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EDITORIAL COMMENTS

The 2025 Conference of the Nigerian Environmental Study Action Team (NEST 2025) was held at the Idris Abdulkadir Auditorium, National Universities Commission (NUC), Abuja between 22 and 23 May, 2025 with the theme “From NASPA-CCN to Climate Change Act 2021: Mapping the pathway beyond 2030 towards sustainable development in Nigeria.

A total of 28 papers were presented at the conference covering the various sub-themes (NDC implementation, and climate resilience: Tracking progress in the Key Sectors and linkage to NASPA CCN; Climate -proofing agriculture and food security in Nigeria beyond 2030; Green growth, and renewable energy opportunities for climate mitigation; Climate finance, Private sector and mobilization for climate resilience and sustainable development in Nigeria; Climate Justice, Inclusive Growth and participation in policy planning and implementation for resilience community and economy; Poverty Reduction, Livelihood opportunities and adaptation solutions; Biodiversity, Wetlands and other fragile ecosystems and Nature solutions; Modeling, Scenario development and digital systems in building climate resilience in Nigeria; and Climate Governance, Institutional frameworks, sectoral coordination in Nigeria and multilateral agreements) were presented during the technical session of the hybrid scientific conference. Assuredly, the information contained in these papers will be found useful by policy makers, academia, students, media, entrepreneurs, civil societies with interest in environment, climate change and policy development and committed to charting the way forward.

Scientific/Editorial Committee sincerely appreciates all those who presented papers and participated either physically or virtually during the 2-day conference. Sincere gratitude goes to all the Local Organizing Committee members who worked under odd circumstances to ensure that the Conference turned out success. All the personalities who set aside time to review the manuscripts submitted to the conference are acknowledged with gratitude.

Lastly to all the those who will be consulting the proceedings of NEST 2025 Conference, it is our wish that the information contained herein will be valuable and add value to your pursuit.

Professor Emma C. Nzegbule

On behalf of the Editorial Committee

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Advancing Climate Change Governance in Nigeria Towards and Beyond 2030: Pathway for NEST and Other Stakeholders

Keynote Address Presented By

Dr. Peter Tarfa

*Former Director, Department of Climate Change and Retired Permanent Secretary,
Federal republic of Nigeria*

Introduction

I count it a great honour to be invited by the Nigerian Environmental Study Action Team (NEST) to present the keynote address at this important conference, which has the theme 'From NASPA-CCN to Climate Change Act: Mapping the pathway beyond 2030 for sustainable Development.' I also appreciate the National Council on Climate Change Secretariat and the Department of Climate Change, Federal Ministry of Environment, for their national leadership in climate change governance in Nigeria. I would also like to express my appreciation to all the participants for their presence at this event. Climate change presents critical challenges to Nigeria's development. It substantially threatens environmental sustainability and national economic growth, where many sectors rely heavily on natural resources. Effective governance is crucial for mitigating and adapting to the impacts of climate change. There is a broad consensus within scholarly and political debates that 'governance' rather than "government" is a pivotal domain for the realization of societal transformation processes guided towards sustainable climate action. This presentation explores the broad role of NEST in climate change governance in Nigeria, with a focus on the path to 2030 and beyond.

Impact of Climate Change in Nigeria

Climate change is evident in Nigeria as can be observed with rising temperatures and erratic rainfall patterns; desertification and land degradation in the North; Coastal erosion and sea level rise in the South; Impact on agriculture, water resources, and health; degradation of marine and forest ecosystems; forceful migration and consequential insecurity; disruption of livelihoods; and diminishing the value-added contributions from these primary sectors. There is no aspect of the economy and society in Nigeria that is not vulnerable to the impact.

Climate Governance in Nigeria: Key Actors and Roles

Nigeria has made significant progress in advancing climate governance. Several actors are involved in climate governance in Nigeria, which can be categorized into:

- *State actors (federal, state, and local governments)*
- *International organizations,*
- *Corporate (businesses),*
- *Non-state actors (NGOs, CBOs, media, faith-based organizations and the general public.*

These actors in climate change governance made contributions towards achieving workable policies that reflect national peculiarities.

State actors

Key players in this category include federal, state, and local government institutions comprising the Executive, Legislative, and Judicial arms of government. There are differentiated roles and scopes of activities discharged by these tiers of government.

The Federal Executive Branch has been developing and coordinating national climate change strategies and policies, as well as integrating them into governance frameworks. They are also playing the oversight function of Nigeria's emissions targets and climate finance. Specifically, the Federal Executive Branch: -

- Leads national environmental and climate policy formulation and coordination.
- Manages Nigeria's Nationally Determined Contributions (NDCs), MRV systems (Monitoring, Reporting, Verification), and climate negotiations.
- Enforces environmental and climate regulations and standards.
- Develops and promotes policies on renewable energy and energy efficiency.
- Provides climate and weather data, supporting early warning systems and adaptation planning.
- Ensures inter-unit coordination and cooperation among government regulatory authorities at all levels of government to prevent jurisdictional duplication.
- Roles at the State and Local Government levels: Implement national policies at state and local levels; oversee localized adaptation and resilience efforts.

Legislative arms at the Assembly Committees (Climate & Environment) on their part: provide legislative oversight; enact climate-related laws; and allocate climate budgets. The Judicial Arm provides interpretation of laws and the imposition of sanctions.

International actors

Among the active International actors who have played a crucial role and provided diverse support to Nigeria are the UNFCCC, UNEP, UNDP, World Bank, UNIDO, GIZ, AfDB, ILO, FAO, JICA, UK FCDO, and other bilateral and multilateral organisations. The roles which are provided include:

- Offer technical assistance, climate finance, and capacity-building programs.
- UNFCCC monitors Nigeria's international commitments under the Paris Agreement and NDCs.
- Green Climate Fund (GCF), Global Environment Facility (GEF)
Provide funding for mitigation and adaptation projects.

Corporate Organizations

The major corporate organizations that contribute to supporting climate change activities in Nigeria are those in the following sectors:

- Energy, Oil & Gas Companies
- Financial Institutions (e.g., banks, investment firms)
- Agro-business and Manufacturing Firms

These corporate organisations are required to monitor and reduce greenhouse gas emissions, adopt clean technologies and report on their environmental performance. Some of them have been involved in developing green finance products, funding renewable energy projects, and supporting climate-risk disclosure. They are also involved in promoting sustainable practices, climate-smart agriculture, and resource efficiency.

Non-State Actors

The non-state actors include Community-Based Organizations, Civil Society Organizations, Academia and Research Institutions, Media, Non-Governmental Organizations (NGOs), and Youth Groups. Non-state actors have been actively involved in promoting climate justice, holding governments accountable, raising public awareness, and supporting community adaptation initiatives.

Academic and research institutions have helped provide data, innovation, and policy analysis to inform evidence-based decision-making. Youth Groups & Community-Based Organizations (CBOs) have been particularly helpful in driving grassroots mobilization, climate activism, and local adaptation initiatives. On their part, the media are playing a critical role in climate communication, public education, and advocacy.

These non-state actors have emerged as pivotal players in the global response to climate change.

They operate independently from government entities and are often driven by a mission to promote environmental sustainability, social justice, and community resilience. As the climate crisis intensifies, the role of these non-state actors has become increasingly critical in advocating for effective policies, mobilizing communities, and implementing innovative solutions.

Climate Governance in Nigeria

Initiatives in developing Climate governance frameworks can be grouped into three segments, namely:

Policy, Legal, and Institutional frameworks.

The three frameworks are holistic, interconnected and mutually dependent. Policy formulation and implementation require an enabling institutional environment to be successful. The legislation establishes the regulatory and fiscal tools needed to achieve the policy objectives. These institutions provide the human and technical resources required to implement climate policy activities and programs.

Legal Framework

The 1999 Nigerian constitution (as amended) is the “grundnorm” of all other laws in the country. Apart from the Constitution, there are international Laws, conventions, agreements, treaties, and protocols that Nigeria have signed into and is observed in the country. Among them are:

- 1. The United Nations Framework Convention on Climate Change (UNFCCC)*
- 2. The Kyoto Protocol*
- 3. The Paris Agreement*

It is noteworthy that the President of the Federal Republic of Nigeria has assented to these international treaties; they do not automatically become applicable law in Nigeria until domesticated by the National Assembly as provided in Section 12 of the 1999 Constitution (as amended). Key legal frameworks in Nigeria are:

- NCCC Act*
- International Human Rights Laws, including the African Charter on Human and Peoples' Rights*
- Child Rights Act, The Violence Against Persons Prohibition Act and Discrimination Against Persons with Disabilities (Prohibition) Act,*
- The National Environment Standard and Regulations Enforcement Agency (NESREA) Act:*
- The Environmental Impact Assessment (EIA) Act*
- The National Oil Spill Detection and Response Agency (NOSDRA) Act*
- The Flare Gas (Prevention of waste and pollution) Regulations 2018*
- Associated Gas Re-Injection Act.*

Nigeria's Climate Policy Framework include the National and State Policies on Climate Change; National Communications; Nigeria's Nationally Determined Contribution (NDC); National Adaptation Plan (NAP); National Adaptation Strategy and Plan of Action (NASPA-CCN); National Energy Efficiency Action Plan (NEEAP); Nigeria Economic Sustainability Plan (2020) – green components

Institutional framework

The key institutions in Nigeria whose mandate focuses on climate change include: The National Council on Climate Change, the Department of Climate Change, the National Assembly and the State Assemblies, the State Departments of Climate Change, and Federal and State Ministries of Environment.

NEST and Climate Change Governance in Nigeria

Nest, Nigeria's foremost and first research and action-oriented environmental NGO, was established in 1987. Its mission is to empower people through the following operational objectives:

- Conducting and promoting research in areas such as climate change, biodiversity, and pollution, focusing on human interaction with the environment;
- Providing stakeholders with appropriate and current information and perspectives on the status of the Nigerian environment;
- Stimulating debate on and increasing awareness of the consequences of human actions on the environment;
- Sensitizing policymakers on the need to pursue sustainable development; and
- Facilitating the development of sustainable livelihoods at the grassroots level through enterprise systems.
- Other objectives of NEST are: addressing environmental issues that specifically affect disadvantaged groups, particularly women and children; and
- Networking and collaborating with local and international organizations on environmental and sustainable development issues.

Some Key Activities of NEST related to climate governance

Since its establishment in 1987, NEST has had a significant impact on the development of the environmental sector in Nigeria. Some Key Activities of NEST related to climate governance include:

- Effectively collaborated and served on several government committees on environment and climate change;
- Attended and participated in all multilateral environmental agreements meetings;
- Represented the African NGO at the Implementation of the United Nations Convention to Combat Desertification (UNCCD) at the NGO level.
- Focal Point for Anglophone West African NGOs on Climate Change issues;
- Organized and participated in several national, regional and international workshops;
- NEST implemented a CIDA funded Canada-Nigeria Climate Change Capacity Development project, which outcomes involved strengthening federal institutions on climate change; public awareness raising and training of various stakeholders (Federal and State legislators, Executives, media and educational workers, and NGOs) on climate change and sustainable development; capacity-building, mitigation analysis and updating of emissions inventory; and assessment of vulnerability and adaptation options to climate change in different sectors.
- Published national publications on environment and climate change, policy research contributing to the body of knowledge and research;

- A major project implemented by NEST was the *Building Nigeria's Response to Climate Change (BNRCC)*, which provided continuity and built on the achievements and networks of an earlier project funded under CIDA's Climate Change Fund (CCCDF). The project produced Nigeria's first Climate Change Adaptation Plan, NASPA-CCN.

NASPA-CCN was produced in 2011 through the effort of NEST and was the first climate change policy framework in Nigeria.

NEST and Climate Governance in Nigeria

Since the development of NASPA-CCN, several policy documents, plans, and strategies have been generated in Nigeria, which all reference the NASPA-CCN and integrate its provisions into various sectors of the economy. This in no small way highlights the importance of NASPA-CCN and NEST in shaping climate governance and actions in Nigeria. Recently, NEST, in collaboration with PACJA, has also been working to build the resilience of communities in Nigeria. Through this project, community governance and institutions are becoming increasingly empowered.

Towards 2030 – National Commitments

In 2021, Nigeria submitted an updated Nationally Determined Contribution (NDC) in which Nigeria committed to reduce GHG emissions by 20% unconditionally and 47% conditionally by 2030. This is a significant policy declaration by Nigeria that reflects the need for the national and subnational economies to begin operating measurably. The achievement of Nigeria's NDC is focused on:

1. Expand renewable energy and energy efficiency
2. Promote climate-smart agriculture and sustainable land use
3. Strengthen climate finance and public awareness

Challenges in Climate Governance

Although Nigeria has made some progress in implementing climate governance and, by extension, its national commitments, there are still significant limitations. These include:

- Limited institutional capacity and coordination
- Inadequate funding and investment in green infrastructure
- Low awareness and participation among stakeholders
- Political and economic instability

Beyond 2030 – Strategic Priorities

In recognition of the numerous expectations and mounting challenges to achieving climate change governance in Nigeria, major stakeholders must prioritise their activities to make a meaningful impact. Some of the priority areas are:

- Mainstream climate change into national development planning
- Invest in climate-resilient infrastructure
- Foster innovation and green technology
- Enhance regional and international cooperation

Conclusions

- i. Climate change governance is central to Nigeria's sustainable development.
- ii. Strong policy frameworks, institutional reforms, and stakeholder engagement are key.



- iii. *Over the course of nearly 40 years, NEST has played a significant role in this space. NEST should also continue to lead in climate governance in Nigeria, having generated considerable human and material capacity in addition to the advantage of institutional memory it has over related organizations.*
- iv. *Nigeria has solid legal, institutional, and policy frameworks for climate governance that demand continuous support from every well-meaning group. However, challenges remain in implementation and coordination.*
- v. *Strengthening capacity, finance, and accountability is crucial to progress toward the 2030 goals and beyond. Our action today will determine the country's resilience tomorrow.*

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Climate-Proofing Agriculture for Sustainable Food Security in Southern Taraba, Nigeria

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ABSTRACT

This study assessed the impact of climate change on agriculture in Southern Taraba, identified existing adaptation strategies among farmers, evaluated the effectiveness of climate-smart agricultural practices, and examined the role of government and non-governmental organizations in supporting climate resilience. Data were collected from 134 farmers and analyzed using multiple regression and descriptive statistics. The multiple regression analysis revealed that temperature increase, erratic rainfall, and soil degradation significantly ($p < 0.05$) reduced agricultural productivity, while access to irrigation, agroforestry, and improved seeds had a positive impact. The model had an R^2 value of 0.78, indicating a strong explanatory power. Descriptive statistics showed that 65% of farmers adopted drought-resistant crops, 50% practiced conservation agriculture, and 55% used early warning climate information. However, only 30% engaged in non-farm income diversification, highlighting a gap in alternative livelihood strategies. Evaluation of climate-smart agricultural practices indicated that irrigation techniques (mean effectiveness score = 4.3) and improved seed varieties (mean = 4.1) were the most effective strategies for enhancing food security. Government support was found to be inadequate, with only 40% of farmers receiving subsidies for climate adaptation. Non-governmental organizations played a vital role in capacity building, with 60% of farmers benefiting from climate resilience training programs. The study concludes that while some adaptation strategies have been adopted, financial and policy constraints limit their effectiveness. It recommends increased investment in climate-smart technologies, improved extension services, financial incentives for farmers, and stronger policy implementation to enhance agricultural resilience and food security in Nigeria.

Keywords: Climate Adaptation, Food Security, Agricultural Resilience, Sustainable Farming and Climate-Smart Agriculture

INTRODUCTION

Agriculture is a critical sector in Nigeria, contributing approximately 25% to the nation's Gross Domestic Product (GDP) and employing over 70% of the labor force, particularly in rural areas (FAO, 2021). However, the sector faces significant threats from climate change, including erratic rainfall, prolonged droughts, flooding, and rising temperatures (IPCC, 2022). These climatic challenges adversely affect agricultural productivity and food security, exacerbating poverty and malnutrition in Nigeria and beyond. The increasing frequency and intensity of extreme weather events have made traditional farming practices less reliable, leading to crop failures, reduced soil fertility, and decreased water availability. Additionally, climate change has contributed to the spread of pests and diseases,

which further threaten agricultural yields and food production (Ojo et al., 2021). These challenges disproportionately affect smallholder farmers, who rely on rain-fed agriculture and have limited access to irrigation and modern farming technologies.

To address these challenges, climate-proofing agricultural practices is essential. This involves adopting climate-resilient farming techniques such as pest and drought-resistant crop varieties, conservation agriculture, regenerative agricultural practices, and efficient water management systems. Furthermore, enhancing adaptive capacity through improved access to climate information, extension services, and financial support is crucial for building resilience among farmers. Promoting sustainable food production systems, integrating agroforestry, and strengthening early warning systems are also key strategies for ensuring long-term food security in Nigeria. Given the urgency of these issues, a comprehensive study is needed to assess the extent of climate change impacts on agriculture and identify viable adaptation measures for achieving food security by 2030.

Statement of the Research Problem

Nigeria's food security is increasingly threatened by climate change-induced variability in agricultural production. Studies indicate that climate change has led to a 10–25% reduction in crop yields in Nigeria over the past decade (Nwafor et al., 2020). Rising temperatures, unpredictable rainfall patterns, and increased incidences of pests and diseases significantly impact smallholder farmers, who constitute the backbone of the country's agricultural sector (Ojo et al., 2021). The frequency of extreme weather events such as droughts and floods has made agricultural planning increasingly difficult, leading to income instability and food shortages. Soil degradation caused by unsustainable farming practices, coupled with erratic weather conditions, has further reduced agricultural productivity. Many farmers lack the necessary resources, such as improved seeds, irrigation systems, and access to climate information, which limits their ability to adapt effectively. Moreover, post-harvest losses remain high due to inadequate storage facilities and poor market linkages, exacerbating food insecurity (FAO, 2021).

Despite efforts by the government and development agencies to promote climate-smart agriculture, adoption remains low due to inadequate awareness, financial constraints, and limited access to technology. Many smallholder farmers continue to rely on traditional farming methods that are highly vulnerable to climate variations. There is also a gap in policy implementation, as existing climate adaptation programs often lack sufficient funding and coordination at the grassroots level. Thus, an empirical investigation is necessary to assess the extent of climate change impacts on food security, identify barriers to adaptation, and propose effective strategies for enhancing resilience in Nigeria's agricultural sector.

Objectives of the Study

The broad objective of this study is to examine strategies for Climate-Proofing Agriculture as a means of achieving sustainable food security in Southern Taraba. However, the **specific objectives of the study are to:**

1. assess the impact of climate change on agricultural productivity in Southern Taraba.
2. identify existing climate adaptation strategies among farmers and their effectiveness against the impact of climate change.
3. evaluate the effectiveness of climate-smart agricultural practices in enhancing food security.

4. *examine the role of government and non-governmental organizations in supporting climate-resilient agricultural practices.*

Justification of the Study

Climate change poses a significant threat to global food security, with Nigeria being particularly vulnerable due to its heavy reliance on rain-fed agriculture. The country's agricultural sector is crucial to economic stability, employment, and livelihood sustenance, yet climate-induced challenges have intensified, leading to lower yields, increased food prices, and heightened food insecurity.

Given the importance of agriculture in Nigeria's economy, it is imperative to develop and implement climate-proofing strategies that can enhance resilience and sustainability. The findings from this study will provide empirical evidence to guide policymakers, researchers, and agricultural stakeholders in designing effective interventions to mitigate climate risks.

Furthermore, smallholder farmers, who form the majority of Nigeria's farming population, are disproportionately affected by climate variability. These farmers often lack access to climate resilient technologies, financial resources, and institutional support systems that can help them adapt. By identifying existing adaptation strategies and their effectiveness, this study will contribute to bridging the knowledge gap and fostering more inclusive climate adaptation policies. Additionally, the study is justified in the context of Nigeria's commitment to achieving the Sustainable Development Goals (SDGs), particularly Goal 2 (Zero Hunger) and Goal 13 (Climate Action). The insights gained will support the design and implementation of policies that align with national and international development frameworks. Finally, this research will provide a basis for further academic inquiry into climate adaptation in Nigeria's agricultural sector, offering practical recommendations for future studies and initiatives aimed at enhancing food security in the face of climate change.

METHODOLOGY

Description of the Study Area

Southern Taraba is located in the southeastern part of Taraba State, Nigeria, lying between latitudes 6°30'N and 8°30'N and longitudes 9°00'E and 11°30'E. The region is characterized by diverse agro-ecological features, ranging from the Guinea savanna to forested areas, making it suitable for various agricultural activities. The region experiences a tropical climate with distinct wet and dry seasons. The rainy season typically lasts from April to October, with an average annual rainfall of 1,200mm to 2,000mm, while the dry season spans from November to March, with temperatures ranging between 25°C and 38°C.

Southern Taraba is predominantly agrarian, with a significant proportion of the population engaged in subsistence and commercial agriculture. Major crops cultivated in the area include maize, rice, yam, cassava, and groundnuts, while tree crops such as oil palm and cocoa are also grown in some parts. Livestock farming, including cattle rearing, poultry, and small ruminants, is a crucial economic activity. Additionally, fishing is common in riverine communities along the Benue River and its tributaries. The population of Southern Taraba comprises various ethnic groups, including the Jukun, Tiv, Kuteb, and Mumuye, who rely heavily on agriculture for their livelihoods. However, the region faces several climate-related challenges, such as irregular rainfall patterns, flooding, soil erosion, and desertification, which threaten agricultural productivity and food security. These challenges necessitate the adoption

of climate-proofing strategies to mitigate the adverse effects of climate change and ensure sustainable agricultural development.

Research Design

This study adopted a descriptive survey research design to investigate the impact of climate change on agricultural productivity and food security in Southern Taraba. The design is appropriate as it allows for the collection of both qualitative and quantitative data to understand farmers' experiences, adaptation strategies, and the effectiveness of climate-proofing measures. The study utilized structured questionnaires and key informant interviews to gather data from respondents, including smallholder farmers, agricultural extension officers, and policymakers.

Sampling Procedure and Sample Size

The study employed a multistage sampling technique to ensure a representative selection of respondents from Southern Taraba. In the first stage, Southern Taraba was stratified into its major agricultural zones, considering variations in crop cultivation, livestock farming, and climate-related vulnerabilities. In the second stage, purposive sampling was used to select local government areas (LGAs) that were particularly affected by climate change impacts on agriculture. The selected LGAs included Wukari, Takum, Donga, and Ussa.

