. Food production is at risk due to climate change (Mutale et al., 2025). Economically, climate-related disasters, such as storms, damage infrastructure and affect livelihoods, especially in sectors like agriculture and fisheries. Mitigation reduces long-term economic losses and supports sustainable development (Adamaagashi et al., 2023). Climate crisis and rising costs have combined in 2022 to create jeopardy for up to 828 million hungry people across the world, and the number of those facing acute food insecurity has soared - from 135 million to 345 million - since 2019. A total of 50 million people in 45 countries are teetering on the edge of famine (Wudil et al, 2022). This prompted the World Food Programme to declare 2022 a year of unprecedented hunger. Climate variability is keeping the world off track in achieving the goal of zero hunger by 2030. Amid these threats of climate change, the effort to eradicate poverty and hunger through agriculture has become more challenging as climate change impacts are stalling progress towards food security (Mugambiwa, S.S. and Tirivangasi, H.M. 2017; Adekoya et al., 2023).

Table 1: Major Climate Change Problems and Their Effects in Nigeria

Climate Change Issue	Evidence in Nigeria	Major Effects
Flooding	Floods affected several states, including Kogi, Bayelsa, Benue, and Anambra.	Destruction of farmlands, displacement of people, and food insecurity
Desertification	About 63.8% of Nigeria's landmass is threatened by desertification	Loss of arable land, migration, and poverty
Rising Temperature	Increased temperatures across northern Nigeria	Heat stress reduces crop productivity
Drought	Frequent drought occurrence in northern Nigeria	Water scarcity and crop failure
Coastal Erosion	Severe erosion in the Niger Delta coastal communities	Loss of settlements and biodiversity
Irregular Rainfall	Delayed rainfall and shorter growing seasons	Reduced agricultural productivity

Source: Ayanlade et al. (2018); Federal Ministry of Environment (2021)

The effects of climate change include mitigation and adaptation strategies. This mitigation focuses on reducing greenhouse gas emissions through renewable energy and sustainable practices, while adaptation involves adjusting to current and future impacts. In recent years, attention has shifted towards nature-based solutions that combine environmental protection with socioeconomic benefits (FAO, 2020). Agroforestry, the deliberate integration of trees, crops, and sometimes livestock on the same land management unit, has gained recognition as One of such sustainable land use systems (Taylor, 2019). Unlike subsistence farming, mixed farming, shifting cultivation, and crop rotation systems, agroforestry enhances ecological interactions, increases carbon storage, improves soil fertility, and diversifies farmers' income sources (Williams, 2020; Toppo, P., and Raj, A., 2018). Although agroforestry was not initially designed specifically for carbon sequestration, growing evidence indicates that 5-15% of global CO2 emissions contribute significantly to climate change mitigation and adaptation (Amin et al., 2025). By incorporating woody perennials into agricultural landscapes, agroforestry

strengthens ecosystem resilience, restores degraded lands, and improves environmental sustainability (FAO, 2023). This paper, therefore, explores agroforestry systems and their contributions to climate change mitigation and sustainable environmental management.

Concept of Agroforestry Systems

Agroforestry refers to a sustainable land use system in which woody perennials are deliberately integrated with crops and /or livestock within the same land management unit in spatial or temporal arrangements (Nair, 2022). The system recognizes the ecological and economic interactions between trees, crops, animals and humans (Kuyah et al., 2019). Unlike conventional agricultural systems, which often separate forestry from farming, agroforestry promotes multifunctional landscapes that enhance productivity while conserving environmental resources.

Agroforestry systems are broadly classified into three major categories in Nigeria:

- Agrisilvicultural systems: The integration of woody perennials (trees and shrubs) with crops on the same farm land. These practices improved land sustainability and support food production in Nigeria. Examples include alley cropping, the taungya system, and parkland or scattered trees on farms. (Olarewaju and Ayinde 2023))
- Silvopastoral systems: The combination of trees and livestock production contributes to sustainable land use and ecological balance. Examples include using fodder trees for animal feeding and grazing livestock under trees. (Oladele et al., 2020).
- Agrosilvopastoral system: Integration of crops, trees, and livestock within the same land unit to maximize land productivity, improve food security, enhance environmental sustainability, and diversify income in Nigeria; examples include home gardens. (Bernard et al., 2021).

These classifications reflect the structural and functional diversity of agroforestry systems and demonstrate their adaptability to various ecological zones and socioeconomic contexts (Akinbami et al., 2022).

Contributions of Agroforestry to Environmental Sustainability

The various agroforestry systems, with different component combinations and their contributions to the Nigerian environment, are presented in Table

(A) 1: Climate regulation and carbon sequestration.

Agroforestry contributed between 20% and 70% of biomass carbon storage on Agricultural land, as trees integrated into farms accounted for the largest share of carbon sequestration. (Zomer et al,2016) significantly to climate regulation through carbon sequestration. Trees absorb atmospheric carbon dioxide and store it in their biomass and soils, thereby reducing greenhouse gas concentrations (Ajibola & Fashina, 2020). By increasing tree cover on agricultural landscapes, agroforestry enhances terrestrial carbon stocks and contributes to ecological balance.

A case study is the Cocoa-based agroforestry system in the Ogbese Forest Reserve, Ekiti State, Southwestern Nigeria. The study showed that while forest conversion reduces total carbon storage, agroforestry acts as a climate-buffering land-use system, preserving substantial carbon stocks and contributing to ecological stability in agricultural landscapes. (Oke, D. and Olatilu, A. 2011).

(B) Biodiversity conservation

ISTF-NIG 2026

Loss of biodiversity weakens ecosystem stability and increases vulnerability to environmental disturbances because ecosystems depend on the interactions among different species of plants, animals, and microorganisms to function effectively. When biodiversity is reduced, ecosystems become less resilient and more vulnerable to environmental disturbances such as climate change, drought, flooding, pests, and diseases. (ICPP, 2022). Agroforestry systems conserve biodiversity by maintaining tree diversity on farmlands and providing habitats for plant and animal species. (Tahir Abdela, 2025). Traditional agroforestry practices also promote in situ conservation of indigenous species, thereby strengthening ecosystem resilience (Kusternmann, 2016; Olatujoye et al., 2025; Rafiu et al., 2026).

(C) Soil fertility improvement

Soil degradation is a major environmental challenge in many tropical regions. Agroforestry improves soil fertility through litterfall, organic matter decomposition, and biological nitrogen fixation (Agbor et al., 2024). The incorporation of leguminous trees enhances nutrient cycling and improves soil structure, thereby increasing agricultural productivity while maintaining sustainability (Horst, G., and Hovorka, A.J., 2019).

A well-documented Nigerian case study demonstrated how leguminous trees improve nutrient cycling, soil structure, and agricultural productivity in the long-term alley cropping system using Leucaena leucocephala and Senna siamea at the International Institute of Tropical Agriculture (IITA), Ibadan. (Atta-Krah, 2008).

(D) Land restoration

Agroforestry plays a vital role in rehabilitating degraded lands. Tree roots stabilize soil, reduce erosion and control runoff on sloping lands (Vikrams et al, 2021). Improved fallow systems and alley cropping practices have been shown to restore soil nutrients and enhance land productivity in tropical environments (Bayala et al., 2014). Another study showed that Improved fallow remains an important component in the restoration of soil productivity of a derived savanna zone of Nigeria (Adekiya et al.,2021)

(E) Microclimate modification

Trees moderate microclimatic conditions by providing shade, reducing wind velocity and regulating temperature through evapotranspiration (Shahidan, M. F. 2015). Shelterbelts and windbreak systems are particularly effective in arid and semi- arid regions, where they reduce wind erosion and enhance moisture retention (Ajayi et al., 2021). Such ecological functions strengthen the capacity for climate adaptation in vulnerable farming systems.

Table 2: Agroforestry systems and combinations

S/N	Agroforestry Systems	Combination Trees (example) with arable crops (example)	Location Where in the world?	Contribution to the environment	References
1	Agrosilvopastora	Mango, Maize and Goat	Middle Belt and Northern Nigeria/ (Benue)	Enhance biodiversity, nutrient recycling	Atangana, A., Khasa, D., Chang, S., & Degrande, A. (2014). Tropical Agroforestry. Springer.

ISTF-NIG 2026

				and climate resilience	
2	Alley Cropping	Leucaena leucocephala, Gliricidia sepium with maize, cassava or yam	Southwestern Nigeria/ (Ibadan)	Improves soil fertility, reduces erosion, increases nitrogen cycling, and conserves moisture	Kang, B. T., Reynolds, L., & Atta-Krah, A. N. (1990). Alley farming advances in humid and subhumid tropics. Agroforestry Systems, 13, 141–158.
3	Improved Fallow System	Sesbania sesban, pigeon pea (Cajanus cajan) with maize and cassava after fallow	Derived savanna zones of Nigeria	Restores soil nutrients, increases soil organic matter, and improves land productivity.	Adekiya, A. O., Aremu, C., Agbede, T. M., et al. (2021). Soil productivity improvement under different fallow types in an Alfisol derived from a savanna ecosystem in Nigeria. Heliyon, 7(4), e06759.
4	Taungya System	Teak (Tectona grandis), Gmelina with maize, yam, cassava	Forest reserves in Ondo, Ogun, and Cross River States	Promotes reforestation, reduces deforestation, and improves forest regeneration	Ansa, J. (2022). SOCIOECONOMIC POTENTIAL OF TAUNGYA FARMING SYSTEM FOR SUSTAINABLE FOOD PRODUCTION IN NIGERIA
5	Home Garden Agroforestry	Fruit trees (mango, orange, oil palm) with vegetables, pepper, and cocoyam.	Southern Nigeria	Conserves biodiversity, improves microclimate, enhances food security	Udoh, D. J., et al. (2017). Home garden agroforestry systems and biodiversity conservation in Southern Nigeria. Nigerian Journal of Agriculture, 22(3), 66–74.
6	Silvopastoral System	Fodder trees (Acacia, Leucaena) with pasture grasses and livestock	Northern Nigeria	Reduces desertification, improves carbon sequestration, and controls land degradation	Buba, T. (2015). Agroforestry practices in Northern Nigeria and their role in environmental sustainability. Journal of Research in Forestry, Wildlife and Environment, 7(2), 45–58.

ISTF-NIG 2026

7	Shelterbelt/Windbreak System	Neem (Azadirachta indica), Eucalyptus around millet, sorghum fields	Northern Nigeria (Sahel and Sudan savanna zones)	Controls wind erosion, combats desert encroachment, and protects crops.	Gwandu, M. B., et al. (2018). Shelterbelt development and desertification control in Northern Nigeria. Environmental Review Journal, 12(1), 55–63.

Sustainable Agroforestry practices for climate change mitigation

Some agroforestry practices that contribute directly to environmental sustainability and climate resilience in Nigeria. A summary of the practices and locations where they have been used in Nigeria is presented in Table 2.

Taungya System

The Taungya system is widely practiced in the forest zone of southern Nigeria (including Oyo, Ogun, Ondo, Ekiti, Cross River, and Edo States), where farmers grow food crops alongside forest trees during the early years of plantation establishment. It helps in carbon sequestration because the planted trees absorb and store atmospheric carbon dioxide in their biomass and soil. (Azeez et al., 2017). Research estimates show that the taungya system can sequester approximately 1–3 tons of carbon per hectare per year, or roughly 3.7–11 tons of CO_2 per hectare per year. The Taungya system integrates forest trees with the temporary cultivation of crops during the early stages of a plantation. This system promotes reforestation while supporting farmer livelihoods (Kumar et al., 2018). Food crops are usually annual or biennial, such as maize (see plate 1 below). Examples of trees used in agro-forestry are *Parkia biglobasa (*Locust bean), *Irvingia spp* (Ogbono), *Chrysophyllum albidum* (African star apple), *Tectona grandis*, *Gmelina spp* (Ishin), *Pinus spp*, and *Vitellaria paradosa* (Shea butter), amongst others.



Plate 1: Taungya System

(Source: Sanou, et al., 2017)

Improved fallowing

Improved fallow involves enriching fallow lands with fast-growing leguminous species to restore soil fertility and control erosion (Manna et al., 2017). Improved fallow agroforestry has been practiced in the southern part of Nigeria, especially in the humid and derived savanna zone, where soil fertility decline is a major problem (Oke 2019). Research findings show that an improved fallow system can significantly increase soil organic carbon. In *Cajanus cajan*, an improved fallow system increased soil carbon stocks by about 15 tonnes of carbon per hectare. (Olujobi, O.J., 2018).Other leguminous woody species used in Nigeria include *Acacia spp*., *Parkia biglobosa*, *Gliricidia sepium, Pterocarpus angolensis*, and *Prosopis africana*. Grain and forage legumes that can be planted include *Sesbania sesban*, *Tephrosia vogelii*, *Pisum sativa*, etc.



Plate 2: Improved Fallow

(Source: Misebo, Amisalu. 2018)

Shelterbelt establishment / Windbreak agroforestry

A shelterbelt consists of closely planted rows of trees designed to reduce wind speed and prevent desertification (FAO, 2020; Udofia & Akpan, 2022). It has been practiced mainly in the semi-arid and Sudan–Sahel regions of Northern Nigeria to reduce desertification, wind erosion, and land degradation, as shown in Plate 3 below. A study from Kanawa Forest Reserve, Gombe State, Nigeria, showed that *Acacia albida*, *Azadirachta indica*, *Acacia senegal*, *and Eucalyptus camadulensis* are used to sequester about 0.29 to 15.21 Mg Carbon per hectare in a year, depending on tree species and management systems (Gadiya, 2018)



Plate 3: Shelterbelt Establishment

(Source: Donald, et al., 2013)

Alley cropping/ Alley farming

Alley cropping involves growing food crops between hedgerows of trees, which are periodically pruned to provide the soil nutrients needed by the arable crop (Jose, 2020). The trees are grown in wide rows, while the arable crops are grown between the rows, as shown in plate 4 below. The fresh branches of the tree crops are sometimes pruned to prevent shading of the companion crop and worked into the soil as organic manure to supply the needed nutrients. It is widely practiced in the humid and sub-humid zones of Nigeria. Alley cropping is practiced primarily in southwestern and southeastern Nigeria; it can sequester about 66.83 tonnes of carbon per hectare. (Nwite and Alu, 2017).



Plate 4: Alley Farming/cropping

(Source: Donald, et al., 2013)

Homestead tree planting

Planting economic trees around homesteads improves environmental quality, enhances household food security, and contributes to climate moderation (Mbow et al., 2021). These practices collectively promote ecological restoration while sustaining agricultural productivity, as shown in plate 5. Homesteading is often practiced as home gardening, small-scale agroforestry, or compound farming, particularly in rural areas, to enhance food security throughout Nigeria. Examples of trees used for homestead planting include *Moringa oleifera*, *Tectona grandis, Gmelina arborea* and *Adansonia digitata (*Adetoye et al., 2017). Studies on homestead forests have shown a total organic carbon stock of approximately 208.8 t C ha-1. (Akpan and Nkanga, 2019)



Plate 5: Homestead tree planting

(Source: Mathewos et al., 2013)

Conclusion

Agroforestry systems represent a multifunctional land use strategy capable of addressing climate change and environmental degradation simultaneously. Through carbon sequestration, biodiversity conservation, improved soil fertility, and microclimate regulation, agroforestry enhances ecosystem resilience and supports sustainable development amid increasing environmental pressures in Nigeria. To increase the benefits of agroforestry systems, there is a need for increased awareness among farmers, extension services and government policies. Promoting agroforestry as part of sustainable land management strategies to contribute significantly to environmental sustainability and climate change mitigation. `

References

Abegunde VO, Sibanda M, Obi A. (2020). Determinants of the adoption of climate-smart agricultural practices by small-scale farming households in King Cetshwayo district municipality, South Africa. *Sustainability* (Switzerland).1;12(1). 883 FRR Vol 7(68):858-883.

Adamaagashi, I., Nzechie, O., Obiorah, J., & Ogar, E. (2023). Analyzing the Critical Impact of Climate Change on Agriculture and Food Security in Nigeria. International Journal of Agriculture and Earth Science (IJAES). 10.56201/ijaes.v9.no4.2023.pg1-27.

Adekiya AO, Aremu C, Agbede TM, Olayanju A, Ejue WS, Adegbite KA, Olayiwola IE, Ajiboye B, Oni AT. (2021).Soil productivity improvement under different fallow types in an Alfisol derived from a savanna ecosystem in Nigeria. *Heliyon.* 15;7(4): e06759. doi: 10.1016/j.heliyon.2021.e06759. PMID: 33898846; PMCID: PMC8060602.

Adekoya, A.,Adenikinju, A.,Olubusoye, O.,Oyeranti, O.,Otekunrin, O.,Ogunbayo, I.,Oyelami, B.Sesan, T.,Alaba, O.,Akano, O.(2023.Household food insecurity and cooking energy access in Nigeria: A panel data approach—*Journal of Energy Nexus,*12(1). DOI-10.1016/j.nexus.2023.100242.

Adetoye, A.M., Okojie, L.O. & Akerele, D. (2017). Agroforestry Practices and Carbon Sequestration Cost Estimates among Forest Land Degraded Households in Nigeria: A Choice Modeling Approach. *Journal of Earth Science and Climate Change*. 8 (10), 1–8.

ISTF-NIG 2026

Agbor, C. E, Udumo, B. O. U, Ogholo. N, and Igwebuike. O (2024). Agroforestry and Organic Farming Agricultural Practice: Towards Climate Change Mitigation in Cross River State, Nigeria. *Journal of Contemporary Research (JOCRES).* Volume 3 (1). Pp21 – 31. www.unicrossjournals.com.

Ajayi, O. C., Akinnifesi, F. K., & Sileshi, G. W. (2021). The role of agroforestry in sustainable agricultural intensification in sub-Saharan Africa. *Agroforestry Systems,* 95(3), 343 356.

Ajibola, M. O., & Fashina, O. S. (2020). Agroforestry practices and their contribution to the green economy in Nigeria—African Journal of Environmental Management, 9(2), 78 95.

Akpan, U. S. & Nkanga, N.A. (2019). Organic Carbon Sequestration Capacity of Soils of Akwa Ibom State, Nigeria. *International Journal of Research and Scientific Innovation (IJRSI)* | 6(6):134-143. ISSN 2321–2705 www.rsisinternational.org

Akinbami, J. F., Adepoju, A. O., & Adebayo, O. O. (2022). Challenges of agroforestry adoption in Nigeria: Policy implications for sustainable land use. *Journal of Sustainable Agriculture,* 14(2), 45–60.

Akinyemi, O., Balogun, A., & Yusuf, K. (2023). Extension services and agroforestry adoption in Nigeria: Bridging the knowledge gap. *African Journal of Sustainable Agriculture,* 19(2), 121–134.

Amin, Md Ruhul, Md. Rezoanul Islam, Shabrin Jahan Shaili, Mst Rahima Khatun, and Md Mahedi. 2025. "Climate Change and Its Impact: A Review of Global Strategies for Adaptation and Mitigation". *Journal of Agriculture and Ecology Research International* 26 (4):205–21. https://doi.org/10.9734/jaeri/2025/v26i4694.

Ansa, J. (2022). SOCIOECONOMIC POTENTIAL OF TAUNGYA FARMING SYSTEM FOR SUSTAINABLE FOOD PRODUCTION IN NIGERIA. *International Journal of Interdisciplinary Research and Innovations,* 7(4).13-21. www.researchpublish.com.

Atangana, A., Khasa, D., Chang, S., & Degrande, A. (2014). Tropical Agroforestry. Springer.

Attah-Krah, A. N. (2008). Alley Farming with Leucaena: Effect of Short Grazed Fallow on Soil Fertility and Crop Yields. *Journal of Experimental Agriculture,* 26(1), 1–10.

Ayanlade Ayansina, Maren Radeny, John F. Morton, Tabitha Muchaba. (2018). Rainfall variability and drought characteristics in two agro-climatic zones: An assessment of climate change challenges in Africa, *Science of the Total Environment. Environment* 6(30): 728–737.

Ayiri, B. A, Etah, E. E. (2025). Agro Forestry Practices and Green Economy for Environmental Sustainability in Nigeria (A case study of Obudu and Obanliku Local Government Areas of Cross River State, Nigeria). *International Journal of Agriculture and Earth Science.* 11(8):13 – 32. www.iiardjournals.org. doi: 10.56201/ijaes.

Azeez, I. O., Popoola, L., & Shulamite, I. O. (2017). An assessment of the forest regeneration potential of the taungya system of farming in Oyo State, southwestern Nigeria. Southern Forests: *A Journal of Forest Science,* 79(2):143–151. https://doi.org/10.2989/20702620.2016.1255425.

Bayala, J.J., Sanou, Z., Teklehaimanot, A., Kalinganire, S.J., Oudraogo (2014). Parklands for buffering climate risk and sustaining agricultural production in the Sahel of West Africa. *Curr. Opin. Environ. Sustain.,* 6 (1):28–34.

Bernard Fungo, Martin Wiesmeier, Rémi Cardinae (2021). Agroforestry 3: Agrosilvopastoral systems: CROPLAND, GRASSLAND, INTEGRATED SYSTEMS AND FARMING APPROACHES PRACTICES OVERVIEW, ResearchGate 1(3,500-511). https://www.researchgate.net/publication/354462045_Agroforestry_3_Agrosilvopastoral_systems

Buba, T. (2015). Agroforestry practices in Northern Nigeria and their role in environmental sustainability. *Journal of Research in Forestry, Wildlife and Environment,* 7(2):45–58.

ISTF-NIG 2026

Donald L. Grebner, Pete Bettinger, Jacek P. Siry (2013). - Common Forestry Practices, Introduction to Forestry and Natural Resources, Academic Press, Chapter 11, Pages 255–285, https://doi.org/10.1016/B978-0-12-386901-2.00011-7.

FAO. (2020). The State of the World's Forests 2020: Forests, biodiversity and people. Food and Agriculture Organization of the United Nations. https://www.fao.org/state-of-forests/en/

FAO. (2023). Agroforestry for climate change mitigation and adaptation. Food and Agriculture Organization of the United Nations. https://www.fao.org.

Federal Ministry of Environment Department of Climate Change (2021). https://ngfrepository.org.ng:8443/jspui/handle/123456789/7140.

Gadiya, B.L.(2018).Assessment of Tree Species Used as Shelterbelt in the Semi-Arid Part of Yobe State, Nigeria.*BMA Journal of Science and Technology,*2(2), 268-279

Griscom B.W., Adams J, Ellis P.W, Houghton R.A, Lomax G., Miteva D.A (2020). Natural climate change solutions revisited. Nature Climate change pp. 123 – 129.

Gwandu, M. B., et al. (2018). Shelterbelt development and desertification control in Northern Nigeria. *Environmental Review Journal*, 12(1), 55–63.

Allie Goldstein, Will R. Turner, Seth A. Spawn, Kristina J. Anderson-Teixeira, Susan Cook-Patton, Joseph Fargione, Holly K. Gibbs, Bronson Griscom, Jennifer H. Hewson, Jennifer F. Howard, Juan Carlos Ledezma, Susan Page, Lian Pin Koh, Johan Rockström, Jonathan Sanderman, & David G. Hole (2020). Protecting irrecoverable carbon in Earth's ecosystems, Nature Climate Change 10 (4), 287–295.

Horst, G. & Hovorka, A.J. (2019). Fuelwood: the other renewable energy source for Africa? Biomass Bioenerg., 33(11): 1605–1616.

IPCC (2022). Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33, doi:10.1017/9781009325844.001.

Jose, S. (2020). Agroforestry for ecosystem services and environmental benefits: An overview. *Agroforestry Systems*, 94(1), 1–10. https://doi.org/10.1007/s10457-019-00399-8.

Kang, B. T., Reynolds, L., & Atta-Krah, A. N. (1990). Alley farming advances in humid and subhumid tropics. *Agroforestry Systems*, 13, 141–158.

Kumar, P., Thakur, C.L., Rai, P., & Attri, K. (2018). Identification of Existing Agroforestry Systems and Socioeconomic Assessment in Kandaghat Block of Solan District, Himachal Pradesh, India. *Int. J. Curr. Microbiol App. Sci.,* 7(4): 3815-3826.

Kusternmann, V. N. (2016). Farming practices and land conservation in Nigeria: Issues and challenges—a seminar presented at an environmental summit in Lagos, Nigeria.

Kuyah, S., Sileshi, G. W., & Njenga, M. (2019). Carbon stocks in agroforestry systems in sub-Saharan Africa: A review. Agriculture, *Ecosystems & Environment,* 283, 106-591. https://doi.org/10.1016/j.agee.2019.106591

Manna, M.C. Ghosh, P.K. & Acharya, C.L. (2018). Sustainable crop production through management of soil organic carbon in semiarid and tropical India. *J. Sustain. Agric.,* 21(3): 85–114.

Mathewos, Melaku & Hundera, Kitessa & Biber-Freudenberger, L. (2018). Planting Fruits and Vegetables in Homegarden as a Way to Improve Livelihoods and Conserve Plant Biodiversity. *Agriculture.* 8. 190. 10.3390/agriculture8120190.

ISTF-NIG 2026

Mbow, C., Van Noordwijk, M., & Luedeling, E. (2021). Agroforestry as a pathway to resilience in sub-Saharan Africa. *Current Opinion in Environmental Sustainability,* 48, 76–83.

Misebo, Amisalu. (2018). The Role of Agronomic Practices on Soil and Water Conservation in Ethiopia; Implications for Climate Change Adaptation: A Review. *Journal of Agricultural Science*. 10. 227-227. 10.5539/jas. v10n6p227.

Mugambiwa, S.S. & Tirivangasi, H.M. (2017). Climate change: A threat towards achieving 'Sustainable Development Goal number two' (end hunger, achieve food security and improved nutrition and promote sustainable agriculture) in South Africa. *Jamba* 27;9(1):350. doi: 10.4102/jamba.v9i1.350. PMID: 29955332; PMCID: PMC6014178.

Mutale, B., Dai, S., Chen, Z., & Maulu, S. (2025). Enhancing food security amid climate change: assessing impacts and developing adaptive strategies. *Cogent Food & Agriculture*, *11*(1). https://doi.org/10.1080/23311932.2025.2519800.

Nair, P.K.R., B. Mohan Kumar & Vimala D. Nair. (2024). An Introduction to Agroforestry: Four Decades of Scientific Developments. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 125(1) (2024) ISSN: 2363–6033 (online); 1612–9830 (print) – website: www.jarts.info Book review by Daniel Callo-Concha∗ 666 p., 2022, Springer International Publishing, ISBN: 978-3-030-75357-3.

Nwite, J. & Alu, M. (2017). Carbon sequestration and assessment of soil fertility status under different land uses for agronomic potential in Abakaliki, South-Eastern Nigeria. *African Journal of Agricultural Research*, 12(11), 871–880. DOI:10.5897/AJAR2016.12053

OKE, D. O. (2019). Growth of Short Rotation Cajanus Cajan Fallow and Its Impact on a Degraded Tropical Alfisol. *International Journal of Natural and Engineering Sciences*, *1*(3), 01–04. Retrieved from https://ijnes.org/index.php/ijnes/article/view/376

Oke, D. & Olatilu, A. (2011). Carbon Storage in Agroecosystems: A Case Study of the Cocoa-Based Agroforestry in Ogbese Forest Reserve, Ekiti State, Nigeria. *Journal of Environmental Protection,* 2(8), 1069–1075.

Oladele, O. N.; Emeghara, U. U.; Ishola, B. F.; Ayodele, J. T.; Awobona, T. A.; Olukotun, O. Adoption of agroforestry practices by arable farmers in Igabi Local Government Area, Kaduna State, Nigeria. *Asian Journal of Research in Agriculture and Forestry*, 2020, 6, 28–37.

Olarewaju A & Ayinde O. (2023). Analysis of Agroforestry Practices among Small-Scale Farmers in the Southern Guinea Savannah Zone of Nigeria. *FARA Research Report* 7(72):936–947. https://doi.org/10.59101/frr072372

Olatoye, C. Foluke, Oladimeji, U. Yusuf, Sanni, A. Sukurat & Abdulkadir Aishat. (2025). Analysis of Agroforestry Farm Profitability and Potential Economic Value of Carbon Sequestered by Agroforestry Lands in Oyo State, Nigeria*, Journal of Agricultural and Rural Development Studies* 2(1) 76–82.

Olatujoye, F., Oluwajuwon. T. V., Olasuyi, K. E. et al., (2025). Farmers' perception of the practices, benefits and challenges of on–farm tree plantings in Akure, Nigeria. *Journal of Agroforestry Systems,* 99(18). http://doi/10.1007/s10457-024-011-9-0.

Olujobi, O. J. (2018). Factors influencing adoption of improved fallow among agroforestry farmers in Gbonyin Local Government, Ekiti State, Nigeria. *International Journal of Agricultural Policy and Research* 6(2):21-27, Available online at https://www.journalissues.org/IJAPR/ https://doi.org/10.15739/IJAPR.18.003

Rafiu,B.O., Omotoso,A.B., Omotayo,A.O. et al., (2026). From farm to resilience: evaluating the role of indigenous food plants in nutrition, market access and livelihood in the forest agroecological zone of Nigeria, *Journal of Agroforestry Systems*. 100(1000. http//doi/10.1007/s10457-026-01439-1.

ISTF-NIGERIA

Shahidan M. F. (2015). Potential of Individual and Cluster Tree Cooling Effect Performances Through Tree Canopy Density Model Evaluation in Improving Urban Microclimate. *Curr World Environ*;10(2) DOI:http://dx.doi.org/10.12944/CWE.10.2.04.

Sanou, Lassina & Savadogo, Patrice & Ezebilo, Eugene & Thiombiano, A. (2017). Drivers of farmers' decisions to adopt agroforestry: Evidence from the Sudanian savanna zone, Burkina Faso. *Renewable Agriculture and Food Systems*. 34. 10.1017/S1742170517000369.

Simon, E. M. (2019). Climate change mitigation: Implications for sustainable agriculture in Nigeria. Enugu: Ugwuowo Press.

Tahir Abdela, Tran. (2025). "Role of Agroforestry in Biodiversity Conservation and Response to Climate Change", *IJAB*, 5(2): 37–42, Oct., doi: 10.54105/ijab.B1061.05021025..

Taylor, G. O. (2019). Competition and facilitation: a synthetic approach to interactions in plant communities. *Ecology,* 78, 58–65.

Toppo, P. & Raj, A. (2018). Role of agroforestry in climate change mitigation. *J. Pharmacog. Phytochem.,* 7(2): 241–243.

Udoh, D. J., et al. (2017). Home garden agroforestry systems and biodiversity conservation in Southern Nigeria. *Nigerian Journal of Agriculture,* 22(3), 66–74.

Udofia, S. I., & Akpan, G. D. (2022). Economic benefits of agroforestry and its role in rural development in Nigeria—Journal of Environmental Economics and Policy, 15(3), 95 112.

Vikram. S, Vishal. J, Rupender. K and Mukesh. C (2021). Socioeconomic and Environmental Assets Sustainability by Agroforestry Systems: A Review. *International Journal of Agriculture, Environment and Biotechnology Citation: IJAEB:* 14(04). DOI: 10.30954/0974-1712.04.2021.6.

WHO (2021), Health and Climate Change Survey Report, Tracking Global Progress. https://www.who.int/publications/i/item/9789240038509

Williams, C. P. (2020). Conservation strategies and management of forest resources for improved rural livelihood. Ibadan: Cymart press

World Agroforestry Centre (ICRAF). (2022). Agroforestry for dryland productivity. https://www. worldagroforestry.org/output/agroforestry-dryland- productivity

World Bank. African Food Systems: The Importance of Climate Adaptation [Internet]. World Bank. 2022. https://www.worldbank.org/en/news/infographic/2022/05/10/african-foodsystems-the-importance-of-climate-adaptation/

Wudil AH, Usman M, Rosak-Szyrocka J, Pilař L, Boye M. (2022). Reversing Years for Global Food Security: A Review of the Food Security Situation in Sub-Saharan Africa (SSA). Int J Environ Res Public Health. 2022 Nov 11;19(22):14836. doi: 10.3390/ijerph192214836. PMID: 36429555; PMCID: PMC9690952.

Zomer, R.J., H. Neufeldt, J.C. Xu, A. Ahrends, D. Bossio, A. Trabucco, M. van Noordwijk, M.C. Wang. (2016). Global Tree Cover and Biomass Carbon on Agricultural Land: the contribution of agroforestry to global and national carbon budgets, Sci. Rep., 6

ISTF-NIG 2026

ASSESSMENT OF THE RESILIENCE OF AGROFORESTRY HOUSEHOLDS TO CLIMATE VARIABILITY IN OMO FOREST RESERVE, OGUN STATE, NIGERIA

[1]Bobadoye, A.O, [2]Aluko, O.J, [2]Odeyale O.C, and [2]Adegbayi, O.R

[1]Forestry Research Institute of Nigeria
[2]Federal College of Forestry, Jericho-Ibadan, Oyo State, Nigeria
Corresponding Email: juliwal2002@yahoo.com/08032878193

Abstract

This study assessed the resilience of agroforestry households to climate variability in the Omo Forest Reserve, Ogun State, Nigeria. Climate variability had increasingly threatened rural livelihoods through irregular rainfall, drought, flooding, and declining agricultural productivity, particularly among forest-dependent communities. A multistage sampling technique was used to select 106 agroforestry households, and primary data were collected using structured questionnaires. Household resilience was measured using a composite resilience index derived from indicators of coping capacity, adaptive learning, preparedness, and recovery ability. Descriptive statistics, logistic regression, and multiple linear regression models were employed for data analysis. Results showed that households exhibited moderate-to-high resilience, with a grand mean resilience score of 3.72, and 64.2% of respondents were classified as highly resilient. Logistic regression results indicated that Education, farming experience, farm size, extension contact, agroforestry adoption, and Access to credit significantly increased the likelihood of household resilience ($p < 0.05$). Similarly, linear regression analysis revealed that agroforestry adoption ($B = 0.175$; $p < 0.01$), Education ($B = 0.041$; $p < 0.01$), farm size ($B = 0.118$; $p < 0.01$), farming experience ($B = 0.022$; $p < 0.01$), extension contact ($B = 0.263$; $p < 0.01$), and credit access ($B = 0.142$; $p < 0.05$) positively influenced the resilience index, while household size negatively affected resilience. The model explained 55.1% of the variations in resilience outcomes. The study concluded that agroforestry practices significantly strengthened household adaptive capacity by enhancing livelihood diversification and ecological stability. Strengthening institutional support systems and improving Access to climate information and financial resources were essential for sustaining resilience among forest-dependent households.

Keywords: Climate variability, Agroforestry, Household resilience, Rural livelihoods, Omo Forest Reserve

Introduction

Climate variability has increasingly emerged as One of the most significant environmental challenges affecting rural livelihoods, particularly in forest-dependent communities of developing countries. Changes in rainfall patterns, rising temperatures, prolonged droughts, and the increased frequency of extreme weather events have disrupted agricultural production systems and threatened food security across Sub-Saharan Africa (Intergovernmental Panel on Climate Change, 2022; Food and Agriculture Organization, 2016). These climatic fluctuations affected not only crop productivity but also soil quality, water availability, biodiversity, and household income stability, thereby increasing the vulnerability of rural populations whose livelihoods depended largely on natural resources (Food and Agriculture Organization [FAO], 2022). In Nigeria, where agriculture and forest resources constituted major sources of

ISTF-NIG 2026

livelihood, climate variability had posed serious risks to sustainable land use and rural welfare (Federal Ministry of Environment, Nigeria, 2015; Food and Agriculture Organization, 2018). Forest-fringe communities, such as dwellers in the Omo Forest Reserve of Ogun State, relied heavily on agroforestry systems that integrated trees, crops, and sometimes livestock within the same land management unit (World Agroforestry Centre, 2013; Nair 1993). Agroforestry has been widely recognized as a climate-smart land-use system that enhances ecological stability while supporting household income and food production. The integration of woody perennials into farming systems improved soil fertility, reduced erosion, enhanced carbon sequestration, and moderated microclimatic conditions, thereby helping farmers adapt to climatic stresses (World Agroforestry Centre, 2015; Food and Agriculture Organization, 2013). Previous studies indicated that agroforestry systems buffered agricultural production against temperature and rainfall variability, contributing to livelihood diversification and risk reduction (Lin *et al.*, 2013; Nair, 2011). These adaptive benefits made agroforestry an important pathway for strengthening rural households' resilience.

Resilience, in the context of climate change, refers to the capacity of households or socio-ecological systems to withstand, adapt to, and recover from climatic shocks while maintaining essential functions and livelihoods (Intergovernmental Panel on Climate Change, 2014). A resilient farming system was therefore One that continued to sustain production and ecological processes despite environmental disturbances (Hughes *et al*., 2005; Lin, 2011). Rural households adopted various coping and adaptation strategies, such as diversifying farm activities, retaining trees on farmland, improving fallow practices, and relying on social support networks to manage climate risks. However, the effectiveness of these strategies often depended on socio-economic characteristics, Access to resources, institutional support, and knowledge of sustainable land management practices. (Ellis Frank, 2000; Adger Neil, 2003). Despite the recognized benefits of agroforestry, adoption and effective utilization among rural dwellers remained uneven due to constraints such as insecure land tenure systems, limited technical knowledge, inadequate extension services, and financial limitations. These challenges reduced farmers' adaptive capacity and increased their exposure to climate-induced risks, leading to declining yields and livelihood insecurity in many forest communities (Mercer Evan, 2004; Food and Agriculture Organization, 2017). Deforestation and unsustainable land use practices further aggravated climate impacts by contributing significantly to greenhouse gas emissions and environmental degradation (Ozor & Nnaji, 2011). Consequently, understanding how rural households built resilience within forest ecosystems became essential for designing effective climate adaptation policies.

Although several studies have examined the impacts of climate change on agriculture in Nigeria, limited empirical attention has been given to assessing household resilience within protected forest landscapes such as the Omo Forest Reserve. Evaluating resilience required not only identifying perceived climate impacts but also examining socio-economic drivers, agroforestry practices, and coping capacities that influenced households' ability to adapt. Therefore, this study assessed the resilience of agroforestry households to climate variability in Omo Forest Reserve, Ogun State, Nigeria, to provide evidence-based insights for improving sustainable forest management and strengthening climate adaptation strategies among forest-dependent communities.

ISTF-NIG 2026

Methodology

Study Area

The study was conducted in the Omo Forest Reserve, a protected tropical rainforest located in Ogun State, south-western Nigeria. The reserve lay approximately between latitude 6°35′N and 7°05′N and longitude 4°19′E and 4°40′E. It was situated about 135 km northeast of Lagos and approximately 80 km east of Ijebu-Ode, forming part of the lowland rainforest ecological zone of Nigeria. The forest reserve covered an estimated land area of about 130,500 hectares (322,000 acres) and constituted One of the largest remaining forest ecosystems in the region. The area's climate was characterized by a humid tropical climate with high annual rainfall averaging about 2,000 mm, distributed mainly between March and November, followed by a relatively short dry season. Temperatures remained generally high throughout the year, while relative humidity was also consistently elevated due to dense vegetation cover (Aluko, 2016). The presence of forest-dependent communities practicing agroforestry, farming, and other livelihood activities within and around the reserve made the area suitable for examining household resilience to climate variability. The interaction between human livelihood systems and forest ecosystems provided an appropriate context for assessing adaptation strategies and resilience mechanisms among rural dwellers facing changing climatic conditions.

Target Population

The study's target population was the household head or representative in the communities around the Omo forest reserves. The household heads are predominantly agroforestry farmers and are in the best position to discuss the problems of resilience on agroforestry plantations.

Sampling Procedure and Sampling Size

A multistage sampling method was used to select the sample for this study. Purposive sampling was used to select the J4 zone (comprising more than 20 enclaves) from the four zones that make up Omo Forest based on records of agroforestry practices. The second stage involved the random selection of four (4) enclaves, primarily engaged in agroforestry practices. These included Owode, Eseke, Korede and Abakurudu. Lastly, household counts were carried out to obtain population figures for each settlement using the participatory rural appraisal (PRA) technique. A 20% proportionate to the size of the individual settlement was then used to select households from the ensuing list. A total of 106 questionnaires were retrieved and selected for the study.

Table 1: Projected Sample and Population of the Sites

Community	Households	Proportionally sampled population @20%	Questionnaire Retrieved
Owode	84	16.8	14
Eseke	140	28	28
Korede	181	36.2	35
Abakurudu	153	30.6	29

Method of Data Collection

Data for this study were collected from primary and secondary sources. The primary source was a well-structured questionnaire and interviews designed to capture agroforestry practices among households. The secondary sources included relevant literature, research journals, and other publications concerning agricultural economics and rural development.

Data Analysis of the Study

The data collected for the study were analyzed using both descriptive and inferential statistical techniques in order to examine the resilience of agroforestry households to climate variability in the Omo Forest Reserve, Ogun State, Nigeria. Descriptive statistics, including frequencies, percentages, and mean scores, were used to summarise respondents' socio-economic characteristics and household resilience levels. In contrast, inferential statistics, including logistic regression and multiple linear regression, were employed to determine factors influencing resilience outcomes.

Measurement of Variables

Dependent Variable

Household resilience to climate variability constituted the dependent variable of the study. Resilience was measured using a composite resilience index constructed from multiple indicators reflecting households' ability to withstand, cope with, and recover from climate-related shocks. The indicators included resilience to weather threats, coping ability during extreme weather events, flood management capacity, drought coping ability, learning from past climate experiences, Access to early warning information, preparedness for climate shocks, and Access to recovery resources. Responses were measured on a five-point Likert scale ranging from *Not at all (1)* to *Very large extent (5)*. Mean scores were computed for each respondent, and the aggregate value formed the resilience index. Based on the computed scores, households were further categorized into high- and low-resilience groups using the sample mean as the decision threshold.

Independent Variables

The independent variables consisted of socio-economic and institutional characteristics hypothesized to influence resilience outcomes. Age of the household head was measured as a continuous variable in years, reflecting accumulated life experience and exposure to climatic events. Gender was measured as a dummy variable (male = 1, female = 0) to capture differences in Access to productive resources and decision-making Power. Educational level was measured as years of completed formal schooling, reflecting human capital and the capacity to process climate information. Household size was measured as the total number of persons living and feeding from the same household, indicating labour availability and consumption pressure. Farming experience was measured in years of engagement in farming activities, reflecting indigenous knowledge accumulation and adaptive learning capacity. Farm size was measured in hectares of cultivated land under agroforestry practices, reflecting production capacity and diversification opportunities.

Institutional variables were also incorporated. Extension contact was measured as the frequency of interaction with agricultural extension agents within a production season (contact = 1, otherwise = 0). Agroforestry adoption was measured as a binary variable indicating

ISTF-NIG 2026

whether the household practiced tree–crop integration (adopter = 1, non-adopter = 0). Access to credit was measured as the availability of financial support from formal or informal sources (Access = 1, no Access = 0). Off-farm income was measured as participation in income-generating activities outside farming (yes = 1, no = 0), capturing livelihood diversification.

Model Specification

Two econometric models were employed to analyze household resilience. First, a logistic regression model was used to examine factors influencing the likelihood of households belonging to the high-resilience category. The model was specified as:

$$\ln(1-PP)=\beta 0+\beta 1X1+\beta 2X2+\cdots+\beta nXn+\varepsilon$$

Where:

P represented the probability of a household being highly resilient,

β0 was the intercept,

βi were estimated parameters,

Xi represented explanatory variables, and

ε was the error term.

Secondly, a multiple linear regression model was employed to identify determinants of the continuous resilience index. The functional form was expressed as:

$$RI=\alpha+\beta 1AGE+\beta 2GEN+\beta 3EDU+\beta 4HHS+\beta 5FEXP+\beta 6FSIZE+\beta 7EXT+\beta 8AGF+\beta 9CRED+\beta 10OFF+\mu$$

Where:

RI = Household resilience index,

AGE = Age of household head,

GEN = Gender,

EDU = Education level,

HS = Household size,

EXP = Farming experience,

SIZE = Farm size,

EXT = Extension contact,

ISTF-NG 2026

AGF = Agroforestry adoption,

CRED = Access to credit,

OFF = Off-farm income,

μ = stochastic error term.

The models were estimated using maximum likelihood and ordinary least squares techniques, respectively. These approaches enabled the study to evaluate both the probability of resilience classification and the magnitude of the explanatory variables' influence on household resilience levels. The specification provided a comprehensive framework for explaining resilience dynamics within agroforestry-based livelihood systems under conditions of climate variability.

Result and Discussion

Socio-Economic Characteristics of Respondents

The socio-economic characteristics of agroforestry households, as presented in Table 2, provided critical insights into their adaptive capacity to climate variability within the Omo Forest Reserve. The dominance of male respondents (64.2%) over females (35.8%) suggested that men largely controlled agroforestry decision-making and Access to productive resources. This finding was consistent with earlier studies in rural Nigeria, where gender disparities in land ownership and resource control limited women's participation in major farming decisions (Ozor Nnanna & Nnaji Chinedu, 2011). The observed pattern could be attributed to prevailing cultural norms and inheritance systems that favoured men, thereby influencing who adopted and benefited from agroforestry practices. The age distribution showed that a majority of respondents (57.5%) were in the economically active age group of 40–59 years, while only 19.9% were 60 years or older. This implied that most respondents were still physically active and able to engage in labour-intensive agroforestry practices, such as tree planting and maintenance. This finding aligned with the work of Below Tobias et al. (2012), who reported that middle-aged farmers were more likely to adopt climate adaptation strategies because they combined experience with active livelihood responsibilities. The result could be explained by the fact that younger farmers often lacked resources, while older farmers tended to be risk-averse and less willing to adopt new practices. Educational attainment among respondents was relatively moderate: 45.3% had secondary Education, 43.4% had primary Education, and only 2.8% had tertiary Education. This distribution suggested that although higher Education was limited, basic literacy was widespread enough to support understanding of extension services and climate-related information. This finding agreed with reports from the Food and Agriculture Organization (2022), which emphasized that Education enhanced farmers' ability to process information and adopt improved agricultural technologies. The result may have occurred because rural areas often had limited Access to higher Education institutions.

However, primary and secondary education remained accessible, thereby shaping the level of knowledge available for adaptation. The high proportion of married respondents (73.6%) indicated stable household structures. This finding supported earlier assertions that married households tended to exhibit stronger resilience due to shared responsibilities, labour pooling, and social support systems (Adger Neil, 2003). The result could be explained by the role of family networks in providing labour and informal insurance during periods of climatic stress,

which enhanced the capacity to cope with shocks. Farming was the primary occupation for 76.4% of respondents, confirming a high level of dependence on agriculture and forest resources. This finding was consistent with the Food and Agriculture Organization's report (2018), which highlighted that rural households in Sub-Saharan Africa relied heavily on agriculture for their livelihoods. The implication was that any climate-induced disruption in agricultural production would directly affect household income and food security. This explained why agroforestry, as a diversified land-use system, played a critical role in enhancing resilience among these households. Household size analysis showed that 55.7% of respondents had 5-8 members, suggesting the availability of family labour for agroforestry operations. This finding was in line with Ellis Frank (2000), who noted that larger households in rural settings often benefited from increased labour supply. However, the negative relationship observed in the regression results suggested that larger household sizes could also exert pressure on available resources, thereby reducing adaptive capacity. This outcome could be explained by increased consumption demands, which limited households' ability to invest in improved technologies or climate adaptation measures.

Table 2: Socio-economic Characteristics of Respondents (n = 106)

Variable	Category	Frequency	Percentage (%)
Gender	Male	68	64.2
	Female	38	35.8
	Total	**106**	**100.0**
Age (years)	20–39	24	22.6
	40–59	61	57.5
	≥60	21	19.9
	Total	**106**	**100.0**
Educational Level	No formal Education	9	8.5
	Primary	46	43.4
	Secondary	48	45.3
	Tertiary	3	2.8
Marital Status	Single	10	9.4
	Married	78	73.6
	Divorced/Widowed	18	17.0
Primary Occupation	Farming	81	76.4
	Trading	13	12.3
	Artisan/Civil Service	12	11.3
Household Size	1–4 persons	28	26.4
	5–8 persons	59	55.7
	≥9 persons	19	17.9

Household resilience to climate variability among agroforestry households in the Omo Forest Reserve was generally moderate to high, indicating that most respondents possessed the capacity to withstand and recover from climate-related shocks. Findings from Table 3 showed that 72.6% of respondents perceived their households to be resilient to a large or very large extent, with a mean score of 3.90, suggesting strong adaptive capacity supported by agroforestry practices. The integration of trees and crops enhanced ecological stability and

reduced vulnerability to climatic extremes, consistent with earlier findings that diversified farming systems strengthened resilience and stabilized agricultural productivity (Lin, 2011; Nair, 2011). Households also demonstrated strong coping capacity during extreme weather events, with 70.8% of respondents reporting high coping capacity (mean = 3.83). This resilience was linked to accumulated local knowledge and adaptive strategies, such as crop diversification and flexible planting periods, supporting observations by Thornton and Herrero (2015) that repeated exposure to climate change improved adaptive learning among farmers. Flood management capacity recorded One of the highest resilience indicators (mean = 3.94; 71.7% response level), reflecting farmers' familiarity with seasonal flooding and the protective environmental functions of agroforestry systems, including improved soil structure and reduced runoff (FAO, 2022).

Similarly, resilience to drought conditions was relatively strong, with 67.0% of respondents reporting effective coping ability (mean = 3.81). Tree cover contributed to moisture retention and microclimate regulation, thereby enhancing drought tolerance, as noted in tropical agroecosystem studies (Mbow *et al.,* 2014). Adaptive learning also remained significant, with 67.0% indicating learning from past climate experiences (mean = 3.81), aligning with resilience theory's emphasis on learning as a core adaptive process (Folke *et al.,* 2010). However, some dimensions reflected only moderate resilience. Access to early warning information and preparedness for future climate shocks both recorded mean scores of 3.45, with only 53.8% reporting adequate Access to climate information services, indicating limited institutional and anticipatory capacity (Below *et al.,* 2012; IPCC, 2022). Access to recovery resources was similarly moderate (mean = 3.54), as households relied largely on social networks due to limited Access to credit and formal insurance, highlighting the importance of social capital in rural resilience systems (Adger, 2003).

Table 3: Household Resilience to Climate Variability (n = 106)

Resilience Statements	Very Large Extent	Large Extent	Little Extent	Very Little	Not at All	Mean
Household resilient to weather threats	32	45	18	8	3	3.90
Ability to cope with extreme weather	28	47	19	9	3	3.83
Capacity to manage flooding	40	36	18	8	4	3.94
Capacity to cope with drought	30	41	23	9	3	3.81
Learning from past climate events	27	44	25	8	2	3.81
Access to early warning information	18	39	28	15	6	3.45
Preparedness for climate shocks	15	42	30	14	5	3.45
Access to recovery resources	21	40	26	13	6	3.54

ISTF NIG 2026

Grand Mean Resilience Score = 3.72

The categorization of household resilience in Table 4 indicated that agroforestry households in the Omo Forest Reserve generally possessed strong adaptive capacity to climate variability. The results showed that 64.2% (68 respondents) were classified as highly resilient, while 35.8% (38 respondents) were classified as low resilient. This distribution suggested that the majority of households were able to cope with and recover from climate-related stresses, although a notable proportion remained vulnerable. The predominance of highly resilient households was attributed to the benefits of agroforestry-based livelihood systems, which integrate trees and crops, improving ecological stability, enhancing soil moisture retention, and diversifying income sources. These findings aligned with earlier studies, which reported that diversified agro ecosystems strengthened resilience by reducing exposure to climatic risks (Lin, 2011; FAO, 2022). Inferential analysis further revealed that socio-economic and institutional factors significantly influenced resilience outcomes. Education level, farming experience, extension contact, and agroforestry adoption positively increased the likelihood of households belonging to the high-resilience category ($p < 0.05$), indicating that resilience was shaped by Access to knowledge, resources, and institutional support rather than occurring randomly (Below *et al.,* 2012). Despite the overall positive outcome, the presence of 35.8% low-resilience households highlighted existing adaptation gaps within the community. Limited financial capacity, inadequate Access to climate information, and smaller farm sizes likely constrained these households' adaptive responses. This variation in resilience levels supported resilience theory, which emphasized that adaptive capacity differed according to disparities in human, social, and economic capital among households (Adger, 2003).

Table 4: Categorization of Household Resilience

Resilience Level	Frequency	Percentage (%)
High resilience	68	64.2
Low resilience	38	35.8
Total	**106**	**100.0**

The logistic regression analysis, as presented in Table 5, showed that the model adequately explained household resilience to climate variability among agroforestry households in the Omo Forest Reserve. The model demonstrated good predictive strength with a Nagelkerke R^2 of 0.56, indicating that about 56% of the variation in resilience was explained by the included variables, and a prediction accuracy of 78.3%. Education ($\beta = 0.145$; $p = 0.013$) significantly increased the likelihood of resilience, suggesting that better-educated farmers were more able to adopt adaptive strategies and understand climate information. Farming experience ($\beta = 0.063$; $p = 0.020$) also positively influenced resilience, suggesting that accumulated indigenous knowledge improved farmers' ability to cope with climatic shocks. Farm size ($\beta = 0.381$; $p = 0.011$) enhanced resilience by allowing diversification and risk spreading across production activities. Institutional and financial factors played major roles. Extension contact ($\beta = 0.917$; $p = 0.022$) significantly improved resilience, with households receiving advisory services being more than twice as likely to be resilient. Similarly, Access to credit ($\beta = 0.684$; $p = 0.043$) strengthened adaptive capacity by enabling investment in climate-responsive practices. Agroforestry adoption showed the strongest positive effect ($\beta = 0.532$; $p = 0.002$), confirming that diversified agroforestry systems substantially enhanced household resilience. Conversely, household size negatively affected resilience ($\beta = -0.072$; $p = 0.065$), indicating that larger

households faced higher dependency pressures. Age, Gender, and off-farm income were not statistically significant determinants.

Table 5: Logistic Regression Analysis of Factors Influencing Household Resilience

Variable	Coefficient (β)	Std. Error	Wald Statistic	Odds Ratio	p-value
Constant	-2.314	1.102	4.41	—	0.036**
Age	0.018	0.011	2.68	1.02	0.102
Gender	0.426	0.392	1.18	1.53	0.277
Education	0.145	0.058	6.24	1.16	0.013**
Household size	-0.072	0.039	3.41	0.93	0.065*
Farming experience	0.063	0.027	5.44	1.07	0.020**
Farm size	0.381	0.149	6.54	1.46	0.011**
Extension contact	0.917	0.401	5.23	2.50	0.022**
Agroforestry adoption	0.532	0.172	9.56	1.70	0.002***
Access to credit	0.684	0.338	4.09	1.98	0.043**
Off-farm income	0.291	0.315	0.85	1.34	0.357

Nagelkerke $R^{2=}$0.56, Prediction accuracy 78.3%,

Significance levels: ***p<0.01**, **p<0.05**, *p<0.10*

The multiple linear regression analysis, as presented in Table 6, showed that the model significantly explained variations in household resilience to climate variability among agroforestry households in the Omo Forest Reserve. The model demonstrated strong explanatory Power with R = 0.742 and R^2 = 0.551, indicating that about 55.1% of the changes in the resilience index were explained by the included socio-economic and institutional variables. The overall model was statistically significant (F = 10.98; p < 0.01). Education (B = 0.041; p = 0.001) positively and significantly influenced resilience, suggesting that educated households were better able to adopt adaptive strategies and interpret climate information. Farming experience (B = 0.022; p = 0.007) also improved resilience, indicating that accumulated farming knowledge enhanced coping capacity. Farm size (B = 0.118; p = 0.001) significantly increased resilience by enabling diversification and risk management. Institutional and financial factors were equally important. Extension contact (B = 0.263; p = 0.006) improved resilience by providing technical guidance, while Access to credit (B = 0.142; p = 0.034) supported investment in adaptation practices. Agroforestry adoption had the strongest positive effect (B = 0.175; p = 0.000), confirming that diversified agroforestry systems substantially strengthened household adaptive capacity. Conversely, household size negatively affected resilience (B = −0.019; p = 0.037), indicating that larger households faced greater resource pressure. Age, Gender, and off-farm income were not statistically significant determinants.

Table 6: Multiple Linear Regression Analysis of Determinants of Resilience Index

Variable	Unstandardized B	Std. Error	Beta	t	Sig.
Constant	1.284	0.421	—	3.05	0.003**
Age	0.006	0.004	0.102	1.45	0.150
Gender	0.083	0.072	0.075	1.15	0.253

ISTF-NIG 2026

Variable	Unstandardized B	Std. Error	Beta	t	Sig.
Education	0.041	0.012	0.268	3.42	0.001***
Household size	-0.019	0.009	-0.156	-2.11	0.037**
Farming experience	0.022	0.008	0.214	2.75	0.007***
Farm size	0.118	0.035	0.246	3.37	0.001***
Extension contact	0.263	0.094	0.201	2.80	0.006***
Agroforestry adoption	0.175	0.041	0.331	4.27	0.000***
Access to credit	0.142	0.066	0.148	2.15	0.034**
Off-farm income	0.051	0.061	0.056	0.83	0.409

$R= 0.742$, $R^2= 0.551$, Adjusted $R^2=0.523$, Std.error=0.412, F=10.98

Significance level *p<0.01,p<0.05,p<0.10

Conclusion

The study concluded that agroforestry households in the Omo Forest Reserve generally demonstrated moderate to high resilience to climate variability. The integration of trees with crops enhanced ecological stability, improved soil moisture conservation, and diversified income sources, thereby reducing vulnerability to climatic shocks. Socio-economic and institutional factors, particularly Education, farming experience, farm size, extension services, agroforestry adoption, and Access to credit, significantly influenced resilience outcomes. Although most households showed strong coping and recovery capacity, a proportion of households remained vulnerable due to limited Access to information, financial resources, and institutional support. Overall, resilience within the study area was largely driven by agroforestry-based livelihood systems and accumulated adaptive knowledge.

Recommendations

The study recommended that government and development agencies should strengthen agricultural extension services to improve farmers' Access to climate information and adaptive technologies. Policies promoting agroforestry adoption should be expanded through training, seedling distribution, and technical support to enhance climate-smart land management. Access to rural credit facilities should also be improved to enable households to invest in resilience-building practices. Furthermore, community-based climate information systems and early warning services should be enhanced to promote anticipatory adaptation rather than reactive coping strategies. Strengthening institutional and financial support mechanisms would significantly improve long-term resilience among agroforestry households in forest-dependent communities.

References

Adger, W. N. (2003). Social capital, collective action, and adaptation to climate change. *Economic Geography, 79*(4), 387–404. https://doi.org/10.1111/j.1944-8287.2003.tb00220.x

Aluko, O. J. (2016). Impact of conflict on the availability of selected non-timber forest products around the Omo Forest Reserves of Ogun State, Nigeria. *Young African Leaders Journal of Development, 1*, Article 22. https://doi.org/10.32727/24.2018.22

ISTF-NIG 2026

Below, T. B., Mutabazi, K. D., Kirschke, D., Franke, C., Sieber, S., Siebert, R., & Tscherning, K. (2012). Can socio-economic household-level variables explain farmers' adaptation to climate change? *Global Environmental Change, 22*(1), 223–235. https://doi.org/10.1016/j.gloenvcha.2011.11.012

Ellis, F. (2000). *Rural livelihoods and diversity in developing countries*. Oxford University Press.

Federal Ministry of Environment. (2015). *Nigeria's intended nationally determined contribution (INDC)*. Government of Nigeria.

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: Integrating resilience, adaptability and transformability. *Ecology and Society, 15*(4), 20. https://doi.org/10.5751/ES-03610-150420

Food and Agriculture Organization. (2013). *Climate-smart agriculture sourcebook*. FAO.

Food and Agriculture Organization. (2016). *Climate change and food security: Risks and responses*. FAO.

Food and Agriculture Organization. (2017). *Agroforestry for landscape restoration*. FAO.

Food and Agriculture Organization. (2018). *The State of the World's Forests 2018*. FAO.

Food and Agriculture Organization. (2022). *The state of food and agriculture 2022: Leveraging automation in agriculture for transforming agrifood systems*. FAO. https://doi.org/10.4060/cb9479en

Hughes, T. P., Bellwood, D. R., Folke, C., Steneck, R. S., & Wilson, J. (2005). New paradigms for supporting the resilience of marine ecosystems. *Trends in Ecology & Evolution, 20*(7), 380–386. https://doi.org/10.1016/j.tree.2005.03.022

Intergovernmental Panel on Climate Change. (2014). *Climate change 2014: Impacts, adaptation, and vulnerability*. Cambridge University Press.

Intergovernmental Panel on Climate Change. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Cambridge University Press. https://doi.org/10.1017/9781009325844

Lin, B. B. (2011). Resilience in agriculture through crop diversification: Adaptive management for environmental change. *BioScience, 61*(3), 183–193. https://doi.org/10.1525/bio.2011.61.3.4

Lin, B. B., Perfecto, I., & Vandermeer, J. (2013). Synergies between agricultural intensification and climate change adaptation. *Global Change Biology, 19*(6), 1828–1835. https://doi.org/10.1111/gcb.12179

Mbow, C., Smith, P., Skole, D., Duguma, L., & Bustamante, M. (2014). Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. *Current Opinion in Environmental Sustainability, 6*, 8–14. https://doi.org/10.1016/j.cosust.2013.09.002

Mercer, D. E. (2004). Adoption of agroforestry innovations in the tropics: A review. *Agroforestry Systems, 61*(1–3), 311–328. https://doi.org/10.1023/B:AGFO.0000029007.85754.70

Nair, P. K. R. (1993). *An introduction to agroforestry*. Kluwer Academic Publishers.

Nair, P. K. R. (2011). Agroforestry systems and environmental quality: Introduction. *Journal of Environmental Quality, 40*(3), 784–790. https://doi.org/10.2134/jeq2011.0076

Ozor, N., & Nnaji, C. (2011). The role of extension in agricultural adaptation to climate change in Enugu State, Nigeria. *Journal of Agricultural Extension and Rural Development, 3*(3), 42–50.

Thornton, P. K., & Herrero, M. (2015). Adapting to climate change in the mixed crop and livestock farming systems in sub-Saharan Africa. *Nature Climate Change, 5*(9), 830–836. https://doi.org/10.1038/nclimate2754

ISTF-NIG 2026

World Agroforestry Centre (ICRAF). (2013). *Agroforestry: The future of global land use*. ICRAF.

World Agroforestry Centre (ICRAF). (2015). *Agroforestry for climate change adaptation and mitigation*. ICRAF.

ISTF-NIG 2026

SIGNIFICANT ROLE OF BIOENERGY IN CLIMATE CHANGE MITIGATION

***Adebisi, A. A, Angruwa, G.T, Ademola, I.T, Kupoluyi, M.O., and Oyewumi, R.O**

Forestry Research Institute of Nigeria, Ibadan.
Corresponding Author: aadebisi14@yahoo.com Tel: +2348036116533

Abstract

This paper reviewed the significant role of Bioenergy in climate change mitigation. Bioenergy plays a significant and multifaceted role in mitigating climate change, functioning as a renewable alternative to fossil fuels that can deliver large-scale greenhouse gas (GHG) savings. Bioenergy deployment offers significant potential in climate change mitigation, but also carries considerable risks. It has been under intense scrutiny over the last ten years, with significant research efforts in many countries aimed at defining and measuring sustainable practices. Sustainable biomass production can make a significant contribution. Substantive evidence exists that many bioenergy cropping systems can deliver multiple benefits and offset environmental problems associated with fossil fuel use, as well as intensive food production and urbanization. Climate targets set limits on future GHG emissions. To stabilize GHG concentrations in the atmosphere, emissions need to peak and decline thereafter. Climate change mitigation is not the only issue to consider when assessing the merits of Bioenergy. Other important aspects include security of energy supply, job Creation and income generation, and consequences for biodiversity, water, and soils. Also, it is important to note that climate change mitigation is just One of many rationales for ecosystem protection.

Keywords: bio-energy, climate change and mitigation.

Introduction

Bioenergy differs from other renewable energy technologies in that it is part of the terrestrial carbon cycle. The carbon dioxide (CO_2) emitted due to bioenergy use was previously sequestered from the atmosphere. It will be sequestered again if the bioenergy system is managed sustainably, even though emissions and sequestration are not necessarily in temporal balance (e.g., due to long rotation periods of forest stands; Dale *et al*., 2010). Bioenergy is crucial for climate change mitigation by replacing fossil fuels with renewable organic materials, providing 5–30% of cumulative carbon emission reductions. It offers a versatile, low-carbon alternative for electricity, heat, and transport, while BECCS (Bioenergy with Carbon Capture and Storage) enables negative emissions. (Souza *et al*, 2017). Bioenergy is important for many sectors and mitigation perspectives, as well as for developmental goals such as energy security and rural development. It is argued that increasing biofuel use will reduce GHG emissions by lowering the transport sector's carbon intensity and addressing energy security concerns (Dale *et al*., 2010). In addition to the threat of global climate change, interest in biofuels is enhanced by growing global energy demand and diminishing crude oil supply. However, there is concern about the existing interlink between biomass, Bioenergy, land use, food supply, water use, and biodiversity. The world is facing an unprecedented climate crisis, with rising global temperatures, more frequent natural disasters, and devastating impacts on ecosystems and human societies (Popp *et al.,* 2014). Climate change mitigation refers to actions or activities that limit the emissions of greenhouse gases (GHGs) from entering the atmosphere and/or reduce their levels in the atmosphere (Popp *et al.,* 2014). The burning of fossil fuels is a significant contributor to this crisis, releasing large amounts of greenhouse gases, such as carbon dioxide (CO_2) and methane (CH_4), into the atmosphere. To mitigate climate change, it is essential to transition to renewable energy sources to reduce our reliance

on fossil fuels (Wirsenius *et al. al* 2010). Bioenergy, produced from organic matter, has emerged as a promising alternative. Global climate and environmental changes, driven by the use of fossil fuels and inequitable development, make it unethical not to pursue more equitable energy development that includes Bioenergy. To achieve sustainable development and competitiveness, the costs of bioenergy production must be addressed in ways that consider not only economic gains but also the development of local knowledge and social and environmental benefits (GNESD, 2011).

Bioenergy Contribution to Climate Stabilisation

Bioenergy contributions to climate change mitigation by replacing fossil fuels, potentially reducing global C_{O2} emissions by 6-9% by 2050. It provides renewable energy for transport, heat, and Power, utilizing organic waste and agricultural residues, while sustainable management can enhance carbon sequestration in soils. However, if not managed properly, Bioenergy can increase emissions through deforestation and land use changes (CKIEA, 2015). Climate targets set limits on future Green House Gas (GHG) emissions. To stabilize GHG concentrations in the atmosphere, emissions need to peak and decline thereafter. Many different emission trajectories are compatible with a given stabilization target. Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilization levels. Drastic changes in the global energy system are needed. However, the establishment of the required new energy technologies and associated infrastructure will, in itself, lead to GHG emissions, implying that a portion of the emission space allowed within the GHG target will need to be invested in energy system transformation. For example, electric vehicle fleets may contribute to rising atmospheric CO_2 levels if electricity is mainly generated from fossil fuels (Stern, 2007). However, promoting electric vehicles can be justified because they can provide efficient transport services with low GHG emissions, provided nations overcome the challenge of shifting their electricity matrix towards cleaner energy sources and relying less on fossil fuels.

Benefits and challenges of Bioenergy

The production and use of Bioenergy present opportunities to tackle major issues such as reducing greenhouse gas emissions, mitigating climate change, providing energy security, saving foreign exchange and creating jobs, and also offer a unique solution to waste management by converting organic wastes into usable energy (Miller, 2007; Bringezu *et al*, 2009; Reid *et al*., 2019). However, there are also serious risks to land use, food, the environment, and biodiversity associated with Bioenergy (Berndes *et al*., 2011; Popp *et al*., 2014; Singh & Walia, 2016). Therefore, an appropriate understanding of the benefits and threats of Bioenergy among stakeholders and the general public is very important for the future growth of the bioenergy industry. Bioenergy offers several benefits, but it also faces significant challenges. Understanding these benefits and challenges is crucial to assessing Bioenergy's potential to mitigate climate change.