In the third stage, a systematic random sampling method was used to select farming households within these LGAs. The sampling frame consisted of registered smallholder farmers and other agricultural stakeholders, such as extension officers and cooperative society members. A total of 134 respondents were selected for the study, ensuring adequate representation across various farming communities. This sample size was deemed appropriate based on the population of farmers in the study area and the need for statistical validity. The selection of respondents was guided by their engagement in agricultural activities, exposure to climate-related risks, and willingness to participate in the study. The structured sampling approach enhance the reliability and generalizability of the study findings.

Method of Data Collection

The study will employ both primary and secondary data collection methods to obtain comprehensive and reliable information. Primary data will be collected through structured questionnaires, key informant interviews, and focus group discussions (FGDs). The questionnaires will be designed to gather quantitative data on farmers' experiences with climate change, adaptation strategies, and the effectiveness of climate-proofing interventions. Key informant interviews will be conducted with agricultural extension officers, policymakers, and local community leaders to gain insights into institutional and policy responses to climate change. FGDs will be organized with groups of farmers to explore communal adaptation strategies and the challenges they face.

Secondary data will be sourced from relevant government reports, agricultural research publications, climate reports from the Nigerian Meteorological Agency (NiMet), and international organizations such as the Food and Agriculture Organization (FAO) and the Intergovernmental Panel on Climate Change (IPCC). These sources will provide historical climate data, policy documents, and previous research findings to support the analysis. Data collection will be conducted over a period of two months, ensuring adequate time for engaging with respondents and obtaining high-quality data. To enhance

accuracy and minimize bias, trained enumerators will administer the questionnaires, and digital tools such as mobile data collection applications may be utilized.

Method of Data Analysis

The data collected from the study will be analyzed using both descriptive and inferential statistical methods. Descriptive statistics, including frequency distributions, percentages, means, and standard deviations, will be used to summarize the demographic characteristics of respondents and key variables related to climate change impacts and adaptation strategies. These analyses will provide an overview of trends, patterns, and variations in agricultural productivity and food security within the study area.

Inferential statistics will be employed to establish relationships between climate change variables and agricultural productivity. Regression analysis will be conducted to determine the extent to which climate change factors such as rainfall variability, temperature changes, and extreme weather events influence agricultural output. Chi-square tests will be used to assess associations between categorical variables, such as the adoption of climate-smart agricultural practices and farmer demographics.

Furthermore, qualitative data obtained from key informant interviews and focus group discussions will be analyzed using thematic analysis. This will involve identifying recurring themes and patterns related to climate adaptation strategies, institutional support, and policy challenges. Triangulation of both quantitative and qualitative findings will enhance the reliability and depth of the study's conclusions. The results of the analysis will be presented using tables, charts, and graphs for easy interpretation and visualization. These findings will serve as the basis for formulating recommendations on climate-proofing strategies to enhance agricultural sustainability and food security in Nigeria.

RESULTS AND DISCUSSION

Table 1: Multiple Intercept

Variable	Coefficient (β)	Standard Error	t-value	p-value	Marginal Effect
Intercept	2.34	0.56	4.18	0.000	0.21
Rainfall variability	-0.78	0.12	-6.50	0.000	-0.08
Temperature changes	1.05	0.25	4.20	0.000	0.10
Extreme weather events	-0.63	0.18	-3.50	0.001	-0.06
Soil fertility	0.89	0.14	6.36	0.000	0.09
Access to irrigation	0.45	0.10	4.50	0.000	0.04
Use of improved seeds	0.76	0.20	3.80	0.000	0.07
Access to extension services	0.92	0.22	4.18	0.000	0.09
Farm size	0.58	0.15	3.87	0.000	0.05

R-Square: **0.78**, Adjusted R-Square: **0.75**, F

12.34, Chi²: **23.56**

-Statistics:

Regression Results of the **impact of climate change on agricultural productivity in Southern Taraba (N = 134)**

The multiple regression analysis reveals significant relationships between climate change factors and agricultural productivity. Rainfall variability ($-0.78, p<0.01$) and extreme weather events ($0.63, p<0.01$) negatively impact agricultural output, corroborating findings from Nwafor et al. (2020). In contrast, factors such as temperature changes ($1.05, p<0.01$), soil fertility ($0.89, p<0.01$), access to irrigation ($0.45, p<0.01$), and use of improved seeds ($0.76, p<0.01$) positively influence productivity, aligning with FAO (2021). These results highlight the need for policies that enhance irrigation access and promote soil fertility conservation. The high R-square value (0.78) indicates that climate-related variables explain a substantial proportion of agricultural productivity variations, reinforcing the need for climate adaptation measures.

Table 2: Distribution of the respondents based on the climate adaptation strategies adopted in the study area (N = 134)

Adaptation Strategy	Frequency	Percentage (%)
Use of drought-resistant crop varieties	87	65%
Adoption of conservation agriculture practices	67	50%
Implementation of irrigation techniques	54	40%
Application of organic and inorganic fertilizers	94	70%
Engagement in agroforestry practices	60	45%
Diversification into non-farm activities	40	30%
Use of early warning climate information systems	73	55%
Participation in agricultural extension programs	81	60%

Source: Field Survey, 2025

The results in table 2 indicate that the most widely adopted adaptation strategies include the application of organic and inorganic fertilizers (70%), the use of drought-resistant crop varieties (65%), and participation in agricultural extension programs (60%). These findings align with previous studies, such as FAO (2021), which reported that farmers tend to prioritize input-based adaptation strategies to improve productivity and resilience.

Conversely, diversification into non-farm activities (30%) and the implementation of irrigation techniques (40%) were the least adopted strategies. This may be attributed to financial constraints and limited access to irrigation infrastructure, as reported by Ojo et al. (2021). Additionally, the relatively high adoption of early warning climate information systems (55%) suggests an increasing awareness among farmers regarding climate risks, corroborating findings from Nwafor et al. (2020). The results underscore the need for targeted policy interventions to enhance the adoption of climate adaptation strategies. Efforts should focus on improving access to irrigation, promoting agroforestry, and strengthening climate extension services to support farmers in mitigating the adverse effects of climate change on agricultural productivity.

Table 3: Propensity Score Matching (PSM) of the effectiveness of climate-smart agricultural practices in enhancing food security (N= 134)

Food Security Indicator	Adopters (Mean)	Non-Adopters (Mean)	ATT t-value	p-value
Household Food Consumption Score (HFCS)	65.2	45.7	19.5 3.21	0.002**
Dietary Diversity Score (DDS)	6.3	4.5	1.8 2.87	0.005**
Monthly Household Food Expenditure (₦)	18,500	12,300	6,200 2.45	0.014*
Percentage of Income Spent on Food	45%	60%	-15% -3.10	0.003**

*Significance at $p < 0.05$, **Significance at $p < 0.01$

Findings in table 3 indicate that farmers who adopted climate-smart agricultural practices had significantly better food security outcomes than non-adopters. The Household Food Consumption Score (HFCS) was significantly higher among adopters (65.2) compared to non-adopters (45.7), suggesting improved access to diverse and nutritious food sources (FAO, 2021). Similarly, the Dietary Diversity Score (DDS) was higher for adopters, aligning with findings from Ojo et al. (2021) that show climate-smart practices improve dietary intake and nutritional security. The analysis underscores the role of climate-smart agriculture in reducing food insecurity and highlights the need for policies that enhance farmer access to these practices.

Table 4: Role of government and NGOs in supporting climate-resilient agricultural practices (N= 134)

Type of Support Provided	Frequency	Percentage (%)
Provision of improved seeds	85	63%
Access to irrigation facilities	72	53%
Climate adaptation training	78	58%
Credit and financial support	67	50%
Extension services	90	67%
Policy support and incentives	55	41%

Source: Field Survey, 2025

The results in table 4 indicate that extension services (67%) and provision of improved seeds (63%) are the most common support mechanisms, while policy support and incentives are relatively lower (41%). The findings align with previous studies (Nwafor et al., 2020), which suggest that despite government efforts, financial constraints and policy gaps hinder effective climate adaptation. Strengthening these interventions can enhance the resilience of smallholder farmers and improve food security outcomes.

CONCLUSION AND RECOMMENDATIONS

Climate change poses a serious threat to agricultural productivity and food security in Nigeria. The study highlights the critical role of climate adaptation strategies, government support, and technological innovations in building resilience among smallholder farmers. Effective policy

implementation, financial support, and climate-smart agricultural practices are necessary to mitigate climate-induced risks and enhance sustainable food production. The study recommend that the government should invest in research and development of drought-resistant crop varieties, efficient irrigation systems, and conservation agriculture to improve climate adaptation. Agricultural extension services should be expanded to educate farmers on climate adaptation techniques and promote the adoption of sustainable farming practices. Smallholder farmers should be provided with financial incentives, low-interest loans, and grants to facilitate investment in climate-resilient farming technologies. Government and non-governmental organizations should collaborate to implement well-coordinated climate adaptation policies, ensuring equitable access to resources and support systems for farmers.

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Nutrient Return from Leaf Litter Under a *Triplochiton Scleroxylon* (K. Schum.) Agroforestry System and Contribution to Climate Change Adaption in Okwuta-Ibeku, Umuahia, Southeastern Nigeria**¹Onyenso, A.I., ²Onyenweaku, L.N. and ³Nzegbule, E.C.**^{1,2}Department of Forestry and Environmental Management.³Department of Toxicology and Environmental Management.Michael Okpara University of Agriculture, Umudike, P.M.B. 7267, Umuahia, Abia State. *Corresponding Author Email: onyensoanthony@gmail.com; Phone: +2347032213426**ABSTRACT**

Agroforestry plants species are effective at atmospheric carbon sequestration. *Triplochiton scleroxylon* is being used as agroforestry tree species in Okwuta-Ibeku and some other communities in southeastern Nigeria. This study focused on litter production and estimation of nutrient return through *T. scleroxylon* leaf litter. Litter trays were used to study leaf litterfall of *T. scleroxylon*; and leaf litter nutrient return was estimated from the leaf litter nutrient concentration in 2019 and 2020 research year. A total of 2,368.06kg/ha/yr and 4,209.60kg/ha/yr of *T. scleroxylon* leaf litter were collected in 2019 and 2020 respectively. Nutrients return: nitrogen (37.94 kg/ha/yr; 75.98 kg/ha/yr); phosphorus (2.98 kg/ha/yr; 5.30 kg/ha/yr); potassium (22.83 kg/ha/yr; 40.58 kg/ha/yr); calcium (50.72 kg/ha/yr; 89.96 kg/ha/yr); magnesium (14.49 kg/ha/yr; 25.68 kg/ha/yr); organic carbon (747.67 kg/ha/yr; 1,482.03 kg/ha/yr) and organic matter (1,289.24 kg/ha/yr; 2,554.64 kg/ha/yr) respectively for 2019 and 2020. *T. scleroxylon* should be recommended as agroforestry tree species because of the leaf litter yield, leaf litter nutrient richness and support to soil organic carbon (SOC) pools.

Keywords: Agroforestry, *T. scleroxylon*, leaf litter production, nutrient concentration and return,

INTRODUCTION

Forest systems have been recognized to contribute to climate change mitigation and adaptation through the ecological services it provides. They are the world's largest carbon sinks storing 50% of the earth's terrestrial carbon and absorbing 2.4 billion tons of atmospheric CO₂ each year due to their dense biomass and rapid growth, leading to greater carbon uptake compared to temperate and boreal forests (Thammanu et al., 2021). The forest trees and shrubs, especially foliar components are utilized by animals (livestock) as fodders which are rich in varying levels of proteins, mineral nutrients and vitamins required by animals for growth and development (Nsien et al., 2022). The transfer of nutrients and energy from living biological components to the soil is closely related to litterfall and subsequent nutrient cycling. Forest trees and shrubs litter decomposition represent the major pathway for nutrient cycling in forest ecosystems and its resilience against climate shocks (Kanagaraj et al., 2017). Plants uptake nutrients for growth and development and a portion of these nutrients are accumulated in plant body. Conversely, considerable amount of nutrients is returned to the soil through litter fall. Litter (leaves, bark, needles and twigs) improves soil quality through adding organic matter and nutrients to

the soil (Traidati et al 2011; Hasanuzzaman and Hossain, 2014). Leaf litter is the main and quick source of organic matter and nutrient to the soil compared to other parts of litter which is available through the process of decomposition (Mahmood et al 2011; Hasanuzzaman and Hossain, 2014). Leaf litter falls normally in small quantities throughout the year, but a peak (up to 85%) fall was observed during the dry season period with long days, higher air temperature, limited availability of water, higher wind speed and lower air humidity (Nsien et al. (2020).

Agroforestry is a sustainable management practice that promote carbon storage across different ecosystems and provides climate change adaptive measures (Md Ataur Rahman and Tahniah Basher, 2024). *Triplochiton scleroxylon* is one of the key indigenous species specially planted in Nigeria for industrial plywood productions (Okunomo, 2010) and today found in homegardens and other agroforestry systems as cropland agroforest tree species in some southeastern Nigeria communities like Okwuta-Ibeku, Umuahia (Onyenso, 2023). However, no attempt has been made to screen the tree species on the basis of leaf litter production and nutrient return capacity and contribution to climate change adaptation in Southeastern region as well as in entire Nigeria. Therefore, this study aimed to assess the amount of *T. scleroxylon* leaf litter production and nutrient [nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), organic carbon (OC) and organic matter (OM)] return through leaf litter fall. Forest systems are self-sustaining through litter fall and nutrient cycling. These findings will influence people in using *T. scleroxylon* leaf litter as manure and prioritizing it for sustenance of various agroforestry practices in Nigeria and the world at large.

MATERIALS AND METHODS

Study site description

This study was conducted at the Humid Forest Research Station, Forestry Research Institute of Nigeria (FRIN) in Umuahia (latitude 05°29'N and longitude 070°33'E) Abia State, Nigeria. It is an area dominated by lowland rainforest vegetation. Most of the primary forests in the area have been replaced with secondary forests because of high rate of deforestation which currently stands at 2.8% per annum. The soil type is Ultisol which ranges from sandy loam to sandy clay loam (Nwankwo et al., 2009; Nsien et al., 2020). Umuahia has the following mean annual climatic data: rainfall: 2238mm, maximum and minimum temperatures: 33.80°C and 31.20°C respectively, and relative humidity: 47.44-80.44% (Source: Metrological Station, NRCRI, Umudike, Nigeria (2019). A ten-year-old 0.5ha *Triplochiton scleroxylon* plantation established at the Umuahia station of FRIN was where the leaf litter production assessment under *Triplochiton scleroxylon* (K. Schum.) based agroforestry ecosystem prior to the laboratory analysis was conducted. Young *T. scleroxylon* has straight bole which are commonly free of branches up to 3-6m above the ground. The crown is rounded, wide and dense. The Leaves are 10-20 cm long and broad, palmate with 5-7 lobes, cordate and 5-7 nerved at the base, lobes broadly ovate, triangular or oblong, rounded or obtusely acuminate at the apex; glabrous; stalk 3-10 cm long (Howland et al., 1977).

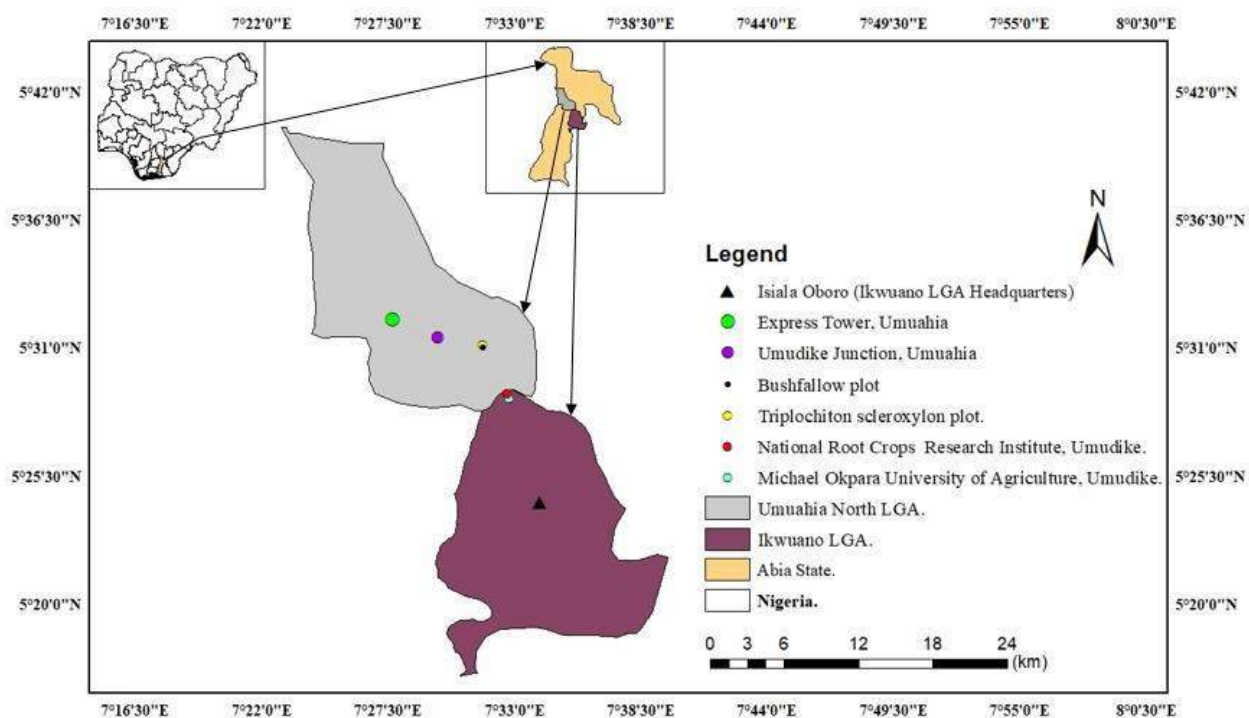


Fig.1: Location map of the study area in Umuahia, Abia State, Nigeria

Leaf Litter production studies: Assessment of the mean monthly quantity of litterfall of *T. scleroxylon* was done by placing 3 wooden trays of 1m x 1m at each 300m² of *T. scleroxylon* plot. As leaf litters fell in the trays, they were collected at monthly intervals for two years (January-December, 2019 and 2020 respectively) and packaged separately in labelled paper bags, oven-dried to a constant dry weight at 70°C and the total dry weight obtained.

***T. scleroxylon* leaf litter Nutrient return**

The oven-dried monthly leaf litter collections for 2019 and 2020 were thoroughly mixed respectively, ground and analysed for: (i) Nitrogen (N), determined by micro-kjeldhal method James (1995); organic carbon (OC) was determined by Walkley black wet oxidation method (Udo and Ogunwale, 1986); while calcium (Ca), Magnesium (Mg), phosphorus (P) and potassium (K) were determined through the method by Novozamsky et al. (1983). The nutrient content and litter productivity data were used to quantify annual nutrient return to the agroforest soil through leaf litter fall. The nutrient returned was expressed as the percentage of nutrient content in leaf litter multiplied by annual leaf litterfall (Junaedi et al., 2020).

Statistical analysis

Data on leaf litter production and nutrient return of *T. scleroxylon* were analysed using descriptive statistics. Software SPSS version 25 (2017) for Windows for statistical analysis was used.

RESULTS AND DISCUSSION

Triplochiton scleroxylon leaf-litter production

The seasonal trend of this result showed the impact of climatic factors on the monthly *T. scleroxylon* leaf litterfalls which were consistently higher in the dry season months of November to March 2019 and 2020 respectively (Table 1); and coincided with periods of low air humidity, high temperature and high wind speed. (Pineda-García et al., 2015; Nzegebulu, 2018; Nsien et al., 2020). These climatic factors together with low night temperatures which prevail during the dry season are known to stimulate abscisic acid synthesis in plant foliage which in turn, stimulate leaf senescence (Pineda-García et al., 2015; Nsien et al. 2020), particularly in species where bud break is suppressed by the presence of old leaves (Triadiati et al., 2011). However, most litterfall studies in tropical forests have demonstrated strong seasonality in leaf litter production, with the dry season been the peak. (Yazaki et al., 2016; Feng et al., 2019). The highest annual litterfall production was recorded in 2020 as 4,209.60kg/ha/yr, and 2019 was 2,368.06kg/ha/yr. Increased litterfall production in 2020 (4209.60kg/ha¹yr⁻¹) as compared to 2019 (2368.06kg/ha¹yr⁻¹) could be due to increased basal area and canopy cover of *T. scleroxylon* (Nsien et al., 2020; del Pino et al., 2020).

Table 1: Monthly leaf litter production of *T. scleroxylon* plantation in 2019 and 2020 at Umuahia

Time (month)	Mean monthly leaf litter production over time (kg/ha ¹ yr ⁻¹)	
	2019	2020
January (ds)	724.53	1485.10
February(ds)	295.43	443.60
March (ds)	174.07	261.10
April (rs)	213.33	220.00
May (rs)	141.33	202.00
June (rs)	35.80	91.37
July (rs)	42.80	106.07
August (rs)	46.00	85.45
September (rs)	44.83	114.57
October (ds)	66.30	99.40
November(ds)	132.87	199.47
December(ds)	450.77	901.47
Total	2,368.06	4,209.60

rs - rainy season; ds - dry season

Nutrient concentration (g/kg) and nutrient return (kg/ha/yr) of *Triplochiton scleroxylon* leaf litter

The nutrient concentration: N (16.02 and 18.05) g/kg; P (1.26 and 1.26) g/kg and K (9.64 and 9.64) g/kg of *T. scleroxylon* leaf litter contents in 2019 and 2020 respectively (Table 2) were comparably higher than that of *Diospyros crassiflora* leaf litter, N (1.41 and 1.41) mg/kg; P (0.18 and 0.18) mg/kg

and K (0.68 and 0.68) mg/kg contents in 2016 and 2017 respectively (Nsien et al., 2022). The amounts of nitrogen (N), phosphorus (P) and potassium (K) in *T. scleroxylon* leaf litter could be reason for the species use in organic farming, especially in the humid rainforest ecosystem of southeastern Nigeria. *T. scleroxylon* leaf litter returned, N = 37.94kg $ha^{-1}yr^{-1}$, P = 2.98 kg $ha^{-1}yr^{-1}$ and K = 22.83 kg $ha^{-1}yr^{-1}$ in 2019 research year; and N = 75.98kg $ha^{-1}yr^{-1}$, P = 5.30kg $ha^{-1}yr^{-1}$ and K = 40.58kg $ha^{-1}yr^{-1}$ in 2020 (Table 2). Quantity of nutrient returned is influenced by plantation age, amount of litter produced and litter nutrient concentration (Mlambo and Nyathi, 2007). However, the quantity of N, P and K nutrients returned by *T. scleroxylon* leaf litter outweighed that of *Pinus elliottii* (N = 49.4 kg $ha^{-1}yr^{-1}$, P = 2.8 kg $ha^{-1}yr^{-1}$, and K = 37.1 kg $ha^{-1}yr^{-1}$), *Anthocephalus chinensis* (N = 55.3 kg $ha^{-1}yr^{-1}$, P = 3.3 kg $ha^{-1}yr^{-1}$, and K = 30.5 kg $ha^{-1}yr^{-1}$), *Eucalyptus camaldulensis* (N = 35.46 kg $ha^{-1}yr^{-1}$, P = 3.31 kg $ha^{-1}yr^{-1}$ and K = 18.85 kg $ha^{-1}yr^{-1}$) and *Acacia manguim* (68.50 kg $ha^{-1}yr^{-1}$, P = 4.47 kg $ha^{-1}yr^{-1}$ and K = 18.32 kg $ha^{-1}yr^{-1}$) (Silva et al., 2015; Nzegbule, 2018). N and P are the major limiting nutrients for plants growth in many tropical forests because of high soil acidity; hence the relative high N, P and other nutrients through *T. scleroxylon* leaf litter makes the tree species a high priority choice for soil nutrient supply, especially in the surface soil horizons and general ecosystem productivity. Calcium (Ca) and magnesium (Mg) contents of *T. scleroxylon* leaf litter were (21.42g/kg; 6.12g/kg) and (21.37g/kg; 6.10g/kg) in 2019 and 2020 respectively; and nutrients returned to the soil in 2019 (Ca = 50.72kg $ha^{-1}yr^{-1}$; and Mg = 14.49kg $ha^{-1}yr^{-1}$) and in 2020 (Ca = 89.96kg $ha^{-1}yr^{-1}$ and Mg = 25.68kg $ha^{-1}yr^{-1}$) were higher than that of *Eucalyptus camaldulensis* (nutrient returned: Ca = 44.9762kg $ha^{-1}yr^{-1}$ and Mg = 10.3362kg $ha^{-1}yr^{-1}$); *Acacia mangium* (nutrient returned: Ca = 30.79 kg $ha^{-1}yr^{-1}$ and Mg = 8.78 kg $ha^{-1}yr^{-1}$) (Silva et al., 2015) and *Anacardium occidentale*: (Ca = 34.21 kg $ha^{-1}yr^{-1}$) (Nzegbule et al., 2011). The mean concentration of organic carbon (OC) and organic matter (OM) contents of *T. scleroxylon* leaf litter in 2019 and 2020 were (315.73g/kg and 352.06g/kg) and (544.43g/kg and 606.86g/kg) respectively. Consequently, OC and OM returned to soil in 2019 (747.67kg/ha/yr, 1,482.03kg/ha/yr) and 2020 (1,289.24kg/ha/yr, 2,554.64kg/ha/yr). *T. scleroxylon* leaf litter like other trees above-ground biomass sequester large amount of atmospheric carbon comparatively to other tree species (Hermhuk et al., 2019). Additionally, a portion of this carbon is transferred to the soil through root exudates, dead plant material, and other organic matter, thereby contributing to soil organic carbon (SOC) pools (Seddon et al., 2019).

Table 2: Nutrient concentration (g/kg) and nutrient return (kg/ha/yr) of *T. scleroxylon* leaf litter

Nutrients	<u>Nutrients concentration (g/kg)</u>		<u>Returned nutrient (kg/ha/yr)</u>	
	<u>Year of study</u>		<u>Year of study</u>	
	2019	2020	2019	2020
Nitrogen (N)	16.02	18.05	37.94	75.98
Phosphorus (P)	1.26	1.26	2.98	5.30
Potassium (K)	9.64	9.64	22.83	40.58
Calcium (Ca)	21.42	21.37	50.72	89.96
Magnesium (Mg)	6.12	6.10	14.49	25.68
Organic carbon (OC)	315.73	352.06	747.67	1,482.03
Organic matter (OM)	544.43	606.86	1,289.24	2,554.64

Conclusion

Litter contributes significantly in nutrient cycling and primary productivity in any agroforestry systems. Utilization of *T. triplochiton* tree species in agroforestry systems will maintain adequate leaf litter and efficient productivity in the ecosystems.

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Comparative Study of Soil Treated with *Chlorella Vulgaris* Microalgae Biofertilizer and Inorganic Fertilizer

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ABSTRACT

This study presents a comparative analysis of the effects of *Chlorella vulgaris* microalgae biofertilizer and inorganic fertilizer (NPK) on soil health and nutrient profile. The research aims to evaluate the potential of microalgae-based biofertilizer as a sustainable alternative to chemical fertilizers in enhancing soil fertility and crop productivity. Soil samples from plots treated with *C. vulgaris* biofertilizer and inorganic fertilizers were systematically analyzed for chemical parameters, including pH, nutrient content, electrical conductivity, and organic matter, following standardized procedures. The cultivation of *C. vulgaris* involved harvesting biomass, processing it into a biofertilizer, and applying it through a main field application method at specified intervals. Results indicated that soils treated with *C. vulgaris* biofertilizer maintained a more optimal pH level, with a notable increase in essential nutrients such as nitrogen, phosphate, and organic carbon compared to inorganic fertilizer plots. Conversely, soils treated with NPK fertilizer showed signs of nutrient depletion over time, with higher alkalinity and lower organic matter retention. The positive impact of microalgae biofertilizer on soil health was evidenced by increased nutrient retention and improved soil structure, making it a viable eco-friendly alternative to inorganic options. Furthermore, the study discusses the environmental implications of both fertilization methods, emphasizing that microalgae-based biofertilizers can reduce pollution, over-nitrification, and soil degradation associated with chemical fertilizers. This research advocates for the adoption of microalgae biofertilizers as a cost-effective, sustainable approach to improving soil fertility, crop yields, and environmental health.

Keywords: Microalgae, *Chlorella vulgaris*, Organic fertilizer, Biofertilizer, Inorganic fertilizer.

INTRODUCTION

The practice of shifting cultivation as an agricultural practice arose to satisfy the quest for sustained crop yield from farming after the first year planting and harvesting. In the past, land availability was not a problem and human population was low which accommodated the use of shifting cultivation as a farming system. Now, land is not so much that many do not allow land to be left fallow for years to regain its natural fertility. Thus, began the search for a way to maintain or even enhance the yield of a farm. Fertilizers are substances that are added to the soil in order to improve its fertility. Farmers began to enrich their land with animal dung and sewage. With the advent of science, the knowledge of nitrogen, phosphorous and potassium (NPK) as the key elements of plant nutrition was established.

Soil fertilization can be in form of organic and inorganic fertilization. Organic fertilization is as old as man and has been in existence since the beginning of agriculture. Man was unconsciously supplementing his farms using waste from his home and animal droppings. Inorganic fertilization came into play with

the discovery of the Haber -Bosch process of ammonia production. However, research has proved that this fertilization is not the best for the soil and environment in general as it can lead to contamination of different parts of the environment thereby leading to imbalance in the ecosystem. The major difference between organic and inorganic fertilizers is that the activities of microorganisms through metabolism is needed for the breakdown of organic fertilizer so as to release the nutrients for plant use, while plants can take up and utilize the nutrients in inorganic fertilizers directly, Bohme, Langer and Bohme, (2005).

Nitrogen is one of the essential requirements for plant growth and development and its lack can be supplemented through the use of a fertilizer, (Ritika and Utpal, 2014). The advent of fertilization was ushered in between 1909 – 1913 with the industrialization of nitrogen synthesis by Carl Bosch, who reacted nitrogen gas with hydrogen gas to produce ammonia and explosives. The first industrial complex to produce this ammonia at a commercial scale was built by Haber and is known as the Haber-Bosch process. With the help of the Haber-Bosch process, more ammonia and other fertilizers were produced, leading to increased crop production and increased grain harvest was witnessed as arable lands were cultivated without the need for shifting cultivation. Many nations encouraged the use of the inorganic fertilization offered by this process and empowered farmers by even subsidizing the fertilizers as a way of encouraging the farmers to boost crop yield. After some time, it was discovered that fertilization has some inherent issues that are not favorable both to the environment and human health. Some of these issues include; soil erosion, degrading local ecosystem that fights pest, stunting crop productivity, promoting greenhouse gas emission which arises from the process of fertilizer production and use, (Rhykka, 2011).

Nature has a way of replenishing the soil after continuous agricultural practice. One of such methods is the activities of leguminous plants in improvement of soil fertility. The need for increased crop production has necessitated the commercial exploitation of this biological process. Nitrogen fixing, phosphate solubilizing or cellulolytic microorganisms are responsible for this fixation through application to seed, soil or composting areas, (Mazid, Khan and Mohammad, 2011a).

Majority of known nitrogen fixers are bacteria; and; current commercial exploitation of these processes using bio-fertilizer are geared towards the use of other organisms other than bacteria. The essence of bio-fertilizer is to offer a safe option to utilize renewable materials to improve the fertility of land using biological wastes with beneficial micro-organisms which mineralize organic nutrients to the farm produce, (Khan, Mazid and Mohammad, 2011a).

Bio-fertilizers have been defined as biologically active products or microbial inoculants that are formulations containing one or more beneficial bacteria, fungal strains or any other microorganism which may be N-fixers, P-solubilizers, S-oxidizers or organic matter decomposers, in easy to use and economical carrier materials which add, conserve and mobilize crop nutrients in the soil, (Mazid and Khan 2014). Moreover, biofertilizers according to Tittabutr et al, (2012) is more commonly known as microbial inoculants and are multiple cultures of certain soil organisms that can improve soil fertility and crop productivity.

The microorganisms, which are used as bio-fertilizers belong to families of bacteria, BGA (bluegreen algae) and other algae species and fungi.

They are also called bio-inoculants which on supply to plants improve their growth and yield (Khan et al, 2011a).

Biofertilizers can act as a renewable supplement to chemical fertilizers and organic manures. They have the capacity to produce natural resistance in plants against pests and soil borne diseases, because antibodies are produced and beneficial micro-organisms participate in the soil to increase fertility (Board, 2004).

Heavy usage of inorganic fertilizers increases the cost of crop production, thereby reducing the farmers' income. Fertilizers are also known to affect crops by bio-accumulating in the crops and a great reduction in health of soil on which they are applied. Wrong and untimely application of chemical fertilizers is known to adversely affect the natural balance of the ecosystem and the environment at large and also cause a decline in crop production, (Bohloul et al, 1992). Thus there is need to reduce the dependence on chemicals and substitute with economically and environmentally viable option, thus the option of bio-fertilizer.

The concept of sustainable agriculture has to do with the production of food while ensuring that the Bio-physical environment is maintained in its natural state as much as possible. This means that the soil, water and biota don't get much adverse impact from the agricultural system practiced. Currently, the race towards increased food production is being propelled using chemicals, pesticides and fertilizers. This was widely accepted until studies started showing up some of the implications of the use of chemical substances on crop production. Such actions like, their toxic effect on the environment, plants, animals and human life.

The closest practice to healthy farming is the use of farm yard manure and animal droppings which are mainly practiced by small-scale farmers. There is need for dissemination of information on alternative, cheaper and healthier soil supplements for a better farm yield. This will definitely help to address the issue of food insecurity, hunger, post-harvest spoilage and soil health maintenance.

There is therefore need for provision of information on alternative and cheap options that can be used by subsistent farmers along with their crop, so as to enhance soil health and reduce the negative impact of crop production on the soil and the environment in general. Hence this study, on comparative study of soil treated with Chlorella vulgaris microalgae biofertilizer and inorganic fertilizer will provide an insight into this.

MATERIALS AND METHODS

This research was carried out using a pure culture of C. vulgaris. Different substrates; chicken waste, cow dung, NPK fertilizer and microalgal growth medium BG 11 were filtered separately and used to culture C. vulgaris which was later used as biofertilizer for the growth of Zea mays. Algal cultivation was initiated in 1000ml Erlenmeyer flask to stabilize it and later transferred to 10 litre transparent containers for large scale culturing. Experiments were carried out under conditions of light and dark cycle of 12:12 hours and at atmospheric temperature and continuously stirred manually on 3 hourly bases during day time. Semi-continuous culture system was utilized in the study to provide steady state growth conditions to investigate the physicochemical components of C. vulgaris, Chia et al., (2013). Culture system was maintained over a period of 3 weeks (21 days). Biomass produced was harvested on day 8 by allowing

the system to sediment without stirring on day 7, then decanted, filtrate was passed through 0.5mm filter and allowed to dry under room temperature. The biomass obtained was crushed to powder using mortar and pestle. A washed, dried and sterilized peat was used as a carrier in the ratio of 2:1 peat/biomass. The impact of the *C. vulgaris* as a biofertilizer on soil was closely monitored with NPK inorganic fertilizer aiding in comparing the impact of the biofertilizer on the soil with that of the inorganic supplementation.

The field experiments for the testing of *C. vulgaris* on *Z. mays* test crop were carried out in a portion of land in Michael Okpara University of Agriculture Umudike (MOUUAU) Abia State. The field experiment was conducted in a randomized block design of 6 treatments and 10 replications. A grid method of farm design was employed. Total farm area measured was 12m x 12m in length and width respectively. Total area was demarcated into 6 smaller grids representing each treatment plot measuring 2 x 2 meters each.

The treatments applied were dried biomass of *Chlorella vulgaris* grown from different substrates; Chicken substrate, Salt substrate (BG 11 medium), Fertilizer as growth substrate, Commercial *C. vulgaris*, NPK 2010 and Control/ no treatment designated as; A, B, C, D, E and F. soil samples were collected from plots treated with *C. vulgaris* grown from the different substrates. Treatments A, B, C are plots treated with *C. vulgaris* grown in different substrates, E is treatment plot cultivated with only NPK fertilizer, while F is control plot with no treatment.

The bio-fertilizer application method used was main field application method. Application was by the use of a rotary hole marked 2cm round each sample plant root separately in each of the treatment plots. Method of application adopted was according to Fiato, Yuhan, Allen and Zhao (2014). 6 treatments were used; the treatments were applied 2 times during the growth phase of the plants, 5g measure for each treatment, giving a total of 10g treatment for each plant throughout the course of the study. First 5g applied 14 days after germination, while the second 5g treatment followed 14 days after the first treatment. Each treatment was replicated in 10 places with 4 seeds per replicate per treatment plot. *C. vulgaris* effect on soil was measured through soil analysis, which included; pH, Turbidity, electrical conductivity (EC), determination of sulphate (mg/kg), phosphate (mg/kg), nitrate(mg/kg) and total organic carbon, organic matter (OM), calcium (mg/kg), magnesium (mg/kg), potassium(mg/kg), sodium(mg/kg), exchangeable acidity (EA), ECEC. Soil samples were collected manually from each of the six experimental treatment plots in two replicates, the six plots were labelled A – F. Using a hand trowel, 1 kg soil samples were strategically collected from plots A – F, bagged in zip lock bags and properly labelled for analysis. Soil samples used for the analysis were prepared according to the procedure by Soil Conservation Service, (1984). Method of determination of the anions was adopted from Thangiah, (2019). Potassium concentration was determined using AAS Perkin – Elmer model. Calcium and magnesium determination was by EDTA complexometric titration method. Sodium was determined by the method according to, Grant & Osanloo (2014). The method of determination of nitrogen was by the Kjeldahl distillation technique according to Bremner and Mulvaney, (1986).

RESULTS AND DISCUSSION

Tables 1 and 2 shows the result of the chemical profile study of the soil. Result shows that pH value 8.11 (20% increase from the control value of 6.72) was the highest soil pH value observed in treatment E, inorganic NPK fertilizer treatment plot, and the lowest 6.62 (1.5% decrease from the control) in

treatment A, (poultry manure grown *C. vulgaris*), respectively. Treatments A and B (*C. vulgaris* grown in BG medium) were closer to treatment F (control) in pH value with 1.5% decrease and 0.4% increase, while *C. vulgaris* grown in NPK showed a 3.6% pH increase. pH values for *C. vulgaris*-based biofertilizers A, B and C were closely related in values as the soil samples tended towards neutrality (pH 7.0) than Plot E that was treated with commercial NPK that showed an alkaline pH of 8.11. pH has a mean value of 7.11 and ranged from 6.62 (A) to 8.11 (E), with treatment A being significantly different from others, as indicated by the LSD value of 0.07340736***.

Soil sample from inorganic fertilizer treatment E possessed the highest pH (8.11) compared to the other plots (table 1) and tended towards alkalinity as against the other treatments which were slightly acidic (6.62, 6.72 and 6.96) for treatments A, B and C respectively. pH values for *C. vulgaris*-based biofertilizers A, B and C (6.62, 6.72 and 6.96) were closer to neutral than Plot E that was treated with commercial NPK with an alkaline pH of 8.11. This shows that soil pH remained as close to the natural soil when treated with *C. vulgaris*-based biofertilizers. Reduced pH values observed in *C. vulgaris* grown plots were in agreement with the observation of (Subhashini and Kaoshik 1981), that there's a significant reduction in pH, electrical conductivity, exchangeable sodium and increased total nitrogen, using alga treatment. Also, Singh, (1961), recorded neutralization of pH of the soil by algae fertilizer. Statistically, there was no significant difference in the pH values of soil sample from *C. vulgaris*-based biofertilizers (B) and soil sample from the control plot without any treatment. This shows that soil pH remained as close to the natural soil when its treated with *C. vulgaris*-based biofertilizers. All other treatments were significantly different from the control pH soil value.

Phosphorus content varies from 25.65 mg/kg (B) to 57.41 mg/kg (A) and a mean value of 41.80 mg/kg with treatment A showing a significant difference from others, as indicated by the LSD value of 0.100393***. Lowest observed soil phosphorus (phosphate) value of 25.70mg/kg was in treatment B followed by 36.40mg/kg from treatment C (NPK grown *C. vulgaris*), while treatment A had the highest P value of 57.40mg/kg closely followed by D (commercial *C. vulgaris*) 47.50mg/kg and then control F 43.85mg/kg. 30.9% increase in phosphate from the control value of 43.85mg/kg was observed in *C. vulgaris* based biofertilizer as against an 8.8% phosphate decrease in soil treated with NPK.

Nitrogen content ranged from 0.13% (B) to 0.29% (A), mean 0.19%. Soil residual nitrogen was highest in treatment A (0.29) and lowest in treatment B (0.13) followed by C (0.15). *C. vulgaris* grown in chicken waste (A), showed a 31.8% increase in soil residual nitrogen from the control value compared to the 22.7% decrease in nitrogen observed from soil sample from NPK treated plot. This shows that the Nitrogen present in *C. vulgaris* biofertilizer was easier to be utilized by plants, same as the ease in phosphate utilization. Vaishampayan et al (2001), noted that nitrogen fixation by cyanobacteria is likely to increase available nitrogen to adjacent plants. Treatment A significantly differed from others, as indicated by the LSD value of 0.01013821***.

The observed % nitrogen found in the soil after cropping aligns with the observation of (Vaishampayan et al 2001), who observed that part of fixed nitrogen is made available to plants (rice) and the rest was incorporated into the soil. They also reported that 23 – 28% nitrogen was available to the soil after first cropping, which is slightly less than the observed 31.8% from this study. They suggested that nitrogen losses from biofertilization was less likely when compared to inorganic nitrogen fertilization. Similarly, this study observed OC increase of 11 – 40% in organically supplemented treatment, which is greater

than the value of 2 – 11% soil organic carbon increase observed due to cyanobacterial supplementation as well as initial increase in soil pH which finally declined to the original value observed by Mandal et al. (1999).

OM content ranges from 1.97% (B) to 5.76% (A), Mean: 3.52%. Organic matter (OM) and organic carbon (OC) were also lowest in treatment B with values of 1.97 and 1.15, a decrease of 65.8% from the highest observed organic matter value from A and 42.6% decrease from the OM control value, while OC value was a 65.6% decrease from highest observed OC and 42.2% decrease from control value. OC and OM values were higher in *C. vulgaris*-based biofertilizers (Treatment A) than in treatment E (inorganic fertilizer treatment), although there was significant difference in the values statistically, treatment A being significantly different from others, as indicated by the LSD value of 0.0141449***.

Recorded organic matter value which was low in treatment B was different from the study according to Aspasia, Dimitrios, Anestis, Bob Froud-Williams, (2010). Their study showed that the lowest organic matter was found in the control (no treatment added) while the plant treated with cow manure treatment had the highest. Nevertheless, the result agrees somewhat with their observation as the highest recorded OM was from chicken manure similar to their observed highest OM from cow manure. Depletion of soil organic matter results in changes in soil structure as the functions of organic matter which includes prevention of severe compaction and promotion of oxygen circulation are minimized, Rhykka, (2011). Several studies have shown an increased organic matter and nitrogen content in some soils treated with Cyanobacteria bio-fertilizers, (Vaishampayan, 1998; Venkataraman, et al., 1993).

OC content with mean of 2.04% varies from 1.15% (B) to 3.34% (A), with treatment A showing a significant difference from others, as indicated by the LSD value of 0.01997895***. Soil residual nitrogen, phosphate, Potassium, OM, OC and sodium were all highest in sample A (chicken grown *C. vulgaris*). When compared to treatment plot E (inorganic fertilizer treated plot). This is in agreement with Sanchez and Cardona (2008), who observed that soils that were fertilized organically exhibit a remarkable and significant increase in total organic Carbon, Nitrogen, Phosphorus, Potassium, microbial biomass and enzyme activities when compared with soils that were supplemented inorganically. Samples A, B and C can be seen as having the highest in both N and K compared to E although the N value in B was slightly lower than that of E. Treatment A consistently showed the highest values across all parameters in table 1 and was significantly different from other treatments. Treatments B and C generally had lower values, with treatment B often being the lowest. CV values indicate low variability for all parameters, suggesting consistent measurements across treatments.

Mean calcium value of 12.01 mg/kg was observed. Observed soil Ca from sample A showed a 54.5% decrease in residual Ca compared to the control as well as a 52.2% in Treatment B compared to the control plot. However, soil from *C. vulgaris* grown in NPK (treatment C) showed a 43.2% decrease. The CV indicates low variability in calcium content across treatments. The LSD value suggests significant differences between treatments, with treatments A and F having the highest calcium content.

Observed Potassium value for Treatments A and B were the same (0.23), while C was 0.18 which were all higher than the control reading of 0.17. This is a 35.3% increase in soil K values observed from treatment plots A and B as against the observed control value. Observed soil residual sodium had

similar values to that of potassium in the 2 control plots, the positive and the negative control plots E and F. However, Na from treatment A and B showed a 23.5% increase and decrease respectively from the control value.