- ✓ **Reduced greenhouse gas emissions:** Bioenergy can reduce CO_2 emissions by substituting for fossil fuels.
- ✓ **Energy security:** Bioenergy: Bioenergy can improve energy security by diversifying the energy mix and reducing dependence on imported fuels.
- ✓ **Rural development**: Bioenergy production can create jobs and stimulate economic growth in rural areas.

The challenges associated with Bioenergy include:-

- ✓ **Land use change:** The production of bioenergy crops can lead to land-use changes, potentially resulting in deforestation and habitat loss.
- ✓ **Water Usage:** Bioenergy production can require substantial water, potentially straining local water resources.
- ✓ **Cost:** Bioenergy can be more expensive than traditional fossil fuels, making it challenging to compete in the energy market.
- ✓ **Emissions:** While Bioenergy has a lower carbon footprint than fossil fuels, some bioenergy production processes can still emit greenhouse gases.
- ✓ **Feedstock competition:** Bioenergy production can compete with food production for land and resources.

Introduction to Bioenergy as a sustainable Alternative to Fossil fuel

Bioenergy is produced from biomass, which includes organic matter such as plants, waste, and algae. Biomass can be converted into energy, including heat, electricity, and transportation fuels. Bioenergy is considered a renewable energy source because biomass can be replenished relatively quickly through sustainable practices, such as reforestation and crop rotation.

Types of Bioenergy and Their Production Processes

Bioenergy encompasses a diverse range of energy sources and production pathways. Understanding the different types of Bioenergy and their production processes is essential to appreciating the potential of Bioenergy to mitigate climate change (Singh & Walia, 2016).

The main types of Bioenergy are:

- ✓ **Biomass**: Solid organic matter used for heat and electricity generation
- ✓ **Biofuels**: Liquid fuels used for transportation, such as ethanol and biodiesel.
- ✓ **Biogas**: Gas produced through anaerobic digestion of organic matter, used for heat, electricity, and fuel.

Discussion of various conversion processes, including:

Fermentation: Microorganisms break down biomass to produce biofuels, such as ethanol.

Transesterification: Vegetable oils or animal fats are converted into biodiesel.

Gasification: Biomass is heated in the presence of a controlled amount of oxygen to produce syngas, a mixture of CO and H_2.

Anaerobic digestion: Microorganisms break down organic matter in the absence of oxygen to produce biogas.

Biomass: firewood, charcoal, pellets, or briquettes.

Strategies to address these challenges

Bioenergy has significant climate potential, which requires implementing comprehensive sustainability assessments, advancing second-generation biofuels that do not compete with food, and leveraging technologies such as Bioenergy with Carbon Capture and Storage (BECCS). Key approaches include using agricultural residues and tax breaks, and fostering international cooperation to improve technical and infrastructure capacity, IRENA 2017.

To address the challenges associated with Bioenergy, several strategies can be employed:

✓ **Technological innovation:** Advancements in conservation technologies and production processes can improve the efficiency and reduce the cost of Bioenergy
✓ **Sustainable land use practices:** Implementing practices such as agroforestry and permaculture can minimize the impacts of land-use change.
✓ **Water Conservation:** Improving water efficiency and using drought-tolerant crops can reduce water usage.

The Future of Bioenergy and Climate Change Mitigation

The bioenergy industry is evolving rapidly, driven by technological innovation, changing energy policies, and growing demand for renewable energy. Understanding the future of Bioenergy is essential, given its potential to mitigate climate change.

Role of Bioenergy in Achieving Global Climate Goals

Bioenergy plays a significant role in achieving global climate goals, such as the Paris Agreement. By substituting for fossil fuels, Bioenergy can reduce CO_2 emissions and help mitigate the worst impacts of climate change.

Conclusion

Bioenergy has the potential to play a significant role in mitigating climate change by reducing greenhouse gas emissions and improving energy security. Despite many potential benefits, One must not take it for granted that Bioenergy will automatically contribute to climate change mitigation, environmental quality, energy security and socio- economic development of a region. While there are challenges associated with bioenergy production, these can be addressed through sustainable land use practices, water conservation, and technological innovation. As the bioenergy industry continues to evolve, it is likely to play an increasingly important role in achieving global climate goals. To mitigate climate change, it is essential to transition to renewable energy sources that can reduce our reliance on fossil fuels. Bioenergy, produced from organic matter, has emerged as a promising alternative. Global climate and environmental changes, driven by the use of fossil fuels and inequitable development, make it unethical not to pursue more equitable energy development that includes Bioenergy (World Bank, 2010). To achieve sustainable development, competitiveness and costs of bioenergy production need to be addressed in a manner that considers not only economic gains but also the development of local knowledge and social and environmental benefits. No doubt, Bioenergy may provide an alternative to fossil fuels to some extent and mitigate climate change. However, this may only be achieved with (i) sustainable growth of biomass feedstock, (ii) implementation of bioenergy certification programmes, (iii) no/minimal natural land conversion to arable land, (iv) using more bio waste for bioenergy production and (v) technologies required for the production of second- and third- generation biofuels being made available in the market Verma,(2021).

References

Berndes G, Bird N, & Cowie A (2011). Bioenergy, Land Use Change and Climate Change Mitigation. IEA Bioenergy, New Zealand.www.osti.gov/etdeweb/servlets/ purl/ 22110 326.

Biofuels, Bio products and Bio refining 3: 219-30; and Environmental Science and Technology 44: 8385-89. (Paper by Dale *et al*. (2010)).

Bringezu S, Schütz H, O'Brien M, Kauppi L, Howarth RW, & McNeely J (2009). Towards sustainable production and use of resources: Assessing biofuels. United Nations

Environment Programme, pp. 1– 118. https:// wed ocs.unep.org/ handle/ 20.500.11822/ 8680

Climate-KIC and International Energy Agency, 2015. Prosperous living for the world in 2050: insights from the global calculator. https://www.gov.uk/government/ uploads/system/uploads/attachment_data/file/398596/Global_calc_report_WEB.pdf (accessed 03.03.16).

GNESD (2011). Bioenergy: The potential for rural development and poverty alleviation. Global Network on Energy for Sustainable Development (GNESD). Summary for policy-makers. GNESD- SPM- BET- 11/ 2011, pp. 1– 29. https:// back end.orbit.dtu.dk/ws/port alfi les/ portal/ 7590 946/ Bioenergy.pdf

IRENA (2017). Biofuel Potential in Sub-Saharan Africa: Raising food yields, reducing food waste and utilizing residues. International Renewable Energy Agency, Abu Dhabi.

Miller GT (2007). People and Environment, Indian Edition. Cengage Learning India Private Limited, New Delhi.

Popp J, Lakner Z, Harani- Rakos M, & Fart M (2014). The effect of bioenergy expansion: Food, energy, and environment. Renewable and Sustainable Energy Reviews 32: 559– 578.

Reid WV, Ali MK, & Field CB (2019). The future of Bioenergy. Global Change Biology 26: 274– 286.

Singh RS, & Walia AK (2016). Biofuels: Historical perspectives and public opinions. In: Biofuels: Production and Future Prospects, eds. Singh RS, Pandey A, & Gnansounou E, CRC Press, Boca Raton, Florida, pp. 3– 23.

Souza GM, Ballester MVR, Cruz CHB, Chum H, Dale B, Dale VH, Fernandes ECM, Foust T, Karp A, Lynd L, Filho RM, Milanez A, Nigro F, Osseweijer P, Verdade LM, Victoria RL, & Wielen LW (2017). The role of Bioenergy in a climate- changing world. Environmental Development 23: 57– 64.

Stern, N (2007). The Economics of Climate Change: The Stern Review. Cambridge University Press, UK.

Verma, O (2021). Climate Change and its impacts with special reference to India. In Water, Cryosphere, and Climate Change in the Himalayas, eds. Talool AK, Kotlia BS, & Kumar K, Springer Nature, Switzerland, pp. 37– 55.

Wirsenius, S., Azar, C. and Berndes, G. (2010). How much land is needed for global food production under scenarios of dietary changes and increases in livestock productivity in 2030?? Agricultural Systems 103(9): 621-638.

World Bank (2010). Bioenergy Development: Issues and Impacts for Poverty and Natural Resource Management. Agriculture and Rural Development, The World Bank, Washington, D.C.

ISTF-NIG 2026

ADAPTING AQUACULTURE TO CLIMATE CHANGE: EVIDENCE FROM SMALLHOLDER FISH FARMERS IN OYO STATE, NIGERIA

[1*]Oyewo, I.O, [2]Kolade, R.I, [3]Farayola, C.O, [2]Adesope, A. A, [2]Oke, D.O, [2]Adesina, Y.O, [2]Oyetoki, A.O

[1]Department of Agribusiness Management, Federal College of Forestry, Forestry Research Institute of Nigeria, P.M.B 5054, Ibadan, Oyo State, Nigeria*
[2]Department of Forest Economics and Extension, Forestry Research Institute of Nigeria
[3]ADEM Department, Agricultural and Rural Management Training Institute (ARMTI), P.M.B 1343, Ilorin -Ajase Ipo Highway, Ilorin, Kwara State
**Corresponding author: ojerry2@gmail.com; oyewo.io@frin.gov.ng, +2348035751159*

Abstract

Climate change poses growing challenges to small-scale aquaculture systems in Nigeria, where fish farming plays a critical role in food security, income generation, and rural livelihoods. This study examines fish farmers' adaptive responses to climate change and productivity constraints in the Akinyele Local Government Area of Oyo State, Nigeria. A four-stage random sampling technique was used to select 100 fish farmers, of whom 98 provided valid responses. Primary data were collected through structured questionnaires and interviews. Descriptive statistics were used to analyze socio-economic characteristics, information sources, perceptions, coping strategies, and adaptation challenges, while multiple regression analysis was used to identify determinants of stocking size, a proxy for farm performance. The results reveal a high level of awareness among farmers regarding climate change impacts, particularly rising water temperatures, irregular rainfall, increased disease outbreaks, and higher production costs. Farmers rely predominantly on social networks, especially associations, friends, and neighborhood interactions as primary sources of climate information, with formal extension services playing a limited role. Adaptation strategies are largely autonomous and include pond siting near water sources, construction of embankments, groundwater utilization, stocking of fast-maturing species, and adjustments in stocking time. However, major constraints to effective adaptation include limited access to reliable climate information, high capital costs of pond construction, inadequate training, and financial limitations. Regression results indicate that total fish production significantly influences stocking size, while most socio-economic variables exhibit weak or insignificant effects. The study concludes that although fish farmers demonstrate strong experiential awareness and adaptive capacity, long-term resilience remains constrained by institutional and financial barriers. Strengthening climate information services, expanding aquaculture-specific extension support, and improving access to climate-resilient financing are essential for enhancing the sustainability of small-scale fish farming under changing climatic conditions.

Keywords: Climate change adaptation; Aquaculture sustainability; Smallholder fish farmers; Coping strategies; Climate resilience; Fish production

Introduction

Aquaculture has become One of the fastest-growing food production systems globally and plays a critical role in addressing protein deficiency, income generation, and livelihood diversification in developing economies (FAO, 2023; World Bank, 2016). In Nigeria,

smallholder fish farming contributes substantially to domestic fish supply and rural employment, particularly in peri-urban communities where demand for affordable animal protein continues to rise (Maina *et al*., 2014; Onyebinam *et al*., 2017). Through its contributions to household income and food availability, aquaculture directly supports Sustainable Development Goals (SDGs) 1: No Poverty, 2: Zero Hunger, and 8: Decent Work and Economic Growth (United Nations, 2015). However, the sustainability of this subsector is increasingly threatened by climate change, manifested through rising temperatures, erratic rainfall patterns, water scarcity, flooding, and heightened disease incidence (IPCC, 2018; Ovie & Ovie, 2023). Climate variability directly affects aquaculture through changes in water temperature, dissolved oxygen levels, and pond hydrology, while indirectly increasing production costs and operational risks (Ahmed *et al*., 2023; Yazdi & Shakouri, 2010). These impacts reduce production efficiency and undermine responsible resource use, posing challenges to SDG 12: Responsible Consumption and Production (Okunsebor *et al*., 2015). Smallholder fish farmers are particularly vulnerable due to limited access to climate information, financial capital, technical skills, and institutional support services (IFAD, 2014; Brugère & De Young, 2015). Unlike large commercial systems, most small-scale producers rely primarily on experiential knowledge and autonomous adaptation strategies, which may be inadequate in the face of increasingly frequent and severe climatic extremes (Issahaku & Campion, 2022; Jiang *et al*., 2021).

Despite growing concern over climate change impacts on Nigerian agriculture, empirical evidence on how smallholder fish farmers perceive climate risks, the adaptation strategies they adopt, and the constraints limiting effective responses remains limited, particularly at the local government level (Asiedu *et al*., 2023). This evidence gap constrains the effective implementation of Nigeria's National Climate Change Policy and National Adaptation Plan, which emphasizes strengthening adaptive capacity in climate-sensitive subsectors such as aquaculture (Federal Government of Nigeria, 2021). Addressing these gaps is essential for advancing SDG 13: Climate Action, particularly in vulnerable rural and peri-urban livelihoods. This study, therefore, examines climate change adaptation among smallholder fish farmers in the Akinyele Local Government Area of Oyo State, Nigeria. Specifically, it analyzes farmers' perceptions of climate change, sources of climate information, coping strategies, and adaptation challenges, while empirically identifying the socio-economic and production factors influencing stocking size as a proxy for farm performance. By linking perceptions, adaptation behaviors, and productivity outcomes, the study provides evidence-based insights to support climate-responsive aquaculture policy, strengthen extension programming, and advance progress toward the SDGs 1, 2, 8, 12, and 13 at the local level.

Methodology

Study Area.

The study focuses on the Akinyele Local Government Area in Ibadan, spanning approximately 465–518 km^2, with its headquarters in Moniya. Bordered by four LGAs, it features a tropical climate with distinct rainy, dry, and harmattan seasons (Efenakpo *et al*., 2016). The population, estimated at 239,745 in 2010, primarily engages in farming fruits, vegetables, and livestock (NBS, 2009). Administratively divided into 12 wards: ward 1(Ikereku), ward 2 (Olanla/Oboda/Labode), ward 3 (Arulogun/Eniosa/Aroro), ward 4 (Olode/Amosun/Onidundu), ward 5 (Ojo-Emo/Moniya), ward 6(Akinyele/Isabiyi/Irepodun), ward 7(Iwokoto/Talonta/Idi-oro), ward8(Ojoo/Ajibode/Laniba), ward9(Ijaye/Ojedeji), ward10(Ajibade/Alabata/Elekuru), ward 11(Olorisa-Oko/Okegbemki/Mele), ward 12(Iroko).

The study's target population comprises fish farmers in Akinyele Local Government Area, Oyo State, Nigeria.

Study Population

The study utilizes a four-stage random sampling procedure to select 100 fish farmers from the Akinyele Local Government Area of Oyo State. In the first and second stages, five wards, Ikereku, Arulogun, Olode, Moniya, and Iroko, were randomly selected from the 12 administrative wards in the LGA. The third and fourth stages involved identifying and randomly selecting three villages within each chosen ward, specifically targeting Oyada, Alakeji, and Talontan (Ikereku); Igbooloyin, Aroro Yerokun, and Aroro Kole (Arulogun); Olode, Onigborogbo, and Amosun (Olode); Moniya, Ajibade, and Olorisaoko (Moniya); and Oretu, Iroko, and Alasoosu (Iroko). Out of 100 questionnaires administered, 98 were valid and used for analysis.

Data Collection

Information was gathered from primary sources through structured questionnaires and interviews, as well as from secondary sources, including research journals and relevant publications. The questionnaire was divided into sections to measure variables such as socio-economic characteristics (Age, gender, and Education), sources of information (using a 4-point scale), and perceptions of climate change (using a 5-point Likert scale). Coping strategies were measured with binary "Yes/No" responses, while challenges were assessed on a 3-point scale. The Pearson Product-Moment Correlation (PPMC) was used as a preliminary reliability check due to the nature of scale construction.

Data analysis

Data were processed using the Statistical Package for Social Sciences (SPSS). Descriptive statistics, including frequencies, percentages, and mean scores, were utilized to analyze objectives One through five. To test the research hypotheses and determine the relationship between variables, multiple regression analysis was employed. This dual approach provides both a clear summary of respondents' profiles and a rigorous statistical evaluation of the factors influencing climate change perceptions and adaptation.

The multiple regression model is specified as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n + \varepsilon$$

where Y represents stocking size (performance), X_1–X_n are the explanatory socio-economic variables, β_0 is the intercept, β_1–β_n are regression coefficients, and ε is the error term.

Where:

Y = Stocking size (performance of fish farmers)

β_0 = Constant term

$\beta_1 X_1$ = Sex of farmer (dummy)

$\beta_2 X_2$ = Age of farmer (years)

$\beta_3 X_3$ = Marital status (dummy)

$\beta_4 X_4$ = Educational level (years)

$\beta_5 X_5$ = Years of rearing experience (years)

β_6X_6 = Household size (actual)

β_7X_7 = Secondary occupation (dummy)

β_8X_8 = Membership of association (dummy)

β_9X_9 = Source of labour (dummy)

$\beta_{10}X_{10}$ = Source of water (dummy)

$\beta_{11}X_{11}$ = Amount of fish produced (Naira)

ε = Error term

RESULTS AND DISCUSSIONS

Table 1: Socio-Economic Characteristics of the Respondents in the Study Area

Variables	Frequency	Percentage (%)
Sex		
Male	74	75.5
Female	24	24.5
Age		
20-30 years	24	24.4
31-40 years	16	16.3
41-50 years	31	31.7
Above 50 years	27	27.6
Marital Status		
Single	18	18.4
Married	68	69.4
Divorced	9	9.2
Widow	3	3.1
Religion		
Christianity	52	53.1
Islam	44	44.9
Traditional	2	2.0
Educational Level		
No formal Education	34	34.7
Primary Education	36	36.7
Secondary Education	28	28.6
Monthly Income		
10000-50000	10	10.2

ISTF-NIG 2026

51000-100000	34	34.7
101000-150000	13	13.3
151000-200000	13	13.3
Above 200000	28	28.5
1-5 years	37	37.8
6-10 years	36	36.7
11-15years	15	15.3
Above 15 years	10	10.2
Household Size		
1-5	59	60.2
6-10	37	37.7
Above 10	2	2.0
Secondary Occupation		
Farming	45	45.9
Artisan	38	38.8
Civil servants	5	5.1
Trading	10	10.2
Membership to Association		
Yes	66	67.3
No	32	32.7
Sources of Labour		
Family	39	39.8
Hired	45	45.9
Both	14	14.3
Numbers		
1-5	90	91.8
6-10	8	8.2
Stocking Size		
1-100	37	37.7
101-200	22	22.6
201-300	5	5.1
301-400	1	1.0
401-500	2	2.0
Above 500	31	31.6
Amount of Fish		

ISTF-NIG 2026

1000-100000	6	6.1
101000-200000	21	21.3
201000-300000	22	22.4
301000-400000	1	1.0
401000-500000	11	11.2
Above 500000	37	37.7
Source of Water		
Borehole	70	71.4
Well	25	25.5
Stream	3	3.1
Quantity		
10-100	33	33.7
101-200	42	42.9
201-300	12	12.2
Above 300	11	11.2
Amount		
₦1000-₦100000	8	8.1
₦101000-₦200000	56	57.3
₦201000-₦300000	14	14.3
₦301000-₦400000	10	10.2
₦401000-₦500000	3	3.0
Above ₦500000	7	7.1

Source: Field Survey, 2025.

The socio-economic characteristics of the respondents, as revealed in Table 1, are male-dominated, with 74.5% of participants being male, a trend that underscores the gender barriers women face in accessing climate adaptation resources and decision-making roles within fisheries (FAO, 2023). Demographically, the study shows that the largest proportion of fish farmers are middle-aged, aged 41-50, while those aged 20–30 represent the smallest group. This age distribution aligns with broader patterns in Sub-Saharan African agriculture, where middle-aged adults typically serve as the primary leadership and resource base for rural systems (Ayanlade *et al*., 2023). Regarding household composition, 60.2% of respondents reported having 1–5 members, a size that reflects the ongoing shift toward nuclear-family structures driven by urbanization and changing social norms across developing regions (UN DESA, 2023). While larger households were historically common in agrarian societies, the trend toward smaller households is increasingly prevalent in contemporary semi-urban settings. Finally, 63.3% of the fish farmers surveyed are active members of professional associations, which serves as a vital indicator of social cohesion and collective resilience. Such memberships are essential for improving smallholders' access to credit, technical training, and market information. As noted by the FAO (2023), these organizational structures are crucial for strengthening a community's capacity to mitigate production risks and navigate the economic challenges associated with a changing climate.

Table 2: Sources of Information on Climate Change in the Study Area.

Variables	Always	Often	Rarely	Never	Mean	Ranking
Friends	80 (81.6)	8 (8.2)	3 (3.1)	7 (7.1)	3.64	2nd

ISTF-NIG 2026

Associations	75 (76.5)	15 (15.3)	5 (5.1)	3 (3.1)	3.65	1st
Neighbourhood	56 (57.1)	36 (36.7)	4 (4.1)	2 (2.0)	3.49	3rd
Agro stores	50 (51.0)	26 (26.5)	11 (11.2)	11 (11.2)	3.14	6th
Television	42 (42.9)	26 (26.5)	11 (11.2)	19 (19.4)	3.07	8th
Radio	30 (30.6)	28 (28.6)	25 (25.5)	15 (15.3)	3.11	7th
Seminars	41 (41.8)	22 (22.4)	19 (19.4)	16 (16.3)	2.90	10th
Extension	34 (34.7)	25 (25.5)	17 (17.3)	22 (22.4)	2.72	12th
Internet	51 (52.0)	22 (22.4)	14 (14.3)	11 (11.2)	3.15	5th
Social media	57 (58.2)	13 (13.3)	15 (15.3)	13 (13.3)	3.16	4th
Magazines	44 (44.9)	6 (6.1)	17 (17.3)	31 (31.6)	2.64	15th
Pamphlets	31 (31.6)	19 (19.4)	21 (21.4)	27 (27.6)	2.55	17th
Mobile	30 (30.6)	22 (22.4)	29 (19.6)	17 (17.3)	2.66	13th
Email	38 (38.8)	14 (14.3)	20 (20.4)	26 (26.5)	2.65	14th
Billboard	32 (32.7)	17 (17.3)	27 (27.6)	22 (22.4)	2.60	16th
Posters	42 (42.9)	13 (13.3)	25 (25.5)	18 (18.4)	2.81	9th
Newspaper	40 (40.8)	13 (13.3)	28 (28.6)	17 (17.3)	2.78	11th

Source: Field Survey, 2025.

The study revealed, as shown in Table 2, that fish farmers in the area rely primarily on social networks for climate change information, with membership-based associations ranking first (mean 3.65). These groups are essential for disseminating technical knowledge and fostering collective adaptation strategies among farmers (Adesina *et al*., 2022). Friends ranked second among the most trusted Sources (mean 3.64), highlighting the critical role of informal, interpersonal communication in building trust and ensuring the practical adoption of climate-resilient practices within rural communities (Adeola, 2021). Local neighborhood interactions ranked third (mean 3.49), serving as a vital grassroots channel for information exchange during daily activities such as market days and community gatherings. These localized settings are crucial for translating scientific climate data into actionable, context-specific advice for rural farmers (Elujulo *et al*., 2023). This method ensures that individuals who may lack access to formal or digital resources remain well-informed about environmental shifts affecting their livelihoods. Finally, social media emerged as the fourth-ranked Source (mean 3.16), signaling a significant shift toward digital communication in rural agricultural sectors. Platforms such as WhatsApp and Facebook provide farmers with rapid, cost-effective access to weather updates and government policy information, particularly among younger demographics (Adeoye, 2021). This growing reliance on digital connectivity represents an ongoing transformation in how rural populations access and share time-sensitive climate information.

Table 3a: Perception of Respondents to Climate Change in the Study Area.

ISTF-NIG 2026

Perception Statements	Strongly Agree	Agree	Undecided	Strongly Disagree	Disagree
Climate change has had a noticeable impact on fish farming in my area.	88 (89.8)	5 (5.1)	2 (2.0)	1 (1.0)	2 (2.0)
Changes in water temperature due to climate change have affected fish growth rates.	58 (59.2)	35 (35.7)	2 (2.0)	1 (1.0)	3 (2.0)
Increased frequency of extreme weather events (such as floods and droughts) negatively affects my fish farming operations.	43 (43.9)	39 (39.8)	16 (16.3)	0 (0)	0 (0)
The availability of suitable water resources for fish farming has been impacted by climate change.	33 (33.7)	54 (55.1)	5 (5.1)	6 (6.1)	0 (0)
Fish disease outbreaks have become more frequent due to climate change.	53 (54.10	26 (26.5)	11 (11.2)	4 (4.1)	4 (4.1)
I believe climate change is a major factor influencing fish population and production levels.	56 (57.1)	22 (22.4)	9 (9.2)	6 (6.1)	5 (5.1)
Climate change has altered the types of fish that can be farmed in my region.	52 (53.1)	31 (31.6)	6 (6.1)	5 (5.1)	4 (4.1)
There are government policies in place to help fish farmers cope with the effects of climate change.	41 (41.8)	42 (42.9)	7 (7.1)	6 (6.1)	2 (2.0)

Table 3b: Perception of Respondents to Climate Change in the Study Area

I have adapted my farming practices to address the impacts of climate change.	47 (48.0)	31 (31.6)	13 (13.3)	6 (6.1)	1 (1.0)
The cost of running a fish farm has increased due to climate change-related factors (e.g., water treatment, infrastructure repair).	55 (56.1)	21 (21.4)	10 (10.2)	4 (4.1)	8 (8.2)
I feel well-informed about the potential future effects of climate change on fish farming.	48 (49.0)	34 (34.7)	4 (4.1)	7 (7.1)	5 (5.1)
Climate change has forced me to alter the species of fish I farm to ensure sustainability.	54 (55.1)	24 (24.5)	11 (11.2)	5 (5.1)	4 (4.1)
The quality of water used for fish farming has deteriorated due to climate change.	47 (48.0)	36 (36.7)	6 (6.1)	5 (5.1)	4 (4.1)
I believe that fish farming is increasingly becoming unsustainable due to climate change.	56 (57.1)	29 (29.6)	10 (10.2)	3 (3.1)	0 (0)
I think the fish farming community needs more support to mitigate the effects of climate change.	59 (60.2)	32 (32.7)	3 (3.1)	1 (1.0)	3 (3.1)

Source: Field Survey, 2025.

Table 3a and b revealed that fish farmers in the study area demonstrate a high level of experiential awareness regarding climate change, with 95% of respondents acknowledging its noticeable impact on their production systems. This perception is not merely conceptual; it is a mainstream concern rooted in daily operational challenges, such as rising water temperatures and unpredictable seasonal shifts that directly impair pond ecology and fish performance

ISTF-NIG 2026

(Ahmed *et al*., 2023). These findings align with broader regional trends in West Africa, where practitioners report significant declines in yield and increased mortality rates attributable to climatic variability (Asiedu *et al*., 2023; Ovie & Ovie, 2023). The direct economic consequences of these environmental shifts, including eroded profits and increased production costs, have led 60.2% of respondents to call for more robust institutional support urgently. By recognizing that these disruptions threaten their livelihoods, farmers are signaling a critical need for targeted mitigation frameworks. This consensus reflects a deep understanding that without external intervention to bolster resilience, the long-term sustainability of small-scale aquaculture in the region remains highly precarious.

Table 4: Coping Strategies towards Climate Change in the Study Area.

Strategies	Yes	No
Build ponds close to water sources	95 (96.9)	3 (3.1)
Erecting cover/shades over ponds, especially in dry weather	95 (96.9)	3 (3.1)
Dig bore holes/wells to supply water during dry seasons	86 (87.8)	12 (12.2)
Build embankments to prevent floodwater	89 (90.8)	9 (9.2)
Adjustment in the time of stocking	85 (86.7)	(13.3)
Use of indoor fish production facilities, e.g., the circulatory system	74 (75.5)	(24.5)
Stocking of quick-maturing fish species	81 (82.7)	17 (17.3)
Procurement of weather/water monitoring kits, e.g. thermometer	81 (82.7)	17 (17.3)
Stocking fish species that are more favoured by climate change	79 (80.6)	19 (19.4)
Building concrete/tarpaulin ponds	79 (80.6)	19 (19.4)
Seeking/listening to information about climate change	83 (84.7)	15 (15.3)
Proper feed management	85 (86.7)	13 (13.3)
Liming of the pond	85 (86.7)	13 (13.3)
Fertilization of the pond	87 (88.6)	11 (11.2)
Proper fish farm record keeping	81 (82.7)	17 (17.3)
Regular change of pond water	80 (81.6)	18 (18.4)
Planting of trees	82 (83.7)	16 (16.3)
Integration farming	87 (88.8)	11 (11.2)
Aeration	86 (87.8)	12 (12.2)
Application of salt	88 (89.8)	10 (10.2)
Adjusting fish stocking time	90 (91.8)	8 (8.2)
Raise the embankment to prevent flooding	95 (96.9)	3 (3.1)

Source: Field Survey, 2025.

Table 4 revealed that the fish farmers in the study area have adopted highly practical, site-specific strategies to manage the volatility of climate change, with 96.9% of respondents prioritizing pond placement near reliable water sources to buffer against unpredictable rainfall. Complementing this, 87.9% of farmers utilize groundwater by digging wells and reservoirs

ISTF-NIG 2026

during dry seasons, an adaptive practice that ensures water security when surface sources fail (Adeoye *et al*., 2023). While these autonomous adaptations are critical for short-term survival, they highlight an urgent need for sustainable groundwater governance to prevent long-term resource depletion (Takeshima *et al*., 2022). To mitigate the escalating threat of extreme weather, 90.8% of respondents actively construct embankments to protect their infrastructure from flooding and erosion. This proactive defense is vital for maintaining the structural integrity of ponds during intense rainfall, which has become a frequent and devastating occurrence for smallholder systems (Ahmed *et al*., 2023). These physical interventions serve as a necessary first line of defense, significantly reducing stock losses and preventing the destruction of aquaculture facilities during seasonal surges. Despite the ingenuity of these grassroots efforts, these strategies remain limited by significant financial and technical constraints. Relying solely on local, autonomous measures is insufficient to ensure long-term resilience against worsening climate scenarios without institutional support. As emphasized by Issahaku and Campion (2022), the path from simple coping to true structural resilience requires integrating these indigenous practices with external scientific training, subsidized climate-smart infrastructure, and coherent water-management policies.

Table 5: Challenges Faced Towards Climate Change Coping Strategies

Challenges	Major	Minor	Not at All
Low access to information	77 (78.6)	11 (11.2)	10 (10.2)
Limited adequate training support	64 (65.3)	29 (29.6)	5 (5.1)
Limited financial assistant	49 (50.0)	43 (43.9)	6 (6.1)
Lack of expertise	54 (55.1)	37 (37.8)	7 (7.1)
Inadequate supply of inputs	64 (65.3)	29 (29.6)	5 (5.1)
High capital cost of pond construction	71 (72.4)	17 (17.3)	10 (10.2)

Source: Field Survey, 2025.

Table 5 shows that smallholder fish farmers in the study area face a critical information gap: 78.6% of respondents struggle to access reliable, timely climate data. This deficiency severely limits their ability to make informed decisions about weather patterns, water quality, and temperature fluctuations, leaving them highly vulnerable to unexpected environmental shocks such as flooding or heat-induced mortality. As noted by Ogundele *et al*. (2023), this constraint is largely exacerbated by the inadequate reach of formal extension services and limited digital literacy, forcing many farmers to rely on potentially inaccurate informal sources. Compounding these information challenges is a significant economic barrier, as 72.4% of farmers report that the high cost of capital for pond construction hinders sustainable production. Climate-resilient infrastructure, essential for withstanding intensifying weather events, demands substantial financial investment, yet most smallholders lack access to the affordable credit required to fund these improvements (Ezeh *et al*., 2023). This capital limitation not only prevents the adoption of better water-management systems but also discourages long-term investment, threatening the overall viability of the aquaculture sector.

ISTF-NIG 2026

Table 6: Determinants of Stocking Size (Performance) among Farmers

Variables	Beta Coefficients	Std. Error	T-Value	Sig.
(Constant)	357.641	520.032	.688	.493
Sex	34.254	177.974	.192	.848
Age	6.119	8.244	.742	.460
Marital status	-294.321	123.474	-2.384	.019
Educational level	-22.034	97.282	-.226	.821
Years of rearing	21.868	12.893	1.696	.093
Household size	27.759	42.486	.653	.515
Secondary occupation	-186.789	84.358	-2.214	.029
Membership	77.535	159.904	.485	.629
Source of labor	180.641	115.163	1.569	.120
Source of water	-85.743	139.686	-.614	.541
Amount of fish	.000	.000	7.696	.000
R^2	.623			

Field Survey, 2025.

Table 6 presents the multiple regression analysis examining the influence of selected socio-economic and production-related variables on stocking size among fish farmers in Akinyele Local Government Area, Oyo State. The results indicate that the model is statistically significant overall ($F = 7.696$; $p < 0.01$), suggesting that the included explanatory variables jointly explain variations in stocking size. The table revealed that most socio-economic factors have a negligible impact on farmer perceptions, with only marital status, secondary Education, and total fish production emerging as statistically significant at the 5% level. In comparison, years of rearing show a positive but marginal influence at the 10% level. Marital status exhibits a negative correlation with performance ($\beta = -0.186$; $t = -2.384$; $p = 0.019$), potentially due to increased domestic responsibilities and resource-sharing pressures that often limit the capital available for reinvestment in aquaculture (Okeke *et al*., 2021). Similarly, secondary Education is negatively associated with productivity, suggesting that general schooling alone may not equip farmers with the specialized technical knowledge required for advanced aquaculture management (Ayanwale *et al*., 2020).