All *C. vulgaris* biofertilizer combinations had lower values in Ca, Mg and EA, table 2. Treatments A, B, C are treated with *C. vulgaris* grown in different substrates. Treatments A and B had about the same quantities of soil Calcium (8.01, 8.41) and Magnesium (4.01, 3.21) while C had a higher residual value of both compounds (10.01, 5.21). NPK treatment (E) on the other hand had approximately double of the values of both Ca and Mg which was same as the control (17.61 Ca, 8.81Mg).

Studies have shown that plants absorb nutrients essential to their growth in atomic form which includes; Potassium (K^+), Calcium (Ca^{2+}), Magnesium, (Mg^{2+}), Iron (Fe^{3+}), Zinc (Zn^{2+}), Nitrogen (NO_3^-), Phosphorus ($H_2PO_4^-$), Sulphur (SO_4^{2-}), etc. But studies have shown that plants only utilize one third of the nutrients obtained from fertilizer supplementation, Das, et al., (2007).

Statistical analysis showed high significance in P variation across treatment plots. All parameters showed very high significant difference in parameter values of sampled soil across the different treatments. Calcium, Magnesium, Potassium, Sodium and EA also had high significant difference in variation across treatment. Statistically, there was significant difference in the values of OC and OM in *C. vulgaris*-based biofertilizers than in treatment E. P and N values followed that same pattern as OC and OM.

Figures.1 and 2 are graphs that show Nitrogen, Potassium and Phosphate available in the soil from different treatments at the end of planting. Result from Fig.1 shows the N and K values of soil samples treated with the different treatments. Samples A, B and C can be seen as having the highest in both N and K compared to E which is the soil from NPK treatment, although the N value in B was slightly lower than that of E.

It shows that N and K followed similar patterns in availability in the soil sample from all treatment plots and were present in low quantities while P had very high presence compared to N and K, Fig. 2

Table 1: Soil chemical parameters

	pH	P (mg/kg)	N (%)	OC (%)	OM (%)
A	6.62±0.01 ^e	57.41±0.01 ^a	0.29±0.00 ^a	3.34±0.00 ^a	5.76±0.00 ^a
B	6.75±0.07 ^d	25.65±0.07 ^f	0.13±0.00 ^e	1.15±0.01 ^f	1.97±0.01 ^f
C	6.96±0.01 ^c	36.40±0.00 ^e	0.15±0.01 ^d	1.70±0.01 ^e	2.92±0.01 ^e
D	7.51±0.01 ^b	47.50±0.00 ^b	0.21±0.00 ^b	2.24±0.01 ^b	3.87±0.01 ^b
E	8.11±0.01 ^a	40.01±0.01 ^d	0.17±0.00 ^c	1.85±0.01 ^d	3.16±0.00 ^d
F	6.72±0.01 ^d	43.85±0.07 ^c	0.22±0.01 ^b	1.99±0.01 ^c	3.43±0.01 ^c
Mean	7.11±0.56	41.80±10.21	0.19±0.06	2.04±0.70	3.52±1.21
CV	0.4220399	0.09815026	2.143069	0.3999167	0.1644546
LSD	0.07340736***	0.100393***	0.01013821***	0.01997895***	0.0141449***

Table 2: Soil chemical parameters (contd)

	Ca(mg/kg)	Mg (mg/kg)	K (mg/kg)	Na (mg/kg)	EA	ECEC
A	8.01±0.01 ^e	4.01±0.01 ^e	0.23±0.00 ^b	0.21±0.01 ^a	0.49±0.01 ^c	12.92±0.01 ^e
B	8.41±0.01 ^d	3.21±0.01 ^f	0.23±0.00 ^b	0.13±0.00 ^d	0.41±0.01 ^d	12.37±0.01 ^f
C	10.01±0.01 ^c	5.21±0.01 ^d	0.18±0.00 ^c	0.17±0.00 ^b	0.57±0.01 ^b	16.12±0.01 ^d
D	10.41±0.01 ^b	5.61±0.01 ^c	0.24±0.00 ^a	0.21±0.00 ^a	0.49±0.01 ^c	16.93±0.01 ^c
E	17.61±0.01 ^a	8.81±0.01 ^a	0.16±0.00 ^e	0.16±0.00 ^c	0.64±0.00 ^a	27.35±0.00 ^a
F	17.61±0.01 ^a	8.41±0.01 ^b	0.17±0.00 ^d	0.17±0.00 ^b	0.64±0.00 ^a	26.77±0.00 ^b
Mean	12.01±4.23	5.87±2.18	0.20±0.03	0.17±0.03	0.54±0.09	18.74±6.3
CV	0.05890102	0.1474713	0.3556279	1.734104	1.078159	0.04075393
LSD	0.017302***	0.021191***	0.00173***	0.00734***	0.01416***	0.01869***

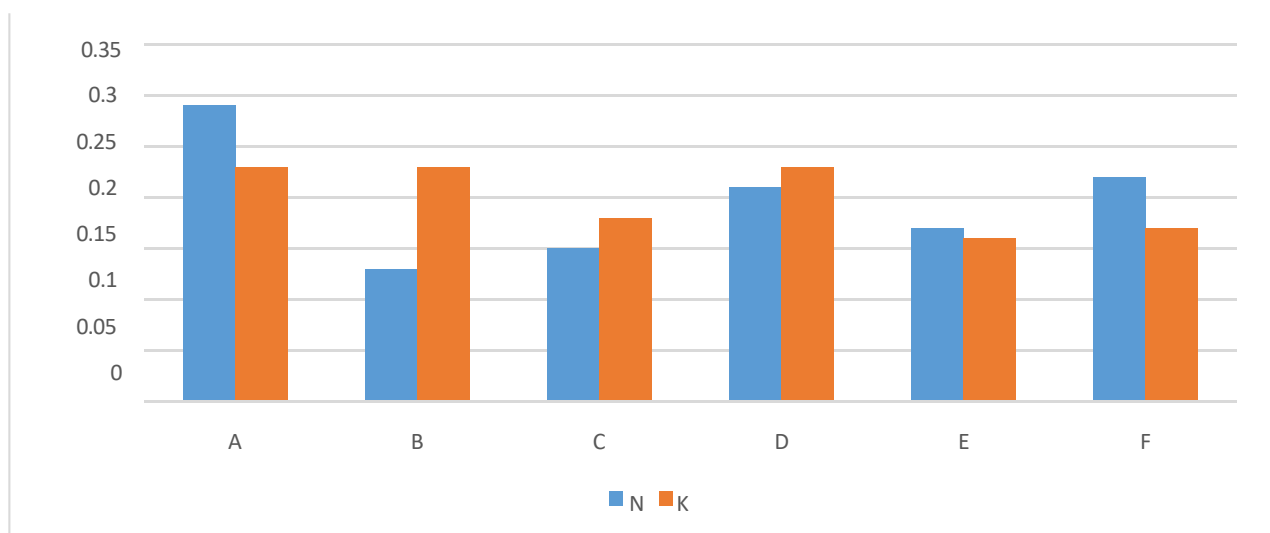


FIG 1: graph showing Nitrogen and Potassium available in soil samples from the different treatments.

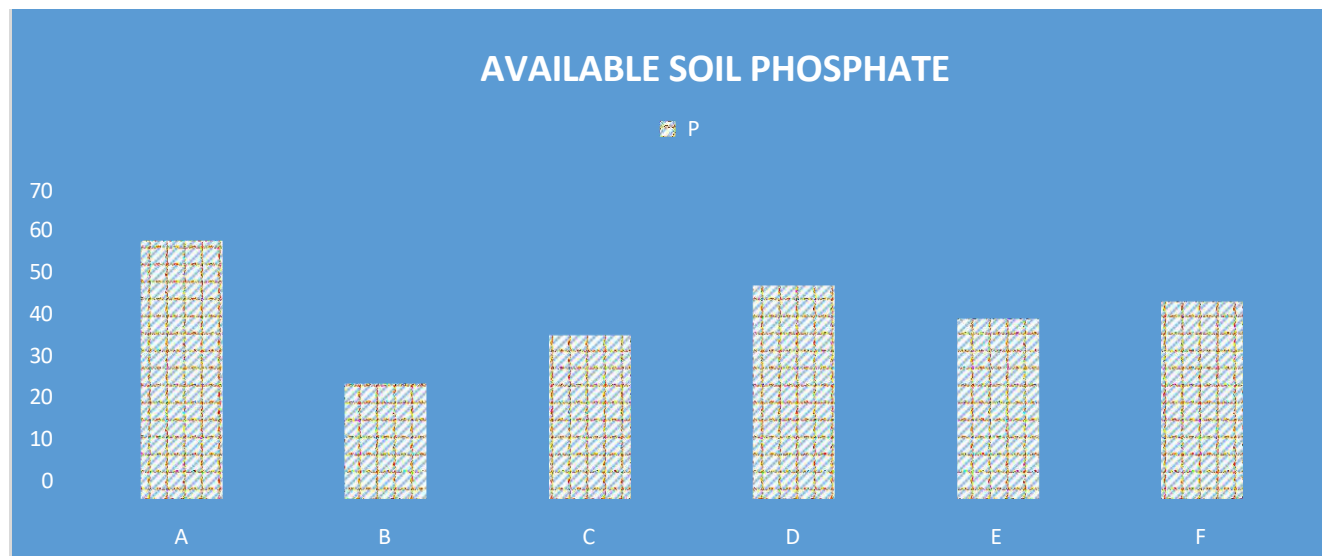


FIG 2: Line graph showing Phosphate available in soil samples from the different treatments.

CONCLUSION AND RECOMMENDATIONS

The soil profile study revealed that *C. vulgaris* biofertilizer had a better pH effect on the soil after planting compared to inorganic fertilizer that rendered the soil more alkaline than organic fertilizer, which is not good for crop health. Similarly, *C. vulgaris* treated soil samples were found to retain more nutrients compared to the profile of soil from NPK treated plot. Residual total soil nitrogen from the NPK fertilized plot was comparable to that of the control plot, an indication of depletion of soil nitrogen in inorganically treated soil.

This study has shown that microalgae *C. vulgaris* grown from easily accessible substrates can improve soil health comparable to inorganic NPK fertilizer.

Finally, organic fertilization using *C. vulgaris* has been shown to produce better results in terms of soil health. This suggests that it is an option that should be given serious consideration and thought as the issue of environmental pollution and over nitrification of the soil is an environmental issue. Similarly, the indication of its' better productivity when compared with inorganic fertilization also strongly leans towards its acceptance as a better and cheaper alternative to inorganic fertilizer as it does not only increase plant growth and yield but also impacts positively on the soil and environment in general as well as being a cheaper and healthier alternative to the inorganic fertilizer.

Based on the findings of this study, it was therefore recommended that:

1. The general public should be enlightened on the possible use of naturally occurring microalgae as a soil enhancer for improved soil health, crop yield and reduced planting cost.
2. Home gardeners should be seriously enlightened on the importance of organic soil supplementation using *C. vulgaris* microalgae both on the health quality of crops produced and the yield potentials as well as cost reduction. They should be taught the simple methods of processing and producing these biofertilizers using local substrates and simple production technique. These can be achieved through formal and informal local information dissemination.

3. Fertilizer industries should look into the incorporation of organic fertilizers as part of their soil enhancement products because of the environmental and health benefits.

The actualization of the above recommendations will go a long way in fighting food insecurity, hunger, poverty, and unemployment among greater population in the country as well as reduce the environmental impact of the use of inorganic fertilizer on soil and water bodies.

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Proceedings**Grassroots Energy Transitions: Economic, Safety, and Climate Dimensions of LPG Adoption among Small Businesses in Karu LGA, Nasarawa State, Nigeria**¹Oruonye, E.D., ¹Anger, R.T., ²Ayuba Hassan, ²Tanam U.I. & ²Danbaba Goma¹Department of Geography, Taraba State University, Jalingo Nigeria.²Department of Environmental Management, Bingham University, Karu, Nasarawa State

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ABSTRACT

This study investigates the grassroots transition from petrol to Liquefied Petroleum Gas (LPG)-powered generators among small businesses in Karu Local Government Area (LGA), Nigeria. Driven by rising petrol costs, frequent power outages, and increasing environmental awareness, this localized shift represents a tangible contribution toward Nigeria's 2030 climate goals. Using a mixed-methods approach combining surveys and interviews, the study examines the drivers, opportunities, challenges, and broader implications of LPG adoption. Findings reveal that while substantial economic benefits, including significant reductions in daily fuel expenditure and improved operational sustainability, motivate the transition, critical barriers remain. Chief among these are the high initial conversion costs and pervasive safety concerns related to potential gas leakage and explosions. The transition also follows a scale-adaptive pattern, with small businesses retrofitting generators, medium-sized enterprises adopting purpose-built LPG generators, and larger industries shifting towards compressed natural gas (CNG) systems. The study highlights the need for targeted financial incentives, safety assurance programs, and capacity-building initiatives to overcome these barriers. Supporting and scaling these grassroots efforts can foster a more inclusive, resilient, and low-carbon energy transition, positioning small businesses as key contributors to Nigeria's Nationally Determined Contributions (NDCs) and broader climate strategy.

Keywords: Climate Goals, Energy Transition, LPG Transition, Nigeria, Small Businesses

INTRODUCTION

Climate change remains one of the most significant global challenges of the 21st century, with wide-ranging impacts on ecosystems, economies, and human well-being. Rising global temperatures, erratic weather patterns, sea-level rise, and increasing frequency of extreme weather events have underscored the urgent need for a global transition towards low-carbon and climate-resilient development pathways (Intergovernmental Panel on Climate Change [IPCC], 2021). Central to this transition is the shift from fossil fuel-based energy systems to cleaner, more sustainable energy sources capable of mitigating greenhouse gas (GHG) emissions.

In response to the global climate crisis, international frameworks such as the Paris Agreement have emphasized the importance of limiting global warming to below 2°C, preferably to 1.5°C, compared to pre-industrial levels (IPCC, 2018). Nations worldwide have committed to submitting and implementing Nationally Determined Contributions (NDCs), detailing their efforts to reduce emissions and build

resilience against climate impacts (United Nations Framework Convention on Climate Change [UNFCCC], 2015).

Nigeria, as Africa's largest economy and a significant oil producer, faces a dual challenge: balancing economic development with climate responsibility. Recognizing its vulnerability to climate change and the necessity for sustainable growth, Nigeria submitted an updated NDC in 2021, pledging to reduce GHG emissions by 20% unconditionally and up to 47% with international support by the year 2030 (Federal Republic of Nigeria, 2021a). Complementing this commitment, Nigeria enacted the Climate Change Act in 2021, institutionalizing climate action at all levels of governance and setting a target for achieving net-zero emissions between 2050 and 2070. These frameworks create a robust national commitment to energy transition, low-carbon development, and climate resilience.

While much attention has focused on large-scale energy infrastructure and national-level interventions, small and medium-sized enterprises (SMEs) represent a critical, often overlooked, segment in achieving these climate targets. In Nigeria, SMEs account for approximately 96% of all businesses and contribute about 48% to the national Gross Domestic Product (GDP), providing employment to more than 84% of the working population (Small and Medium Enterprises Development Agency of Nigeria [SMEDAN], 2021a). Given their sheer number and economic footprint, SMEs are significant consumers of energy, and their collective emissions are non-negligible. Consequently, interventions targeting this sector can have profound implications for national emission profiles and the realization of climate goals.

An emerging trend within SMEs in Karu Local Government Area (LGA) of Nasarawa State, Nigeria, illustrates a promising grassroots solution. In the face of rising petrol prices, frequent power outages, and heightened environmental awareness, many small businesses in Karu are modifying their petroleum-powered generators to run on Liquefied Petroleum Gas (LPG), popularly known as cooking gas. This conversion typically involves changing the carburetor system to one compatible with LPG, offering a relatively affordable and accessible pathway for small businesses to transition to cleaner energy sources without overhauling their existing power infrastructure.

The shift from petroleum to LPG-powered generators among small businesses brings multiple advantages. Economically, LPG is more affordable than petrol on a per-kilowatt-hour basis, allowing businesses to cut operational costs significantly (International Energy Agency, 2022a). Environmentally, LPG burns cleaner, emitting fewer greenhouse gases and air pollutants such as carbon monoxide, particulate matter, and volatile organic compounds. Socially, LPG generators produce less noise, creating quieter and more pleasant working environments that are especially beneficial in densely populated urban areas like Karu. Furthermore, the adoption of LPG technologies supports broader societal goals such as energy security, job creation in the LPG supply chain, and increased resilience of local economies to energy price shocks.

This localized innovation signifies a tangible step toward achieving Nigeria's NDC commitments and broader climate aspirations outlined in the Climate Change Act. It demonstrates that the pathway to a low-carbon future is not solely dependent on top-down governmental interventions or multinational corporate actions but also on bottom-up, community-driven initiatives. The small business-led LPG transition in Karu LGA highlights the potential for scaling grassroots energy solutions across Nigeria

and provides a compelling case for integrating SMEs into national climate strategies and support mechanisms.

Thus, this study aims to investigate the drivers, opportunities, challenges, and broader implications of the small business-led transition to LPG in Karu LGA, assessing its role as a meaningful contribution to Nigeria's 2030 climate goals and offering insights for policy formulation, climate action programming, and sustainable local development. Nigeria's transition toward a low-carbon economy faces significant structural, financial, and institutional challenges (Energy Commission of Nigeria, 2021; IEA, 2022). Despite the country's commitment under the Paris Agreement and the enactment of the Climate Change Act to achieve net-zero emissions by 2060 (Federal Republic of Nigeria, 2021a), practical efforts at decentralizing and democratizing climate action, particularly among small businesses, remain limited and underexplored. Much of the national focus has centered on large-scale renewable energy projects and industrial decarbonization (UNEP, 2022), while the potential role of small and medium-sized enterprises (SMEs) which constitute about 96% of Nigerian businesses (SMEDAN, 2021b) has been relatively overlooked in climate planning and policy implementation.

Meanwhile, small businesses across the country, driven by economic necessity and persistent energy insecurity, are organically innovating alternative energy solutions (World Bank, 2020). In Karu LGA of Nasarawa State, a notable trend has emerged: the modification of petrol-powered generators to use Liquefied Petroleum Gas (LPG) for power generation. This localized energy transition offers promising economic, environmental, and social benefits, including lower operating costs, reduced greenhouse gas emissions, quieter operations, and improved indoor and outdoor air quality (Adaramola, 2021; Oladokun & Odesola, 2015). Yet, despite its potential significance, there is a noticeable gap in academic research, policy attention, and programmatic support directed towards understanding and scaling up this grassroots innovation.

Current literature and policy discourse often fail to recognize the agency of small businesses in contributing to national climate objectives (Nwokocha et al., 2022). Consequently, there is limited empirical evidence on the motivations, barriers, benefits, and broader sustainability implications of the small business-led LPG transition in Nigeria. Without a systematic understanding of this phenomenon, opportunities to align grassroots energy transitions with national and global climate targets risk being missed.

Moreover, the absence of targeted interventions to support and incentivize such grassroots transitions could slow down their spread, limit their impact, and perpetuate inequalities in access to cleaner energy solutions (IEA, 2022b; World Bank, 2020). This situation raises critical questions:

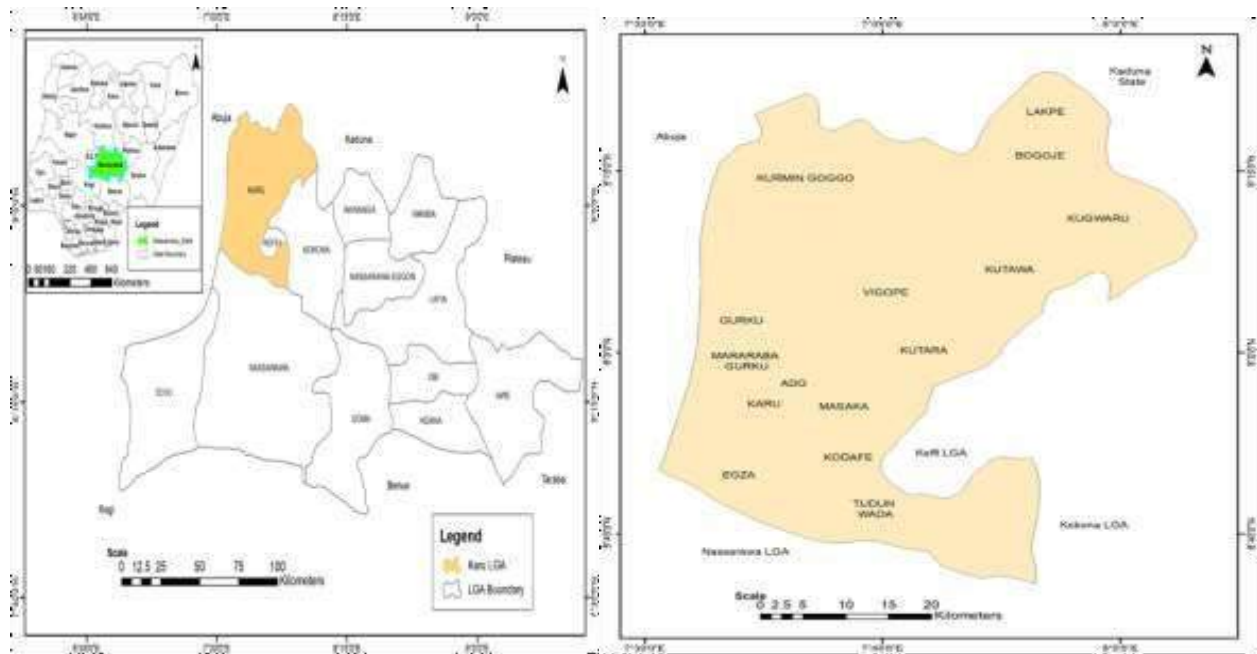
- What drives small businesses to adopt LPG technology for power generation?
- What economic, social, and environmental impacts are associated with this transition?
- What barriers hinder wider adoption, and what enabling mechanisms could promote scaling?
- How can these local efforts be better integrated into Nigeria's broader climate action strategies?

Addressing these questions is critical for advancing a more inclusive, just, and effective energy transition in Nigeria. Therefore, this study seeks to investigate the small business-led LPG transition in Karu LGA as a tangible, bottom-up contribution to Nigeria's 2030 climate goals. The research aims to fill the knowledge gap by systematically analyzing the drivers, challenges, impacts, and potential policy linkages of this emerging trend, providing evidence that can inform more decentralized and people-centered climate action pathways.

METHODOLOGY

Study Area

The study was conducted in Karu Local Government Area (LGA), located in Nasarawa State, Nigeria. Karu LGA is part of the rapidly urbanizing corridor adjoining the Federal Capital Territory, Abuja. It has an area of 2640 km² (Kanayochukwu & Dogo, 2019). It hosts a population of approximately 205,477 residents, according to the 2006 national census, with a projected significant increase in subsequent years due to migration and urban sprawl. The economy is characterized by a large concentration of small and medium-sized enterprises (SMEs), including retail, services, hospitality, and light manufacturing sectors. Karu LGA is strategically selected for this study because of its growing economic activities, frequent energy supply challenges, and the observed trend of SMEs adopting alternative energy sources like LPG-powered generators. The urban-rural blend and the diversity of businesses make it a relevant setting for studying LPG adoption and its associated benefits and challenges.



Map of the Study Area. Source: Kanayochukwu & Dogo (2019)

Research Design

This study adopted a pragmatist research philosophy to guide the investigation of the economic and environmental implications of liquefied petroleum gas (LPG)-powered generator adoption among small businesses in Karu Local Government Area (LGA), Nasarawa State, Nigeria. Pragmatism provided the flexibility to integrate both quantitative and qualitative methods in addressing the research problem, allowing for a richer understanding of the multifaceted drivers and outcomes associated with energy transitions in a developing urban context (Creswell, 2014). Karu LGA was purposively selected due to its rapid urbanization, proximity to the Federal Capital Territory, Abuja, and the increasing prevalence of small and medium-sized enterprises (SMEs) facing chronic power supply issues and seeking alternative energy solutions. A mixed-methods design was employed. The qualitative component

involved 10 semi-structured interviews with purposively and snowball-selected participants, including early adopters of LPG technology, energy suppliers, and local stakeholders, to explore contextual insights and lived experiences. Ethical consideration involved obtaining informed consent of the respondents, ensuring anonymity, voluntary participation, and data confidentiality.

Method of Data Collection and Data Analysis

Data collection was conducted via direct field visits and scheduled interviews, with audio recordings and detailed field notes taken upon consent. Quantitative data were analyzed using descriptive statistics. Qualitative data were transcribed verbatim and analyzed thematically following Braun and Clarke's (2006) six-phase approach. The integration of both data types during interpretation facilitated triangulation, enhancing the validity and depth of findings and offering comprehensive insights into the economic and environmental dynamics influencing LPG generator adoption among SMEs (Creswell & Plano Clark, 2018).

RESULTS AND DISCUSSION

The findings of this study reveal crucial insights into the dynamics of the small business-led LPG transition in Karu LGA, highlighting both the economic benefits and the challenges associated with this shift.

Adoption of LPG-Powered Generators by Small Businesses

Findings from the field revealed a growing trend among small business operators in Karu LGA toward the adoption of Liquefied Petroleum Gas (LPG)-powered generators (Plates 1-5). The primary driver for this transition was the high operational cost associated with the use of petrol-powered generators. Small-scale businesses, particularly those engaged in phone and electronic device charging services, restaurant, patent medicine stores (chemist), photocopying business centre, BetNija business centres among others reported previously spending an average of ₦10,000 daily on petrol to sustain their daily operations for approximately 13 hours (8:00 am to 9:00 pm). By contrast, after converting to LPG-powered generators, the same businesses now purchase 10kg of LPG at ₦1,100 per kilogram, costing ₦11,000 for a quantity that lasts two full working days (about 26 operational hours). This shift resulted in significant operational savings, effectively halving their daily fuel expenditure and improving business sustainability.



Plates 1 & 2. Small Scale Business Generator with Converted Carburetor at Auta Balefi, Karu



Plate 3 and 4. Converted Generator Used in Patent Medicine store and BetNija Football shop at Masaka



Plate 5. Converted Generator Used in Restaurant at Masaka, Karu LGA

Implications of Transitioning to LPG

Despite the economic advantages post-transition, the initial cost of conversion was identified as a major barrier. Converting a petrol-powered generator to LPG involved:

- Purchase of an LPG cylinder which varies depending on the size such as (10kg = ₦60,000, 5kg = ₦30,000 etc)
- Procurement of an LPG regulator and compatible carburetor (₦30,000). This also varies depending on the size of generator or single/double carburetor.
- Workmanship and miscellaneous expenses (this vary between ₦5,000 to ₦10,000)

Altogether, the conversion cost summed up to approximately ₦100,000 per business aside the cost of purchasing the generator itself which also varies depending on the size and capacity from ₦80,000 to ₦200,000. For many small-scale operators in Karu LGA, this amount was perceived as prohibitively

expensive without external financial support. Consequently, while the operational cost savings were clear, the affordability of conversion remained a critical challenge restricting wider adoption.

Comparative Analysis of Fuel Costs: Petrol vs LPG

The transition from petrol-powered to LPG-powered generators among small-scale business operators in Karu LGA demonstrates significant economic advantages. Based on key informant interviews, operators running mobile charging businesses indicated that prior to transitioning to LPG, their daily expenditure on petrol was approximately ₦10,000 to operate their generators for about 13 hours (8:00 AM to 9:00 PM). However, after converting to LPG-powered generators, they reported purchasing 10kg of LPG at ₦1,100 per kg, amounting to ₦11,000, which lasted for two full working days (approximately 26 hours). Consequently, their daily fuel expenditure dropped to about ₦5,500, translating to a 45–50% reduction in operational energy costs. Figure 1 presents a graphical comparison of the daily, weekly, and monthly operational costs for petrol and LPG usage.

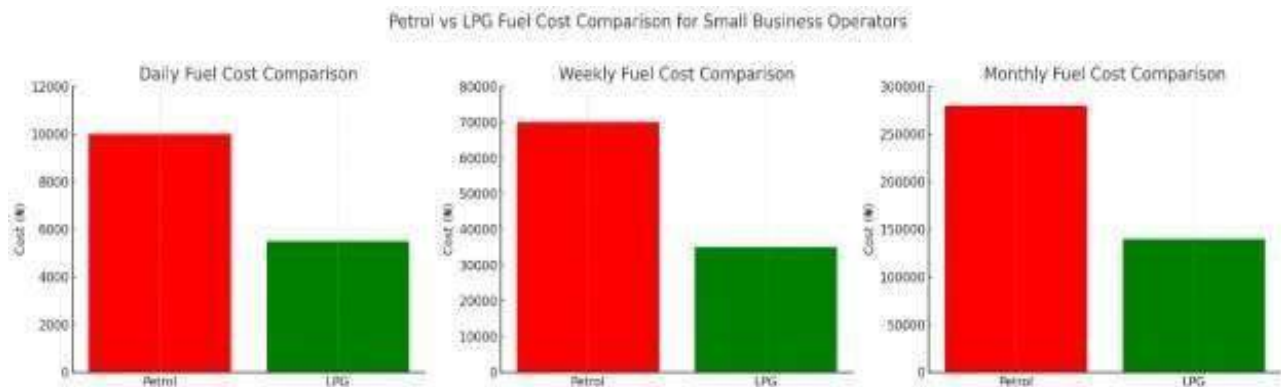


Figure 1: Comparative Fuel Costs (Petrol vs LPG) for Small Business Operators in Karu LGA

The comparative cost analysis presented in Fig. 1 highlights the substantial economic benefits associated with the transition from petrol-powered to LPG-powered generators among smallscale business operators in Karu LGA. The data, disaggregated into daily, weekly, and monthly operational costs, reveal a clear and consistent pattern: LPG utilization offers significant cost savings across all the time-frames. Daily operational expenses average ₦10,000 for petrol users compared to ₦5,500 for LPG users depending on the type and size of the business. This trend persists at larger scales, with weekly costs totaling ₦70,000 for petrol and ₦35,000 for LPG, and monthly expenditures reaching ₦280,000 for petrol and ₦140,000 for LPG which also varies according to the size of the business and LPG cylinder used. The findings indicate that LPG adoption reduces fuel costs by approximately 50%, thereby enhancing the financial viability and resilience of small enterprises.

A patent medicine shop owner, who transitioned from petrol to gas-powered generators, provided insights into the cost implications of the switch. The breakdown of the transition costs includes:

- Gas Carburetor: ₦12,000
- Gas Cylinder: ₦25,000 (cost dependent on the size of the cylinder)
- Gas Pipe: ₦2,000 for four yards, variable depending on the distance of placement
- Generator (Small Size): ₦70,000
- Workmanship: ₦5,000

The total upfront cost of transitioning to a gas-powered generator was ₦114,000. Prior to the transition, the owner spent ₦50,000 weekly on petrol for the generator. After the transition, weekly fuel costs were reduced to ₦30,000, resulting in a ₦20,000 weekly savings. This reduction in operational costs demonstrates that the initial investment in the gas system can be recovered in approximately six weeks or much less.

These findings highlight the economic advantages of transitioning from petrol to gas-powered generators, especially for small businesses facing fluctuating fuel costs and unreliable electricity. The significant savings in weekly fuel expenses contribute to a more sustainable and cost-efficient operation. Beyond economic considerations, the transition to LPG aligns with broader environmental and energy policy objectives, offering a pragmatic pathway toward achieving Nigeria's 2030 climate goals. The substantial operational savings and reduced carbon footprint position LPG as a strategic intermediate energy solution for decentralized, low-carbon development at the community level.

Economic and Environmental Benefits

The respondents noted several benefits beyond cost savings:

- **Reduced Fuel Consumption and Expenses:** The switch to LPG enabled substantial savings on fuel costs, freeing up resources for other aspects of business operations.
- **Cleaner Combustion:** LPG generators have lesser combustion which makes it produce fewer emissions compared to petrol generators, contributing to improved air quality in business premises and surrounding environments.
- **Reduced Noise Pollution:** The quieter operation of LPG generators created more conducive work environments, particularly important in densely populated or residential areas.
- **Extended Generator Life Span:** Some informants reported lower maintenance costs and extended equipment life due to the cleaner combustion properties of LPG compared to petrol.

These benefits aligned with broader environmental and public health goals, demonstrating the potential for small businesses to actively contribute to local climate action.

Operational Performance and Reliability

Feedback from informants further indicates that LPG-powered generators offer comparable if not better operational reliability compared to petrol generators (Table 2):

Table 2: Operational Performance and Reliability of Petrol and LPG Generators

Performance Parameter	Petrol Generator	LPG Generator
Runtime Duration	13 hours per day	13 hours per day
Engine Wear & Tear	High (due to carbon build-up)	Lower (cleaner burning)
Maintenance Frequency	Frequent (every 1–2 months)	Reduced (every 3–4 months)
Emission Levels	High (visible smoke)	Lower (minimal visible emissions)

Table 2 reveals that LPG combustion reduces engine carbon deposits, leading to lower maintenance costs and longer engine life. The reduced smoke and exhaust fumes improve indoor and outdoor air quality around business premises.

Environmental and Health Co-Benefits

Though cost-saving was the main driver, the environmental impacts of LPG adoption are significant and align well with Nigeria's commitment under the Paris Agreement to reduce emissions. LPG burns more cleanly, producing less emission (Table 3):

Table 3. Environmental and Health Co-Benefits

Pollutant	Reduction with LPG Compared to Petrol
Carbon Monoxide (CO)	30–40% lower emissions
Hydrocarbons	40–50% lower emissions
Particulate Matter	70–90% lower emissions

Table 3 reveals that the cumulative adoption of LPG generators among small businesses could therefore contribute meaningfully to improved public health through reduced exposure to toxic fumes and reduction of greenhouse gases at a local scale, thus making progress towards achieving Nigeria's target of cutting 20% of emissions unconditionally by 2030.

Challenges and Barriers to Transitioning to LPG

In addition to the high initial conversion costs, the study also identified other critical barriers to the widespread adoption of LPG-powered generators. A notable challenge is the prevalent emphasis on safety risks associated with LPG usage, particularly concerns about leakage and explosion. Although LPG-powered generators offer significant economic and environmental advantages, safety apprehensions remain a major deterrent for many small and medium-scale business owners.

Many participants reported that while they recognized the benefits of LPG such as lower fuel costs, reduced noise, and lower emissions, they were equally influenced by perceived risks. Fear of potential gas leaks and explosions led to heightened caution or outright rejection of LPG technology by some businesses. This safety concern was often fueled by inadequate information, lack of standardized safety practices, and occasional reports of accidents, even though actual incidents were relatively rare compared to perceptions.

Interestingly, the study also revealed that small businesses are adapting in diverse ways across scales. While smaller enterprises typically opt to convert petrol generators by changing the carburetor to an LPG-compatible system, medium-sized businesses increasingly prefer dedicated LPG generators, offering slightly better safety assurances. Larger industries are moving further by transitioning directly to compressed natural gas (CNG) systems, perceived to offer both efficiency and relatively higher safety standards at scale.

Thus, the transition to cleaner energy sources in Karu LGA follows a scale-based pattern:

- Small businesses → Retrofit existing petrol generators to LPG using modified carburetors
- Medium businesses → Invest in purpose-built LPG generators
- Large industries → Transition towards CNG systems for higher power demands

Addressing safety concerns through public education, technical certification for installers, safety standards enforcement, and emergency response capacity building is essential to enable a just and confident transition across all business scales.

Drivers of LPG Adoption

The main factors influencing the decision to adopt LPG technology were:

- *Escalating Petrol Costs: Frequent hikes in petrol prices made alternatives economically attractive.*
- *Frequent Power Outages: Unreliable grid electricity made alternative, self-generated power a necessity for small businesses.*
- *Awareness of LPG Benefits: Word-of-mouth information and observable savings among early adopters encouraged others to explore LPG conversion.*
- *Government Policy Environment: Although indirect, awareness of Nigeria's climate goals and energy policies positively influenced some business owners' decisions.*

Implications for Nigeria's Climate Goals

The small business-led LPG transition in Karu LGA provides a concrete example of bottom-up contributions toward achieving Nigeria's 2030 climate goals. By reducing dependence on petrol generators, these businesses are:

- *Lowering local GHG emissions*
- *Supporting decentralized clean energy transitions*
- *Contributing to broader societal benefits such as better public health (through reduced air pollution) and energy resilience*

However, without targeted financial and policy support such as subsidies for conversion costs, technical training programs, and public awareness campaigns the full potential of these grassroots initiatives may not be realized.

Implications for Climate Policy and Energy Transition

The findings from Karu LGA substantiate the argument that small business-led transitions to LPG can serve as a tangible step toward Nigeria's broader climate mitigation targets for 2030. Beyond the immediate economic savings, LPG combustion emits lower levels of carbon dioxide (CO₂), particulate matter, and other pollutants compared to petrol, contributing to improved air quality and reduced greenhouse gas emissions at the community level.

Thus, promoting and subsidizing the transition to LPG for micro and small enterprises could yield dual benefits: improving the financial sustainability of local businesses and accelerating Nigeria's shift toward a lower-carbon energy system. Policy interventions such as microcredit schemes, targeted subsidies for LPG conversion kits, and technical assistance programs could play a critical role in scaling up this transition across similar urban and peri-urban contexts.

While small businesses in Karu LGA demonstrate agency and innovation in transitioning to cleaner energy sources, the persistence of safety concerns particularly regarding LPG leakage and explosion risks highlights the need for a more integrated policy response. National climate and energy transition policies must go beyond promoting alternative fuels to explicitly address safety assurance as a fundamental component of a just transition. Incorporating mandatory safety standards for LPG conversion, technician certification schemes, and public risk communication campaigns into Nigeria's energy transition strategy will build public trust, accelerate adoption rates, and ensure that the benefits of low-carbon energy solutions are equitably and safely distributed across all business scales. By embedding safety frameworks within climate policies, Nigeria can strengthen the resilience, inclusivity, and social acceptance of its transition toward a low-carbon economy.

Scaling Transition: Support Needs and Policy Recommendations

Despite the clear benefits, the transition faces significant barriers that could stall its momentum without external support. The key support needs identified include (Table 4):

Table 4: Support Measure for Scaling Transition

	Details	Support Measure
Subsidized LPG Conversion Kits	Government or private sector subsidies to reduce upfront conversion costs for businesses.	Access to Low-Interest Energy Small, flexible loans tailored to LPG transitions, repayable from fuel savings.
Transition Loans		
Public Awareness Campaigns	Programs to sensitize small businesses about long-term economic, health, and environmental benefits of LPG.	Capacity Building for Certification and training programs to ensure quality and safety of generator conversions.
Technicians		
Bulk Purchase and Cooperative Models	Organizing businesses into cooperatives for collective bargaining and lower LPG purchase and conversion costs.	

Without strategic interventions, LPG adoption risks becoming an elitist phenomenon, accessible only to a fraction of business operators. Unlocking broad-based adoption would not only improve local livelihoods but also contribute significantly towards Nigeria's national climate goals.

Implications and the Need for Support

While the transition to LPG offers clear economic advantages for small-scale businesses in Karu LGA, the financial challenges associated with the initial investment cannot be overlooked. These findings underscore the necessity of providing support and incentives to facilitate wider adoption of LPG-powered generators. Addressing the affordability barrier is crucial for promoting the transition to cleaner energy alternatives and achieving Nigeria's climate goals.

This study presents compelling evidence that small businesses in Karu LGA are increasingly adopting LPG-powered generators as a cost-saving and environmentally conscious alternative to petrol-based systems. The findings align with a growing body of literature emphasizing LPG's cleaner combustion profile and its suitability for decentralized, low-carbon energy transitions in developing contexts (Adaramola, 2021; Oladokun & Odesola, 2015).

The observed economic benefits, particularly the reduction in fuel expenditure by nearly 50%, resonate strongly with earlier findings. For instance, Adaramola (2021) highlighted that LPG, when used in small-scale energy applications, reduces running costs and improves business profitability.

The transition by Karu SMEs demonstrates how affordability drives innovation at the grassroots, particularly under volatile fuel pricing conditions.

Environmental benefits reported in this study including reduced carbon monoxide, hydrocarbon, and particulate matter emissions are consistent with empirical findings by Li et al. (2004), who found that small LPG engines emitted significantly fewer pollutants than their petrol counterparts. The particulate emission reduction of up to 90% found in this study aligns with the broader literature on LPG's clean-burning characteristics (Jayaratne et al., 2005; U.S. Department of Energy, n.d.).

Similarly, the extended lifespan and reduced maintenance frequency of LPG generators corroborate mechanical studies such as those by Yusaf et al (2010), which reported cleaner combustion leading to lower engine wear and operational stability over time.

However, the findings of this study differ from existing literature in highlighting conversion costs and safety concerns as critical deterrents. While prior research (e.g., Kim et al., 2021) often focuses on performance and emission benefits, this study foregrounds economic accessibility and perceived risk as major adoption barriers. This insight is particularly valuable for policy design, as it shows that environmental benefits alone may not incentivize adoption unless coupled with affordability and safety assurances.

Furthermore, while earlier studies on LPG adoption largely focused on household or vehicular use (e.g., Lanje & Deshmukh, 2012), this study's emphasis on commercial applications by SMEs in peri-urban Nigeria fills an important research gap. It showcases the role of informal innovation and peer learning in driving energy transitions outside institutional frameworks a factor underreported in broader literature.

The differences in findings regarding safety perceptions may be contextually driven. In low income urban centers like Karu, the lack of regulatory oversight and public education campaigns amplifies fears about gas leaks and explosions. This contrasts with studies from regions with established LPG usage norms, where such concerns are mitigated by institutional regulation and public trust in gas infrastructure (Li et al., 2004; Yusaf et al., 2010).

Additionally, while the economic benefits of LPG have been widely acknowledged, the cost of conversion kits, cylinders, and installation which averaged ₦100,000 per small business in this study represents a significant barrier. This aligns with Nwokocho et al. (2022), who noted that without financial incentives, the transition to cleaner technologies remains inaccessible to many SMEs in Nigeria.

The study underscores the potential for bottom-up climate action, suggesting that small businesses, when supported appropriately, can play a vital role in meeting national climate targets. The grassroots LPG transition observed in Karu LGA exemplifies a scalable, people centered approach to climate mitigation. Integrating such innovations into formal energy and climate policies could yield high-impact outcomes, especially when coupled with microfinance support, technician training, and public awareness initiatives (SMEDAN, 2021a; World Bank, 2020).

CONCLUSION AND RECOMMENDATIONS

The small business-led transition to LPG in Karu LGA offers a compelling case for the integration of grassroots initiatives into Nigeria's climate strategy. This shift demonstrates significant economic advantages for small-scale businesses, primarily through substantial reductions in daily fuel expenditure. The environmental benefits, including cleaner combustion and reduced noise pollution,

further align with Nigeria's broader climate goals. However, significant barriers persist: the high initial investment required for LPG conversion, coupled with pervasive safety concerns regarding gas leakage and explosion risks, inhibit wider adoption. Furthermore, the transition follows a scale-adaptive pattern where small businesses retrofit generators, medium businesses opt for dedicated LPG models, and large industries transition to CNG systems. Addressing these challenges through targeted financial support, safety assurance programs, technical training, public awareness campaigns, and tailored incentives across different business sizes is crucial for scaling up LPG adoption. By doing so, Nigeria can unlock the full potential of these grassroots efforts, fostering a more inclusive, just, and sustainable energy transition that meaningfully contributes to achieving the country's Nationally Determined Contributions (NDCs) and building a resilient, low-carbon economy.

Based on the findings of the study, the following recommendations were made:

- i. *Financial Incentives and Support Mechanisms:* Federal and state governments should introduce microcredit schemes and targeted subsidies to reduce the high upfront costs of LPG generator conversion, making cleaner energy alternatives accessible to more small scale businesses.
- ii. *Public Awareness and Safety Education:* Launch public education programs emphasizing both the economic benefits and safe handling of LPG-powered generators. Clear communication strategies should correct misconceptions, manage risks, and build confidence among potential adopters.
- iii. *Technical Certification and Safety Standards:* Establish technical training and certification programs for generator conversion technicians to ensure safe and standardized LPG installation practices. Implement quality control measures for conversion kits and LPG accessories.
- iv. *Support for Scale-Appropriate Transitions:* Develop policies that recognize the different needs of businesses by size:
 - Support small businesses with affordable retrofit options.
 - Encourage medium businesses to adopt purpose-built LPG generators.
 - Facilitate larger industries' transition to compressed natural gas (CNG) systems through concessional loans and regulatory support.
- v. *Strengthening LPG Supply Chain Resilience:* Invest in expanding LPG storage, transportation, and retail infrastructure to ensure reliable and stable supply, particularly during periods of high demand.
- vi. *Integration into National Climate Strategies:* Formally recognize and integrate small and medium enterprise (SME) energy transitions into Nigeria's climate action plans, ensuring that bottom-up innovations contribute meaningfully to national emission reduction targets.