Years of rearing show a positive relationship with farmers' performance (stocking size) ($\beta = 0.148$), indicating that increased farming experience tends to enhance performance. However, the effect is not statistically significant at the 5% level ($p = 0.093$) but is marginally significant at the 10% level, suggesting that experience alone is insufficient to influence stocking decisions substantially. This finding implies that while experiential learning contributes to improved management capacity, its impact is constrained by external factors, such as capital constraints, climate risks, and limited access to modern aquaculture technologies. Thus, experience must be complemented by targeted technical support and financial interventions to yield significant productivity gains. In contrast, the Amount of fish produced stands out as the most significant driver of success, showing a strong positive effect on overall outcomes. This confirms that production scale is the primary determinant of profitability, aligning with economic theories that emphasize the importance of yield-focused strategies (Ezeh & Onyeneke, 2022). Consequently, interventions that prioritize higher stocking density, high-quality feed, and precise water management are likely to yield the

ISTF-NIG 2026

greatest improvements in farmers' livelihoods and sector-wide performance. These results suggest that the immediate operational output of the farm, the actual volume of fish harvested, effectively overshadows other secondary socio-economic inputs in determining the overall productivity and economic sustainability of fish farming in the study area.

Conclusion

The findings of this study demonstrate that smallholder fish farmers in Akinyele Local Government Area possess strong experiential awareness of climate change and its implications for aquaculture production, consistent with national climate vulnerability assessments. Farmers widely perceive rising water temperatures, erratic rainfall, flooding, disease outbreaks, and escalating production costs as major threats to farm sustainability. In response, they have adopted a broad range of autonomous adaptation strategies, including pond-siting based on water sources, embankment construction, groundwater utilization, adjustment of stocking times, and selection of fast-maturing or climate-tolerant fish species. These adaptive responses contribute directly to SDG 13 (Climate Action) by reducing climate-related risks at the farm level and support SDG 2 (Zero Hunger) through sustained fish production. However, the study reveals that these efforts are constrained by limited access to reliable climate information, weak extension support, inadequate technical training, and high capital costs of climate-resilient infrastructure. The heavy reliance on informal social networks for climate information further highlights institutional gaps in the delivery of public agricultural services.

Regression results indicate that farm performance is driven primarily by production output rather than socio-economic characteristics, suggesting that productivity-enhancing interventions—such as improved water management, quality inputs, and technical efficiency—are more critical than demographic targeting alone. Without deliberate policy intervention, the adaptive capacity of smallholder fish farmers is likely to remain reactive and insufficient to meet long-term climate resilience objectives outlined in Nigeria's national adaptation agenda. Overall, the study underscores the need to move from autonomous coping strategies toward structured, policy-supported adaptation pathways that integrate smallholder aquaculture into Nigeria's broader climate-resilient agricultural development framework.

Recommendations

1. Federal and state governments should explicitly integrate smallholder aquaculture into the implementation of Nigeria's National Adaptation Plan (NAP) and National Climate Change Policy, recognizing fish farming as a priority climate-sensitive livelihood. This will strengthen alignment with SDG 13 and enhance sector-specific resilience planning.

2. Aquaculture-focused extension services should be expanded to deliver localized climate forecasts, water quality advisories, and disease management guidance. Partnerships among meteorological agencies, extension units, and farmer associations can improve last-mile delivery of climate information, advancing SDG 12 (Responsible Production).

3. Targeted financial instruments—such as low-interest loans, credit guarantees, and infrastructure subsidies—should be developed to reduce the high capital cost of climate-resilient ponds, water systems, and adaptive technologies. This supports SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth) by lowering investment risk for smallholders.

ISTF-NIG 2026

4. Structured training programs on climate-smart aquaculture practices, including pond engineering, water conservation, species selection, and record keeping, should be institutionalized through research institutes and extension agencies. This will enhance farmers' adaptive efficiency and technical competence.
5. Given their central role in information dissemination, farmer associations should be formally engaged as implementation partners in climate adaptation programs. Strengthening cooperative governance will improve collective access to inputs, finance, and training while reinforcing community-level resilience.

6. Policies should encourage integrated farming systems, responsible groundwater use, and ecosystem-based adaptation measures to prevent long-term resource degradation. This aligns with SDG 12 and supports environmentally sustainable aquaculture growth

References

Adeleke, M.L., Al-Kenawy, D., Nasr-Allah, A.M., Murphy, S., El-Naggar, G.O., & Dickson, M. (2018). Fish farmers' perceptions, impacts and adaptation to climate change in Africa: The case of Egypt and Nigeria. In F. Alves, W.L. Filho & U. Azeiteiro (Eds.), *Theory and Practice of Climate Adaptation* (pp. 269–295). Springer, Cham.

Adeola, G.(2021). Informal social networks and agricultural knowledge sharing among rural farmers. *Journal of Rural Sociology*, 12(2), 77-88.

Adeoye, K. (2021). Social media use in agricultural communication: Opportunities and challenges for climate change awareness. *African Journal of Communication Studies*, 9(1), 34-47.

Adeoye, A.S., Ojo, T.O., & Bello, M.O. (2023). Water resource adaptation strategies among smallholder aquaculture farmers in Southwest Nigeria. *Journal of Water and Climate Change*, 14(3), 1124–1136.

Adesina, A.A., Ibrahim, M., & Musa, A. (2022). The role of farmer associations in climate information dissemination and adaptation strategies in Nigeria. *Journal of Agricultural Extension and Rural Development*, 14(3), 45-54.

Ahmed, N., Bunting, S.W., & Garnett, S.T. (2023). Temperature stress and climate adaptation in aquaculture: Evidence from tropical regions. *Science of the Total Environment*, 873, 162173.

Asiedu, B., Nuhu, H., & Oteng, R. (2023). Climate change and aquaculture in West Africa: Farmer perceptions and adaptive responses. *Aquaculture and Fisheries*, 8(2), 104–112.

Ayanlade, A., Radeny, M., & Morton, J.F. (2023). Demographic dynamics and agricultural adaptation in Sub-Saharan Africa. *Climate Risk Management*, 40, 100476.

Ayanwale, A.B., Adekunle, O.A., & Ogunwale, A.S. (2020). Education and productivity among smallholder farmers in Nigeria. *Journal of Agricultural Economics and Development*, 9(1),12–21.

Brugère, C., & De Young, C. (2015). Assessing Climate Change Vulnerability in Fisheries and Aquaculture. FAO Fisheries and Aquaculture Technical Paper No. 597. FAO, Rome. Italy.

Busari, A.O. (2018). Economic analysis of homestead fish farming in Osun State, Nigeria. *Nigerian Journal of Fisheries and Aquaculture*, 6(2), 19-26.

Efenakpo, O.D., Adejuwon, J.O., & Balogun, I.A. (2016). Climatic characteristics of the Ibadan region. *Journal of Geography and Regional Planning*, 9(4), 60–71.

Elujulo, O., Olatunji, A., & Fagbemi, S. (2023). Community-based climate adaptation and local knowledge systems in Sub-Saharan Africa. *Climate and Development*, 15(6), 529–541.

ISTF-NIG 2026

Ezeh, C.I., Okafor, O.C., & Ogbu, J.E. (2023). Financial barriers to sustainable aquaculture development in Southeast Nigeria. *Journal of Agricultural Finance and Development*, 14(2), 101–112.

Ezeh, C.I., & Onyeneke, R.U. (2022). Productivity determinants in small-scale aquaculture systems. *African Journal of Agricultural Research*, 17(4), 512–521.

Federal Government of Nigeria. (2021). National Climate Change Policy for Nigeria. Federal Ministry of Environment, Abuja.

Food and Agriculture Organization of the United Nations (FAO). (2023). The State of World Fisheries and Aquaculture 2023. FAO, Rome.

International Fund for Agricultural Development (IFAD). (2014). Climate Change and Smallholder Agriculture.

Intergovernmental Panel on Climate Change (IPCC). (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). (2018). Global Warming of 1.5°C. IPCC, Geneva.

Issahaku, G., & Campion, B.B. (2022). Climate adaptation pathways among smallholder farmers in Africa. *Sustainability*, 14(6), 3451.

Jiang, L., Wu, F., & Liu, Y. (2021). Barriers to climate adaptation in aquaculture systems. *Aquaculture Economics and Management*, 25(4), 421–438.

Maina, J.G., Beamesderfer, R.C., & Owiti, D.O. (2014). Contribution of fish to food and nutrition security. *African Journal of Food, Agriculture, Nutrition and Development*, 14(1), 8508–8525.

National Bureau of Statistics (NBS). (2009). Social Statistics in Nigeria. NBS, Abuja.

Ntiedo Ekott, I. (2020). Nigeria's GDP grows by 2.48% in Q3 2020-NBS: Premium Times, November 22.

Ogundele, O.O., Ojo, T.O., & Alimi, T. (2023). Agricultural extension services and gaps in climate information in Nigeria. *Journal of Agricultural Extension*, 27(1), 88–101.

Okeke, C.C., Nwankwo, I.U., & Onyekachi, C.J. (2021). Household structure and farm performance in Nigeria. *Journal of Rural Development*, 40(3), 367–382.

Okunsebor, S.A., Okoh, R.N., & Omonona, B.T. (2015). Climate variability and fisheries productivity in Nigeria. *Journal of Environmental Science and Policy*, 5(2), 33–42.

Onyebinam, C.O., Okoro, U.S., & Eze, S.O. (2017). Fisheries and food security in Nigeria. *International Journal of Fisheries and Aquatic Studies*, 5(6), 45-52.

Ovie, S.I., & Ovie, K.E.(2023). Climate change impacts on inland fisheries and aquaculture in West Africa: *Aquaculture Reports*, 28, 101529.

Sadiq, M.S., Singh, I.P., & Ahmad, M.M. (2015). Gender roles in fisheries value chains. *Journal of Fisheries Economics and Development*, 17(2), 101–112.

Sunderarajan, M. (2001). Women's participation in fisheries development. FAO Fisheries Circular, No. 966. FAO, Rome.

Takeshima, H., Adeoti, A., & Salau, S. (2022). Groundwater governance and agricultural sustainability in Nigeria. *Water Resources Research*, 58(4), e2021WR030615.

Troell, M., Naylor, R.L., Metian, M., Beveridge, M., Tyedmers, P.H., & Folke, C. (2014). Does aquaculture enhance the resilience of the global food system? *Proceedings of the National Academy of Sciences of the United States of America,* 111(37), 13257–13263.

United Nations Department of Economic and Social Affairs (UN DESA). (2023). World Population Prospects 2023. United Nations, New York.

ISTF-NIG 2026

World Bank. (2016). Fish to 2030: Prospects for Fisheries and Aquaculture. World Bank, Washington, DC.

Yazdi, S.K., & Shakouri, B. (2010). The effects of climate change on aquaculture. *International Journal of Environmental Science and Development*, 1(4), 378–382.

ISTF-NIG 2026

EVALUATING CLIMATE-INDUCED CHANGES ON FISH SPECIES RESILIENCE IN ERINLE RESERVOIR, OSUN STATE, NIGERIA.

Adams Ovie IYIOLA[*1], Ayotunde Samuel KOLAWOLE[1], Adeola Michael ODEKUNLE[1], Ademola Michael AKINSOROTAN[2], Mabel Omowumi IPINMOROTI[1]

[1]*Department of Fisheries and Aquatic Resources Management, Osun State University, Nigeria.*
[2]*Department of Fisheries and Aquaculture, Federal University, Oye Ekiti, Nigeria.*
**Corresponding email: adams.iyiola@uniosun.edu.ng*

Abstract

Erinle reservoir was investigated to determine the influence of climatic dynamics on fish species and to identify the necessary management procedures for sustainability. Three points (A, B, C) were randomly selected within the reservoir, and water quality and fish species were sampled fortnightly from October 2019 to August 2020. Fish species were sampled using varying mesh sizes, identified using field guides, and their abundance was recorded. Rascal climatic data were retrieved for the study area from 1980 to 2020 to observe the trends in climatic patterns using climatic models. Water quality was measured in situ, and the mean values for Temperature (17.07 ± 0.72 °C0.72 °C), dissolved oxygen (2.83 ± 0.31 mg L^{-1}), and pH (5.55 ± 0.11) were below the recommended limits, while ammonia was high (0.1 ± 0.03 mg L^{-1}). A total of 213 individuals belonging to 15 species, with cichlids as the most abundant family (58.2%), were identified. C. mariae was the most abundant species (18.8 %), and May was the most abundant month (18.8 %). Rainfall showed an increasing trend (t = 1.62), while rainfall (b = -0.45), minimum Temperature (b = -0.97), and maximum Temperature (b = -2.2) had negative effects on fish species in the reservoir. It was observed that the fish abundance was low, human activities affected the water quality and increased rainfall negatively affected fish abundance in the reservoir. It is therefore important to preserve biodiversity by ensuring and enforcing a clean environment.

Keywords: Fish species, Sustainability, Water quality parameters, Weather Parameters,

Introduction

Climate change is a global phenomenon and is increasingly threatening fish species in aquatic ecosystems and posing uncertainty in the sustainability of these resources (Huang et al., 2021). As reported by NiMET (2019), human activities are the major contributors to climate change, as they have catalyzed the breakdown of the ozone layer, leading to global warming. This phenomenon dictates rainfall patterns, Temperature, seasons, and all life processes of living resources because living things are directly connected to their immediate environment (Iyiola et al., 2024; IPCC, 2007). Fish species derive their sustenance from aquatic systems that are affected by seasonal changes and declines in fish abundance due to climatic factors have been reported in some tropical waters (Iyiola et al., 2025; Olanrewaju et al., 2017). Fish species are highly vulnerable to changes in climatic parameters and must be sustained, as outlined in United Nations Sustainable Development Goal (UNSDG) 14, which focuses on conserving life underwater.

FAO (2020) reported that the last decade has seen an increase in industrialization and urbanization, thereby generating greater waste. Presently, the forms of waste generated differ from the types of natural processes that can degrade them, thereby persisting in the environment. Some of these

wastes from various human activities were observed around Erinle reservoir, with most of them flowing into the reservoir, thereby affecting water quality and its secondary uses. There have been reports on fish abundance in the reservoir in relation to diverse human activities (Badejo & Oriyomi, 2015; Iyiola & Iyantan, 2021), but there is a paucity of documented information on the trends and effects of weather dynamics on fish species in the reservoir. This study is timely given the prevalence of climate change worldwide and the need for management procedures to sustain fish species.

Materials and Methods

Study Area

Erinle reservoir is located between Longitudes 4° 27' E - 4° 28' E and Latitudes 7° 45' 28" N - 7° 46'46' 00" E, and serves as a water source for domestic use and as a protein source. The reservoir is surrounded by agricultural and domestic activities, with an influx of cattle and waste discharge observed in some areas. Three sampling points (SP_A, SP_B, and SP_C) were purposively selected based on accessibility and logistical factors, and their coordinates were determined using a Garmin handheld Global Positioning System model Etrex 10 (Table 1). Fortnightly sampling of fish species and water quality was conducted at these points for 12 months (October 2019 – August 2020). Climatic data on rainfall and temperature for the study area were also retrieved to investigate trends.

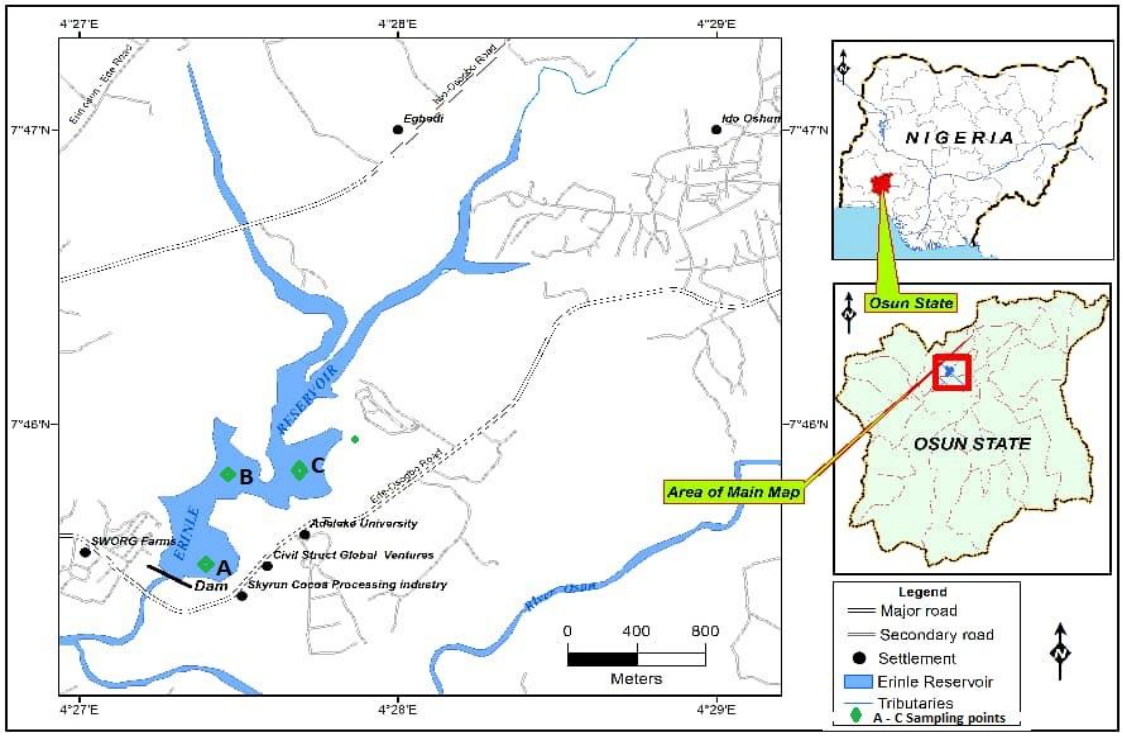


Figure 1: Map of Erinle Reservoir

Source: (Iyiola & Iyantan 2021)

Table 1: Description of sampling points

Sampling Point (SP)	Coordinates	Characteristics
SP_A	Longitude 4° 27′ 3′′E Latitude 7° 45′ 05′′ N	It was located close to the dam wall, and the water flow was almost static, except for surface movements driven by wind. The activities here were farming, washing of clothes, and extraction by water tankers for domestic use.
SP_B	Longitude 4° 27′ 5′′E Latitude 7° 45′ 08′′ N	It was located upstream, away from the dam wall, and had characteristics similar to those of SP_A but was less accessible. Sand islands and floating aquatic weeds were observed.
SP_C	Longitude 4° 27′ 7′′E Latitude 7° 45′ 09′′ N	It was located farther away from the dam wall. This area is covered with dense vegetation and aquatic weeds. Agricultural activities were observed in this area.

Assessment of Water Quality

Water samples were collected fortnightly between 7.00 am and 9.00 am from SP_A - SP_C. *In situ*, measurements of temperature, pH, dissolved oxygen, and ammonia were carried out. Water temperature was measured with a mercury-in-glass thermometer and recorded in degrees Celsius (°C). pH was measured with a handheld Hanna pH meter. Dissolved Oxygen (DO) was measured using a Dissolved Oxygen meter DO-5509 manufactured by Lutron, United Kingdom, and readings were recorded in milligrams/Liter (mg/L) when the digital meter was steady. Ammonia was measured using the API Master Freshwater Test Kit (MARS Fishcare, USA), and readings were recorded in mg/L.

Fish Sampling

Monofilament gill nets of mesh sizes 44mm, 56mm, and 60mm, set at each of the sampling points in the evening (8.00 pm) and retrieved the next morning (7.00 am), were used for fortnight sampling. The collected fish species were sorted and identified using guides (Holden & Reeds, 1978; Froese & Pauly, 2021), and their abundance was recorded.

Rainfall and Temperature Trends

Climatic data on rainfall, minimum and maximum Temperatures from 1981 to 2020 for the study area were downloaded from WorldClim 2.0 and processed. Their trends were determined using Box and Jenkins Linear Trend Model (Box & Jenkins, 1994) (Equation I), and their relationship with fish abundance using the Cobb-Douglas Multiple Regression function (Equation II). Monthly weather data during the study (2019 – 2020) were downloaded, and their relationships with fish abundance were also determined.

ISTF NG 2026

$$Yt = b_0 + b_1 x\ t \quad \text{---------- Equation I}$$

Where Y = Dependent variable

b_0 = constant/ intercept

b_1 = coefficient/ slope of the trend line

t = time

$$Y = b_0 + b_1 X \quad \text{---------- Equation I}$$

Where: Y = Dependent variable (Fish abundance)
b_0 = Constant
b_1 = Regression coefficient/trend coefficient
X = Independent variable (rainfall/temperature)

Statistical Analysis

Simple descriptive statistics, including means and percentages, were used to present data on fish abundance. Tukey's pairwise comparisons were used to assess the significance of differences among water quality parameters.

Results and Discussion

Assessment of water quality

Water in its right quantity and quality is required for the sustenance of fish species in an aquatic system (Obot & Etim, 2016). The results of the parameters measured from SP_A to SP_C are presented in Table 1. For DO, the mean value was highest in SP_A at 2.91 ± 0.31 mg/L and lowest in SP_B at 2.82 ± 0.01 mg/L, which was statistically different from SP_A and SP_C ($p<0.05$). The overall mean value of 2.86 ± 0.30 mg/L was slightly below the 3.0 mg/L recommended level by Boyd (2010). For Temperature, the highest mean value was measured in SP_B (17.38 ± 0.12 °C) and the lowest in SP_C (17.11 ± 0.10 °C), with differences between points statistically significant. The overall mean value of 17.23 ± 0.70 °C was lower than the recommended range of 20-30 °C by Boyd (2010). The highest mean pH was observed in SP_A and SP_B at 5.80 ± 0.01 and 5.71 ± 0.02, respectively, while the lowest was in SP_B, which was statistically different ($p<0.05$) from the other sampling points, which were statistically similar. The overall mean of 5.77 ± 0.10 across the sampling points was below the recommended range of 6.5–8 (Boyd, 2010). The mean ammonia concentration was highest in SP_A (0.11 ± 0.00 mg/L), while the lowest values were measured in SP_B (0.10 ± 0.01 mg/L) and SP_C (0.10 ± 0.00 mg/L). The overall mean value of 0.10 ± 0.00 mg/L across the sampling points was higher than the recommended limit of < 0.05mg/L. All these mean values indicated poor water conditions, and similar occurrences were reported by Badejo and Oriyomi (2016), who attributed the poor water conditions to human activities around the reservoir. The elevated ammonia levels, re a major parameter that inhibits oxygen in water, can be attributed to the influx of agricultural and livestock wastes into the reservoir. A similar occurrence of human activities resulting in elevated ammonia concentrations in the Ogunpa River and the Aiba Reservoir has been reported (Iyiola, 2015; Kolawole & Iyiola, 2018).

ISTF-NIG 2026

Table 1: Mean water quality parameters measured from the sampling points during the study

Months	SP_A	SP_B	SP_C	Mean
DO (mg/L)	2.91 ± 0.31^b	2.82 ± 0.01^a	2.86 ± 0.00^b	2.86 ± 0.30
Temperature (°C)	17.20 ± 0.02^a	17.38 ± 0.12^c	17.11 ± 0.10^b	17.23 ± 0.70
pH	5.80 ± 0.01^b	5.80 ± 0.01^b	5.71 ± 0.02^a	5.77 ± 0.10
Ammonia (mg/L)	0.11 ± 0.00^a	0.10 ± 0.01^a	0.10 ± 0.00^a	0.10 ± 0.00

Mean values with different characters across the rows are significantly different (P<0.05)

Assessment of fish abundance

The abundance of fish species identified across SP_A to SP_C during the study is presented in Table 2. Some fish species were observed not to be encountered during the study; One species (*Hemichromis bimaculatus)* in SP_A, three species in SP_B (*M. tapirus, Synodontis sorex and Oreochromis niloticus*) and four species in SP_C (*Chrysichthys aluuensis*, *Oreochromis niloticus, Phago loricatus*, and *Synodontis sorex*). During the study, a total of 213 individuals were identified and grouped into 15 species, which was lower than the 561 species across 12 families reported by Badejo and Oriyomi (2016) from the reservoir. The principal reason for this decline might be poor water quality, as water is the medium in which fish live and must be of adequate quality and quantity (Boyd 2010).

Coptodon mariae was the most abundant in SP_A (57.5%), SP_B (27.5%), and SP_C (15.0%) with an overall value of 18.8% during the study. *Chrysichthys aluuensis* was the least in SP_A (55.5%), *Hemichromis elongatus* (12.5%), and *Schilbe isidori* (9.09%) were the least in SP_B. In comparison, *Hemichromis elongatus* (12.5%), *Mormyrus rume* (6.25%), *M. tapirus* (12.5%), *Sarotherodon melanotheron* (11.11%), and *Synodontis violaceus* (11.11%) were the least fish species in SP_C. The least overall fish species across the sampling points was *Synodontis sorex* with 2.8%. The Abundance of *C. mariae*, a cichlid, was expected, as they can undergo rapid reproductive activity, thereby populating aquatic systems.

Table 2: Abundance of fish species identified across the sampling points during the study

Fish species	SP_A	SP_B	SP_C	Total	Total (%)
Alestes nurse	8	7	4	19	8.9
Chrysichthys aluuensis	5	4	NE	9	4.2
Coptodon mariae	23	11	6	40	18.8
C. zillii	13	7	3	25	11.7
C. guineensis	16	3	2	21	9.9
Hemichromis bimaculatus	NE	2	0	12	5.6
H. elongatus	6	1	1	8	3.8
Mormyrus rume	11	4	1	16	7.5
M. tapirus	7	NE	1	8	3.8
Oreochromis niloticus	9	NE	NE	9	4.2
Phago loricatus	6	2	NE	8	3.8
Sarotherodon melanotheron	6	2	1	9	4.2
Schilbe isidori	7	1	3	11	5.2
Synodontis sorex	6	NE	NE	6	2.8

ISTF-NIG 2026

S. violaceus	7	3	1	11	5.2
Total	13	23	16	213	100
Total (%)	6.1	10.8	7.5		

NE – Not Encountered

Assessment of Climatic Variables

Mean and trend of climatic variables from 1981 – 2020.

The mean rainfall, maximum and minimum Temperatures from 1981 to 2020 across the study area fluctuated over the years, as shown in Figures 2, 3, and 4, respectively. The highest mean rainfall was recorded in 2013 (196.4mm), which coincided with flooding in the Southwestern regions of Nigeria, resulting in the displacement of people from their homes and significant economic losses (Falaye, 2013). The highest minimum and maximum temperatures were recorded in 2014 and 2018, at 27.0 ºC and 32.5 ºC, respectively.

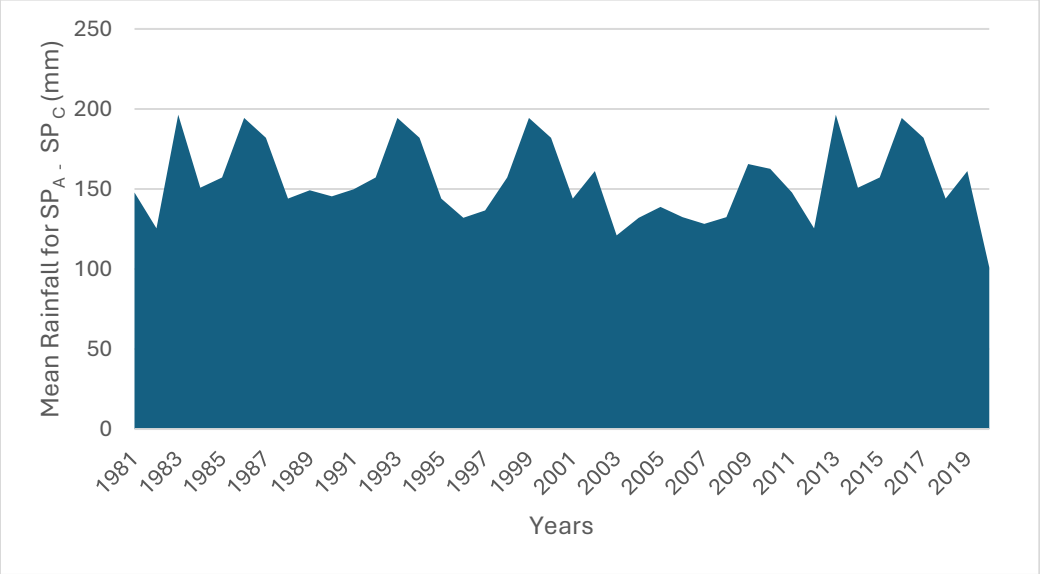


Figure 2: Area graph for mean rainfall across SP_A - SP_C from 1981-2020

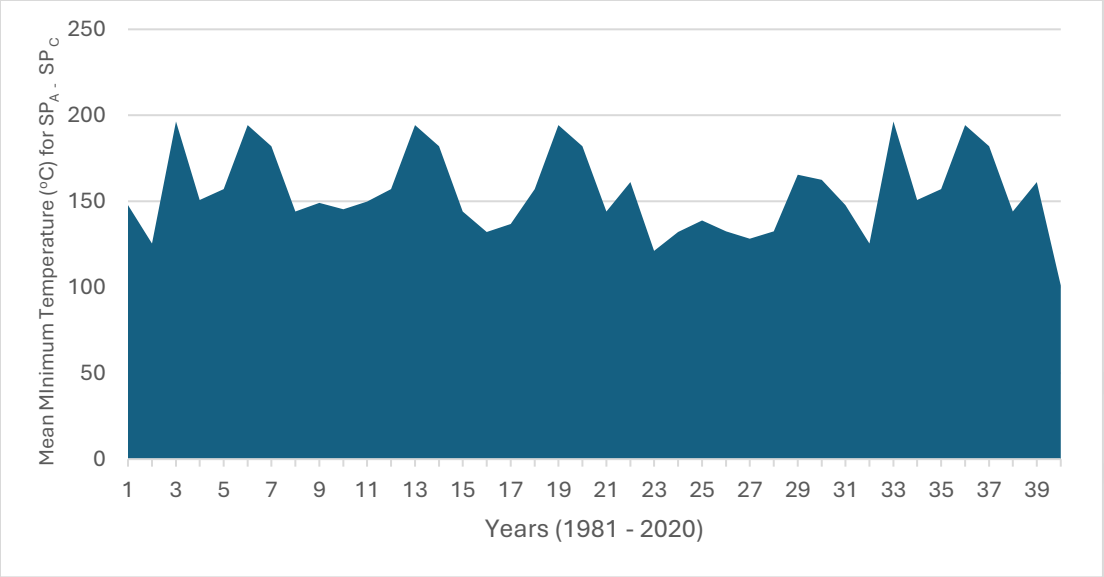


Figure 3: Area graph for mean minimum Temperature across SP_A - SP_C from 1981 to 2020.

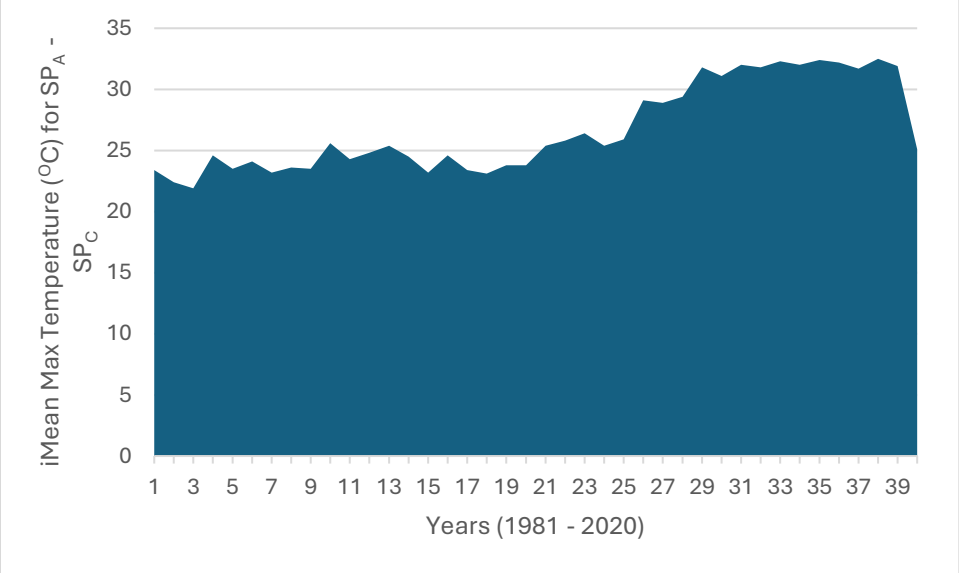


Figure 4: Area graph for maximum Temperature across SP_A - SP_C from 1981 to 2020

3.3.2 Linear trend analysis of climatic variables (1981 – 2020)

The linear trend analysis for rainfall, minimum Temperature, and maximum Temperature is presented in Table 3. The mean annual rainfall had a positive b-value of 1.60 and a trend of 15%, indicating that rainfall has increased by 1.60 units per year at a rate of 15%. The minimum and maximum Temperatures had negative b values of -0.02 (t = 11%) and -0.22 (t = 12%), indicating decreases of 0.02 and 0.22 units across the years, with magnitudes of 11% and 12%, respectively. These imply that the reservoirs are exposed to the effects of climate change, have been reported, and are experienced in coastal states like Lagos, Nigeria (Omitoyin 2009; NiMET, 2012), as well as in some reservoirs such as Asejire (Ipinmoroti et al., 2022) and Owalla (Iyiola et al., 2022).

Table 4: Summary of Linear trend analysis of rainfall and Temperature from 1981 to 2020

Parameters	b (t)	t (%)
Rainfall (mm)	1.60	15
Minimum Temperature (ºC)	-0.02	11
Maximum Temperature (ºC)	-0.22	12

b(t) - coefficient of trend, t (%) - Magnitude of trend.

Mean monthly and trends of weather variables (2019 – 2020)

The mean monthly weather parameters across the sampling months during the study (October 2019 – August 2020) are presented in Table 6. The mean annual rainfall was 440.8mm, and the average minimum and maximum temperatures were 20.6 °C and 28.7 °C, respectively. The highest rainfall, minimum Temperature, maximum Temperature, and fish abundance were measured in June (98.3mm), November (21.6 ºC), January (31.8 ºC), and May (18.8%), respectively while the least was measured in January (1.5m), June and August (19.4 ºC), June (25.2 ºC) and February (3.8%) respectively. Fish abundance fluctuated across the months of the study, reflecting their direct connection to their immediate environment. The highest mean rainfall was in June (98.3mm), as expected because it falls during the wet season, while the minimum and maximum Temperatures were measured in January (22.5 °C) and October (30.8 °C), as expected because they are in the dry season (NiMET, 2019).