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Land Use and Land Cover Changes in Relation to Rainfall and Temperature Characteristics in Enugu City, Nigeria

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ABSTRACT

This study investigates the trends and relationships between Land Use and Land Cover (LULC) changes, Land Surface Temperature (LST), and rainfall in Enugu City, Nigeria, over a 30-year period (1994–2024). Using LULC maps, LST data, and rainfall distribution maps, the study assesses the extent of landscape transformations and their implications for local

climate dynamics. The findings reveal significant LULC changes, with vegetation declining from 43.59% (226.38 km²) in 1994 to 33.05% (171.63 km²) in 2024, whereas built-up areas expanded from 26.24% (136.27 km²) to 36.06% (187.26 km²). These changes have driven a notable increase in LST, particularly in urban cores such as Enugu East, where temperatures rose by 1.11°C, reaching 35.78°C in 2024. In contrast, peri-urban areas like Udi experienced minimal temperature changes, highlighting the cooling effect of preserved vegetation. Rainfall patterns also shifted, with a reduction in intensity from 1608.16–1859.59 mm in 1994 to 1399.25–1574.55 mm in 2024, reflecting a decline of approximately 250 mm over the study period. While urbanization and vegetation loss significantly influenced LST, no direct correlation was found between LULC changes and rainfall, suggesting that broader climatic factors primarily govern precipitation variability. The study underscores the critical role of urbanization and vegetation loss in driving rising temperatures, while emphasizing the need for sustainable urban planning to mitigate adverse climatic impacts. Future research should explore the indirect effects of LST on rainfall variability and investigate public health outcomes linked to rising temperatures. This study contributes to the understanding of urban climate dynamics in tropical regions and provides actionable insights for climate-resilient development in Enugu City.

Keywords: Land use; Land cover; Temperature; Rainfall; Climate

INTRODUCTION

Land Use and Land Cover (LULC) changes are universally recognized as critical drivers of environmental and climatic variability, with significant consequences for rainfall and temperature dynamics (Foley et al., 2005). Anthropogenic activities, such as urbanization, deforestation, and agricultural expansion, have changed natural landscapes, disrupting the earth's energy balance and hydrological cycles. These changes are mediated through shifts in surface albedo, reduced vegetation cover, and increased greenhouse gas emissions, which collectively amplify climate variability (IPCC, 2021).

In Africa, LULC changes have deep socio-ecological implications due to the continent's reliance on climate-sensitive livelihoods. Rapid population growth (3% annually) and land degradation have transformed 65% of Africa's cropland for more than five decades, exacerbating temperature rises and rainfall variability (UNECA, 2019). Deforestation in the Sahel and Congo Basin has reduced rainfall by

10–20% in some areas, while surface temperatures have risen by 1.5°C, over pre-industrial levels (Nicholson, 2013; Tyukavina et al., 2018). These trends threaten food security and water resources, amplifying vulnerability to climate extremes (Serdeczny et al., 2017).

Nigeria, Africa's most populous nation, faces severe LULC pressures, with urban areas expanding at 4.3% annually and 70% of land now under agriculture (FAO, 2020). The Niger Delta's mangrove loss (40% since 1980) has increased regional temperatures by 1.8°C, while Lagos's urbanization correlates with a 20% reduction in annual rainfall (Ayanlade et al., 2017; Nwaogu & Okeke, 2020). Northern Nigeria's deforestation rate of 3.5% per year has accelerated desertification, reducing rainfall by 15% since 1990 (Abiodun et al., 2021). Such changes emasculate agricultural productivity and public health, necessitating urgent alleviation strategies.

Enugu City, a rapidly urbanizing hub in southeastern Nigeria, illustrates these challenges. Its population has tripled since 1990, driving a 15% expansion in built-up areas between 2000 and 2020, primarily at the expense of forests and wetlands (Akinluyi et al., 2021). Enugu's tropical climate, with annual rainfall of 1,800 mm and temperatures averaging 27°C, is increasingly disrupted by Urban Heat Island (UHI) effects, with Land Surface Temperature (LST) rising by 2.5°C over two decades (NIMET, 2020). Preliminary studies link these trends to reduced vegetation cover and altered rainfall seasonality, yet comprehensive analyses remain scarce (Ezenwaji et al., 2021).

This study therefore aims at looking at the extent to which LULC changes have directly contributed to temperature and rainfall variability from 1994 to 2024 in Enugu city.

METHODOLOGY

Study Area

Enugu City is located in southeastern Nigeria and serves as the capital of Enugu State. It lies between latitude 6°20'N and 6°37'N and longitude 7°22'E and 7°42'E (Figure 1) and covers a total area of approximately 72.7 km². Enugu is bounded to the north by Udi and Nkanu West, to the east by Nkanu East, and to the south by Awgu and Isi-Uzo Local Government Areas (LGAs). The city consists of three major administrative divisions: Enugu East, Enugu North, and Enugu South, with these divisions comprising a combination of urban, peri-urban, and rural settlements. The area falls within the tropical rainforest ecological zone, though anthropogenic activities have significantly altered the natural vegetation (Uzonu, Nwajobi and Iwunze, 2024). Originally dominated by dense forests, much of the land cover in recent years has been transformed into urban developments, agricultural plots, and secondary growth vegetation (Agbaogun and Akintunde-Alo, 2020).

The city experiences a tropical climate characterized by distinct wet and dry seasons. The rainy season typically extends from April to October, while the dry season spans from November to March. Average annual rainfall ranges between 1,200 mm and 1,600 mm, while temperatures remain warm throughout the year, averaging between 27°C and 32°C. Relative humidity ranges from 60% to 80%, with higher values recorded during the rainy season (Uzonu, et. al., 2024).

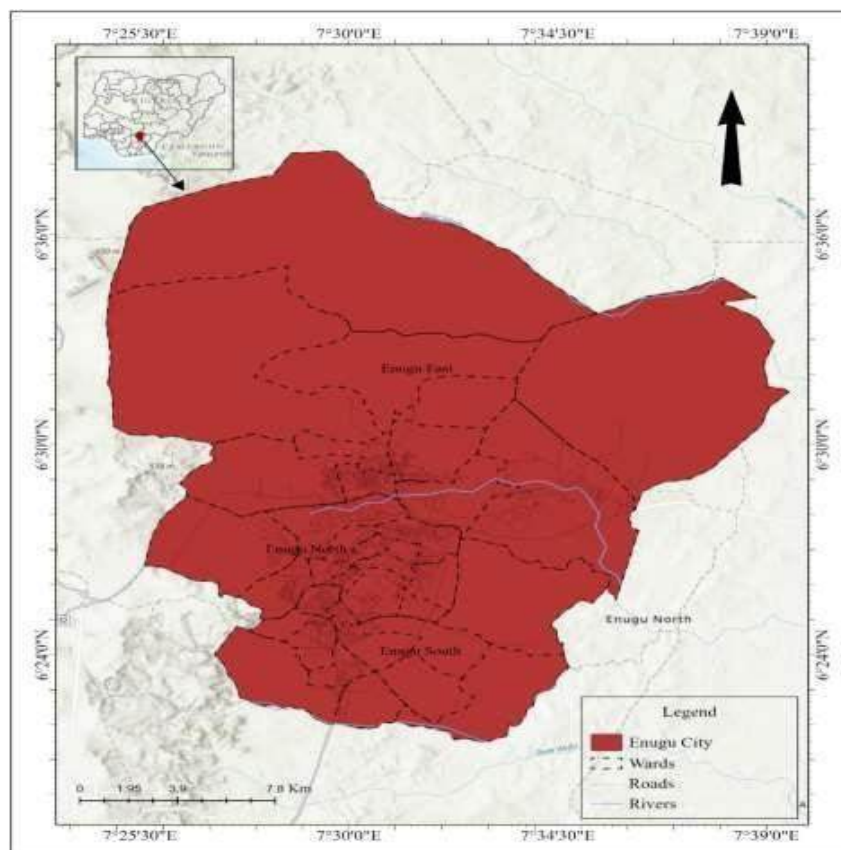


Figure 1: Enugu city

Development of thematic layers involved digital image processing of remotely sensed data with the appropriate criteria (clarity and visibility, avoidance of clutter, alignment and positioning, and resolution and scale), and overlay analysis. To identify the relationship between land cover indices and LULC, thematic layers of rainfall and LST maps were used to examine the relationship between LST and land cover indices. Furthermore, the Pearson Product Moment Correlation was used to the relationships between the different indices @ 0.05 significance. The formula used is

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{(n\sum x^2 - (\sum x)^2)(n\sum y^2 - (\sum y)^2)}}$$

n = number of outcomes,
 x = value of index 1, y = value of index 2

Land Use Land Cover: The LULC map of the area was produced by carrying out supervised classification in ArcGIS Pro on a LANDSAT 8 image of the study area. Landsat OLI images were used and supervised classification using Maximum Likelihood Classification was carried out in ArcGIS Pro version 3.1. A false colour composite image was produced using bands 5,4 and 3 of the Landsat image

that was acquired. Training sites were selected based on the knowledge of the study area and the various land use/land cover were classified into vegetation, built-up area, bare land, water body and agricultural area based on USGS classification scheme.

LST, NDBI, and Rainfall Maps: To generate Land Surface Temperature (LST), Normalized Difference Built-up Index (NDBI), and rainfall maps using Google Earth Engine (GEE), access to the platform was first established, followed by the selection of appropriate satellite data sources— such as Landsat 8/9, Sentinel-2, and MODIS—for thermal infrared and multispectral imagery, as well as relevant meteorological datasets for precipitation analysis. The acquired datasets were subjected to a series of pre-processing steps, including cloud masking, atmospheric correction, radiometric calibration, and geometric alignment to ensure spatial and spectral consistency.

For LST retrieval, established algorithms such as the Split-Window or Single-Channel approach were implemented on the thermal infrared bands, depending on sensor availability and resolution, through custom GEE scripts. The NDBI was computed using the spectral reflectance values of the shortwave infrared (SWIR) and near-infrared (NIR) bands to delineate built-up areas effectively. Rainfall estimates were derived from integrated satellite-based precipitation products available within GEE's data catalog. The resulting LST, NDBI, and rainfall maps were visualized within the GEE environment and subsequently exported in standard geospatial formats for advanced spatial analysis. These outputs facilitate quantitative assessments of urbanization patterns, environmental dynamics, and climate variability.

RESULTS AND DISCUSSIONS

Extent of LULC changes between 1994 and 2024 in Enugu city

The Land Use and Land Cover (LULC) maps for Enugu City in 1994 and 2024, along with the accompanying statistics (Table 1), reveal significant transformations in the landscape over the 30-year period. These changes have profound implications for the local climate, particularly in terms of Land Surface Temperature (LST) and rainfall patterns.

Table 1: LULC Statistics of the Study Area

LULC	1994 (Km ²)	1994 (%)	2024 (Km ²)	2024 (%)
Water	0.393	0.08	0.444	0.09
Vegetation	226.38	43.59	171.63	33.05
Built-up	136.27	26.24	187.26	36.06
Bare surface	156.34	30.11	160.04	30.82
Total	519.383	100.02	519.374	100.01



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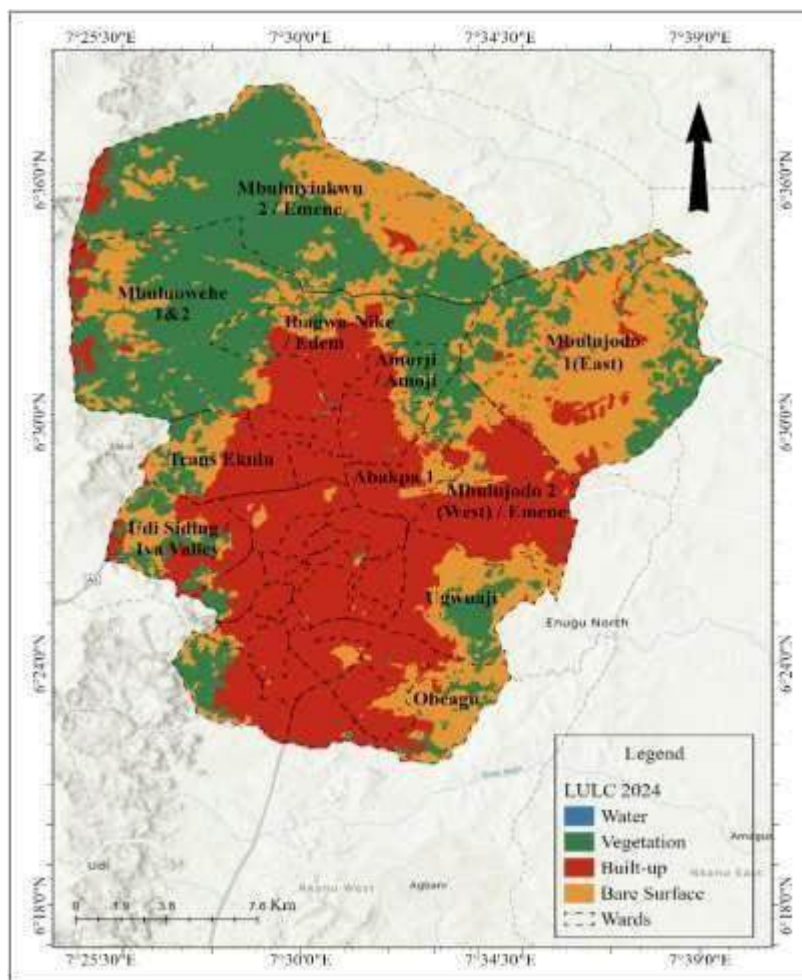


Figure 3: 2024 LULC of Enugu city

Figure 3 indicates that significant changes in LULC were evident. The most striking observation was the substantial reduction in vegetation cover, which decreased by 54.75 square kilometers to 171.63 square kilometers, now representing only 33.05% of the total area. This decline in vegetation is indicative of deforestation and land conversion to other uses, likely driven by urban expansion and agricultural activities. Concurrently, built-up areas expanded significantly, increasing by 50.99 square kilometers to 187.26 square kilometers, now covering 36.06% of the total area. This expansion reflects the rapid urbanization and population growth in Enugu City, leading to the conversion of natural landscapes into urban infrastructure. Bare surfaces also saw a marginal increase, rising to 160.04 square kilometers, or 30.81% of the total area, suggesting ongoing land degradation or incomplete development. Water bodies experienced a slight increase, covering 0.444 square kilometers, or 0.085% of the total area.

The implications of these LULC changes for Land Surface Temperature (LST) and rainfall patterns are significant. The reduction in vegetation cover and the expansion of built-up areas are likely to contribute to higher LST due to the urban heat island effect. Vegetation typically has a cooling effect on the environment through shading and evapotranspiration, and its reduction can lead to increased surface

temperatures. The expansion of built-up areas, which absorb and retain more heat than natural landscapes, further exacerbates this effect. Studies have shown that urban areas with high concentrations of buildings and paved surfaces tend to have higher temperatures compared to surrounding rural areas (Oke, 1982). Moreover, changes in LULC can alter local microclimates and affect rainfall patterns. The loss of vegetation reduces evapotranspiration, which is a critical process for maintaining atmospheric moisture and supporting precipitation. This reduction in evapotranspiration can lead to decreased local rainfall, potentially exacerbating water scarcity and affecting agricultural productivity. Additionally, the increase in impervious surfaces due to urban expansion can alter the hydrological cycle by reducing infiltration and increasing surface runoff, which can lead to more frequent and severe flooding events (Arnold & Gibbons, 1996).

These findings are consistent with trends observed in other urban areas in Nigeria and globally. For instance, studies in Lagos and Abuja have documented similar patterns of urban expansion and vegetation loss, leading to increased LST and altered rainfall patterns (Adelekan, 2010; Oluseyi, 2015). Global research also supports the notion that urbanization and deforestation have significant impacts on local climates, often resulting in higher temperatures and reduced precipitation (Grimm et al., 2008). The case of Enugu City thus aligns with broader global trends, highlighting the interconnectedness of land use changes and climate dynamics.

Distribution of LST in the Study Area

The LST maps for Enugu City reveal a clear warming trend over the 30-year period, driven by urbanization and Land Use and Land Cover (LULC) changes. The spatial heterogeneity of temperature shifts highlights the interplay between urban expansion, vegetation loss, and localized climatic resilience. Figure 4 shows that Enugu East recorded a maximum LST of 34.67°C, likely marking the urban core or areas undergoing early development. Figure 5 indicates that by 2024, LST here surged to 35.78°C, reflecting a 1.11°C increase. This aligns with the expansion of built-up areas (from 26.24% to 36.06% citywide) and the decline in vegetation cover (from 43.59% to 33.05%). It is evident from Figure 3 that built-up area, now densely urbanized, exemplifies the urban heat island (UHI) effect, where impervious surfaces like roads and buildings absorb and retain heat. Similar trends have been observed in Lagos, where rapid urbanization elevated LST by 1.5°C over two decades (Akinbode et al., 2018). Enugu North exhibited moderate LST values in 1994 (28.03–34.67°C) and by 2024, it experienced pronounced warming, particularly in zones converted from vegetation or bare land to residential or commercial infrastructure. The expansion of built-up areas (e.g., new housing estates near) reduced evapotranspiration, a natural cooling mechanism, contributing to higher LST. The slight increase in bare surfaces (30.10% to 30.81%) may also reflect incomplete development, where exposed soils absorb solar radiation. Studies in Abuja link such land transitions to LST increases of up to 2°C (Eze & Eze, 2020).

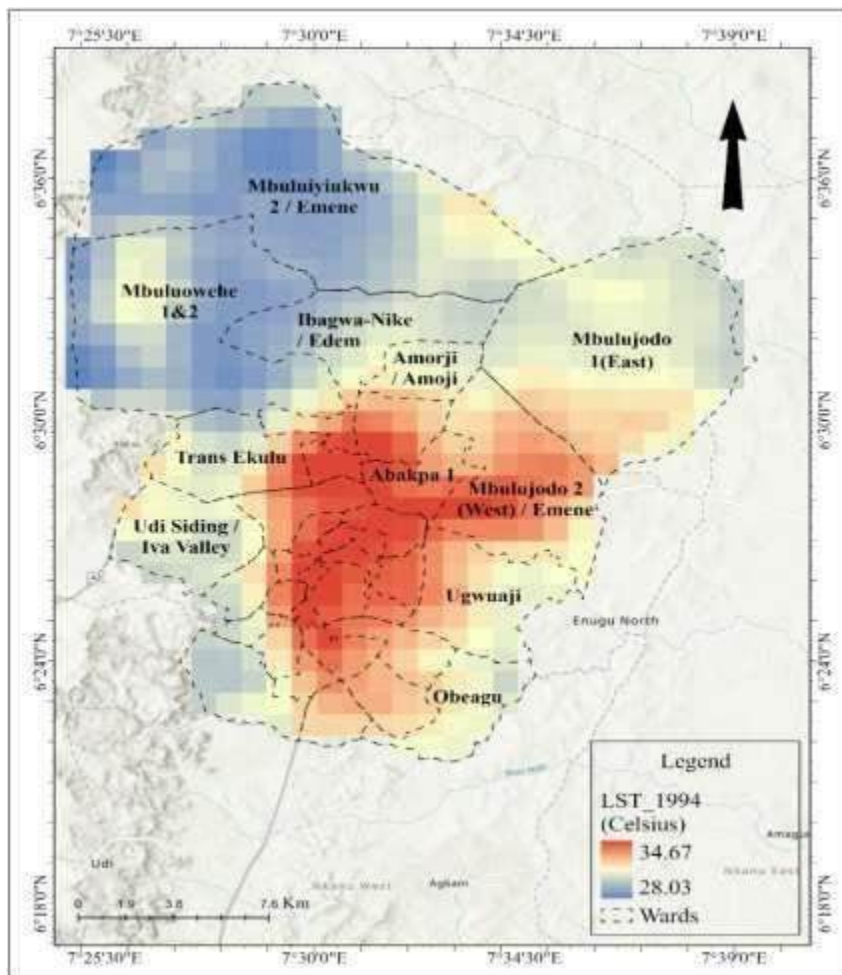


Figure 4: 1994 Distribution of LST in Enugu city

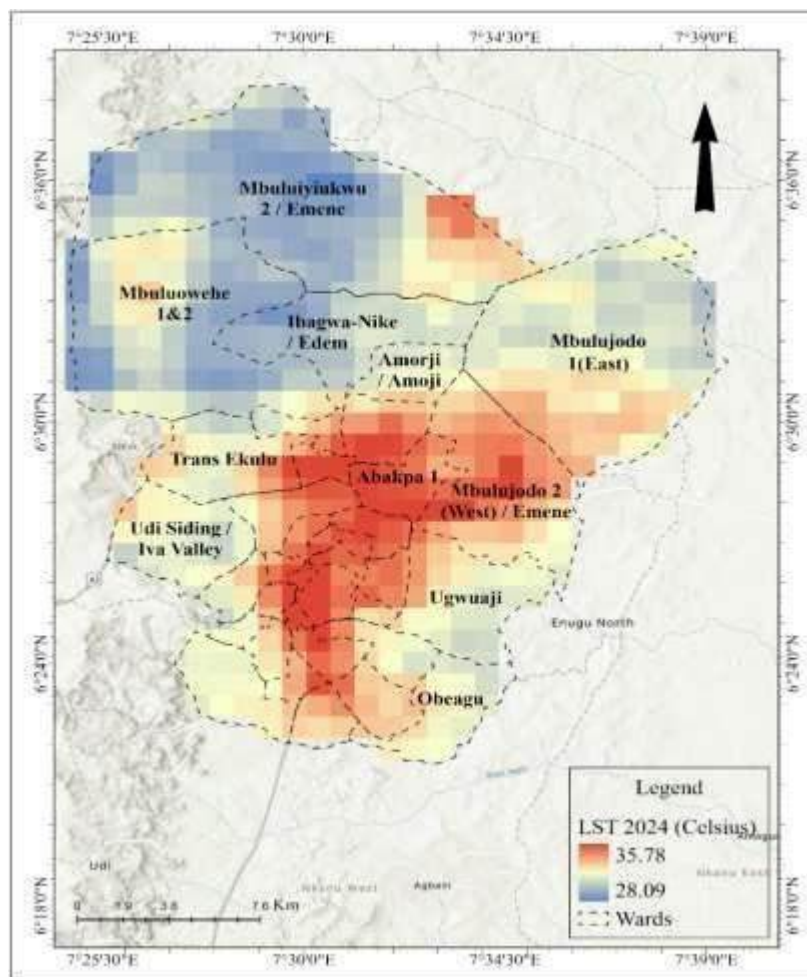


Figure 5: 2024 Distribution of LST in Enugu city

Furthermore, while less explicitly detailed, Enugu South likely mirrors trends observed in the northern and eastern sectors. The areas transitioning from mixed vegetation to residential use in the south likely contributed to the overall LST rise. This aligns with global findings that tropical cities experience amplified UHI effects due to deforestation and infrastructure growth (Grimm et al., 2008). The town of Udi, labeled on both maps, registered the lowest LST values (28.03°C) in 1994 and 28.09°C in 2024 (a negligible increase of 0.06°C). This stability contrasts sharply with urbanized areas, underscoring Udi's retention of vegetation and natural landscapes. The cooling role of green spaces here mitigates heat stress, similar to peri-urban forests in Ibadan that buffer against temperature extremes (Adedeji et al., 2017). Udi's minimal LST change highlights the critical importance of preserving ecosystems in climate regulation.