Table 6: Mean monthly rainfall, minimum and maximum Temperature, and fish abundance

Months	Rainfall (mm)[1]	Minimum Temperature (ºC)[2]	Maximum Temperature (ºC)[3]	Fish abundance[4]	Fish relative abundance
October	23.5	21.4	30.8	13	6.1
November	12.5	21.6	30.1	23	10.8
December	10.8	21.5	29.0	16	7.5
January	1.5	22.5	31.8	19	8.9
February	16.4	21.1	30.3	8	3.8
April	48.7	20.0	28.0	18	8.5
May	68.1	19.9	27.4	40	18.8
June	98.3	19.0	25.2	23	10.8
July	83.0	20.4	26.7	24	11.3
August	78.0	19.0	27.5	29	13.6
Mean Total	440.8	20.6	28.7	213	100

[1-3]Rascal Climatic Data, [4]Recorded during the study (October 2019 – August 2020), No records for March because of the COVID-19 lockdown.

Linear Trend Analysis of climatic variables (1980 – 2020)

The linear trend analysis for rainfall, minimum Temperature, maximum temperature, and fish abundance during the months of study is presented in Table 7. Rainfall showed a positive trend with a slope coefficient (b_1=1.00), indicating that rainfall generally increased over the study period. However, the fitted equation suggests an increasing relationship over time, as indicated by the positive coefficient. For minimum Temperature, it exhibited a negative trend (b_1 = -0.31), indicating a gradual decrease over time. The fitted equation further confirms that the minimum

Temperature declined slightly during the study period. For maximum Temperature, Maximum Temperature showed a positive trend (b_1=0.53), suggesting that maximum Temperature increased over time. However, the fitted equation indicates an increasing trend. Fish abundance displayed a negative trend (b1=−0.20), implying a reduction in fish abundance over time. The fitted equation supports this observation, showing that fish abundance declined steadily throughout the study period. From this analysis, the decrease over time in minimum Temperature and fish abundance indicates a possible ecological or climatic stress on the aquatic ecosystem. The rainfall and maximum Temperature increased, while the declining trend in fish abundance may be associated with variations in climatic factors such as Temperature and rainfall, which can influence aquatic habitat conditions, breeding cycles, dissolved oxygen levels, and food availability (Iyiola et al., 2026).

Table 7: Summary of Linear trend analysis of rainfall, temperature, and fish abundance over time

Parameters	b_0	b_1	Trend	Fitted trend equation ($Y_t = b_0 + b_1 x t$)
Rainfall	1.04	1.00	Positive	Rainfall $_t$ = 2.23 + 1.62 x t
Min Temperature	1.35	- 0.31	Negative	Min. Temp $_t$ = 1.34– 0.02 x t
Max Temperature	1.50	0.53	Positive	Max Temp $_t$ = 1.52 – 0.22 x t
Fish abundance	1.10	-0.20	Negative	Fish Abundance $_t$ = 2.66 – 1.19 x t

Y = dependent variable, b_0 = constant, b_1 = intercept, X = independent variable, t = linear trend

Weather parameters and fish abundance (2019 – 2020)

The regression analysis between fish abundance (dependent variable) and rainfall, minimum and maximum temperature during the study (October 2019 – August 2020) is presented in Table 8. Rainfall was negatively associated with fish abundance (regression coefficient =- 0.15). The regression equation indicates that fish abundance decreases by 0.15 units for every unit increase in rainfall. R^2 = 0.37 indicates that rainfall explains about 37% of the variation in fish abundance, suggesting a moderate influence of rainfall on fish populations. Increased rainfall may lead to flooding, habitat disturbance, and increased turbidity, which can negatively affect fish abundance. Minimum Temperature also showed a negative relationship with fish abundance (b_1 = -0.58). The regression equation implies that fish abundance decreases by 0.58 units with every unit rise in minimum Temperature. The R^2=0.21indicates that minimum Temperature accounts for 21% of the variation in fish abundance, suggesting a relatively weak relationship. This may indicate that rising temperatures create stressful environmental conditions that reduce fish survival and reproduction. Maximum Temperature exhibited a negative relationship with fish abundance, with a reported coefficient of −0.36. The regression equation suggests that increases in maximum Temperature reduce fish abundance. R2 = 0.27 indicates that maximum Temperature explains about 27% of the variation in fish abundance, suggesting a moderate effect on fish populations.

Table 8: Summary of Regression analysis between fish abundance and rainfall, and Temperature

Parameters	b_0	b_1	R^2	Regression equation ($Y = b_0 + b_1X$)
Rainfall	1.17	-0.15	0.37	Fish Abundance = 1.17 - 0.15 Rainfall
Min Temperature	2.00	-0.58	0.21	Fish abundance = 2.00 - 0.58 Min Temperature
Max Temperature	1.94	-0.36	0.27	Fish Abundance = 1.94 – 20.36 MaxTemperature

ISTF-NIG 2026

Y = dependent variable, b_0 = constant, b_1 = intercept, X = independent variable

Conclusion

During the study, it was observed that the recorded fish abundance was lower than that in similar reservoirs in the region. Ammonia, a product of organic matter decomposition, was high due to agricultural activities and cattle herding around the reservoir. This increased level reduced dissolved oxygen concentration, which may be a principal cause of the reservoir's low dissolved oxygen levels. Therefore, such activities should be minimized around the reservoir, and the ban on agricultural activities should be enforced to support a healthy aquatic system and reduce the release of gases into the environment. These measures will support the conservation of fish species, as set out in Sustainable Development Goal 14. The climatic parameters fluctuated across the months of the study and across years. The trend in the mean rainfall patterns was observed to increase over the years and months, with a reduced effect on fish abundance. This trend led to reductions in fish abundance and other climatic parameters during the study period. Overall, the regression analysis revealed that all the climatic variables examined negatively affected fish abundance. Rainfall showed the greatest explanatory Power, followed by maximum and minimum Temperatures. These findings suggest that climatic fluctuations may significantly influence fish abundance by altering water quality, habitat conditions, temperature stress, and ecological balance within the aquatic ecosystem.

References

Badejo, O. A. and O. Oriyomi, 2016. Seasonal Variation, Abundance and Condition Factor of Fish Species in Erinle Reservoir. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS),* 12(1):. 136-142.

Box, G.E.P. and G.M. Jenkins, 1994. Time Series Analysis: Predicting and Control (3rd Edition. Prentice Hall, 1994)

Boyd, C. E. (2010). Dissolved oxygen concentration in pond aquaculture. Available at: https://www.researchgate.net/publication/281309202_Dissolvedoxygen_concentration_in_pond_aquaculture

Falaye, A. E. 2013. Fish: A Jewel in Land and Sea Environment, An Inaugural Lecture 2012/2013, (University of Ibadan Publication, 2013).

FAO. 2020. The state of the World's Fisheries and Aquaculture. Sustainability in action; Food and Agriculture Organization, Rome, 2020. Available at: https://dx.doi.org/10.4060/ca9231en

Froese, R. & D. Pauly. (2013). World Wide Web electronic publication. Available at: https:// www.fishbase.org.

IPCC. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.)). Cambridge University Press, Cambridge, United Kingdom and New York, NY, US, p. 996

Ipinjolu, J. K., I. Magawata, & B. Shinkafi (2014). Potential Impact of Climate Change on Fisheries and Aquaculture in Nigeria. 1224775570533/MultiagencyPolicyBriefCOP15.pd, 2014.

Ipinmoroti, M.O., A.O. Iyiola, O.A. Akanmu, O. Orisasona, and N. Fawole 2018. Diversity and Distribution of Fish Species in Lake Asejire, South West Nigeria. In A. Kallel, M. Ksibi,

H. Ben Dhia, N. Khélifi (Eds.,) Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions pp. 1447 – 1448, Springer. https://dx.doi.org/10.1007/978-3-319-70548-4_422.

Ipinmoroti, M.O., Iyiola, A.O., Akanmu, O.A. (2022). Association of some weather factors with fish assemblage in Asejire Lake, SouthWestern Nigeria. *J. Agric. Environ. Sci*. 7(2): 26-37

Iyiola, A. O. and A. Jenyo-Oni, (2018). Abundance and Diversity of Fish Species in the Osun River Catchment, Nigeria. In O.A. Fagbenro, E.K. Ajani, I. Magawata, B.A. Shinkafi, S.O. Ayoola, & O. Orisasona, (Eds) Proceedings of the First Annual Conference**,** pp. 251–255. University of Ibadan.

Iyiola, A. O. and E. A. Iyantan, 2021. Fish Assemblage and Diversity in Erinle Reservoir, Osun State, Nigeria. *Nigerian Journal of Fisheries* 18(1):2204 – 2209

Iyiola, A.O., Ipinmoroti, M.O., Kolawole, A.S., Akinsorotan, A.M., Oyewole, E.O., & Akinrinade, A.J. (2022). Weather factors and their implications for fish species in Owalla reservoir, Osun State, Nigeria. *Journal of Global Affairs and Sustainable Development (JoGASD),* 1:93-106. http://doi.org/10.13140/RG.2.2.29444.33926

Iyiola A.O., Afolabi O.A., Alimi, S.K., Akingba, O.O., Izah S.C., and Ogwu, M.C. (2024). Climate Change and Water Crisis in the Global South. In S.C. Izah et al. (eds.), *Water Crises and Sustainable Management in the Global South* https://doi.org/10.1007/978-981-97-4966-9_4. Pp 111-139

Iyiola, A.O., Jenyo-Oni, A., and Taiwo, O.J (2025). Investigation of Climatic Parameters on Fish Composition in Asejire Reservoir, Southwestern Nigeria. In: Magdalena Micińska & Przemysław Osóbka (eds), International Legal Aspects of Climate Change, p30-40. ISBN 978-83-974964-0-8

Iyiola A O, Taiwo Y F, Ipinmoroti M O (2026). Influence of Selected Water Quality Parameters on Fish Species Abundance in Eko-Ende Reservoir, Nigeria. *Curues J. Agri. Food Sci* 2 : es44497-025-00047-8. doi:https://doi.org/10.7759/s44497-025-00047-8

Kolawole, A. S. & A.O. Iyiola (2018). Investigation of Human Activities on the Water and Bacteriological Properties of a Tropical Reservoir in Osun, Nigeria*. Nigerian Journal of Fisheries* 15(1):1308–1313.

Negi, R. K. & S. Mamgain. (2013). Species diversity, abundance, and distribution of the fish community and conservation status of the Tons River of Uttarakhand State, India. *Journal of Fisheries and Aquatic Science,* 83:671 - 626.

Nigerian Meteorological Agency (NiMet). (2012). 2012 Nigerian Climate Review, p. 59, Nigerian Meteorological Agency (NIMET), Abuja.

Nigerian Meteorological Agency (NIMET) (2019). Food Security Cluster: Nigerian Meteorological Agency (NiMET) 2019. Seasonal Rainfall Prediction (SRP).

Obot, O. I., L. Etim, & G. S. David (2016).A review of the physical and chemical properties of some Nigerian creeks. Nigerian Journal of Agriculture, Food and Environment, 12(4): 82-90

Olanrewaju, A. N., E.K. Ajani, & O.K. (2017). Kareem Physico-Chemical Status of Eleyele Reservoir, Ibadan, Nigeria. *J Aquac Res Development,* 8:512.

Omitoyin, S. A. (2009). Impact of Climate Change on Livelihood and Food Security of Artisanal Fisherfolk in Lagos State, Nigeria, Paper Presented at Copenhagen Conference on Climate Change, Denmark, December 12-15, 2009.

Raghuvanshi, T. K., L. Negassa, & P.M. Kala. (2015). GIS-Based Grid Overlay Method versus Modeling Approach- A Comparative Study for Landslide Hazard Zonation (LHZ) in Meta Robi District of West Showa Zone in Ethiopia. *The Egyptian Journal of Remote Sensing and Space Science,* 18(2):235–250.

Taiwo, Y.F., A.A. Adedeji, & T.A. Adesakin (2018). The Ecological Balance of the Fish Community in an Aging Reservoir. *Natural Resources,* 9:327-335. doi: 10.4236/nr.2018.99020.

ISTF-NIG 2026

ECOLOGICAL DISTRIBUTION AND CONSERVATION STATUS OF THE GENUS VITEX IN NIGERIA.

[1]Kehinde Adegoke Adeniji and [2]Adullahi Allanamu Abdulrahaman

[1]Forestry Research Institute of Nigeria, P.M.B 5054, Jericho, Ibadan.
[2]Department of Plant Biology, Faculty of Life Sciences, University of Ilorin, Nigeria
Corresponding Email: obalomo2016@gmail.com

Abstract

The ethnomedicinal significance of *the Vitex* species in Nigeria is well documented. Despite this, the total number of *Vitex* species, their ecological distribution and conservation status of these valuable species are yet to be ascertained. A total of 239 herbarium specimens of Vitex were examined in four Herbaria in Nigeria, of which 10 species were recognized, namely: *Vitex agnus-castus* (9 specimens), *Vitex chrysocarpa* (7), *Vitex doniana* (108), *Vitex grandifolia* (38), *Vitex ferruginea* (8), *Vitex simplicifolia* (22), *Vitex thyrsiflora* (23), *Vitex oxycuspis* (11), *Vitex rivularis* (11) and Vitex bongalensis (2). The information from the Herbarium records was used to generate the distribution map. The IUCN (International Union of Conservation of Nature) Red List web platform was used to determine the conservation status and threats of the *Vitex* species found in Nigeria. It was revealed that *Vitex bogalensis* and *Vitex feruginea* are threatened species in Nigeria. *Vitex doniana* is widely distributed throughout the country. However, *Vitex Oxycuspsis* and *Vitex bogalensis* are narrowly distributed. Conservation efforts are necessary to protect these species from habitat loss, over- exploitation and other threats.

Keyword: Taxonomy, Ecology, Distribution and Conservation

Introduction

The genus *Vitex* L., belonging to the family Lamiaceae (formerly classified under Verbenaceae), comprises approximately 250 species distributed in tropical and subtropical regions of the world (Harley *et al*., 2004). Members of the genus are known for their diverse morphological forms, ecological adaptations, and wide range of ethnobotanical uses, particularly in traditional medicine, where they are employed to treat various ailments, including fever, inflammation, infertility, and microbial infections (Burkill, 1997; Fakeye *et al*., 2000). In Nigeria, the genus is moderately represented, yet taxonomic delimitation of its species remains unresolved due to overlapping morphological characters, environmental plasticity, and limited integrative taxonomic studies. *Vitex* tends to be common across a range of habitats, including primary rainforest and swamp habitats (de Kok, 2008), and is prevalent in secondary growth and disturbed vegetation, largely associated with coastal habitats or those influenced by a fire regime (de Kok, 2008). Recently, Vitex has been placed in the family Lamiaceae based on DNA sequence data (Thomas *et al.,* 2012). According to the APG IV System of Flowering Plants Classification (2016), it has also been classified under Lamiaceae. The most recent major revision of the genus in Africa is that of Pieper (1928). *V*arious authors have reported Vitex; Keay (1989) reported 7 species, and Ayodele and Young Yang (2012) reported 9 species from Nigeria. The infraspecific variability of these species

ISTF-NIG 2026

has not been thoroughly investigated in Nigeria to date; this study aims to provide ecological distribution patterns and conservation status for the genus *Vitex* in Nigeria.

Materials and Methods

A thorough herbarium search was conducted in four herbaria, including the Forest Herbarium Ibadan (FHI). University of Ibadan Herbarium (UIH), IFE Herbarium and University of Ilorin Herbarium (UILH). We documented all the records of the genus *Vitex* in these herbaria. Records of the habitat type were extracted from the herbarium along with the occurrence data. A geographical distribution map was constructed from herbarium records to show the natural distribution areas of the genus *Vitex* in Nigeria. A Chart showing the habitat types of the genus *Vitex* was constructed to illustrate the species' predominant habitats in Nigeria. Using the IUCN Red List, the conservation status and threats for each *Vitex* species discovered in the herbarium were extrapolated from the IUCN website and presented in Table 1.

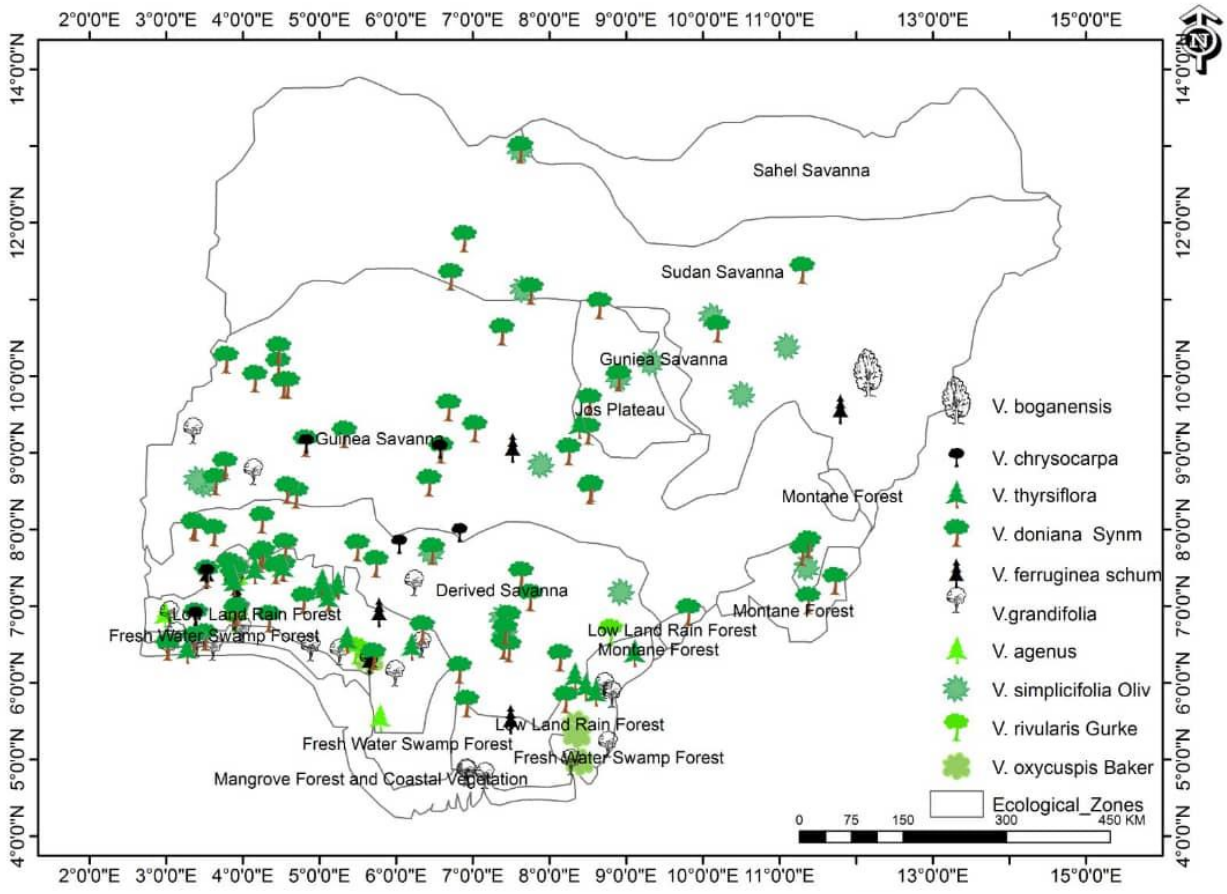


Fig. 1: Ecological distribution of *Vitex* in Nigeria

Table 1: List of *Vitex* species in herbaria records, their conservation status and the threats they are facing

Species	Conservation status	Uses
Vitex agnus-castus	Least concern	Medicinal
Vitex chrysocarpa	Least concern	Medicinal, ornamental
Vitex doniana	Least concern	Timber, Food, and Medicinal.
Vitex grandifolia	Least concern	Medicinal and Food.
Vitex ferruginea	Vulnerable	Medicinal
Vitex simplicifolia	Least concern	Medicinal
Vitex thyrsiflora	Least concern	Medicinal
Vitex oxycuspis	Least concern	Medicinal, ornamental, and wood.
Vitex rivularis	Least concern	Medicinal
Vitex bongalensis	Vulnerable	Medicinal

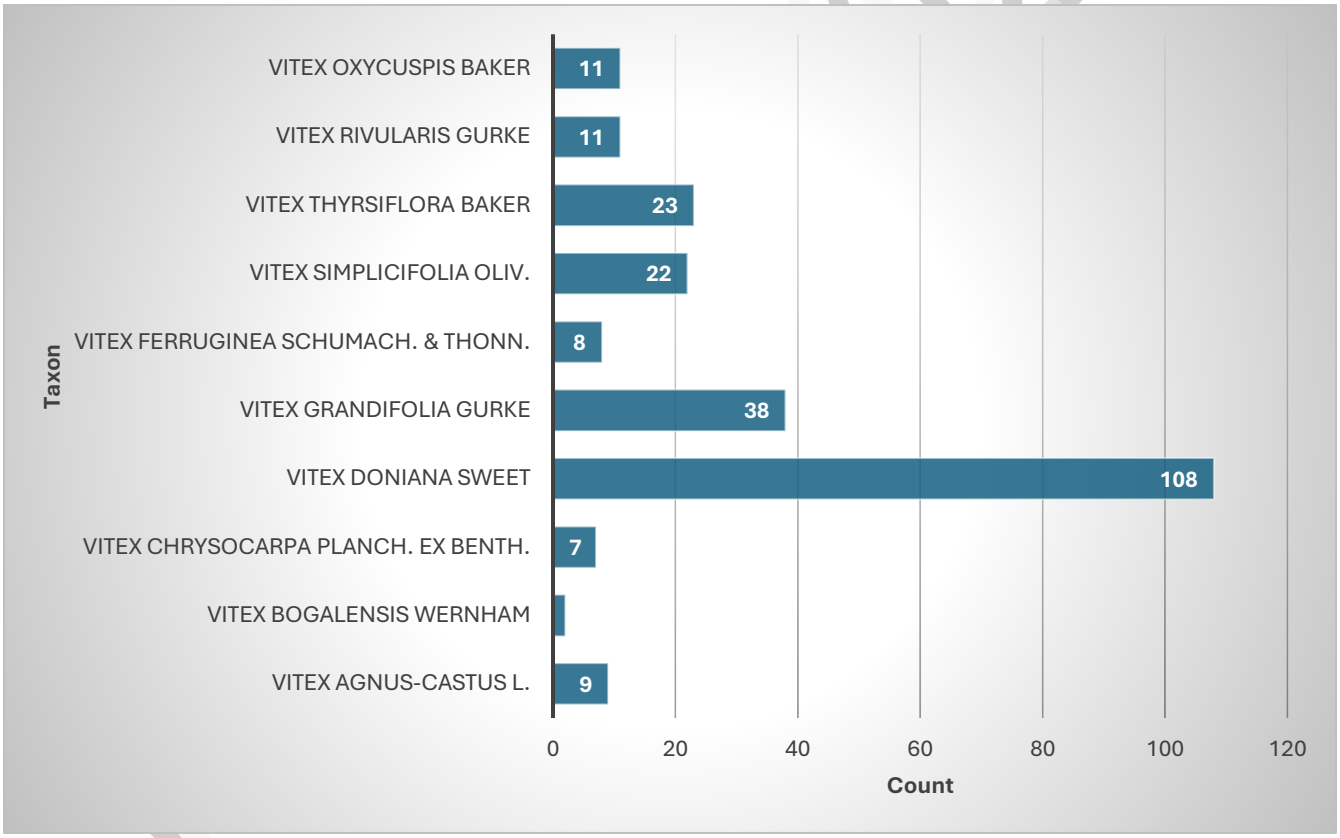


Fig 2: Frequency of recorded Vitex Taxa in Four Herbaria in Nigeria

Results and Discussion

A total of 239 herbarium specimens of *Vitex* were examined in four herbaria, of which 10 species were recognized, namely: *Vitex agnus-castus* (9 specimens), *Vitex chrysocarpa* (7), *Vitex doniana* (108), *Vitex grandifolia* (38), *Vitex ferruginea* (8), *Vitex simplicifolia* (22), *Vitex thyrsiflora* (23), *Vitex oxycuspis* (11), *Vitex rivularis* (11) and *Vitex bongalensis* (2). According to Groombridge's

(1992) definitions, abundant species are those taxa with herbarium collections of 11 or more specimens and a relatively wide distribution. Rare species are taxa with 6-10 herbarium collections and are thinly distributed, with little or no collection in recent times within their range. Endangered species are scarce, with fewer than 5 herbarium collections and none in recent years. *Vitex bogalensis,* with 2 herbarium collections, is listed as endangered by the IUCN, but it is categorized as Vulnerable. Groombridge (1992) reported that rare species are taxa usually found within restricted areas or habitats; *V. bogalensis* has a narrow distribution. Pierre (2020) reported that *V. bogalensis* has a narrow distribution range, in the north of Cameroon, from 9°30' to 11°N, just extending to the adjoining regions of Nigeria. This work is in accordance with Pierre (2020), and efforts to conserve this species must be implemented. *Vitex* species are widely distributed across Nigeria's diverse vegetation zones, reflecting both ecological adaptability and habitat specificity within the genus. *Vitex doniana* emerged as the most widely distributed species, occurring across all major vegetation types in Nigeria, except for swamp forests. This broad distribution underscores its ecological versatility and widespread ethnobotanical relevance. This is in line with the findings of Ayodele and Yong Yang (2012)

By contrast, *Vitex oxycuspis* was found only in the high forest zones of Cross River and Edo States, indicating a narrower ecological range. *Vitex grandifolia* showed a strong association with humid habitats, such as rainforests, mangroves, and swamp forests. From our findings, specimens were collected from a wide range of locations, including Badagry, Epe, Egbado, Oka, Edo, Irele, Okomu, Eleme, Ogunmakin, Ibadan, and Ilaro, as well as ecologically significant sites such as the Lagos–Badagry Road, the *Rhizophora*-dominated swamps near Lagos University, and various forest edges and riverine zones in Edo, Ondo, and Cross River States. *Vitex simplicifolia* was restricted primarily to the savanna zone, with collections from Shaki, Jos, Ago-Are, Gombe, Keffi, Katsina, Bauchi, Igbeti, Kaduna, Lokoja, Kishii, and Nsukka. This suggests a strong ecological affinity for drier, open landscapes. *Vitex thyrsiflora*, in contrast, was found in rainforest zones including Idanre, Ikire, Ibadan, Ife, Delta, and Jos, indicating a preference for more humid conditions.

Vitex agnus-castus showed a wider ecological amplitude, with specimens collected from both rainforest and savanna zones—specifically from Ibadan, Ife, Zaria, and Delta State—implying an ability to thrive under varied climatic and edaphic conditions. *Vitex chrysocarpa* was observed exclusively in the savanna zone, with specimens collected in Badeggi, Ogun, Lokoja, Olokemeji, Jebba, and Kabba. At the same time, *Vitex bogalensis* was represented by only two specimens, both from savanna habitats in Adamawa and Biu. In addition, *Vitex ferruginea* was collected from several rainforest localities, including Umudike, Umuahia, Olokemeji, Ibadan, Sapoba, and the Onigambari Forest Reserve, further supporting its classification as a rainforest species. The work is in line with Keay (1989)

Conclusion

These findings emphasize the ecological breadth, conservation status and biogeographic spread of *Vitex* species in Nigeria. While some species, such as *V. doniana*, exhibit widespread adaptability, others, such as *V. oxycuspis*, *V. grandifolia*, and *V. bogalensis*, demonstrate narrow ecological preferences. This pattern highlights the need for species-specific ecological assessments and conservation planning, especially for narrowly distributed taxa. Moreover, understanding the

ISTF-NG 2026

ecological distribution of *Vitex* species is crucial for guiding future ethnobotanical research, habitat conservation efforts, and systematic revisions of this ecologically and medicinally valuable genus.

References

APG IV. (2016). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Bot J Linn Soc. 2016; 181:1–20.

Ayodele, A. E. and *Yang Yong* (eds.) (2012). *Diversity and distribution of Vascular plants in Nigeria*. Qingdao Publishing House, China. 350pp.

Burkill, H. M. (1997). The useful plants of West Tropical Africa (Vol. 4). Royal Botanic Gardens, Kew.

De Kok, R.P.J. (2008). The genus *Vitex* (Labiatae) in the Flora Malesiana region, excluding New Guinea. *Kew Bull*. 63:17–40.

Fakeye, T. O., Itiola, O. A., & Odelola, H. A. (2000). Evaluation of the antimicrobial property of the stem bark of Vitex doniana (Sweet). Phytotherapy Research, 14(4), 368–370.

Groombridge, B. (1992). Global Biodiversity. Status of the Earth's Living Resources. A Report Compiled by the World Conservation Monitoring Centre, Chapman and Hall. London. 585pp.

Harley, R. M., Atkins, S., Budantsev, A. L., Cantino, P. D., Conn, B. J., Grayer, R., ... & Paton, A. (2004). Labiatae. In: Kubitzki, K. (ed.), *The Families and Genera of Vascular Plants*, Vol. 7, Springer, Berlin, pp. 167–275.

Keay, R.W.J. (1989). Trees of Nigeria. A revised version of Nigerian trees (1960, 1964) by R.W.J. Keay, C.F.A. Onochie and D.P. Stanfield. Clarendon Press, Oxford, United Kingdom. 476 pp.

Moreira, A. D. S., Silva, O. L. M. D., Cordeiro, I., & Torres, D. S. C. (2023). Typification and synonymizations in Jatropha martiusii (Euphorbiaceae). Phytotaxa. https://doi.org/10.11646/phytotaxa.585.3.7

Oloruntoba, B., Senjobi, C. T., Ajiboye, O. F., Odeyemi, O. O., Ajayi, S. O., Ajani, B. A., & Odewo, S. A. (2025). USING HERBARIUM RECORDS AND IUCN RED LIST TO UNRAVEL EXTINCTION RISK PATTERN IN GENUS GARCINIA IN NIGERIA. https://doi.org/10.62050/fjst2025.v9n1.378

Pierre, M (2020). The genus Vitex (Lamiaceae) in the flora of Cameroon Phytotaxa 434 (2): 131–150 https://www.mapress.com/j/pt/

ISTF-NIG 2026

BIOMASS ACCUMULATION, STAND STRUCTURE, AND CARBON STOCK ESTIMATION OF *TECTONA GRANDIS* PLANTATION IN AGO-OWU FOREST RESERVE, S OUTHWESTERN NIGERIA

***Agbo-Adediran, A.O[1]., Adenuga, D.A[1]., Jayeoba, F.M[1]., Abodunrin, E.K[1]. and Adewoye, A.A[2].**

[1]Department of Forestry and Environmental Technology, FCF, Ibadan.
[2] Department of Horticultural Technology, FCF, Ibadan.
**Corresponding e-mail: agboadediranadewale@gmail.com*

Abstract

This study assessed the stand growth characteristics, biomass accumulation, and carbon sequestration potential of *Tectona grandis* (teak) plantation in Ago-Owu Forest Reserve, Osun State, Nigeria. The objective was to evaluate the plantation's structural development and estimate its capacity for carbon storage and CO_2-equivalent sequestration to support climate change mitigation. Data on diameter at breast height (DBH), total height, basal area, and volume were collected from sampled trees within the plantation. Stand structure was analyzed using frequency distribution of diameter and height classes, while biomass was estimated using standard allometric equations for tropical tree species. Carbon stock was derived from above-ground biomass using a carbon fraction coefficient, and the corresponding CO_2 equivalent was computed to quantify the climate regulation potential of the plantation. Results indicated a moderately developed stand structure with a higher concentration of trees in the middle diameter and height classes, suggesting an even-aged plantation with active growth dynamics. The mean DBH and height values reflected good stand productivity, while basal area and volume estimates confirmed substantial timber accumulation potential. Carbon stock analysis revealed that the plantation stores a considerable amount of carbon in its biomass, with a significant CO_2 equivalent, indicating its importance as a carbon sink. The study concludes that *the Tectona grandis* plantation in the Ago-Owu Forest Reserve plays a vital role in carbon sequestration and climate change mitigation while also providing economic value through timber production. Sustainable management of such plantations is therefore recommended to enhance both ecological and economic benefits.

Keywords: Stand structure, Biomass estimation, Carbon sequestration, Ago-Owu Forest Reserve, Climate change mitigation, *Tectona grandis*

Introduction

Forests play a fundamental role in maintaining global ecological balance by supporting biodiversity, regulating climate, and providing essential ecosystem services. In recent decades, rising atmospheric concentrations of greenhouse gases—particularly carbon dioxide (CO_2)—have heightened global climate change concerns, underscoring the critical role of forests as carbon sinks. Through carbon sequestration, forests absorb atmospheric CO_2 and store it in biomass and soils, thereby contributing significantly to climate change mitigation (Kauffman & Donato, 2012). Tropical forests play a crucial role in the global carbon cycle due to their high productivity and rapid biomass accumulation, which enable them to sequester large amounts of atmospheric carbon dioxide (CO_2) (Mitchard, 2018; Tang *et al*., 2026). These ecosystems act as major carbon sinks,

storing substantial quantities of carbon in aboveground biomass and contributing significantly to climate regulation. However, widespread deforestation, forest degradation, and land-use changes have significantly reduced tropical forests' capacity to sequester carbon, particularly in developing countries where anthropogenic pressures are high (Mitchard, 2018; Sierra *et al.,* 2012). In many cases, disturbed or logged tropical forests may even transition from carbon sinks to carbon sources due to biomass loss and ecosystem degradation (Harris *et al.,* 2023).

These challenges have necessitated the adoption of sustainable forest management strategies, including plantation forestry and forest restoration initiatives, to rehabilitate degraded landscapes, enhance timber production, and improve carbon storage capacity (Tang *et al.,* 2026; Kauffman & Donato, 2012). Plantation forests, in particular, have been recognized as effective tools for increasing biomass accumulation and contributing to long-term carbon sequestration in tropical regions. The assessment of stand growth characteristics, including diameter at breast height (DBH), tree height, basal area, and volume, is essential for understanding forest structure, productivity, and dynamics. These parameters serve as critical inputs for estimating forest biomass and carbon stock, which are key indicators of carbon sequestration potential (Ige, 2018; Dida & Tiburan, 2020). Studies have shown that tree growth variables, particularly DBH, are strongly correlated with biomass accumulation and carbon storage, making them reliable predictors of forest carbon dynamics (Bhatta *et al*., 2018).

Recent empirical studies have emphasized the importance of forest plantations in carbon sequestration. For example, Abebe *et al*. (2021) reported significant biomass and carbon storage in bamboo forests in Ethiopia, while Adeyemi and Adeleke (2021) demonstrated substantial carbon sequestration potential in forest ecosystems within southwestern Nigeria. Similarly, Akintunde-Alo *et al*. (2024) found considerable biomass accumulation and carbon storage in *Parkia biglobosa* plantations, highlighting the role of plantation forests in climate change mitigation. Further studies in Nigeria and beyond have reinforced the relationship between forest structure and carbon storage. Dada *et al.* (2021) established a strong nexus between biomass, carbon stock, and CO_2 emissions in forest ecosystems, while Akhabue *et al.* (2021) emphasized the importance of assessing both aboveground biomass and soil properties for comprehensive carbon evaluation. In addition, Dongs *et al.* (2024) demonstrated that species diversity and stand structure significantly influence the potential for carbon sequestration in forest ecosystems.

Carbon stock in forest ecosystems is often expressed as carbon dioxide equivalent (CO_2e), which represents the amount of CO_2 removed from the atmosphere and stored in biomass. This standardized metric allows comparison of the climate-mitigation potential of different ecosystems and supports global carbon accounting frameworks. Converting carbon to CO_2e provides a clearer understanding of forests' role in reducing atmospheric concentrations of greenhouse gases (Dada *et al*., 2021). Despite the increasing recognition of the importance of plantation forests in carbon sequestration, there remains a paucity of site-specific data on the growth characteristics and carbon storage potential of teak plantations in Nigeria. While studies such as Ige (2018) and Dongs *et al*. (2024) have provided valuable insights into biomass and carbon dynamics in other forest ecosystems, comprehensive assessments of teak plantations in the Ago-Owu Forest Reserve are limited. Given the ecological and economic importance of teak plantations, there is a need for a detailed evaluation of their growth performance, biomass accumulation, and carbon sequestration potential. Such information is essential for optimizing plantation management, enhancing carbon storage, and contributing to climate change mitigation efforts at both national and global levels.

ISTF-NIG 2026

Therefore, this study aims to assess the stand growth characteristics, carbon sequestration potential, and CO_2 equivalent of *Tectona grandis* in Ago-Owu Forest Reserve, Osun State, Nigeria. The findings are expected to provide valuable insights into the productivity and climate mitigation potential of teak plantations, thereby supporting sustainable forest management and environmental policy development.

Methodology

Study area

The study was conducted in the Ago-Owu Forest Reserve, located in Osun State, southwestern Nigeria. The reserve lies within the tropical rainforest belt of Nigeria and forms part of the forest ecosystems that support biodiversity conservation and timber production in the region (Adeyemi & Adeleke, 2021; FORMECU, 1999). Ago-Owu Forest Reserve is situated within Ayedaade Local Government Area and is accessible through surrounding communities such as Ago-Owu and Ikire. The forest reserve falls approximately between Latitude 7°05′N and 7°15′N and Longitude 4°10′E and 4°20′E (FORMECU, 1999; Ojo, 2004). The area experiences a tropical humid climate characterized by two distinct seasons: the wet season, which typically extends from March to October, and the dry season from November to February (Adefolalu, 2007; Nigerian Meteorological Agency (NiMet), 2020). The mean annual rainfall ranges from 1,200 to 1,500 mm, while the average temperature is about 26–28°C. Relative humidity is generally high throughout the year, particularly during the rainy season (Adefolalu, 2007).

The vegetation of Ago-Owu Forest Reserve is predominantly tropical rainforest, although parts of the reserve have been modified due to plantation establishment and anthropogenic activities. The forest comprises both natural and plantation species, particularly teak (*Tectona grandis*), which is widely cultivated for timber production (Evans & Turnbull, 2004; Adeyemi & Adeleke, 2021). Other associated tree species commonly found in the area include *Gmelina arborea*, *Terminalia* spp., *Albizia* spp., and various indigenous hardwood species typical of lowland rainforest ecosystems in southwestern Nigeria (Keay, 1989; Onyekwelu *et al.,* 2008).

Method of data collection

Data for this study were collected through field sampling using a systematic line transect sampling technique. This method is commonly used in forest ecological studies to obtain reliable information on tree growth characteristics and stand structure. Line transects were first established across the teak plantation in the Okodowo axis of the Ago-Owu forest reserve to serve as the baseline for plot establishment. Along this transect line, ten (10) sample plots were systematically laid out at 200 m intervals to ensure adequate coverage of the study area and to minimize sampling bias. Each sample plot measured 20 m × 20 m. The plots were positioned alternately along the transect line to maintain uniform spacing and representativeness of the plantation stand. Within each established plot, all woody tree species with a diameter at breast height (DBH) of 10 cm or greater were identified and recorded. The following tree growth parameters were measured and documented for each tree encountered in the plots:

(a) Diameter at Breast Height (DBH) – The DBH of each tree was measured at 1.3 m above ground level using a diameter tape.
(b) Tree height – Total tree height was measured using a Haga altimeter

ISTF-NIG 2026

The data collected from the sampled plots were later used to compute important forest growth and structural parameters, as well as the plantation's sequestration potential, such as basal area, tree volume, above-ground biomass, and carbon sequestration estimates. These measurements provided quantitative information on the growth characteristics and stand structure of the teak plantation in Ago-Owu Forest Reserve.

Data analysis

The data from field measurements were compiled and analyzed using descriptive statistics and allometric equations to determine the growth characteristics and CO_2e of trees in the teak plantation of the Ago-Owu Forest Reserve.

Basal Area

The basal area of each tree was calculated using the formula:

$$BA = \frac{\pi D^2}{4} \quad \text{..... (1)}$$

Where:

BA = Basal area (m^2)

D = Diameter at breast height (DBH) in meters

π = Constant (3.142)

Tree Volume

Tree volume is the amount of wood contained in a tree's stem and is an important measure of forest productivity and timber yield.

The formula is expressed as:

V = B.A. x H ..... (2)

Where:

V = Volume of the tree (m^3)

B.A= Cross-sectional area at the midpoint of the tree stem (m^2)

H = Height of the tree (m)

Biomass Estimation

The standing biomass of each tree was estimated using the allometric equation developed by Terakumpisut and Amin (2012) for tropical rainforests. The functions were expressed as follows:

$Ws = 0.0509*(D^2*H)^{0.919}$ ..... (3)

$Wb = 0.00893*(D^2*H)^{0.977}$ ..... (4)

$Wl = 0.014* (D^2*H)^{0.669}$ ..... (5)

ISTF-NIG 2026

Where: Ws = stem biomass (tons/individual tree); Wb = branch biomass (tons/individual tree); Wl = leaf biomass (tons/individual tree); D = diameter at breast height (cm); H = height (m). The stem, branch and leaf biomass together constitute the standing biomass of an individual tree.

Carbon Stock Estimation

The above-ground carbon content was estimated using the allometric equations developed by Kauffman & Donato (2012) and adopted by Dada *et al.* (2024). The equations are as follows

AGCs = (Ws + Wb + Wl)*0.50…… (6)

Where: AGCs = Aboveground Carbon stock, Ws = stem biomass, Wb = branch biomass, Wl = leaf biomass.

Estimation of CO_2 Equivalent

The estimated carbon stock was converted into CO_2 equivalents (Bhatta *et al*., 2018; Dada *et al*., 2024). This is given by-

$CO_2e = C \times 3.67$…….....…… (7)

Where CO_2e = CO_2 Equivalent, C = Carbon stock

Results and Discussions

Results

The results obtained from the teak plantation in Ago-Owu forest reserve reveal important insights into the growth characteristics, structural stability, and carbon sequestration potential of a coppice stand regenerated after clear felling. The mean DBH (37.14 cm) and mean height (10.72 m) indicate that the stand has achieved substantial post-harvest regeneration and growth, which is typical of teak coppice systems. Following clear felling, teak (*Tectona grandis*) is known for its strong coppicing ability, producing vigorous shoots from stumps that often exhibit rapid early growth due to an already established root system (Kollert & Kleine, 2017). The wide variation observed in DBH (15.5–76.1 cm) and height (1.8–13.9 m) (Table 3.1) reflects heterogeneity in coppice shoot development, which may arise from differences in stump size and vitality, number of sprouts per stump, competition among coppice shoots, site-specific factors such as soil nutrients and moisture availability.

This variability is consistent with studies indicating that coppice stands often exhibit uneven growth patterns compared to seedling plantations, especially when thinning or shoot selection has not been rigorously applied (Forrester *et al.,* 2021).

Table 3.1: Range of the growth parameters and sequestered carbon in the study area

	DBH (cm)	H(m)	B.A (m^2)	Vol (m^3)	TSC	Std. Biomass (kg)	Seq. Carbon (kg)	tCO2e
N	158	158	158	158	158	158	158	158
Min	15.5	1.8	0.02	0.1	4.6	62.4	31.2	0.11
Max	76.1	13.9	0.45	5.7	49.1	2013.3	1006.6	3.69
Sum	-	-	18.71	213.6	4813.7	82458.8	41229.2	151.27

ISTF-NG 2026

Mean	37.14	10.72	0.12	1.35	30.47	521.89	260.94	0.96
Std. error	0.91	0.15	0.01	0.08	0.55	28.38	14.19	0.05

DBH- Diameter at breast height, B.A- Basal area, Vol- Volume, TSC- Tree slenderness coefficient, Seq. Carbon – Sequestered carbon, tCO_2e- CO_2 equivalent (tons)

The relatively high mean basal area (0.12 m^2) and volume (1.35 m^3) further demonstrate that coppiced teak stands can rapidly rebuild stand structure and biomass after harvesting, making them suitable for short-rotation forestry systems.

Height Class Distribution of Trees in Ago-Owu Teak Plantation

The height class distribution of trees in the Ago-Owu teak plantation reveals important structural characteristics of the stand, particularly in relation to its coppice origin following clear felling. The distribution shows that the majority of trees are concentrated within the 6–10 m (82 trees) and 11–15 m (75 trees) height classes, with only One tree recorded in the 1–5 m class. This pattern indicates a well-established, actively growing stand, with the intermediate and upper canopy layers dominant. The dominance of trees within the 6–15 m height range suggests that the plantation has progressed beyond the early establishment phase and is currently in a mid-rotation developmental stage. In coppiced teak (*Tectona grandis*) stands, rapid height growth is commonly observed due to the presence of pre-existing root systems, which facilitate efficient water and nutrient uptake and accelerate shoot development after disturbance (Kollert & Kleine, 2017). This explains the high frequency of trees in the upper height classes, reflecting vigorous regrowth following clear felling. The relatively balanced distribution between the 6–10 m and 11–15 m classes suggests a transitioning canopy structure, where a significant proportion of trees are moving from intermediate to dominant height classes. This reflects ongoing competition and stratification within the stand, which is typical of even-aged or coppice-origin forests. Similar patterns have been reported in tropical plantation forests, where height distribution tends to cluster around middle and upper classes as stands mature and competition intensifies (Forrester *et al*., 2021).

From a structural perspective, the observed distribution indicates a semi-uniform canopy with limited vertical stratification, which may have implications for both productivity and stability. While such uniformity can enhance overall stand biomass accumulation, it may also increase competition-induced stress and promote the development of slender stems, especially in densely stocked coppice stands. This aligns with previous findings that excessive competition in plantation forests can lead to increased height growth at the expense of diameter increment, thereby affecting mechanical stability (Pretzsch, 2019). In terms of management, the height class distribution suggests that the stand would benefit from silvicultural interventions such as thinning and shoot selection. These practices would help reduce competition, improve resource allocation, and promote balanced growth between height and diameter. Effective management at this stage is crucial to enhancing timber quality, structural stability, and the potential for carbon sequestration.

Overall, the height class distribution demonstrates that the Ago-Owu teak plantation is a vigorous, mid-aged coppice stand characterized by dominance of intermediate and upper height classes, minimal regeneration, and active competition-driven dynamics. This structure reflects both the resilience of teak under coppice regeneration and the need for appropriate management to sustain long-term productivity.

ISTF-NIG 2026

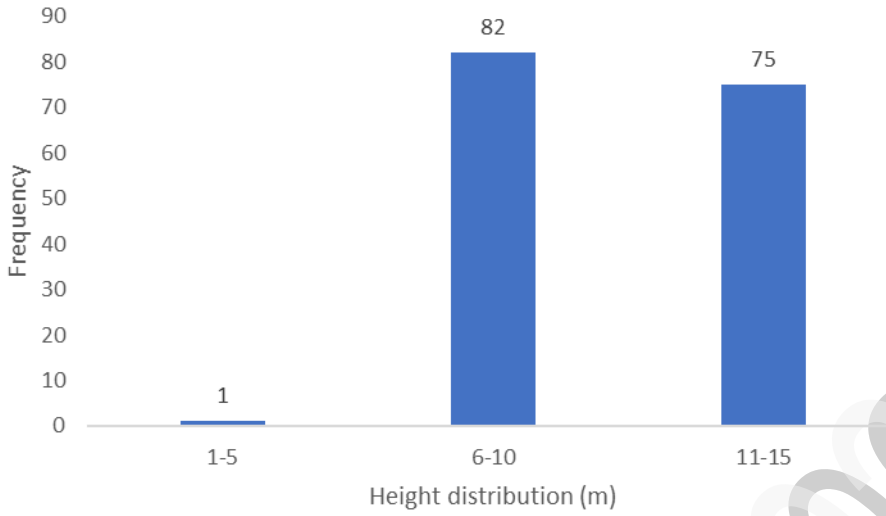


Figure 1: Height class distribution of trees in Ago-Owu teak plantation

Diameter Class Distribution of Trees in Ago-Owu Teak Plantation

The diameter class distribution shows a clear concentration of trees in the middle diameter classes. The dominance of trees in the 30–39 cm (53 trees) and 20–29 cm (44 trees) diameter classes indicates that the stand is largely composed of medium-sized stems, which is characteristic of a maturing coppice forest. This pattern suggests that the stand has undergone substantial growth following clear felling and is now transitioning toward a more mature structural state, based on Adekunle (2006), who reported 48 cm as the minimum merchantable tree size, as contained in the logging policy of Southwestern, Nigeria. In teak (*Tectona grandis*) plantations, such distributions are typical of even-aged or coppice-origin stands, where growth is relatively synchronized due to simultaneous regeneration after disturbance (Kollert & Kleine, 2017).

The gradual decline in frequency toward the higher diameter classes (40–79 cm) reflects the progressive reduction in tree numbers with increasing size, a pattern consistent with self-thinning processes. As competition intensifies, smaller and suppressed stems are eliminated, allowing a limited number of dominant trees to continue growing into larger diameter classes. This phenomenon aligns with the 'minus 3/2' self-thinning rule (Yoda's rule), which describes how stand density decreases as individual tree size increases (Yoda *et al*., 1963; Pretzsch, 2019).

The relatively lower number of trees in the smallest diameter class (10–19 cm) suggests limited recent recruitment, which is expected in a coppice stand where regeneration occurs primarily immediately after harvesting rather than continuously over time. The near absence of very small stems further indicates that the stand has moved beyond the establishment phase and is experiencing canopy closure and competitive exclusion. The presence of trees in the larger diameter classes (50–79 cm), although fewer in number, is particularly significant. These trees represent dominant individuals that have successfully outcompeted others, benefiting from better access to Light, nutrients, and space. Such trees contribute disproportionately to stand biomass and carbon storage, as biomass accumulation increases exponentially with diameter (Chave *et al.,* 2014). Their presence highlights the productive potential of the coppiced teak stand.

ISTF-NIG 2026

Structurally, the distribution exhibits a bell-shaped pattern skewed toward the middle diameter classes, which is typical of even-aged plantation forests. This contrasts with natural uneven-aged forests, which often show reverse J-shaped distributions. The observed pattern confirms that the stand structure is largely influenced by its coppice regeneration following clear felling, resulting in relatively uniform age but variable growth performance among stems.

From a management perspective, this diameter distribution suggests that the stand would benefit from selective thinning interventions, particularly in the overcrowded middle diameter classes (20–39 cm). Reducing competition in these classes would enhance diameter increment of selected trees, improve stem form and timber quality, reduce the development of high slenderness ratios, and increase overall carbon sequestration efficiency by promoting the growth of larger trees.

In addition, the retention and protection of larger diameter trees should be prioritized, as they play a crucial role in carbon storage and structural stability within the stand. Overall, the diameter class distribution indicates that the Ago-Owu teak plantation is a well-established, mid-rotation coppice stand characterized by strong competition, active self-thinning, and dominance of medium-sized trees, with a smaller proportion of large, high-value individuals. This structure reflects healthy stand development but also underscores the need for appropriate silvicultural management to optimize productivity and sustainability.

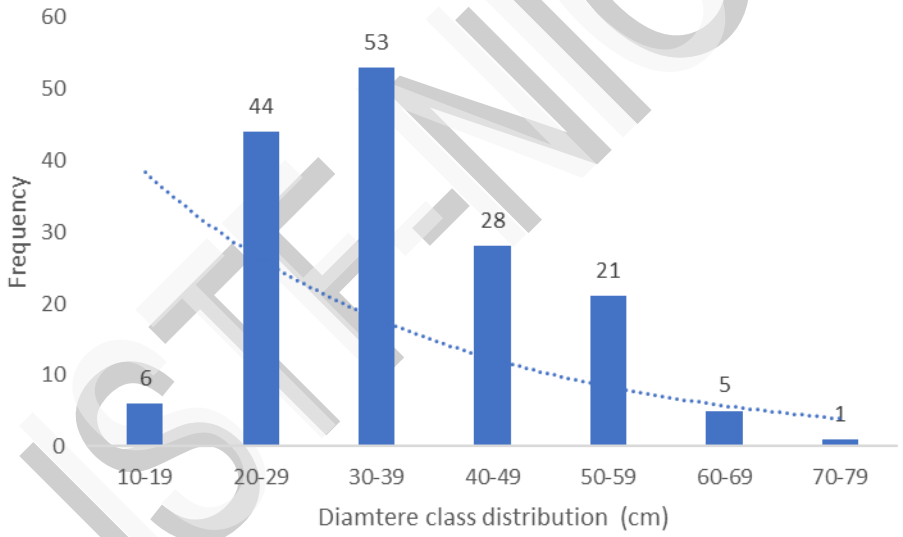


Figure 2: Diameter class distribution

Tree Slenderness Coefficient and Structural Stability in Coppice Stands

The tree slenderness coefficient indicates that the trees in the stand are structurally stable, despite being coppice shoots. In coppiced systems, shoots often exhibit rapid height growth, especially under high competition, which can increase slenderness in early stages. However, the observed TSC range (4.6–49.1) indicates that all of the trees fall within acceptable stability limits (<70). In coppice stands, multiple shoots emerging from a single stump compete intensely for Light, often

leading to tall, slender stems if not properly thinned. The negative relationship between TSC and DBH, and the positive relationship between TSC and height (figures 4 & 5), further support this, as dominant shoots allocate more growth to diameter, thereby improving stability (Pretzsch, 2019; Forrester *et al*., 2021). The presence of structurally stable trees suggests that natural self-thinning or previous management interventions may have reduced excessive competition among coppice shoots.

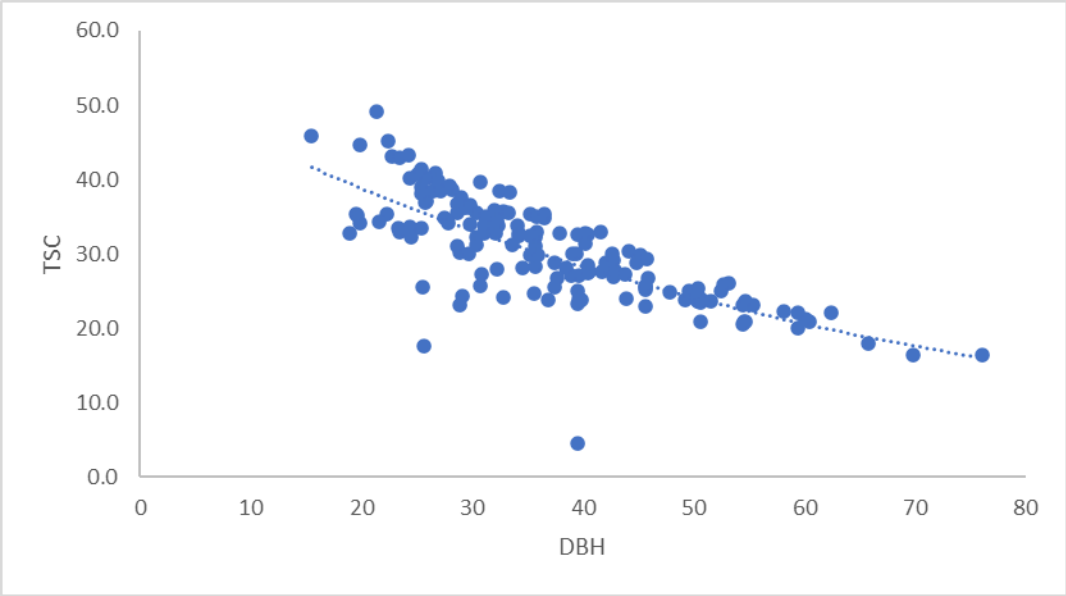


Figure 4: Correlation between the tree slenderness coefficient and the diameter of trees

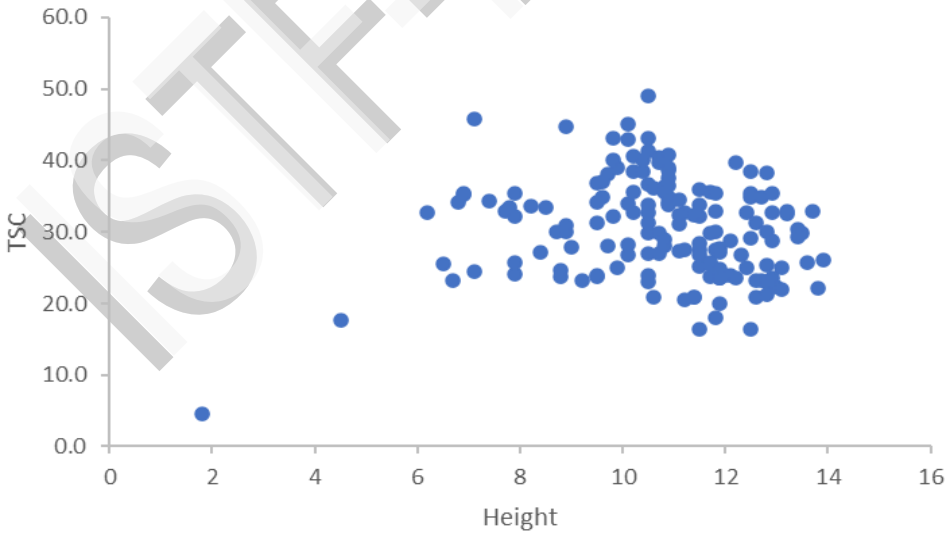


Figure 5: Correlation between the tree slenderness coefficient and the height of trees

Biomass Accumulation, Carbon Sequestration, and CO_2 Equivalent

The coppice stand demonstrates strong biomass accumulation, with a mean of 521.89 kg per tree, and corresponding mean carbon stock (260.94 kg) and CO_2 equivalent (0.96 tCO_2e). This highlights the efficiency of coppice systems in carbon recovery following disturbance. Coppiced forests are known to exhibit higher early carbon sequestration rates than newly planted stands because the pre-existing root system supports rapid shoot growth, nutrient uptake is more efficient, and there is reduced establishment lag (Kollert & Kleine, 2017).

The total CO_2 equivalent of 151.27 tCO_2e underscores the role of coppiced teak plantations as effective carbon sinks, particularly in managed tropical forest landscapes where repeated harvesting occurs.

Conclusion

The teak plantation in the Ago-Owu forest reserve, regenerated through coppicing after clear felling, demonstrates rapid growth recovery, substantial biomass accumulation, acceptable structural stability, and significant carbon sequestration potential. These findings highlight the importance of coppice management for sustaining both forest productivity and climate change mitigation. When properly managed, coppiced teak stands can serve as a cost-effective and ecologically viable alternative to replanting, particularly in tropical forestry systems.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

- Coppice thinning (shoot selection) should be carried out early by retaining 1–2 dominant shoots per stump to reduce intra-stump competition and promote diameter growth.
- Controlled regeneration practices should be applied during subsequent coppice cycles to maintain stand productivity.
- Larger and well-formed trees should be retained and protected, as they contribute disproportionately to biomass and carbon storage.
- The plantation should be managed with longer rotation periods where feasible to maximize carbon accumulation and climate-mitigation benefits.
- Further studies should investigate below-ground biomass, soil carbon, and long-term productivity of coppice versus planted stands.
- Capacity-building and training programs for forest managers and local communities should be strengthened to ensure the implementation of best management practices.

References

Abebe, S., Minale, A.S., Teketay, D., Jayaraman, D., & Long, T.T. (2021). Biomass, Carbon stock and sequestration potential of Oxytenanthera abyssinica forests in the Lower Beles River Basin, Northwestern Ethiopia. *Carbon Balance and Management*, 29(16).

ISTF-NIG 2026

Adefolalu, D. O. (2007). Climate change and economic sustainability in Nigeria. Paper presented at the International Conference on Climate Change and Economic Sustainability, Nnamdi Azikiwe University, Nigeria.

Adekunle, V.A.J. (2006). Conservation of tree species diversity and structure of a Nigerian Strict Nature Reserve. *Journal of Tropical Forest Science*, 18: 91-101.

Adeyemi, A.A. & Adeleke, S.O. (2021). Assessment of land cover changes and carbon sequestration potentials of tree species in J4 section of Omo forest Reserve, Ogun state, Nigeria. *Ife Journal of Science*, 22(1), 137–152.

Akhabue, E.F., Chima, U.D &Eguakun, F.S. (2021). Assessment of the aboveground carbon stock and the soil physicochemical properties of an Arboretum within the University of Port Harcourt, Nigeria. *Journal of Forest and Environmental Science*, 37(3), 193-205

Akintunde-Alo, D.A., Onilude, Q.A., Ige, P.O., & Adeoti, O.O. (2024). Stand growth, biomass and carbon sequestration potentials of Parkia biglobosa (Jacq.) Bench Plantation in Southwestern Nigeria. *Journal of Applied Science and Environmental Management,* 28(4), 1297-1304

Bhatta, S.P., Sharma, K.P., & Balami, S. (2018). Variation in carbon storage among tree species in the planted forest of Kathmandu, Central Nepal. *Current Science*, 115: 274–282.

Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B. and Vieilledent, G. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology, 20*(10), 3177–3190

Dada, A., Olaniran, J. & Odiwe, A.I. (2021). Nexus between Carbon stock, biomass, and CO_2 emission of woody species composition: evidence from Ise-Ekiti Forest Reserve, Southwestern Nigeria. *Carbon Research*, 3(40), 1-16

Dida, J.J.V., & Tiburan Jr., C.L. (2020). Aboveground biomass estimation of trees in the University of the Philippines Los Banos Campus, Philippines. *The Technical Journal of Philippines Ecosystems and Natural Resources* 30(2), 89–103.

Dongs, Y.D., Saka, M.G & Adedotun, A. (2024). Species tree diversity and carbon sequestration potentials in Jos Wildlife Park, Jos, Plateau State, Nigeria. *South Asian Journal of Agricultural Science*, 4 (1), 28-36

Evans, J., & Turnbull, J. W. (2004). Plantation forestry in the tropics (3rd ed.). Oxford University Press.

Federal Department of Forestry (FORMECU). (1999). Forest resources study, Nigeria—Federal Ministry of Environment, Abuja.

Forrester, D. I., Tachauer, I. H., Annighöfer, P., Barbeito, I., Pretzsch, H., Ruiz-Peinado, R., del Río, M. (2021). Generalized biomass and leaf area allometric equations for European tree species incorporating stand structure, tree age and climate. *Forest Ecology and Management, 396*, 160–175.

Harris, N. L., Silva, E.A.N.A., Silva, M.H.G., Rocha, A.N., Oliveira, R.S., Silva, J.T., Ewers, R.M. and Aragão, L.E.O.C. (2023). Logged tropical forests are a persistent net carbon source to the atmosphere—Proceedings of the National Academy of Sciences (PNAS).

Ige, P.O. (2018). Above-Ground Biomass and Carbon Stock Estimation of Gmelina arborea (Roxb). Stands in the Omo Forest Reserve, Nigeria. *Journal of Research in Forestry, Wildlife & Environment,* 10(4), 71-80

Kauffman, J. B. & Donato, D.C. (2012). Protocols for the measurement, monitoring, and reporting of structural, biomass, and carbon stocks in Mangrove forests. Bogor, Indonesia: Cifor, Pg. 25

ISTF-NIG 2026

Keay, R. W. J. (1989). *Trees of Nigeria*. Clarendon Press.

Kollert, W. & Kleine, M. (2017). The global teak study: Analysis, evaluation and future potential of teak resources. Food and Agriculture Organization (FAO).

Mitchard, E. T. A. (2018). The tropical forest carbon cycle and climate change. *Nature*, 559, 527–534.

Nigerian Meteorological Agency (NiMet). (2020). Climate review bulletin. Abuja, Nigeria.

Ojo, L. O. (2004). The fate of a tropical rainforest in Nigeria: Abeku sector of Omo Forest Reserve. *Global Nest Journal*, 6(2), 116–130.

Onyekwelu, J. C., Mosandl, R. & Stimm, B. (2008). Tree species diversity and soil status of primary and degraded tropical rainforest ecosystems in southwestern Nigeria. *Journal of Tropical Forest Science*, 20(3), 193–204.

Pretzsch, H. (2019). Forest dynamics, growth and yield: From measurement to model. *Springer* p.145

Sierra, C. A., del Valle, J. I., & Restrepo, H. I. (2012). Total carbon accumulation in a tropical forest landscape. *Carbon Balance and Management*, 7(12).

Tang, W., Hall, J. S., Phillips, O. L., Brienen, R. J. W., Wright, S. J., Wong, M. Y., Hedin, L. O., van Breugel, M., Yavitt, J. B., Hannam, P. M., & Batterman, S. A. (2026). Tropical forest carbon sequestration accelerated by nitrogen. *Nature Communications*. https://doi.org/10.1038/s41467-025-66825-2

Yoda, K., Kira, T., Ogawa, H., & Hozumi, K. (1963). Self-thinning in overcrowded pure stands under cultivated and natural conditions. *Journal of Biology,* Osaka City University, 14, 107–129.

ISTF-NIG 2026

KNOWLEDGE LEVEL AND CONSTRAINTS FACED BY SMALLHOLDERS FARMERS IN COPING WITH THE EFFECTS OF CLIMATE CHANGE IN OYO STATE.

[1]Oyewole, A.L., [2]Oyewole, S. O., Abegunrin, O. O., [1]Adekunle, A. and [1]Adegbayi, O. R.

[1]Federal College of Forestry, Jericho Hills, Ibadan;
[2]Forestry Research Institute of Nigeria, Jericho Hills, Ibadan.
Corresponding author's email: oyewole.so@frin.gov.ng

Abstract

Knowledge gap is One of the important issues that affects the ability of the smallholder farmers to adopt appropriate adaptation strategies against climate change. This study examined the level of knowledge and constraints faced by smallholder farmers in coping with the effects of climate change in Oyo State, Nigeria. A multi-stage sampling procedure was used to select 172 farmers across the Ibadan/Ibarapa and Saki agricultural zones of Oyo State. Data were collected using structured questionnaires and analyzed using descriptive statistics and weighted mean scores. Findings revealed that a majority of farmers demonstrated moderate to high awareness of climate indicators, particularly changes in weather patterns, temperature fluctuations, and rainfall seasonal variability. However, misconceptions persist regarding certain indicators such as sunshine intensity and isolated rainfall events. The study further identified key constraints to climate change adaptation, including land tenure issues, unfavourable government policies, limited access to credit facilities, and the high cost of adaptation measures. Although extension services and access to innovations were recognized as constraints, they were only minor ones. The study concludes that while farmers have basic knowledge of climate change, structural and institutional constraints limit their coping capacity. Therefore, addressing these constraints is critical for enhancing resilience, improving agricultural productivity, and ensuring sustainable livelihoods among smallholder farmers in the study area.

Keywords: Knowledge, Climate, Climate change

Introduction

Nigerian agriculture is being faced with several problems, ranging from climatic variability, land tenure or ownership systems that affect accessibility to land, lack of basic amenities such as good and motorable roads, marketing facilities, inadequate or costly agricultural inputs such as seeds, fertilizers, herbicides, high post-harvest losses, and environmental changes, among others (Ahmad et al., 2025; Kehinde et al., 2023). One of the great threats to agricultural productivity and a cause of declining crop yield in the tropics is climate change (Reppin *et al.,* 2020). Onyekunu and Marchant (2016) highlighted prolonged drought, the intensity of irregular rainfall patterns,patterns, deforestation, flooding, etc.etc., as environmental changes that causecause adverse effects on crop growth and reduce agricultural productivity. The increasing temperatures, erratic rainfall patterns, and extreme weather events are the effects and aftermath of climate change. Climate is the atmospheric condition of a place over a long period of time, usually 30-35 years. The climatic condition of a place is the sum of all climatic elements, such as rainfall, temperature, solar radiation, and humidity, and their changes over a long period of time. (Ayoade, 2004).