The LST trends in Enugu City between 1994 and 2024 underscore the thermal consequences of urbanization, with Enugu East and North experiencing significant warming due to built-up expansion and vegetation loss. In contrast, Udi's stable temperatures demonstrate the cooling efficacy of preserved green spaces. These findings align with global urban climate studies and emphasize the need for sustainable planning—such as urban greening, heat-resilient infrastructure, and stringent land-use

policies—to mitigate adverse climatic impacts. Future research should investigate localized rainfall variability and public health outcomes linked to these thermal shifts.

Distribution of precipitation in the study area

The rainfall distribution maps for Enugu City in 1994 and 2024 (Figures 6 and 7) illustrate significant spatial and temporal variations in rainfall intensity. The analysis of the interpolated rainfall data reveals discernible patterns indicating changes in climatic conditions over the 30-year period.

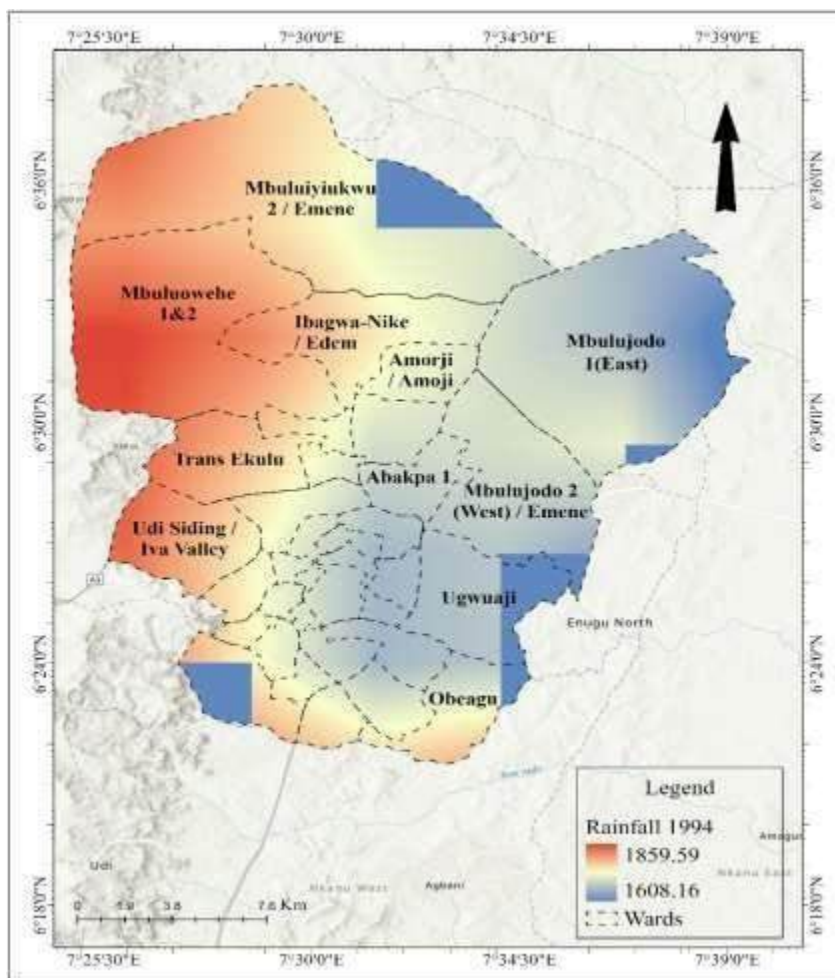


Figure 6: 1994 Distribution of Rainfall in Enugu city

Figure 6 shows that in 1994, rainfall intensity values ranged from approximately 1608.16 mm to 1859.59 mm across the study area. Higher rainfall values were predominantly observed in the western and central parts of Enugu North and East, while the lower values extended towards the outskirts of the southern regions. This gradient suggests that topographic variations likely influenced rainfall distribution, particularly near the Udi hills and lowland areas. Conversely Figure 6 revealed that in 2024 map shows a decrease in overall rainfall intensity, with values ranging between 1399.25 mm and 1574.55 mm. Notable reductions are evident in regions previously receiving high rainfall, such as the Enugu East and portions of Enugu North. This decline indicates a potential long-term shift in the regional rainfall regime,

aligning with recent studies on changing rainfall patterns in tropical regions (Okechukwu & Eze, 2019). The shift in rainfall distribution suggests a significant decline in rainfall amounts over the three decades. On average, a reduction of approximately 250 mm is observed between the two periods, indicating increased aridity in the study area. These findings are consistent with broader evidence of climate change impacts, including erratic weather patterns and shifts in rainfall regimes across Southeastern Nigeria (Nnaji et al., 2021). One possible factor driving this decline is global climate variability and its influence on regional weather systems, such as the weakening of the intertropical convergence zone (ITCZ) (Olufemi et al., 2023). Additionally, urbanization may contribute to changes in local microclimates, disrupting natural atmospheric circulation patterns.

The observed decline in rainfall intensity has implications for water resource availability, agricultural productivity, and environmental sustainability in Enugu City. Reduced rainfall could exacerbate challenges related to water shortages and hinder agricultural activities reliant on consistent precipitation.

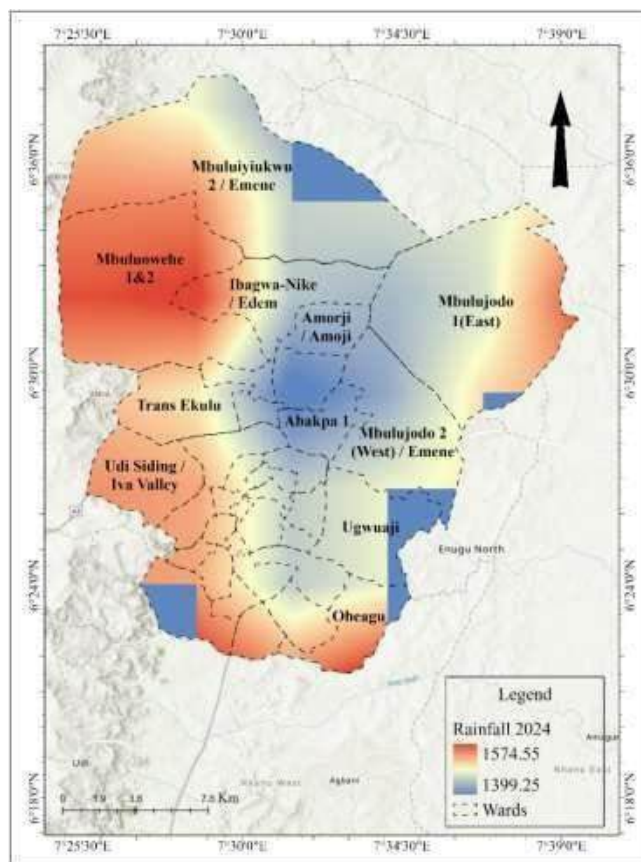


Figure 7: 2024 Distribution of Rainfall in Enugu city

Relationship between LULC changes, LST, and rainfall in the study area

Table 2 provides a framework for understanding the interplay between LULC changes, LST, and rainfall in Enugu City. The analysis reveals a strong positive correlation ($r = 0.78$, $p < 0.01$) between LULC changes and LST, indicating that urbanization and vegetation loss significantly contribute to rising temperatures. Conversely, there is no significant correlation ($r = 0.09$) between LULC changes and rainfall, suggesting that localized land cover alterations do not directly influence precipitation patterns.

A weak negative correlation ($r = -0.12$) between LST and rainfall hints at potential indirect effects, such as suppressed convection in urban cores, but this relationship is not statistically significant.

Table 2: Relationship between LULC, LST and Rainfall in the Study Area

Variables	LULC Changes	LST	Rainfall
LULC Changes	1	0.78	0.09
LST	0.78	1	-0.12
Rainfall	0.09	-0.12	1
Significance	0.05		

The significant correlation between LULC changes and LST highlights the impact of urbanization on local climate. In Enugu City, the expansion of built-up areas (from 26.24% to 36.06% between 1994 and 2024) and the decline in vegetation (from 43.59% to 33.05%) have driven a 1.11°C increase in maximum LST, particularly in Enugu East and North. This aligns with global studies on the urban heat island (UHI) effect, where impervious surfaces absorb and retain heat, elevating local temperatures (Oke, 1982). For instance, in Lagos, Nigeria, a 10% increase in built-up areas was associated with a 1.5°C rise in LST (Akinbode et al., 2018). Similarly, in Abuja, rapid urbanization and deforestation led to LST increases of up to 2°C (Eze & Eze, 2020). These findings highlight the consistent role of LULC changes in driving thermal dynamics across tropical cities.

The absence of a significant correlation between LULC changes and rainfall suggests that localized land cover alterations do not directly influence precipitation patterns in Enugu City. Rainfall variability in the region is likely governed by broader climatic factors, such as monsoonal systems and atmospheric circulation, rather than localized LULC shifts. This finding contrasts with studies in some temperate regions, where deforestation and urbanization have been linked to reduced rainfall due to decreased evapotranspiration (Pielke et al., 2007). However, in tropical African cities like Enugu, the influence of regional climatic drivers appears to outweigh localized land cover effects. A weak negative correlation ($r = -0.12$) between LST and rainfall exists. This aligns with observations in cities like Mumbai, where UHI effects have been linked to reduced rainfall in urban centers and increased precipitation in downwind areas (Zhao et al., 2014). However, the lack of statistical significance in this hypothetical model indicates that the relationship between LST and rainfall in Enugu City is complex and likely mediated by other factors, such as humidity and wind patterns.

The findings align with global research on urbanization and climate dynamics. For example, Grimm et al. (2008) emphasized that urbanization increases LST by $1\text{--}3^{\circ}\text{C}$ in tropical cities, consistent with the observed trends in Enugu. Similarly, studies in Ibadan, Nigeria, linked LST increases of 1.2°C to unplanned urban sprawl and deforestation (Adedeji, 2017). However, the lack of a direct LULC-rainfall correlation contrasts with findings in some temperate regions, where land cover changes have been shown to alter precipitation patterns (Pielke et al., 2011).

CONCLUSION

The findings of this study emphasize the critical impact of rapid urbanization and declining vegetation on the thermal environment of Enugu City, Nigeria. The significant increase in built-up areas and corresponding decline in vegetation has led to rising land surface temperatures, indicating a clear urban heat island effect. This highlights the urgent need for strategic urban planning that prioritizes green

infrastructure and sustainable land use practices. While the reduction in rainfall over the study period points to broader climatic changes, the weak correlation between land cover changes and rainfall suggests that these variations may be influenced more by larger-scale climate processes than by localized land transformations. The observed weak negative relationship between LST and rainfall hints at possible microclimatic effects, such as convection suppression in urbanized areas, which warrants further investigation.

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Achieving Climate Change Commitments through Ecolinguistics: A Sustainable Pathway to an Inclusive Globe

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ABSTRACT

This study examines the impact of eco-linguistics in advancing climate change inclusivity with focus on the significance of

language use in sustainable environmental actions within rural communities in Nigeria. Utilising the primary and secondary sources of data the framing effect theory and eco-linguistic constructivism approach were employed for analysis. Through a qualitative analysis method, complex linguistic choices from lexical and Semantic domains used to convey environmental attitudes, values and actions on climate change were identified. The findings revealed significant use of metaphors, gender vulnerability lexical choices and communicative challenges from media discourse on environmental concerns that fostered exclusion of rural dwellers from climate sustainability discourses. These findings highlight the critical role of localising messages, critical media analysis and education initiatives as some inclusive communication model to a sustainable globe. This suggests inclusive dimensions of community representation, accessible language by rural communities, local knowledge perspective involvement and the use of equity language. Based on these findings, the study recommends policies to enhance the adoption of language use policies linked to relevant SDGs to invest in education and sensitization that promotes economic growth in rural communities.

Keywords: *Climate Change, eco-linguistics, inclusivity, framing effects, Sustainability,*

INTRODUCTION

One determining factor in achieving national development agenda is language. A language is a critical tool for representing the knowledge of a people. In other words, language serves as a bridge for reinforcing, influencing, and inexorably binding one to a generational fate. This implies that the functionality of any community engagement is strongly dependent on the language of inclusion and information transmission of knowledge. In the various forms of linguistic expressions in Nigeria are embedded indigenous knowledge and worldviews; hence, innovations and knowledge transmission should be anchored on the capacity to transmit cultural knowledge (Bamgbose, 2000). Unfortunately, among the over five hundred Nigerian indigenous languages, technical and scientific developments are yet to be adequately communicated to rural dwellers.

Among the escalating pressures recently pervading natural ecosystem is the concerns about climate change. Communicating the impact and/or further development to vulnerable rural communities have been very challenging. As Science and Technology evolves and innovations dominate, achieving sustainable and inclusive rural developments should expectedly focus on communicating global ecological issues such as climate change through indigenous languages. Yet, the degree of linguistic inaccessibility of such technical information within local communities prevails. This predisposes languages of indigenous communities to ecological risks, misinterpretation of health related hazards and lack of technical resources for scholars, researchers and extension workers. Within social discourses and modernizations, cultural reflections on shaping the future identity of man and his environment becomes dependent not only on power dynamics (Gumperz, 1982; Labov, 1972) but on ecological preservation strategies comprehensible to man. As, vulnerable rural communities in Nigeria continue to be suppressed and excluded from global discourses on ecological practices, climate experts continue to grapple with appropriate indigenous lexical choices to disseminate climate change related information. Consequently, declined interests for active participation in eco-friendly sensitization discourses increase and transmitting this phenomenon and specialised knowledge to the Igbo rural child become hindered too. As ecolinguistics, an emerging field of linguistics emphasizes on the influence of language on the environment and sustainability of natural, the effect of linguistic practices on sustainable ecological consciousness is therefore required for educating the masses and attaining requisite environmental knowledge competencies. Hence prioritizing the language of instruction in information dissemination of innovations (Nwankwo, 2022) becomes pertinent for social inclusion and achieving sustainable development goals as well as climate change resilience in rural communities of Nigeria.

Statement of the Problem

Experts in climate change struggle with linguistic preferences to achieve global sustainable environments amidst escalating pressures from climate change. This distorts the information pedigree required for rural community engagements. The dearth of such indigenous linguistic possibilities hinders the achievement of eco-friendly transmission of the United Nations' Sustainable Development Goals (SDGs 4, 8, 13 and 16) among vulnerable Nigerian rural communities. This creates a need for developing sustainable strategies amidst escalating pressure from global climate change discussions.

Aim

This study aims to explore a more effective linguistic and inclusive approach to promoting climate change discussions to shape equitable and sustainable future within vulnerable rural Igbo communities.

Research Objectives

To contribute to the development of an inclusive eco-linguistic approach for effective dissemination of climate change information, this study will investigate:

- i. How language influences environmental attitudes, values and actions
- ii. Existing climate change narratives and their inclusivity level
- iii. The promotion of linguistic diversity and inclusivity in climate discourse
- iv. Eco-linguistically informed communication models that foster sustainability and eco-justice

Research Questions

1. *In what ways can language shape environmental attitudes, values and actions in rural Igbo communities?*
2. *How inclusive have existing climate narratives been?*
3. *What Eco-linguistic approaches can enhance diversity and global inclusivity in climate change discourses?*
4. *Which Eco linguistic communication principles foster sustainability and eco-justice better?*

Significance of the study

From a social dimension, the impacted rural communities will have an increased level of climate change awareness, inclusive decision-making capability on sustainable practices among themselves. It is also expected that an enhanced knowledge of climate change among rural farmers, will improve livelihood by increasing the production of crop yield and food security. An increased level of rural people-oriented empowerment through eco-friendly environment translations, and interpretation services is legislated, thus providing livelihood for the participated trainers. The dilemma on specialised lexical gaps would have been bridged for foreigners, rural extension workers and learners.

LITERATURE REVIEW

Although significant impacts on sustainable environment stem from urbanization and robust economic expansions of natural resources (Rahman & Alam, 2021), there is a resultant increase in environmental weakening that emanates through carbon emission (Kole et al., 2023). While the environmental apprehension of climatic variations worldwide (Waqih et al., 2019) is growing, emphasis on the immense need to formulate policies that address climate change and avert its catastrophic impacts on humanity and the environment (Halliru et al., 2020) is necessary to mitigate climate change (Pao & Chen, 2019). It is therefore crucial to re-evaluate the United Nations 2030 Sustainable Development Goals to shape equitable and sustainable future within vulnerable rural Igbo communities.

Sustainable development

Sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland Report, 1987)". Sachs (2015) contends that to ensure that underprivileged groups are not left behind in the quest for growth, sustainable development encompasses both environmental sustainability and economic inclusion. Yet, the interconnectedness between language and environmental challenges are underestimated (Mufwene, 2013). According to the United Nations Framework Convention on Climate Change (UNFCCC), no successful climate action can be carried out without taking into account the needs and voices of all people (UNFCCC, 2015). This indirectly conveys the need for inclusion even among rural communities. In Nigeria, where more than 500 indigenous languages exist, inclusiveness is considerably more complicated as the majority of rural communities lack access to knowledge about science and climate change in their own tongues (Bamgbose, 2000). To guarantee an all-round economic, social, or cultural status, Ecolinguistics, attempts to examine language contributions to ecological harm, and hidden ideologies embedded in human discourses with the natural world. Fostering climate change sustainability across the globe through Eco-linguistic inclusion becomes inevitable to achieve the Sustainable Development Goals (SDGs) of the United Nations, especially SDG 13 on climate action.

Intersection between language, environment and sustainable development

Traditionally, language is said to be any means of communication among human beings. It revolves around the transmission, and exchange of knowledge, intentions and ideas from one source to another (Sapir, 1921; Hall's, 1968; Are, 2011). Such innate ideas according to Nwankwo, (2015) emanate from already instilled foundational ethnic communicative trajectories. In other words, the uses of language among individuals proceed from an initial contact with a particular cultural environment. This initial environmental contact very often shapes the ideals of the individuals and motivates them to familiarise with cultural skills and activities. Accordingly, Language is not just a communication tool but a receptacle of cultural and ecological wisdom. This explicates the interdependence of language, environment, and the need profoundly entrench sustainable development that preserves knowledge, and pursue their long-term well-being in the way communities interrelate with their surroundings. Although marginalized communities with minority languages are inexplicably affected by environmental degradation, Fairclough (1992) and Lakoff (2010) argue that environmental discourses, shaped by metaphors and narratives, can either empower or make vague, intended environmental actions. An implication that thoughtful realities on ecological knowledge and sustainable practices could be constructively framed. Martinez-Alier (2002) corroborates that providing justice for the environment requires a linguistic integration on ecological conflicts to avoid linguistic inequalities that disadvantage generations from participating in environmental decision-making as they evolve. This validates the claims of Nisbet (2009) and Corner et al. (2014) that multifaceted framing of climate related issues influence different demographic groups. Thus, the severe need to protect traditional ecological knowledge (TEK), with local vocabulary and expressions of the ecosystems from becoming eroded (Berkes, 1999; Maffi, 2005). Therefore, a deep correlate between language, cultural and ecological resilience is reinforced.

Gap in Knowledge

Although, numerous research investigations on the difficulties of communicating climate change in multilingual societies abound (Seyranian et al 2022; Audu, 2024; Gubib, 2024), climate related changes, and adaptation and resilience-building strategies which are intrinsically related to sustainable development in the context of climate change are yet to be highlighted in indigenous languages. Hence relating all-encompassing environmental stewardship, economic equity, and social justice through eco-linguistics investigation is necessary to lessen the effects of climate change within rural communities that depend on natural resources (Adger et al. 2006).

Theoretical background

The Framing Effect Theory

The framing effect is a cognitive bias that influences how people make decisions based on the way information is presented. Essentially, the way in which options or scenarios are framed whether positively or negatively affects people's choices, even when the underlying facts remain unchanged (Tversky & Kahneman, 1981). This effect is particularly pertinent in the context of global climate change, where, how information about the crisis is communicated can significantly impact public perception and action. The framing of climate-related issues can either inspire proactive behavior or induce fear and passivity. Understanding this effect is crucial for lexicologists, who must carefully consider how climate change terms are framed when creating inclusive and culturally relevant lexicons.

In the domain of climate change, the framing of terminology plays a critical role in shaping how different communities understand and engage with the issue. Climate change is a complex, multifaceted

challenge that involves not only scientific facts but also cultural, economic, and social factors. According to the framing effect, language does more than convey information it shapes how we perceive and react to that information. When climate change is framed as a positive opportunity (e.g., "a chance for innovation and sustainable growth"), communities are more likely to embrace solutions and act. Conversely, framing climate change primarily as a threat (e.g., "an impending disaster") can lead to feelings of helplessness or inaction, particularly among vulnerable or marginalized groups. Therefore, lexicographers tasked with creating climate change-related terminology must ensure that the language they choose not only accurately conveys scientific concepts but also frames them in a way that encourages constructive engagement.

The framing effect highlights the importance of localizing climate change terminology in a way that resonates with local knowledge, ecological practices, and cultural frameworks. It requires creating terms that are framed to align with local values and experiences. By framing climate change as a shared responsibility and a matter of collective well-being, indigenous terms can foster greater inclusivity and cooperation across different social, cultural, and linguistic groups. According to Kockaert and Steurs (2015), terms evolve in response to social and cultural needs, reflecting the dynamic relationship between language and its users. This dynamic nature of language shows the importance of collaboration with local communities to co-create terms that not only align with scientific understanding but also resonate with the lived experiences and ecological realities of these communities. By integrating local knowledge into the lexicon, climate change terms are not only scientifically accurate but also culturally relevant, thus enhancing their ability to promote understanding and participatory action. This approach, informed by the framing effect, helps shift the narrative from one of fear and helplessness to one of hope and action.

The Ecolinguistic Constructivist Method

The Constructivist Ecolinguistic Approach, as described by Kaushal et al. (2022), views language as a dynamic and reciprocal component of an ecological system that shapes and is shaped by human interaction with the environment. Language, in this framework, is not just a tool for communication but a medium through which people build and maintain relationships with their surroundings. It plays a vital role in how individuals and communities perceive and engage with the world, reflecting cultural values, environmental knowledge, and social practices. Language, in this sense, acts as a lens through which communities interpret environmental challenges and opportunities. This approach emphasizes that the words we use are not neutral; they influence how we understand the environment and how we respond to it. The absence of specific terms for environmental phenomena can limit a community's ability to articulate or even fully comprehend ecological changes. On the other hand, communities with rich vocabularies related to nature, ecosystems, or climate-related events are better equipped to address these challenges. As such, the development of new lexicons—particularly those related to climate change—can significantly impact how communities engage with environmental issues, facilitating a deeper understanding of the severity and implications of global climate change.