Climate change is the change in the global atmospheric composition caused by human activities or natural changes over a period. Climate change is attributable to human activities, ,while climatic variability is attributable tis o natural sources (Farautta, 2011). The extreme weather conditions in many parts ofofof the world lead tolead tolead to chronic socio-economic impactssocioeconomic impactssocio-economic impacts, such as extreme heat, loss of lives, destruction of homes and property, and soil and air pollution. It has also been revealed that food security and population displacement, especially among vulnerableamong vulnerableamong vulnerable people, will remain a concern in 2023 due to the hazards posed by weather and climate in many parts of the world. (WMO, 2022). Farmers' knowledge about climate change is very important for mitigation and adaptation, because those who understand its effects will take steps to cope and increase produFarmers' knowledgege indicators among famong farmersamong farmersindicators of climate change has been identiidentified as anidentified as anfluencing theirinfluencing theon to climateinfluencing thareience to dateinfluencing agricultural production have been predicted to worsento worsen in the years to come, and most economies, especially Sub-Saharan African economies, depend on the agricultural sector. (Omotoso *et al*, 2023). Given the threat to food production in the near future, it is necessary to assess farmers' knowledge of climate change and the constraints they face in coping with its effects in Oyo State. Adaptation to climate change among smallholder farmers will reduce climate change vulnerability, generate high returns from land resources, and ensure sustainable food production (Douxchamps *et al.*, 2016). This study will therefore assess the level of knowledge among smallholder farmers on climate change in the study area and identify the constraints to their adaptation to its effects.

Methodology

Study Area

Oyo State is an inland State in Southwestern Nigeria. It covers 27,107.93 square kilometers (Oyo State Government, 2010). The State lies between latitudes 7 °N7 °N and 9 °N9 °N of the equator and between longitudes 2.5 °E2.5 °E and 5 °E5 °E of the prime meridian (Oladejo *et al*., 2011). Oyo State is bounded in the south by Ogun State, in the north by Kwara State, in the west by Ogun State and the Republic of Benin, and in the east by Osun State. Oyo State has a population of 5,580,894 as at the 2006 population census, ranking 5th in population size in Nigeria, with a population growth rate of 3.2% (NPC, 2006). The projected population as of 2022 was 7,976,100. Oyo State exhibits the typical tropical climate of averagely high temperatures, high relative humidity and generally two rainfall maxima regimes during the rainfall period of March to October (Olaoye *et al.,* 2013). The average temperature is 27 °C. The rainfall pattern is bimodal, with peaks in June and September, while November to February is characterized by the harmattan, a dry, dusty air mass brought about by the north-easterly trade winds from the Sahara Desert.

Oyo State spans from swamp forests to western uplands. In between are rainforests and deciduous forests/savannas. The agricultural sector forms the foundation of the State'sate's State's overall develoState, with farming as the main occupation of the people in the area. The climate in the StateStateStateState favours the cultivation of crops such assuch as maize, yamsyams, cassava, millet, rice, plantains, cocoa, palm produce, and ,and cashew,cashew etc. There are several government farm settlements in Ipapo, Ilora, Eruwa, Ogbomoso, Iresa-Adu, Ijaiye, Akufo and Lalupon (Oladejo *et al.,* 2011).

ISTF-NIG 2026

Population of the study

The study population comprised all farmers in Oyo State, while the target population comprised all arable crop farmers in Oyo State.

Sampling Procedure and Sample Size

A multi-stage sampling procedure was employed to select the respondents for the study. The first stage involved the random selection of two Agricultural zones from the State. The second stage involved randomly selecting One agricultural block from each selected zone. The third stage involved random selection of four cells from each selected block. The final stage involved random selection of 172 smallholder farmers, proportional to the population of the selected cells, as provided by the Oyo State Ministry of Agriculture and Natural Resources. Oyo State has four (4) agricultural zones, namely Oyo, Ogbomoso, Ibadan/Ibarapa, and Saki. Of these agricultural zones, Ibadan/Ibarapa and Saki were selected at random. The second stage involves the random selection of One (1) agricultural block from each zone. Ido and Saki East were selected from Ibadan and Saki zones, respectively. The third stage involved randomly selecting four (4) cells from each block. The selected cells were Akufo, Omi, Koguwo, and Esarun from Ido and Oje-Owode, Ogboro, Sepeteri, and Ago Amodu from Saki East.

Data Collection and Data Analysis

Farmers' level of knowledge on climate change

The variable was measured using a knowledge test comprising 9 (nine) items or statements on arable crop farmers' knowledge of climate change. The statements were dichotomized into Yes = 1 and No = 0. The maximum score was 9 points, while the minimum was 0. The mean and standard deviation were used to categorize arable crop farmers into Low level (0-3), Medium level (4-6), and High level (7 and above).

Constraints associated with adaptive capacity to climate change

Farmers were asked to select from a list of constraints, graded on a three-point rating scale. Major constraints=1, Not a constraint = 0, and Minor constraints =2. This was later ranked to determine the constraints faced by the farmers.

Results and Discussion

Knowledge level of arable crop farmers on climate change in Oyo State

The results in Table 1 revealed that the majority (68.5%) of the respondents strongly agreed that weather changes indicate that climate is changing, and 53.9% strongly agreed that when the temperature is very high, there is climate change. About 62% and 43%, respectively, agreed that there is climate change when there is a a late arrival/ onset of rainfall,, and that climate change is an evident when the the rainfall season arrives early. Too much sunshine does not translate to climate change, as agreed upon by 43% of the respondents, while about 46% strongly disagreed that low sunshine means climate change. This result negates the findings of Omay *et al.*(2025) that

ISTF-NIG 2026

the timing of the onset of annual rainfall does not reflect a changing climate, as a single annual rainfall season cannot explain climate change, which, in a broad sense, refers to long-term changes over many years. Also, Ojo *et al.* found that the intensity of sunshine varies on a daily and seasonal basis, which may be due to reduced cloud cover and atmospheric conditions, but not necessarily to long-term climate change.

Table 1: Knowledge level of arable crop farmers on climate change in Oyo State

Items	Strongly Agree	Agree	Undecided	Strongly Disagree	Disagree	WMS
The changes in the weather mean that the climate is changing	113(68.5)	45(27.3)	5(3.0)	1(0.6)	1(0.6)	4.6
Climate change means that when the temperature is very high	89(53.9)	35(21.2)	12(7.3)	29(17.6)	-	4.1
Late arrival/ onset of rainfall means climate change	27(16.4)	103(62.4)	1(0.6)	29(17.6)	5(3.0)	3.7
Heavy downpour leading to erosion does not mean climate change	41(24.8)	46(27.9)	3(1.8)	69(41.8)	6(3.6)	3.3
Even if the rainfall is a little, it is normal, and the climate is not changing	63(38.2)	55(33.3)	13(7.9)	34(20.6)	-	3.9
Early arrival/ onset of the rainfall season evidently shows that the climate is changing	71(43.0)	71(43.0)	12(7.3)	8(4.8)	3(1.8)	4.2
Too much sunshine does not translate to climate change	34(20.6)	76(46.0)	13(7.9)	32(19.4)	10(6.1)	3.6
Low sunshine means climate change	13(7.9)	38(23.0)	8(4.8)	75(45.5)	31(18.8)	2.6
The climate is changing when there are incidents of occasional destructive winds	78(47.3)	66(40.0)	9(5.5)	8(4.8)	4(2.4)	4.2

Constraints associated with adaptive capacity to climate change among arable crop farmers in Oyo state

The results presented in Table 2 showed the constraints to climate change adaptation among arable crop farmers in Oyo State. The findings were similar to the constraints identified among the respondents in Ogun State. Land tenure and government policies ranked first among the major constraints, with a weighted mean score of 2.8. The majorityThe majority of respondents identified land tenure problemsproblems (79.4 percent) and unfavourable government policies (78.2 percent) as major constraints. According to the the World Farmers Association (2019), land tenure is One of the major challenges farmers face, especially in developing countries. The majorityThe majority

ISTF-NIG 2026

(72.1) of the respondents identified inadequate access to credit facilities as One of the major constraints to climate change adaptation capacity. The majorityThe majority of respondents (65.5%) stated that adapting to climate change is expensive. The majorityThe majority of respondents (63.0 percent) noted that a the lack of of or inefficient extension and advisory services is a minor constraint to climate change adaptation capacity in Oyo State. Those who noted that inadequate training and Education on new farming methods constitute a minor constraint constitute 53.3 percent. Other minor constraints identified by the respondents include low benefits from adaptation measures (55.8 percent) and low access to new farming innovations (67.3 percent). Inadequate training and Education on new farming methods and cultural norms were not constraints on farmers' climate change adaptation capacity. Dahiru et al (2025) stated that major constraints to adopting climate adaptation strategies included inadequate technical knowledge, land tenure challenges, and limited market access.

Table 2: Constraints associated with adaptive capacity to climate change among arable crop farmers in Oyo state

Constraints	Major	Minor	Not a constraint	WMS	Remark
Land tenure problem	131(79.4)	28(17.0)	6(3.6)	2.8	A constraint
Inadequate access to credit facilities	119(72.1)	39(23.6)	7(4.2)	2.7	A constraint
Lack or inadequate information on climate variables	77(46.7)	82(49.7)	6(3.6)	2.4	A constraint
Lack of or inefficient extension and advisory services	40(24.2)	104(63.0)	21(12.7)	2.6	A constraint
Inadequate training and Education on new methods of farming	64(38.8)	88(53.3)	13(7.9)	2.3	Not a constraint
Inadequate or low interaction among farmers	17(10.3)	58(35.2)	90(54.5)	1.6	Not a constraint
Government policies	129(78.2)	31(18.8)	5(3.0)	2.8	A constraint
Cultural or religious norms	15(9.1)	66(40.0)	84(50.9)	1.6	Not a constraint
Low benefits from adaptation measures	63(38.2)	92(55.8)	10(6.1)	2.3	A constraint
Adapting to climate change is expensive	108(65.5)	50(30.3)	7(4.2)	2.6	A constraint

No or low access to new farming innovations	46(27.9)	111(67.3)	8(4.8)	2.2 A constraint

Conclusion and Recommendations

The study found that smallholder farmers in Oyo State have a relatively good level of knowledge of climate change, particularly regarding temperature and rainfall variability as indicators. However, gaps in an the accurate understanding of climate change indicators remain, which may affect the appropriateness of adaptation responses. However, farmers' coping capacity is mostly constrained by insecure land tenure systems, limited access to credit, unfavourable government policies, and the high costs associated with adaptation measures. These constraints outweigh knowledge levels and hinder smallholder farmers' response to the effects of climate change. This study therefore recommends that:

1. Agricultural extension systems should be strengthened to provide accurate, relevant, and timely climatic information and advisory services to farmers.
2. Government and ,Non-Governmental Agencies, including financial institutions,, should make affordable, accessible credit facilities available to smallholder farmers.

References

Ahmad, M., Magaji, S., & Ismail, Y. (2025). Financial and technical constraints in the adoption of sustainable land management practices by smallholder farmers in Nigeria. *International Journal of Research and Innovation in Social Science*, 9(9), 1922–1932.

Ayoade, J. O. (2004). *Introduction to climatology for the tropics*. Ibadan: Spectrum Books Ltd.

Azeez, I. O. & Oyekanmi, T. T. (2021). Farmers' knowledge and perception of climate change impact on crop production in Southwestern Nigeria. *Journal of Advanced Agriculture and Horticulture Research*, 1(1), 1–10.

Douxchamps, S., Van Wijk, M.T., Silvestri, S., Moussa, A.S., Quiros, C., Ndour, N.Y.B., Buah, S., Somé, L., Herrero, M., Kristjanson, P., Ouedraogo, M., Thornton, P.K., Van Asten, P., Zougmoré, R., and Rufino, M.C. (2016). Linking agricultural adaptation strategies, food security and vulnerability: evidence from West Africa. Reg. Environ. *Change*, 16 (5), 1305–1317.

Farauta, B. K. (2011). Farmers' perceptions of climate change and adaptation strategies in northern Nigeria. *African Journal of Agricultural Research*, 6(6), 1239–1246.

Kehinde, M. O., Shittu, A. M., Oriade, O. A., & Edewor, S. E. (2023). Land tenure, land use antecedents, and willingness to embrace resilient farming practices among smallholders in Nigeria. *Frontiers in Sustainable Food Systems*. https://doi.org.10.3389/fsufs.2023.999905

National Population Commission, Nigeria (2006). *Population and housing census of the Federal Republic of Nigeria*. Abuja: NPC.

Oladejo, J. A., Ajetomobi, J. O. and Fabiyi, Y. L. (2011). Transaction costs and agricultural household supply response of maize farmers in Oyo State, Nigeria—*Journal of Agric.Soc. Sci.*, 7: 69–74.

Omotoso, A.B.; Letsoalo, S., Olagunju, K.O., Tshwene, C.S., Omotayo, A. O. (2023). Climate change and variability in sub-Saharan Africa: A systematic review of trends and impacts on

ISTF-NG 2026

agriculture. *Journal of Cleaner Production***.** 414. https://doi.org/10.1016/j.jclepro.2023.137487

Onyekuru N. A., & Marchant R. (2016). Climate variability and agricultural productivity in Nigeria. *Climate Risk Management*, 13, 45–56.

Oyo State Government (2010). *Oyo State official diary*. Ibadan: Government Press.

Reppin, S., Kuyah, S., de Neergaard, A., Oelofse, M., & Rosenstock, T. S. (2020). Contribution of agroforestry to climate change mitigation and livelihoods in Western Kenya. Agroforestry Systems**,** 94, 203–220.

World Meteorological Organization (2022). *State of the global climate 2022*. Geneva: WMO.

World Farmers Organisation (2019). *Land tenure and farmers' access to resources*. Rome: WFO.

ISTF-NIG 2026

ABOVE GROUND BIOMASS, CARBON SEQUESTRATION POTENTIAL AND BIODIVERSITY OF TREE SPECIES IN AHMADU BELLO UNIVERSITY, BOTANICAL GARDEN IN SAMARU – ZARIA, KADUNA STATE, NIGERIA.

***Sodimu, A. I[1], Bayo, D[2]., Rasheed, F.M[3] and Kureh, G. I[4]**

[1]Savanna Forestry Research Station, Forestry Research Institute of Nigeria, PMB 1039, Samaru – Zaria, Kaduna, Nigeria
[2]Northern Guinea Research Station, Forestry Research Institute of Nigeria, Nasarawa, Nigeria.
[3]Federal College of Forestry Mechanization, Forestry Research Institute of Nigeria, P.M.B 2273, Afaka – Kaduna, Nigeria
[4]Department of Forestry and Wildlife Resources Management, Ahmadu Bello University, Samaru – Zaria, Kaduna State, Nigeria.
**Corresponding e- mail: tunsod88@gmail.com*

Abstract

The need to control Greenhouse Gas (GHG) emissions, and the concern aboute negative impacts climate change have led scientists to focus their research on stabilizing on CO_2 emissions. This research was conducted on this premise to study Above-Ground Biomass, carbon sequestration potential, and biodiversity of tree species in the the Ahmadu Bello University Botanical Garden, Samaru–Zaria, Kaduna State. A quadrat-line transect sample technique was employed, in which three (3) 30m x 30m plots were laid. All tree species with DBH > 0.1m that fell on the transect line were enumerated using a diameter tape, and total height was measured using a Haga altimeter. Wood Density from the Global Wood Density Database was used to estimate AGB and C for each tree felled along the transect. Diversity indices were analyzed using the Shannon–Wiener and Pielou's Evenness formulas. The study revealed a total of 32 stems distributed among the nine (9) tree species belonging to 6 families. *Baulunia monandra* Kurz is a dominant species, indicating its ecological importance and maturity in the garden. Family Fabaceae recorded the highest FIV value of 26.72%. According to Pielou, the Shannon-Weiner diversity index and species equitability index for the study were 1.16 and 0.53, respectively. The species with the highest AGB and estimated carbon stock were *Senna siamea* (Lam.) Irwin et Barneby (85.69kg; 38.56 kg), closely followed by *Bombax pentandrum* L. (84.21kg; 38.00kg). Species with the lowest AGB and Carbon estimate was *Khaya senegalensis* (Dear.) A. juss (19.86kg;8.94kg), followed by *Baulunia monandra* Kurz (25.06kg;11.28kg). Species with the highest AGB have the highest estimated carbon stock. Total Aboveground Biomass (AGB) of the trees was 491.33kg, while the estimated Carbon of the tree species was 221.22kg. The study revealed the efficacy of a partially disturbed Botanical Garden in in-situ conservation. Active regeneration and enrichment planting should be carried out for proper stocking. Consideration of species to be planted should include native tree species with high biomass and high efficiency of carbon fixation; not only mitigating pollution but also serving as a carbon sink and helping in bioremediation processes.

Keywords: Above Ground Biomass, Biodiversity, Carbon Sequestration, Botanical garden.

ISTF-NIG 2026

Introduction

Biodiversity conservation and carbon storage are two significant, linked environmental ecosystem services. Carbon storage in the biosphere is seen as an alternative for mitigating climate change (Bunker *et al.,* 2005), suggesting a close link between biodiversity and carbon stocks. Although One of the largest carbon reservoirs in the ecosystem is the soil, plant aboveground biomass may still be a significant and beneficial influence on carbon storage (Dixon, 1995). Since the Industrial Revolution, atmospheric concentrations of greenhouse gases (GHGs) have increased sharply, particularly carbon dioxide (CO_2). Before the Industrial Revolution, the mean atmospheric CO_2 level was approximately 280 ppm, and as of August 2018, it was 407 ppm (NOAA, 2019). Studies have shown that trees in Nigeria have substantial carbon sequestration potential, with an estimated 6,577 million tons of CO_2e sequestered after 20 years and approximately 12,947 million tons of CO_2e after 60 years beyond the baseline (Bada *et al.,* 2018). Afforestation, reforestation and enrichment planting are One of the major potent options to increase forest and tree cover in the country's forest reserves, botanical gardens, vacant space along major roads and in parks/gardens—these help to mitigate the adverse effects of climate change. A tree removes (sequesters) carbon dioxide (CO_2) from the atmosphere through photosynthesis, separates the Carbon and oxygen atoms and releases oxygen in the atmosphere. In doing so, the tree stores a tremendous amount of Carbon, and the annual growth (called mean annual increment) increases carbon storage in the standing tree, but only up to a threshold level, depending on species. Therefore, there is growing interest in researching tree plantations, forest reserves, botanical gardens, vacant spaces along major roads, and parks/gardens for capturing and storing atmospheric Carbon. Reducing fossil fuel emissions and planting large, healthy tree species are extremely urgent to maximize CO_2 sequestration in botanical gardens.

Forests (including botanical garden tree species) have received attention in recent years for their potential as carbon sinks, given their high carbon uptake by fast-growing, young plants (Jo, 2002; Nowak and Crane, 2002; Liu and Li, 2012). Young plants sequester more atmospheric Carbon as they grow and accumulate biomass, whereas ageing trees lose more Carbon to the atmosphere through respiration, tree cutting, and decomposition (Nowak and Crane, 2002; Hai *et al.,* 2015). However, the botanical gardens' tree species play a role not only in conservation and improved climatic conditions, but also in significantly increasing the country's vegetated area. Trees growing in botanical gardens, whether ownedor gardens ownedowned or naturally occurring, perform the ecological function not only of reducing the pollution load but also of sequestering carbon and mitigatingand mitigating climate change (Da Silva *et al.,* 2010; Singh and Singh, 2015; Sodimu *et al.,* 2024). Additionally, trees in a botanical garden provide many benefits. for example, social benefits (recreational opportunities, improving physical/mental health); aesthetic benefits (landscape variations through different colors/textures/forms and densities of plants); climatic benefits (conservation, cooling, wind control, air pollution reduction, atmospheric carbon storage, impact on climate) and economic benefits (increased property values, tourism and providing fruits. Carbon sequestration from the atmosphere can be advantageous from both environmental and socio-economic perspectives. It. It. At the same time, the concurrent development of tradable carbon credits provides financial incentives to consider carbon storage in forest management decisions (Siry *et al.,* 2006). Understanding carbon sequestration potential in botanical garden trees contributes to local climate mitigation planning and aligns with Nigeria's REDD+ and NDC goals.

ISTF-NIG2026

The concept of biodiversity has evolved rapidly during the past decades. It is widely accepted that biodiversity can be divided into three spheres: genetic diversity (within-species diversity), species diversity (number of species), and ecosystem diversity (community diversity) (Harper and Hawksworth, 1995; Sodimu *et al.,* 2024). Typically, the focus is on species biodiversity and carbon sequestration of tree species. The relationship between biodiversity and ecosystem functioning and productivity has received increasing attention within the scientific community during the past decades (McNaughton, 1994). Biodiversity assessment has therefore developed to become an important part of conservation biology and functional ecology. Tree Species diversity is a crucial concept in biodiversity, intuitively simple yet conceptually complex. A quantitative assessment of tree species diversity and volume is thus essential for effective biodiversity conservation, carbon sequestration potential, and management (Magurran, 2004). Measures of tree species biodiversity usually include two components: richness and evenness. Richness represents the total number of tree species within a given area, while evenness measures the similarity of their abundances (Hurlbert, 1971). Species richness and evenness are two independent criteria that may respond differently to local habitat factors. The assessment of biodiversity is of great global interest, especially in the context of the Kyoto Protocol, where each nation must maintain CO_2 emissions below a certain threshold, calculated by accounting for both CO2 sources and sinks, including those absorbed and stored in trees. (Lindner and Karjalainen 2007; Tonolli *et. al.,* 2011). Thus, having detailed knowledge of forest stem volume and the biodiversity of a forest estate is indispensable for management, timber allocation, and the Power to sequester Carbon. Evidence indicates that inadequate information on biodiversity, carbon sequestration, and tree volume assessment has resulted in poor forest policies, planning, and management in the forest estate (Bisong and Mfon, 2006). Estimates of carbon stocks and changes in tree biomass are essential for participation in the United Nations Framework Convention on Climate Change (UNFCCC) programme and for compliance with the Kyoto Protocol. The present study aims to assess Above Ground Biomass (AGB), biodiversity, and the carbon sequestration potential of trees in Ahmadu Bello University (ABU) botanical garden, and to suggest potential species for high biomass and high carbon fixation efficiency in the garden.

Materials and Methods

Study area

The study was conducted in the Botanical Garden of Ahmadu Bello University, Zaria. The garden lies at latitude 11° 11'N, longitude 7° 38'E. Zaria is located in the Northern sub-humid-sub-humid-sub-humid-sub-humid Guinea savannah ecological belt, with distinct rainy and dry seasons and variations in temperature and relative humidity. The Botanical Garden was established in 1962 as an in-situ conservation site that is rich in plant species. The dry season typically runs from mid-October (Jahake, 1982). Zaria has an annual rainfall of 100-114 mm, with relative humidity ranging from 70-80% in August and 15-20% in December. Daily temperatures average about 23.6°C in April and about 23.3°C in August (Tanko, 2005). The garden covers an area of about 41,886.04 m^2 (Tanko,2005). The entire garden is divided into sections for management purposes. (Ahmed *et. al.,* 2014). Concrete walkways in the garden divide the vegetation into sections. The garden comprises both indigenous and naturalized exotic plant species (Fig. 1). The garden was formerly a relatively unexploited area. Today, parts of the garden are still cultivated for experimental purposes by the Department of Botany and Biology at ABU Zaria. Nonetheless, no

ISTF-NIG 2026

hunting or grazing is allowed. Thus, exotic plant species in the garden are not native to Nigeria or West Africa; they were introduced.

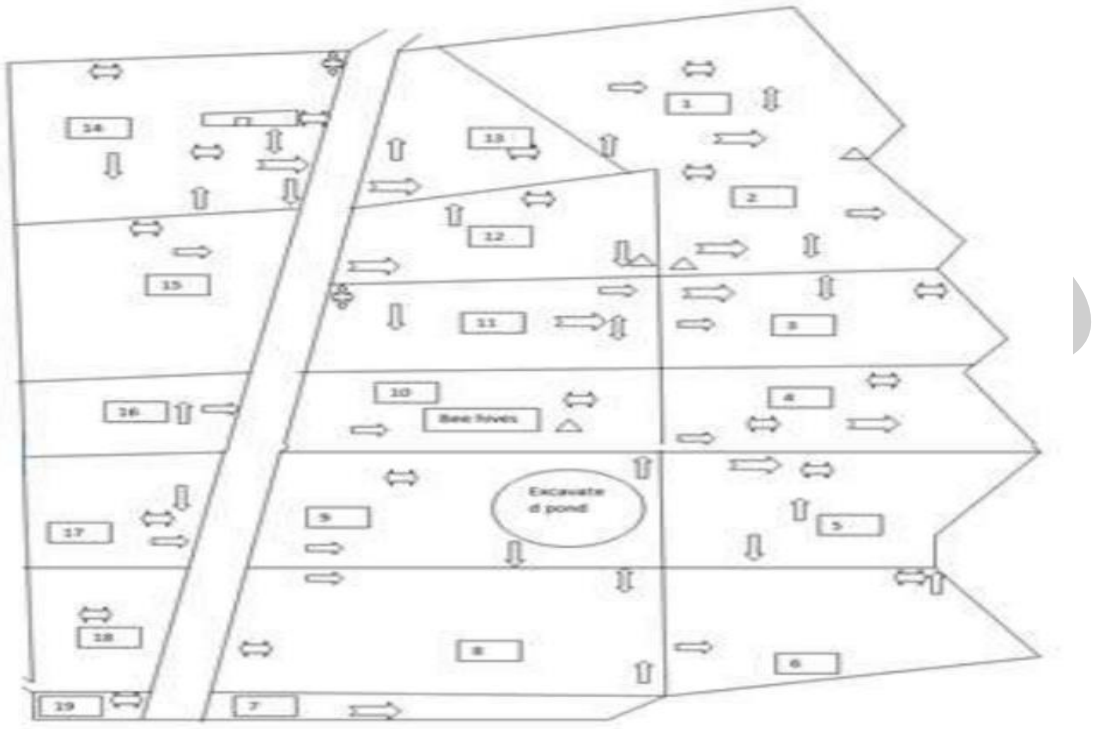


Fig.1: Map of the study area, Ahmadu Bello University Botanical Garden, Zaria.

Source: Ahmed *et. al.,* (2014)

Sampling Technique

The use of a quadrat line transect sample technique was employed, where by 30m x 30m quadrant plot was established and a transect line was drawn and pegged perpendicular to the baseline, at an interval of 10m, resulting in the formation of three (3) line transect for each plot, all tree species with DBH > 0.1m that fell on the transect line was enumerated. Total tree height was measured using a Haga altimeter, and DBH was measured using a diameter tape. A total of three (3) plots were laid out, and the methodology was repeated in each plot, with an interval of 15m between plots. All trees that cannot be identified in the field were collected, placed in a plant press and taken to the Department of Botany Herbarium, Ahmadu Bello University and the Savanna Forestry Research Station for identification by taxonomists. DBH ≥ 0.1 m was used to estimate tree species diversity and abundance.

Data analysis

The data collected were analyzed using the following formulae:

(i) Species relative density was computed using the equation adopted from Brashears *et. al.* (2004)

$$\mathbf{RD} = \frac{ni}{N} \times \mathbf{100} \quad \text{..... (1)}$$

Where: RD (%) = Species Relative Density; n_i = number of individuals of species i; N = total number of all tree species in the entire community.

(ii) **Species Relative Dominance** (RD_0 (%)) was computed using the equation of Foody and Culter (2003)

$$\mathbf{R.D_0} = \frac{\sum Bai \times 100}{\sum Ban} \quad \text{..... (2)}$$

Where: Ba_i = basal area of individual tree belonging to species i and Ba_n = stand basal area.

(iii) **Shannon's Diversity index:** The Shannon–Wiener diversity index, as given by Price (1997), was used to calculate tree species diversity.

$$\mathbf{H} = -\sum_{i=1}^{s} p1 \ln(p1) \quad \text{..... (3)}$$

Where H' = Shannon diversity index, S = the total number of species in the community, pi = proportion S (species in the family) made up of the Ith species and ln = natural logarithm.

(iv) To determine the Species evenness (E) in each community, Pielou's Species Evenness index equation was adopted as stated by Kent and Coker (Kent and Coker,1992)

$$\mathbf{E_h} = \frac{H}{Hmax} = \frac{\sum pi \ln(pi)}{\ln(s)} \quad \text{..... (4)}$$

Where pi = proportion S (species in the family) made up of the ith species, S = the total number of species in the community and ln = natural logarithm

(v) **The Family Importance Value Index (FIV**) was obtained using an equation adopted from Gillespie *et. al.* (2004)

$$\mathbf{FIV} = \frac{RD + RDo}{2} \quad \text{..... (5)}$$

Where: RD (%) = Species Relative Density and RDo (%) = Species Relative Dominance

The resulting FIVI values provide insight into species' ecological importance by integrating their abundance and structural contribution. Higher FIVI values indicate species that dominate both numerically and structurally, while lower values reflect species of limited ecological influence in the stand.

(vii) **Above-ground biomass (AGB)** was estimated from formulae adopted from Chave *et al.* (2014)

ISTF-NIG 2026

$$\mathbf{AGB = 0.0673 \times (\rho \times D^2 \times H)^{0.976}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

where AGB = Above-Ground Biomass (kg), ρ = wood density (g/cm^3), D = DBH (cm), and H = height (m). Wood density (ρ) values were obtained from the Global Wood Density Database (Zanne *et al.,* 2009), which forms the basis of the Chave *et al.* (2014) Allometric model.

Carbon stock estimation was calculated using formulae adopted from **Stoffberg *et al.* (2010).** The estimated aboveground biomass (kg) of the trees was multiplied by 0.45 to obtain the amount of Carbon for the tree species.

(i) **Estimated carbon stock (Kg)**

C (kg) = AGB × **0.45 …**………………………………………………… (7)

Results and Discussion

Stems and tree species in the study area

The number of stems and tree species encountered in the study area is presented in Figure 2 below. The study revealed a total of 32 stems distributed among the nine (9) tree species belonging to 6 families. *Baulunia monandra* Kurz had the highest number of stems (15). This was followed by *Tecoma stans* (L.) Juss. Ex kunth (05) stems. *Delonix regia* (Boj. ex Hook) Raf., *Senna siamea* (Lam) Irwin et Barneby and *Blighia sapida* K.D. Koenig, *Bombax pentandrum* L., *Mangifera indica* L., *Khaya senegalensis* (Desr.) A. Juss., and so on were all represented by One stem each.

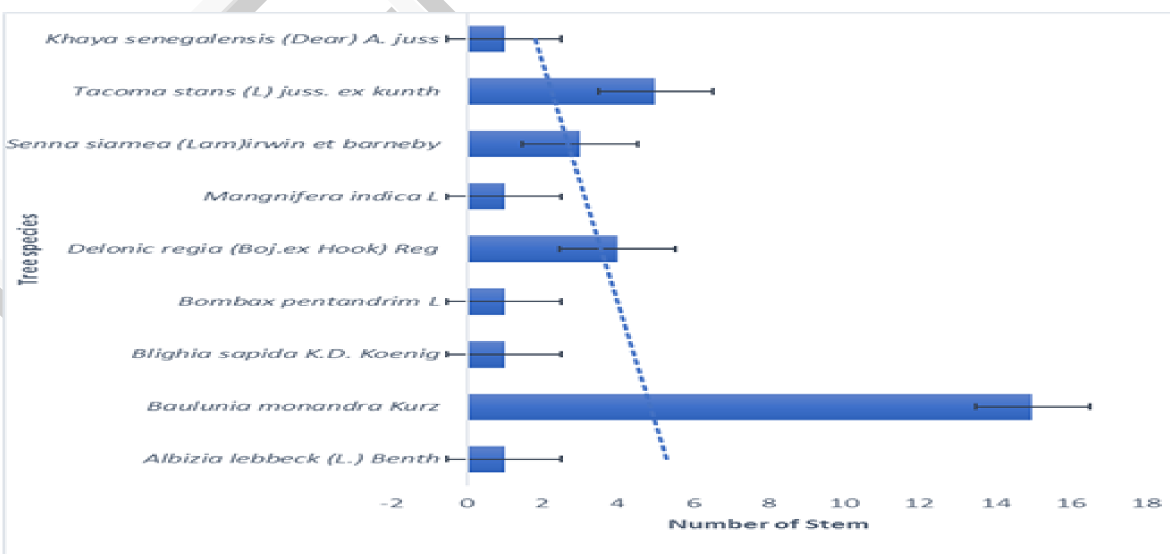


Figure 2: Tree Species abundance in Ahmadu Bello University (ABU), Zaria.

Figure 2 above further shows that *Baulunia monandra* Kurz is the most dominant species, indicating its ecological importance and maturity in the garden. The above assertion is in line with the work of Upahi U025), who conducted a similar study on carbon sequestration, and reported that dominant species have ecological and environmental significance. Tropical ecosystems have been adjudged the richest ecosystems in the world due to their species richness and diversity (Akindele and LeMay, 2006). The tree species encountered in the study area are typical of the Northern Guinea Savannah ecosystem, in accordance with the findings of Sodimu *et al.* (2022) at Afaka forest reserve, which is located similarly to the study area, also, in conformity with Sodimu *et. al.* (2024), who reported similar species in the garden.

Tree species diversity indices in the study area

Biodiversity indices are produced to bring the diversity and abundance of species across different habitats to a similar scale for comparison, and the higher the value, the greater the species richness (Hawthorne *et al*., 2013). The Shannon index is an indicator of high species diversity and reflects the dominance of a few tree species in the forest.

Table 1: Tree species diversity indices in the study area

S/N	Diversity Indices	Values
1	No. of Tree	32
2	No. of Species	09
3	No. of Families	06
4	Shannon Weiner	1.16
5	Pielou's evenness index	0.53

The Shannon Weiner diversity index (H^1) of 1.16 in Table 1 above shows that the forest is not biologically diverse. The value is outside the reported range (3.34 - 3.66) for some tropical forest sites in Nigeria (Adekunle, 2006). However, the Shannon index of this study is low. The lower species evenness observed in this study indicates that the tree species in this botanical garden are not evenly distributed; this can be attributed to the fact that parts of the garden are cultivated for experimental purposes by the Department of Botany and Biology, ABU Zaria. The results in Table 1 agree with the work of Gillespie *et al*. (2004), who observed that species richness and the number of stems available decrease in a disturbed reserve, which tends to have overall effects on biomass, volume, and carbon sequestration of the tree species.

Family Importance Value Index (FIV) of tree species in the study area

The FIV results in Table 2 revealed a community strongly dominated by the Fabaceae family with 4 tree species (*Albizia lebbeck* (L.) Benth, *Baulunia monandra* Kurz, *Delonic regia* (Boj.ex Hook.) Reg and *Senna siamea* (Lam) Irwin et Barneby), which recorded the highest FIV value of 26.7%,

ISTF-NIG 2026

with *Baulunia monandra* Kurz having the highest number of stems (15). At the same time, the lowest was observed in the family Anacardiaceae, Bignoniaceae, Malvaceae, Meliaceae and Sapindaceae with One species each.

Table 2: Family importance Value index of tree species in the study area

S/N	Family	No. of Spp.	R.D(%)	RD_0 (%)	FIV (%)
1	Anacardiaceae	01	11.11	13.01	12.06
2	Bignoniaceae	01	11.11	0.50	5.81
3	Fabaceae	04	44.44	9.00	26.72
3	Malvaceae	01	11.11	33.05	22.08
4	Meliaceae	01	11.11	0.98	6.05
5	Sapindaceae	01	11.11	16.45	13.75

RD =Relative Density, RD_0 = Relative Dominance, FIV=Family Importance Index Value

ISTF-NIG 2026

The fact that Fabaceae is the dominant family in the study area is in contrast with the study of (Sarumi *et. al.,* 1996 and Adekunle, 2007), who all reported that Nigerian tropical forest is dominated by members of the Sterculiaceae, Moraceae, and Euphorbiaceae, but in support of the work of (Onyekwelu *et. al.,*2008), which observed that members of Euphorbiaceae, Sterculiaceae, Meliaceae, Mimosoideae and Fabaceae families are dominant in tree forest estate ecosystems in Nigeria. The tree species distribution within this family corresponds with what was reported by Sodimu (2016) in the Buruku forest reserve in a similar study, who reported that the Kaduna Northern Guinea Savannah ecological zone is dominated by species from the Fabaceae, Anacardiaceae, Moraceae, and Meliaceae families.

Biomass and Carbon Stock Estimates

The estimated Above Ground Biomass (AGB) and Carbon stock in the botanical garden are presented in Table 3 below. Species with the highest AGB and estimated carbon stock was *Senna siamea* (Lam) Irwin et Barneby (85.69kg;38.56kg), closely followed by *Bombax pentandrim* L (84.21kg;38.00kg). The species with the lowest AGB and Carbon estimate was *Khaya senegalensis* (Dear.). A. juss (19.86kg; 8.94kg), followed by *Bauhinia monandra* Kurz (25.06kg; 11.28kg). Total Above Ground Biomass (AGB) of the trees was 491.33kg, while the total estimated Carbon of the tree species was 221.22kg. The study revealed the efficacy of a partially disturbed Botanical Garden in in-situ conservation. low mean AGB and estimated Carbon sequestration imply that the trees are moderately disturbed; perhaps due to the use of the garden for experimental purposes involving cultivation, which also resulted inin inconsequential biomass accumulation in the botanical garden. This is contrary to the assertion of (Babalola 2016, Dharmendra *et al.,* 2020). However, the estimated carbon sequestration is ≤ 47% of the biomass, indicating low mitigation potential. The aboveThe above results are in agreement with the works of Xu *et al.* (2018) and Upahi (2025) on vegetation carbon stocks and the carbon sequestration potential of tree species.

Table 3: Above-Ground Biomass and Carbon Estimation

S\N	Family	Species	P	Mean DBH (cm)	Mean Ht. (m)	AGB (kg)	C (kg)
1	Fabaceae	*Albizia lebbeck* (L.) Benth	0.46	111.00	13.90	51.12	23.00
2	Fabaceae	*Baulunia monandra* Kurz	0.62	40.33	11.28	25.06	11.28
3	Fabaceae	*Delonic regia* (Boj.ex Hook.) Reg	0.69	43.75	13.98	30.24	13.61
4	Fabaceae	*Senna siamea* (Lam) Irwin et Barneby	0.70	122.33	11.99	85.69	38.56
5	Sapindaceae	*Blighia sapida* K.D. Koenig	0.71	100.31	11.00	71.28	32.08
6	Malvaceae	*Bombax pentandrim* L	0.33	255.00	18.10	84.21	38.00

ISTF-NIG 2026

7	Anacardiaceae	*Mangnifera indica* L	0.46	160.00	13.43	73.66	33.15
8	Bignoniaceae	*Tacoma stans* (L.) juss. ex kunth	0.50	100.31	11.01	50.21	22.60
9	Meliaceae	*Khaya senegalensis* (Dear.) A.juss	0.45	44.00	7.00	19.86	8.94
		Total		**977.03**	**111.69**	**491.33**	**221.22**

ρ = Wood density, DBH = Diameter at breast height (cm), Ht. = Total height (m), AGB = Above ground biomass (kg), C = Estimated carbon (kg)

Conclusion and Recommendation

Deforestation and degradation threaten forest productivity. This research revealed the current status of the Botanical Garden at Ahmadu Bello University, Zaria, in terms of its Above Ground Biomass (AGB), carbon sequestration potential, and biodiversity, with a focus on its role in biodiversity conservation in a partially disturbed botanical garden. These outcomes highlight the ecological and climatic significance of trees in sequestering atmospheric Carbon and supporting biodiversity within the institutional landscape. Given the above, we recommend that, when planting trees or carrying out enrichment planting in the institution's garden, species to be planted include native tree species with high biomass and high carbon-fixation efficiency. Also, efficient planting should be carried out to properly stock the botanical garden and improve the carbon sequestration of the species. Periodic assessment of the tree species diversity in the study area is also needed. However, the department should limit the useuse of the garden for experimental cultivation, and if it must be done, it should be closely monitored.

References

Adekunle, V.A. (2006). Conservation of tree species diversity in the tropical rainforest ecosystem of South-West Nigeria. *Journal of Tropical Forest Science*. 91-101.

Adekunle V. A. (2007). Ecological and environmental implications of national development: A case study of Obanla natural forest, Federal University of Technology, Akure, Nigeria. *Research Journal of Environmental Science*. 4:127-40.

Ahmed J, Tanko D, Odiba A.I and Chai A.M (2014). The roles of botanical gardens in plant conservation and their tourism potentials: A case study of Ahmadu Bello University garden, Zaria, Nigeria. *BEST*, 11(1): 122-134.

Akindele S.O and LeMay V.M (2006). Development of tree volume equations for common timber species in the tropical rain forest area of Nigeria. Forest Ecology and Management. 226(1-3):41-8.

Babalola, F.D. (2016). Perception of Urban Trees at the Main Campus of the University of Ilorin, Ilorin, Kwara State, Nigeria. *Applied Tropical Agriculture* 21 (1), 60-67

Bisong, F.E. and Mfon, P (2006). Effect of logging on stand damage in the rainforests of South–Eastern Nigeria. West African Journal of Applied Ecology 10, 1 – 10.

Brashears, M.B, Fajvan, M.A., and Schuler, T.M. (2004). An assessment of canopy stratification and tree species diversity following clearcutting in Appalachian hardwoods. Forest Science. 50(1):54–61.

ISTF-NIG 2026

Bunker, D. E., DeClerck, F., Bradford, J. C., Colwell, R. K., Perfecto, I., Phillips, O. L., Sankaran, M., and Naeem, S. (2005). Species loss and aboveground carbon storage in a tropical forest. *Science*, 310(5750), 1029–1031. https://doi.org/10.1126/science.1117682

Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B., and Vieilledent, G. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology*, 20(10), 3177–3190. https://doi.org/10.1111/gcb.12629.

Da Silva, A. M., Braga Alves, C. and Alves, S. H. (2010). Roadside vegetation: Estimation and potential for carbon sequestration. Forest, *Biogeosciences and Forestry*, 3, 124–129. https://doi.org/10.3832/ifor0550-003.

Dharmendra, D., Srirag, S., Ankit, K., Pandey, A., Paul, D., Dev, S., Krishna, D., Nidhi, S., Shivani, V., Shourya, N., Shruti, G., and Pradeep, C. (2020). Carbon sequestration potential of trees planted along roadsides: A case from Bhopal city, India. *International Journal of Environment*, 9(1), 104–119. https://doi.org/10.3126/ije.v9i1.29296

Dixon, R. K. (1995). Agroforestry systems: Sources or sinks of greenhouse gases? *Agroforestry Systems*, 31(2), 99–116.

Foody, G.M., and Cutler, M.E. (2003). Tree biodiversity in protected and logged Bornean tropical rain forests and its measurement by satellite remote sensing. *Journal of Biogeography.* 30(7):1053-66.

Gillespie, T.W, Brock, J. and Wright, C.W. (2004). Prospects for quantifying structure, floristic composition and species richness of tropical forests. International Journal of Remote Sensing. 25(4):707-15.

Hai, T. H., Sambo, A. S., and Gamaniel, K. S. (2015). Carbon sequestration potential of urban trees in Maiduguri Metropolis, Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, 7(2), 1–12.

Harper, J. and Hawksworth, D. (1995). Preface. In J. Hawksworth (Ed.). Biodiversity: Measurement and Estimation. Chapman and Hall, London.

Hawthorne, W. D, Marshall, C. A, Juam, M. A., and Agyeman, V.K. (2013). The impact of logging damage on tropical rainforests, their recovery, and regeneration. An Annotated Bibliography. 2011;47-121. 27.

Hurlbert, S.H. (1971). The Non concept of species diversity: A critique and alternative parameters. *Ecology.* 52, 577 – 586.

Jahake, H.E. (1982). Livestock Production System and Livestock Development in Tropical Africa. Keiler Wissenschaffs. Verlagvank, 253p.

Jo, H. K. (2002). Impacts of urban forests on offsetting carbon emissions from urban development in Korea. *Journal of Environmental Management*, 64(1), 115–126. https://doi.org/10.1006/jema.2001.0491.

Kent, M and Coker, P. (1992). Vegetation Description and Analysis. A Practical Approach. John Wiley and Sons, New York, pp. 319.

Liu, C., and Li, X. (2012). Carbon storage and sequestration by urban forests in Shenyang, China. *Urban Forestry & Urban Greening*, 11(2), 121–128. https://doi.org/10.1016/j.ufug.2011.03.002.

Lindner, M. and Karjalainen, T. (2007). Carbon inventory methods and carbon mitigation potentials of forests in Europe: A short review of recent progress. European Journal of Forest Research. 126(2):149-56.

Magurran, A. E. (2004). Measuring biological diversity. Blackwell Science, Oxford.pp 45

McNaughton, S.J. (1994). Biodiversity and function of grazing ecosystems. (Eds.) Schulze, E.D. and Mooney, H.A. Springer – Verlag, Berlin, Germany. pp. 361 – 383.

ISTF-NIG 2026

NOAA Global Monitoring Laboratory. (2019). Trends in CO2: Monthly mean CO2 at Mauna Loa Observatory. https://gml.noaa.gov/ccgg/trends/.

Nowak, D. J., and Crane, D. E. (2002). Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution*, 116(3), 381–389.

Nowak, D. J., Greenfield, E. J., Hoehn, R. E., and Lapoint, E. (2013). Carbon storage and sequestration by trees in urban and community areas of the United States. *Environnemental Pollution*, 178, 229–236.

Onyekwelu, J.C, Mosandl, R. and Stimm, B. (2008). Tree species diversity and soil status of primary and degraded tropical rainforest ecosystems in south-western Nigeria. *Journal of Tropical Forest Science.* 193-204.

Onyekwelu, J. C., Adekunle, V. A., and Adeduntan, S. A. (2005). Does the tropical rainforest ecosystem possess the ability to recover from severe degradation? In Sustainable forest management in Nigeria: Lessons and prospects. *Proceedings of the 30th Annual Conference of the Forestry Association of Nigeria.* pp. 145 – 163.

Price, P.W. (1997). Insect ecology (3rd ed.). New York: Wiley, pp.45

Sarumi, M.B, Ladipo, D.O, Denton, L, Olapade, E.O, Badaru, K., and Ughasoro, C. (1996). Nigeria: Country report to the FAO International Technical Conference on Plant Genetic Resources, Leipzig. Pp. 108.

Singh, K. and Singh, G. (2015). Roadside vegetation diversity of Jodhpur district and its role in carbon sequestration and climate change mitigation. *Advances in Forestry Science,* 2(2), 23-33. https://doi.org/10.34062/afs.v2i2.2157

Siry, J. P., Newman, D. H., & Sills, E. O. (2006). Carbon sequestration and forest management: Environmental and socio-economic perspectives. Journal of Forestry, 104(5), 265–271.

Sodimu, A.I., David, D and Adamu, I. (2022). Empirical study of forest regeneration potential of natural forest in Kaduna Northern Guinea Savannah: A case study of Afaka forest reserve, Nigeria. *Russian Journal of Agriculture and Socio-Economic Sciences,* 10 (130), 54 -60.

Sodimu, A. I., Bichi, A. M., and Kureh, G. I. (2024). Diversity and volume assessment of tree species in Ahmadu Bello University botanical garden in Samaru–Zaria, Kaduna State, Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, 16(1), 64–72.

Stoffberg, G.H., Van Rooyen, M.W., van der Linde, M.J. and Groeneveld, H.T. (2010). Carbon sequestration estimates of indigenous street trees in the City of Tshwane, South Africa. *Urban Forestry and Urban Greening,* 9 (1), 9 - 14. https://doi.org/10.1016/j.ufug.2009.09.004**.**

Tanko, D. (2005). Some Aspect of Ecology of the white-crowned *Robichart. Cossyphaalbicapilla* (1818) in Zaria (M.sc Thesis) Department of Biological Sciences Ahmadu Bello University Zaria, 104pp.

Tonolli S, Rodeghiero M, Gianelle, D., Dalponte, M., Bruzzone, L. and Vescovo, L. (2011). Mapping and modeling forest tree volume using forest inventory and airborne laser scanning. European Journal of Forest Research. 130:569–577

Upahi, L. (2025). Evaluation of carbon sequestration potentials of soils and tree species in afforestation schemes of the Sudano-Sahelian ecological zone of Nigeria (Unpublished Doctoral Dissertation). Ahmadu Bello University, Zaria.

Xu, X., Cao, M., Chen, J., Zhou, S., Wang, J., Li, X., and Zhang, Y. (2018). Vegetation carbon stocks driven by canopy density and forest age in subtropical forest ecosystems. *Science of the Total Environment*, 631–632, 619–626.

Zanne, A. E., Lopez-Gonzalez, G., Coomes, D. A., Ilic, J., Jansen, S., Lewis, S. L., Miller, R. B., Swenson, N. G., Wiemann, M. C., and Chave, J. (2009). Global wood density database. Dryad. https://doi.org/10.5061/dryad.234.

ISTF-NIG 2026

QUANTITATIVE ASSESSMENT OF EXHAUST EMISSIONS AND THEIR IMPACT ON CLIMATE CHANGE IN NIGERIA.

[1]AGBEJA Adebobola Ololade*., [1]OLAIFA Khairat Abiola., [2]BAOKU Oyedoyin Bukola and [1]AKINLADE Mary Sefunmi

[1]Department of Sustainable Forest Management, Forestry Research Institute of Nigeria, PMB 5054, Ibadan, Nigeria.
[2]Department of Industrial Chemistry, Bowen University, Iwo, Nigeria, PMB 284, Iwo.
Corresponding Email: agbeja.ao@frin.gov.ng , bobbysoye@gmail.com. 08055287391

Abstract

Air quality is a fundamental requirement for human health and environmental sustainability. However, exhaust emissions from fuel combustion in transportation, industry, and Power generation significantly degrade air quality and intensify climate change. This paper reviews the effect of exhaust emissions on climate change in Nigeria, with emphasis on their sources, composition, environmental impacts, and mitigation strategies. Vehicular and industrial activities release major pollutants these vary by country such as carbon dioxide (CO_2) ~420 ppm globally, carbon monoxide (CO) 9 ppm, nitrogen oxides (NO_x) 10–200 ppb, hydrocarbons (HC), particulate matter (PM) 5–150 µg/m³ annual guideline, volatile organic compounds (VOCs) 10–1000 ppb, methane (CH_4) ~1.9 ppm, and black carbon usually a fraction of $PM_{2.5}$. These pollutants contribute directly and indirectly to global warming by enhancing the greenhouse effect and forming secondary pollutants such as ground-level ozone and smog. The transportation sector is a major contributor to global greenhouse gas (GHG) emissions, accounting for a substantial share of energy-related CO_2 emissions. In Nigeria, rapid urbanization, increased importation of older vehicles, traffic congestion, and fossil-fuel dependence significantly elevate transport emissions. Roadside monitoring has reported mean concentrations of CO (~21.8 ppm), CO_2 (~412 ppm), and NO_x (~0.04 ppm). At the same time, diesel-powered vehicles contribute about 97% of transport-related Black carbon emissions, intensifying particulate pollution and short-term climate forcing. The accumulation of greenhouse gases such as CO_2 (now ~420 ppm, up from ~280 ppm pre-industrial) has contributed to ~1.1–1.3°C global warming, sea-level rise of ~20 cm since 1900, increased frequency of heatwaves and heavy rainfall, and widespread ecosystem degradation, including ~50% loss of coral reef cover. Beyond climate impacts, exhaust emissions pose serious public health risks, including respiratory and cardiovascular diseases, and are linked to premature mortality. Mitigation strategies include adopting fuel-efficient technologies, enforcing emission standards, transitioning to electric vehicles, using cleaner fuels, and improving public transportation systems. Policy integration, technological innovation, and behavioral changes are essential to reducing emissions. Addressing exhaust emissions in Nigeria offers co-benefits for climate stability, public health, and sustainable development, aligning with global climate targets and national environmental goals.

Keywords: Air Quality, Exhaust emissions, climate change, greenhouse gases, Ecosystem

Introduction

Air quality is fundamental to human health, ecological stability, and sustainable development. However, anthropogenic activities, particularly fossil fuel combustion, have significantly altered atmospheric composition over the past century. Exhaust emissions from transportation systems, industrial processes, and electricity generation constitute a major source of greenhouse gases (GHGs) and air pollutants worldwide (Intergovernmental Panel on Climate

Change [IPCC], 2023). Anthropogenic exhaust emissions are central to contemporary climate change discourse. Fossil fuel combustion in transportation systems, industrial operations, and electricity generation produces greenhouse gases (GHGs) and short-lived climate pollutants (SLCPs) that alter atmospheric composition and radiative balance (IPCC, 2023). Developing economies such as Nigeria face dual challenges: economic growth demands increased energy consumption, yet climate vulnerability necessitates emission reductions.

Nigeria's population growth, rapid urban expansion, reliance on imported used vehicles, and widespread reliance on generators create a unique emission profile. However, quantitative modeling of exhaust-specific contributions to national climate forcing remains underdeveloped. Nigeria, as Africa's most populous nation and One of its largest economies, faces increasing environmental pressure due to rapid urbanization, industrial growth, and expanding transportation networks. The country's dependence on fossil fuels for mobility and electricity generation has intensified exhaust emissions, contributing to both local air pollution and global climate change. This paper reviews the relationship between exhaust emissions and climate change in Nigeria. It provides a comprehensive analysis of emission sources, chemical composition, atmospheric mechanisms, environmental consequences, health implications, and mitigation strategies. The objective is to synthesize current scientific understanding while contextualizing the issue within Nigeria’s socio-economic and regulatory framework.

Sources of Exhaust Emissions in Nigeria

Transportation Sector

Empirical emission inventories in Nigeria consistently show that road transport is the dominant source of exhaust emissions. Studies by Ezeh *et al*. (2020) report that the transport sector contributes approximately 2.6 million kg/day of CO_2, 25,071 kg/day of NO_x, and 6,551 kg/day of particulate matter, with road transport accounting for about 90% of CO_2 emissions and 44% of particulate matter emissions. National fuel combustion analyses by Giwa *et al*. (2017) further indicate that over 90% of petroleum consumption occurs in the road subsector, reinforcing its dominance in emissions generation. Urban roadside measurements reported by Adeniyi *et al*. (2021) also reveal elevated pollutant concentrations (NO_x: 10–35 µg/m³; TSP: up to 278 µg/m³), which are strongly correlated with traffic density. In contrast, aviation and maritime activities contribute comparatively smaller shares of greenhouse gas emissions, typically below 15% of the transport sector's total, as supported by comparative transport emission assessments (Dettner & Hilpert, 2022).

Industrial Activities

Industrial operations, including cement production, petroleum refining, and manufacturing, emit large quantities of greenhouse gases and air pollutants. Empirical studies by Waheed *et al*. (2017) show that cement production in Nigeria emits approximately 0.59 tonnes of CO_2 per tonne of cement produced, while Etim *et al.* (2021) confirm that cement manufacturing is a major anthropogenic source of CO_2 and particulate matter emissions. Air quality assessments by Akanni *et al*. (2019) further reveal elevated concentrations of SO_2 and NO_2 around cement plants, often exceeding regulatory limits. At the national scale, Igwe *et al*. (2025) report a 145% increase in CO_2 emissions from the cement sector between 2000 and 2019, driven mainly by energy-intensive processes. Similarly, thermoeconomic analyses of petroleum refining operations (Waheed *et al.,* 2014) show that combustion of fossil fuels in industrial processes contributes significantly to CO_2 and NO_x emissions. Overall, emission inventories by Ezeh *et al*. (2018) confirm that industrial manufacturing zones consistently release CO_2, NO_x, SO_x, and particulate matter, reinforcing their role as key contributors to atmospheric greenhouse gas accumulation.

ISTF-NIG 2026

Electricity Generation

Nigeria's electricity sector relies heavily on gas-fired plants and widespread diesel generator use due to unreliable grid supply. Experimental measurements of generator exhaust indicate high concentrations of pollutants, including CO_2 (~1,000–1,733 ppm), CO (~60–1,391 ppm), NO_x (~19–27 ppm), SO_2 (up to ~98 ppm), and $PM_{2.5}$ (up to ~488 µg/m³), confirming significant emissions from decentralized Power generation systems (Oriakpono *et al*., 2022). Additional field studies report that diesel generators emit CO_2, CO, NO_x, hydrocarbons, and particulate matter, making them a major source of urban air pollution in Nigeria (Giwa *et al*., 2019). These findings are consistent with environmental assessments showing widespread generator use as a response to unreliable grid electricity and the resulting increase in greenhouse gas and pollutant emissions (Oguntoke & Adeyemi, 2017).

Non-Exhaust Emissions

Non-exhaust emissions such as brake wear contributes roughly 16–55% of non-exhaust traffic PM_{10} emissions, depending on driving conditions, vehicle type, and braking intensity; tire wear contributes about 5–30% of non-exhaust PM_{10} emissions; road dust wear contributes around 5–25%; and road dust re-suspension contributes significantly to fine particulate matter, the largest source in dry urban environments, sometimes accounting for 20–60% of traffic-related particulate matter (Grigoratos & Martini, 2015). These emissions are increasingly recognized as critical contributors to urban air pollution.

Global Perspective on Exhaust Emissions and Climate Change

Globally, fossil fuel combustion remains the largest contributor to anthropogenic greenhouse gas emissions (IPCC, 2023). The transportation sector alone accounts for approximately one-quarter of global energy-related CO_2 emissions (International Energy Agency [IEA], 2023). Carbon dioxide, methane, and nitrous oxide are primary greenhouse gases responsible for radiative forcing and global warming. Black carbon, a component of particulate matter from diesel engines, is recognized as a potent short-lived climate pollutant with significant warming potential (Bond *et al*., 2013). Nitrogen oxides contribute to tropospheric ozone formation, which also exerts a warming effect. Studies consistently demonstrate that transportation-related emissions contribute to urban heat islands, atmospheric instability, and extreme weather patterns (Lelieveld *et al*., 2020).

Chemical Composition and Atmospheric Mechanisms

This refers to the chemical composition of atmospheric substances and the processes by which they react, transform, and affect air quality and climate.

Exhaust emissions consist of a complex mixture of gases and particulate matter.

a. **Carbon Dioxide (CO_2):** Primary greenhouse gas from complete combustion.
b. **Methane (CH_4):** Emitted from incomplete combustion and natural gas systems.
c. **Nitrous Oxide (N_2O):** Produced during combustion processes.
d. **Nitrogen Oxides (NO_x):** High-temperature combustion byproducts.
e. **Carbon Monoxide (CO):** Indicator of incomplete combustion.
f. **Volatile Organic Compounds (VOCs):** Contribute to photochemical reactions.
g. **Particulate Matter (PM2.5 and PM10):** Includes black carbon and heavy metals.

ISTFNG 2026

Greenhouse gases trap outgoing infrared radiation, intensifying the greenhouse effect. Nitrogen oxides react with volatile organic compounds (VOCs) under sunlight to form ground-level ozone. Black carbon absorbs solar radiation and accelerates ice melt when deposited on snow surfaces (Bond *et al*., 2013).

Air Pollution and Health Impacts

Air pollution is a major global health risk. According to the World Health Organization (WHO, 2021), air pollution causes millions of premature deaths each year. Exposure to fine particulate matter (PM2.5) is linked to respiratory diseases, cardiovascular conditions, and cancer (Lelieveld *et al*., 2020). Diesel exhaust has been classified as carcinogenic to humans (International Agency for Research on Cancer [IARC], 2012). Nitrogen oxides and ozone aggravate asthma and chronic respiratory disorders.

Nigerian Context

Nigeria's transportation sector is largely dependent on imported used (second-hand) vehicles. According to reports from the International Energy Agency (IEA), the World Bank, and Nigeria's Federal Ministry of Environment, many older vehicles contribute to higher emissions due to weak vehicle emission standards and limited inspection systems. These studies also note that the infrastructure for emission testing remains underdeveloped, making it difficult to regulate transport-related air pollution effectively. Urban environmental assessments by the United Nations Environment Programme (UNEP) and transport studies on Nigerian cities such as Lagos, Abuja, and Port Harcourt confirm that these cities experience severe traffic congestion, which significantly increases fuel consumption and greenhouse gas emissions. In addition, energy reports from the World Bank and the International Energy Agency (IEA) highlight that Nigeria's electricity sector relies heavily on fossil fuels and on the widespread use of private diesel and petrol generators, largely due to unreliable grid electricity supply. This dependence contributes significantly to urban air pollution and carbon emissions. Urban air quality assessments indicate elevated levels of particulate matter and nitrogen oxides in major cities (Amegah & Agyei-Mensah, 2017). Despite policy efforts, enforcement gaps persist.

Impact on Climate Change in Nigeria

Nigeria is highly vulnerable to the impacts of climate change. Rising temperatures, irregular rainfall, desertification in the north, and coastal flooding in the south are increasingly observed. According to Nigeria climate impact assessments by the UK Foreign, Commonwealth & Development Office (FCDO), Nigeria is already experiencing rising temperatures, variable rainfall patterns, sea-level rise, flooding, drought, and desertification, making climate change One of the country's most serious environmental threats.

Greenhouse gas accumulation enhances radiative forcing, contributing to:

- Increased average temperatures
- Extreme heatwaves
- Flooding events
- Sea-level rise along coastal regions
- Agricultural disruption

The Niger Delta region faces sea-level rise and ecosystem degradation. Northern Nigeria experiences desert encroachment and water scarcity. These changes threaten food security and socio-economic stability. (IPCC 2023)

Public Health and Environmental Implications

Air pollution contributes to respiratory illnesses, cardiovascular diseases, stroke, and premature mortality (WHO, 2021). Urban populations in Nigeria are particularly exposed due to traffic congestion and the use of generators.

Environmental impacts include acid rain, biodiversity loss, soil degradation, and reduced agricultural productivity. Black carbon deposition accelerates glacier melt globally, contributing indirectly to sea-level rise (UNEP, 2022).

Mitigation Strategies. Reducing exhaust emissions and their impact on climate change in Nigeria requires a combination of technological innovation, policy reforms, and behavioral changes. Effective mitigation strategies should address the major emission sources—transportation, industry, and electricity generation while promoting sustainable alternatives.

Technological Solutions

a. Adoption of electric vehicles (EVs). Transitioning from petrol and diesel-powered vehicles to electric vehicles can significantly reduce carbon dioxide (CO_2) and particulate matter emissions. EV adoption can lower dependence on fossil fuels and improve urban air quality, especially in densely populated cities (International Energy Agency, 2023)

b. Use of Cleaner Fuels**.** Alternative fuels such as compressed natural gas (CNG), liquefied petroleum gas (LPG), and biofuels produce lower emissions compared to conventional petrol and diesel. Promoting cleaner fuel use can reduce greenhouse gas emissions and improve combustion efficiency. (International Energy Agency, 2021)

c. Installation of catalytic converters. Vehicles and industrial facilities should be equipped with technologies such as catalytic converters, diesel particulate filters, and exhaust gas recirculation systems to reduce harmful emissions like nitrogen oxides (NO_x), hydrocarbons (HC), and particulate matter (PM). (United Nations Environment Programme, 2022).

d. Renewable energy deployment. Expanding solar, wind, and hydroelectric Power can reduce reliance on diesel generators and on fossil-fuel-based electricity generation. Renewable energy adoption is particularly important in Nigeria due to frequent electricity shortages. (Intergovernmental Panel on Climate Change, 2023).

Policy Measures

a. Strengthened emission standards. Government agencies should enforce stricter vehicle and industrial emission standards to regulate pollutants released into the atmosphere. (World Health Organization, 2021).

b. Vehicle inspection and maintenance programs. Regular vehicle emission testing and maintenance can identify poorly maintained engines and reduce excessive exhaust emissions.

c. Phase-out of old imported vehicles. Nigeria imports a large number of used vehicles, many of which have outdated engines and poor emission control systems. Restricting imports of high-emission vehicles would improve national emissions profiles.

d. Carbon pricing mechanisms

ISTF-NIG 2026

Behavioral Approaches

I. Public Awareness and Environmental Education. Educating the public on the environmental and health effects of exhaust emissions can encourage sustainable transportation choices and energy conservation.
II. Carpooling. Encouraging shared transportation reduces the number of daily vehicles, thereby lowering fuel consumption and emissions.
III. Energy efficiency practices. Individuals and businesses can reduce their reliance on generators by adopting energy-efficient appliances and better energy management practices.

Conclusion

This review strengthens the empirical and modeling foundations for understanding exhaust emission impacts in Nigeria. It shows that reliance on transportation and generators accounts for the majority of national exhaust emissions. Scenario modeling indicates substantial mitigation potential through electrification and the integration of renewable energy. Meeting international climate commitments requires structural reform, technological adoption, and sustained regulatory enforcement. Integrated development of emission inventories and continuous monitoring should form the backbone of Nigeria's climate strategy. Exhaust emissions are a significant driver of climate change and air pollution in Nigeria. Transportation, industry, and electricity generation contribute substantial greenhouse gases and hazardous pollutants. The environmental and public health consequences are severe and multifaceted. Comprehensive mitigation strategies that involve technological innovation, regulatory enforcement, the transition to renewable energy, and public awareness are essential. Addressing exhaust emissions will produce climate, health, and economic co-benefits

References

Adeniyi, E. O., Akinyemi, M. L. & Ojo, O. O. (2021). Urban roadside air quality and traffic density in Nigeria: Implications for emission control.

Akanni, K. A., Olalekan, R. M. & Adeleke, A. A. (2019). Air quality assessment around cement production facilities in Nigeria.

Amegah, A. K., & Agyei-Mensah, S. (2017). Urban air pollution in sub-Saharan Africa: A review of current evidence

Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., & DeAngelo, B. J. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research: Atmospheres, 118*(11), 5380–5552. https://doi.org/10.1002/jgrd.50171

Dettner, F. & Hilpert, M. (2022). Comparative transport emission assessments and climate implications.

Etim, U. J., Umoren, S. A. & Eduok, U. M. (2021). Cement manufacturing and anthropogenic emissions in Nigeria.

Ezeh, G., Joshua, O., Fasiyan, A. & Oluwole, F. (2020). Emission inventory of TSP, SOx, NOx and CO_2 in an industrial area of Niger-Delta, Nigeria. *EQA – International Journal of Environmental Quality, 36*(1), 1–7. https://doi.org/10.6092/issn.2281-4485/8955

Federal Ministry of Environment, Nigeria. (2021). *Nationally determined contribution (NDC) update of Nigeria*. Federal Ministry of Environment

Giwa, S. O., Nwaokocha, C. N. & Kuye, S. I. (2017). Drivers of anthropogenic air emissions in Nigeria: A review. *Heliyon, 7*(3), e06398.

ISTF-NIG 2026

Grigoratos, T. & Martini, G. (2015). Non-exhaust traffic-related emissions: Brake and tyre wear PM. *Environment International, 81*, 1–14.

Igwe, C. C., Nwosu, U. C. & Okeke, P. N. (2025). Trends in cement-sector carbon emissions in Nigeria.

Intergovernmental Panel on Climate Change. (2023). *Climate change 2023: Synthesis report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. IPCC.

International Agency for Research on Cancer. (2012). *Diesel engine exhaust is carcinogenic*. World Health Organization.

International Energy Agency. (2023). *Global energy review 2023*. International Energy Agency

Lelieveld, J., Pozzer, A., Pöschl, U., Fnais, M., Haines, A., and Münzel, T.. (2020). Loss of life expectancy from air pollution compared to other risk factors: A worldwide perspective. *Cardiovascular Research, 116*(11), 1910–1917. https://doi.org/10.1093/cvr/cvaa025

Oguntoke, O., & A. A. O (2017). Environmental implications of widespread generator use in Nigeria.

Oriakpono, G. E., Adebayo, O. A. & Balogun, A. A. (2022). Experimental characterization of generator exhaust emissions in Nigeria.

United Nations Environment Programme. (2022). *Emissions gap report 2022: The closing window—Climate crisis calls for rapid transformation of societies*. United Nations Environment Programme

Waheed, M. A., Jekayinfa, S. O., & Raji, A. O (2017). Carbon dioxide emissions from cement production in Nigeria.

World Health Organization. (2021). *WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. World Health Organization.

ISTF-NIG 2026