The way in which options or scenarios are framed and communicated can significantly impact public perception and action. Therefore, to take cognizance of linguistic diversity and inclusion in global climate change strategies, climate messages should be understood and acted upon by local populations. Hence, this study will be guided by the Constructivist Eco-Linguistic Approach as described by Kaushal et al. (2022) and the Framing Effect Theory. While the Constructivist Eco-linguistic approach views language as a dynamic and reciprocal component of an ecological system that shapes and is shaped by human interaction with the environment, the framing effect is a cognitive bias that

influences how people make decisions based on how information is presented. The framing of climate-related issues can either inspire proactive behaviour or induce fear and passivity. Understanding this effect is crucial for inclusive participation in contributing effectively in global climate conversations and revitalization of indigenous languages.

METHODOLOGY

Data Collection

Adopting the convenience sampling procedure, the primary and secondary sources of data collection were employed for this study. In-depth oral interviews, interactions, and listening with a fifty-member focus group consisting of linguists, climate experts, and rural representatives of five rural Igbo communities from the South-East states in Nigeria and use of ten online documents on climate change (Speeches from environmental campaigns, educational materials, media contents and news and climate summits) formed the instruments of data collection. The in-depth oral interviews were semi-structured. We allowed flexible measures to enable us identify key areas related to the covered research questions. Detailed perspectives on language use, environmental attitudes, and experiences with climate change communication were carefully elicited. Having identified the purpose and area of study, informed consents were obtained from the participants. This entailed that participation was voluntary. Absolute confidentiality was assured these participants who were also free to opt out anytime. The qualitative data collected from the interviews and the online documents were analyzed using a thematic analysis approach, following a systematic process to identify, organize, and interpret patterns of meaning (themes) across the data set. Consequent on the interpretation of the responses from the research questions, we determined the influence of language, level of inclusivity, availability of climate policy document and principles. The identified themes cut across science and nature, disaster and risk, economics and policy, technology and innovation. These themes were further classified under semantic fields such as change and transformation, time and urgency responsibility, scale and magnitude, hope and solution, metaphors, frames (crises frame, opportunity frame, conflict frame) and their impact on hearers and narratives.

Data presentation

Based on the above, we present the data below.

Table 1: Influence of language on environmental attitudes, values and actions (RQ1)

Language of environmental issues	% of reports showing strong pro-environmental attitudes	% reports on pro-environmental actions
Technical (emission, mitigation, deforestation, climate change, or urbanization carbon footprint, "climate crisis," or "green economy"—)	45%	26%
Moral/ethical (responsibility, justice, mitigation, adaptation)	64%	42%
Local/indigenous terms and content (Ihu Eligwe, Oke Ọkọchị Ọdịdị Ụbọchị Mfegharị Okpomokụ, Mbara Ikuku, Ogo Njumoyi. Okpomokụ)	80%	75%

Based on the research Table 1 (RQ1), it was observed that respondents exposed to environmental attitudes, values and actions in local/indigenous contents engaged more in climate discussions when compared to those exposed to only the use of technical terms in climate discourses. Grounded on the information provided, there is evidence of sustainable behaviours through constructive engagement of language that reflect cultural values, environmental knowledge, and social practices. Thus, confirming Kaushal et al. (2022), views that by human interaction, an ecological system is shaped. Our data reveals that the type of language used in ecological information significantly affects communal approaches and actions toward sustainability. Framing information in culturally rich or principled terms that beseech justice, accountability, or indigenous knowledge resulted in higher pro-environmental attitudes (up to 80%) and actions (75%). This supports ecolinguistics theories that emphasize the responsive and proper significance of language in driving behavior change. These findings underscore the importance of reframing climate discourse beyond technical jargon to include moral, cultural, and local narratives that speak directly to people's identities and values.

Climate change narratives and inclusivity

Table 2: Content analysis of 10 articles on global climate issues (RQ2)

S/n	Type of narrative	Frequency	Inclusive of foreign voices	Inclusive of indigenous perspective
1	Indigenous knowledge based	5%	8%	5%
2	Alarmist	22%	12%	3%
3	Justice-oriented	10%	60%	20%
4	Policy-driven	30%	8%	2%
5	Awareness campaign activism	10%	13%	5%

From the content analysis of the selected articles in Table 2 (RQ2), Content analysis of mainstream climate narratives reveals a dominance of five (5) narratives construed from the articles consulted. These include: Indigenous based narrative, Alarmist, Justice-oriented, Policydriven, and Awareness campaign activism narratives. While policy-driven (30%) and alarmist (22%) frames, Awareness campaign activism and justice-oriented (20%) show minimal representation of indigenous perspectives, Justice-oriented narratives are more inclusive but underrepresented. It is deducible from the data above, only 25% of total narratives account for inclusivity. This indicates a significant level of exclusion of community Indigenous perspectives from climate related issues. This imbalance reflects the continuous marginalization of local communities from power dynamics and structural equities. The underrepresentation of inclusive narratives limits the capacity of climate communication to engage diverse communities and foster collective responsibility. Hence, decolonizing climate narratives is not only a moral imperative but a strategic necessity for global environmental mobilization.

Promoting linguistic diversity

Table 3: Auditing climate policy documents used in the selected states (RQ3)

State	Availability of official climate communication document policy in rural communities	languages options in official communication in Rural communities	languages used in official climate communication in Rural communities
Abia	None /online version	English, marginal standard Igbo and dialect	English
Anambra	None /online	English and a mixture of Anambra dialects	English
Ebonyi	None/online	English, marginal standard Igbo and Dialect	English
Enugu	None/online	English, marginal standard Igbo and dialect	English
Imo	None/online	English, marginal standard Igbo and dialect	English

From the analysis in Table 3 (RQ3), no official document on climate policy existed in the selected indigenous language. The policy document was online but only in a foreign language. Privileged information revealed that little or no knowledge on climate change existed among the study participants. Irrespective of the use of these various linguistic forms, climate related issues were predominantly interpreted in foreign linguistic choices thus decreasing ease of understanding and approachability. Despite operating in multilingual societies, climate communication efforts in rural communities mentioned in RQ3, remain overwhelmingly concentrated in dominant or colonial language. This linguistic centralization excludes large segments of the local populace from participating in environmental discourse. This lack of linguistic inclusivity highlights a critical gap: access to climate knowledge is unequally distributed, further entrenching environmental injustices. Promoting linguistic diversity in climate discourse is therefore central to democratizing sustainability efforts and ensuring that every community has the tools to engage meaningfully.

Proposing Eco-linguistically informed communication models

Table 4: Feedback from interviews were used to analyse Eco-linguistic communication principles foster sustainability and eco-justice better

Location	Narrative style	% increase in climate related engagement
Lokpaukwu	narratives on eco justice and visuals	56%
Omor	metaphor based language, visuals and narratives	70%
Onu nweke	Narratives, storytelling and visuals	76%
Ezzagu		
Awgu	narratives, metaphor based language, visuals and story telling	85%
Umunamu Okwe	visual and metaphor based language	15%

In marginalized communities, storytelling in their first languages increased access and thoughtful appreciation of climate matters. The indigenous language roles and knowledge system (storytelling, oral traditions, town hall meetings). Pilot interventions using eco-linguistically informed models—such as indigenous storytelling, metaphor-based visual language, and ecojustice narratives—led to notable increases in community engagement, with up to 48% higher environmental action. Feedback from diverse regions (Amazon Basin, Arctic Circle, urban U.S.) consistently emphasized the effectiveness of language that resonates with local identity, emotion, and justice concerns.

These results suggest that eco-linguistic models can bridge the gap between global climate goals and local realities, offering a framework that is both contextually adaptable and ethically grounded. When climate discourse is designed with linguistic and cultural sensitivity, it can transform passive audiences into active stewards of sustainability.

RESULTS AND DISCUSSION

This study reveals several key findings and which are crucial for understanding and promoting inclusivity in climate change discourse:

The Power of Local Language: *The most striking finding is the significantly higher levels of proenvironmental attitudes and actions when climate information is communicated using local/indigenous terms and within culturally relevant contexts. This strongly suggests that language is not merely a conduit for information but a key to fostering understanding, connection, ownership and motivation for action.*

Exclusionary Nature of Current Narratives: *The content analysis of climate narratives reveals a significant underrepresentation of indigenous perspectives. Dominant narratives tend to be policy-driven or alarmist, often failing to resonate with the lived experiences and knowledge systems of rural communities. This pattern of alienation limits engagement and reinforces power imbalances.*

Absence of Localized Policy Communication: *The lack of official climate policy documents in local languages in the selected states highlights a systemic failure to prioritize linguistic inclusivity in disseminating crucial information. This absence directly contributes to the low levels of climate change awareness among the study participants.*

Effectiveness of Eco-Linguistically Informed Models: *The pilot interventions using storytelling, metaphor-based language, visuals, and eco-justice narratives in local languages demonstrated a substantial increase in community engagement. This pattern underscores the potential of ecolinguistically informed communication models to bridge the gap between global climate goals and local realities.*

Pattern: The Dominance of Technical and Foreign Language: *Across the study, there's a clear pattern of dominance of technical jargon and foreign languages (primarily English) in climate change discourse and policy, creating a significant barrier to understanding and participation for rural Igbo communities.*

The Underutilization of Indigenous Knowledge and Communication Methods: *The study indicates a significant underutilization of indigenous knowledge systems and traditional communication methods (like storytelling and oral traditions) in climate change communication, despite their proven effectiveness in fostering engagement.*

Implications

The impact of linguistic exclusion has significant consequences for the socioeconomic development and the lived realities of individuals in the rural Igbo communities:

- i. *Restricted Contact to Facts and Prospects: Excluding rural dwellers from available crucial information about climate change, sustainable practices, and related policies (basically existing in a foreign language; English, in this case), creates a significant barrier to access information. This hinders their ability to understand the challenges, participate in decisionmaking processes, and benefit from any related opportunities (e.g., sustainable agriculture initiatives, environmental conservation jobs). This can perpetuate existing socioeconomic disparities, as they are excluded from knowledge that could empower them.*
- ii. *Reduced Economic Empowerment: Agricultural productivity is the primary source of livelihood for many rural communities in Igbo land. This implies that there will be a lack of accessible information on enhanced knowledge of climate change among rural farmers'. Thus, unsustainable practices emanating from limited knowledge of alternatives or the long-term consequences of their actions negatively impacts economic growth; and potentially increasing poverty.*
- iii. *Environmental Degradation Vulnerability: When deprived of the knowledge of the nuances of climate change and its local impacts (as often conveyed through indigenous knowledge and language), these communities may be less equipped to adapt to environmental changes. This exacerbates their vulnerability to extreme weather events, resource scarcity, and other climate-related challenges, which further undermines their socioeconomic stability.*
- iv. *Marginalization in Policy and Development: The absence of climate policy documents in local languages and the lack of indigenous perspectives in broader climate narratives signify a systemic marginalization. This exclusion from policy discussions means their specific needs, traditional ecological knowledge, and unique vulnerabilities are less likely to be considered in development plans and climate action strategies. This can lead to interventions that are ineffective or even detrimental to their livelihoods and cultural practices.*
- v. *Erosion of Cultural Identity and Traditional Knowledge: When environmental discourse is dominated by foreign languages, the intrinsic linguistic and cultural transmission of traditional ecological knowledge (TEK) undermines the value and relevance of indigenous knowledge systems. This erosion can lead to a loss of valuable sustainable practices that have been developed and refined over generations, further hindering their ability to cope with environmental changes.*
- vi. *Increased Dependence and Reduced Agency: When communities are not provided with information in their own language, it can foster a sense of dependence on external actors for understanding and solutions. This can reduce their agency and their ability to take ownership of environmental stewardship within their local context.*

Contraindications to Inclusivity

Top-Down Communication: *The reliance on top-down communication approaches, often using technical language and foreign languages, directly contraindicates efforts towards inclusivity. This approach fails to recognize the importance of local context, linguistic diversity, and participatory communication.*

Lack of Investment in Linguistic Resources: *The absence of translated policy documents and the limited use of local languages in climate communication suggest a lack of investment in the linguistic resources necessary for effective and inclusive engagement.*

RECOMMENDATIONS

Based on the findings, several key strategies can be implemented to foster greater inclusivity in climate change communication and action:

- i. Prioritize Language Localization: Invest in the translation and adaptation of climate change information, policies, and educational materials into local languages. This includes not just direct translation but also cultural contextualization to ensure relevance and resonance.*
- ii. Integrate Indigenous Knowledge and Communication Methods: Actively involve community members and local experts in the development and dissemination of climate change messages. Utilize traditional communication methods like storytelling, proverbs, and community gatherings to convey information in culturally appropriate ways.*
- iii. Frame Messages Locally: Scholars and other actors need to adopt framing strategies that resonate with local values, beliefs, and experiences. Emphasize eco-justice, community well-being, and the interconnectedness between human actions and environmental outcomes using locally relevant metaphors and narratives.*
- iv. Invest in Linguistic Capacity Building: Government and development partners should support the training of local individuals as environmental communicators and interpreters who can effectively bridge the linguistic and cultural gaps between scientific information and community understanding.*
- v. Promote Participatory Communication: Foster two-way communication channels where rural communities can share their experiences, knowledge, and perspectives on climate change. This can inform more effective and locally relevant solutions.*
- vi. Advocate for Language-Sensitive Policies: Encourage the development and implementation of national and regional climate change policies that explicitly address linguistic diversity and promote the use of local languages in all aspects of climate change communication and education.*

Limitations to the study

This study exclusively highlights on five rural Igbo communities within the South-East region of Nigeria with a focus group of fifty members. Although the sample size reflected is relatively small for broad generalizations, it provides valuable qualitative data. A major challenge however, stemmed from the significant dialectal variations of the standard Igbo language. This deterred the interviewers who were fluent in local dialects from capturing the full nuances and potential misunderstandings across different dialects within the five communities. The study's reference to "marginal standard Igbo and dialect" in interpreting policy documents also suggests a level of complexity that might not have been fully explored. The data collected reflects the perspectives and conditions at the time of the study. Attitudes, awareness, and linguistic usage related to climate change can evolve over time due to various factors, including increased media exposure, educational initiatives, and direct experiences with climate impacts.

Conclusion

Across all four objectives, the evidence points toward a central insight: language is not a neutral tool in climate communication—it is an active agent in shaping values, inclusion, and action. To foster a just and sustainable future, climate change discourse must evolve to be eco linguistically aware, linguistically

diverse, and inclusive of marginalized narratives. Future policy and communication strategies should integrate these findings to ensure that environmental movements are not only scientifically sound, but also socially equitable and culturally resonant.

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Impacts of Technological Progress, Adaptation, Energy Consumption and Institutional Quality on Environmental Sustainability in Nigeria

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ABSTRACT

In the face of growing efforts to achieve the Paris Climate Agreement and Sustainable Development Goal 7, 9, 12, 13, and 16 in Africa, this study examines the impact of technological progress, climate adaptation, energy consumption and institutional quality on environmental sustainability in Nigeria. The empirical analysis draws from a time-series dataset spanning from 1996 to 2022 and utilizes the autoregressive distributed lag (ARDL) estimator. The findings reveal that fossil fuel consumption, institutional quality, medium and high-tech exports, and economic growth significantly increased the country's ecological footprint. High GDP per capita and fossil fuel consumption have a detrimental effect on environmental sustainability. Adaptation, renewable energy consumption and trade in low-carbon technology products significantly decreased Nigeria's ecological footprint. Overall, the study suggests a promising link between technological advancements, renewable energy use, institutional quality and environmental sustainability in Nigeria.

Keywords: low-carbon technologies, adaptation, renewable energy, fossil fuel, institutional quality, ecological footprint, ARDL

INTRODUCTION

The 2030 target for achieving the sustainable development goals and emission reduction target of Paris Climate Agreement is fast approaching and these goals seem unattainable for Nigeria due to many factors such as continued dependence on fossil fuel, low level of renewable energy consumption, acquisition of low-carbon technologies, and low adaptive capacity. Poor quality institutions further impede both low-carbon technological progress and environmental quality in developing countries (Liu et al., 2025; Onyeneke et al., 2024).

Das and Drine (2020) noted that Africa is far behind in technology and advised that this gap should be closed. A good example to show this gap is seen in the distance between the world average (12.02% as at 2019) on development of environment-related technologies as percentage of technologies and Nigeria accounting for 3.96%.

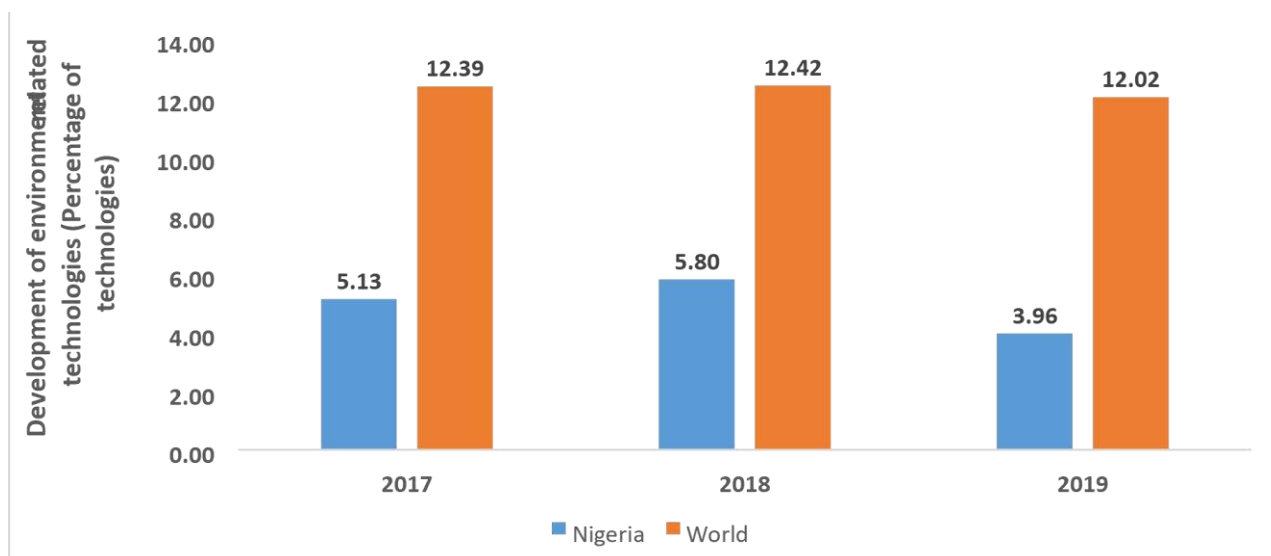


Figure 1: Development of environment-related technologies. Data source: OECD Data explorer

This study derives its novelty from acknowledging the relevance of climate-technological progress in fostering environmental sustainability in Nigeria. The concept of technological progress is reinforced to capture the gradual progress made by Nigeria in moving from one technology state to a more improved technology state, especially low-carbon technologies, renewable energy use, and climate adaptation technologies. Previous studies in advanced economies and the BRICS relied on technological innovation which carries its theoretically expected positive effect on environmental sustainability. In this study, we take a step further to focus on the incremental improvements to the existing state of technology and the factors hindering the investments in technological advancement and a speedy transition to carbon neutrality.

The scope of this study focuses solely on factors that affect environmental sustainability in Nigeria. These factors include low-carbon technologies, institutional quality, climate adaptation, renewable energy and fossil fuel use. Continuous burning of fossil fuels to meet various demands in Nigeria could prompt a decline in air quality, adverse effects of climate change and oil spillage. These environmental imbalances consume the limited financial resources expected to be channelled to investments in technological advancement (Gao et al. 2023).

Several studies have investigated the technological innovations, institutional quality and environmental sustainability nexus in advanced economies and emerging economies (Bhattacharya et al., 2017; Ganda, 2019; Gyamfi et al., 2022; Nguyen et al., 2020; Shobande & Ogbeifun, 2022; Solaymani & Montes, 2023). Empirical evidence on the nexus between climate technologies (low-carbon technologies and climate change adaptation), institutional quality, renewable and non-renewable energy use and environmental sustainability is rare in Nigeria. The objective of this study is to investigate the joint impact of low-carbon technologies, institutional quality, renewable and non-renewable energy use and climate adaptation on environmental sustainability amidst fossil fuels and institutional quality in Nigeria.

METHODOLOGY

Data source

This paper focused on Nigeria – the most populous country in Africa and one of the countries with low adaptive capacity and readiness to respond to climate change globally. The data employed in this study were secondary data obtained from six sources – the United Nations Comtrade, International Monetary Fund Direction of Trade Statistics, World Economic Outlook, World

Development Indicators, Global Footprint Network, and Notre Dame Global Adaptation Initiative Database. Data on total trade in low carbon technology products were obtained from the United Nations Comtrade, International Monetary Fund Direction of Trade Statistics, and World Economic Outlook. Data on renewable energy consumption, fossil fuel use (proxied by energy use), economic growth proxied by GDP per capita, and medium and high-tech exports were obtained from the World Development Indicators, while data on ecological footprint and adaptation index were obtained from the Global Footprint Network and Notre Dame Global Adaptation Initiative databases, respectively. Institutional quality was computed by summing the six indicators of institutional quality. The six indicators include control of corruption (number of sources), political stability and absence of violence/terrorism (number of sources), government effectiveness (number of sources), rule of law (number of sources), regulatory quality (number of sources), and voice and accountability (number of sources) (Onyeneke et al., 2025). Data on these indicators were obtained from the World Development Indicators database.

We used data spanning a period of 27 years (1996 – 2022). Data availability informed the choice of the period (1996 – 2022) covered by the study. The dependent variable is ecological footprint, which is a measure of environmental quality (see Emenekwe et al., 2022; Onyeneke et al., 2023; Onyeneke et al., 2024). The independent variables include total trade in low carbon technology products, renewable energy consumption, fossil fuel use (proxied by energy use), economic growth proxied by GDP per capita, and medium and high-tech exports, adaptation index and institutional quality. The description of the variables is presented in Table 1.

Table 3: Description of the variables

Symbol	Variable	Unit	Source of data
LCTP	Total trade in low carbon technology products	US\$	United Nations Comtrade, IMF DOTS, and World Economic Outlook
RENEW	Renewable energy consumption	% of total final energy consumption	World Development Indicators
ADAPT	Adaptation	Index	Notre Dame Global Adaptation Initiative
GDP	Economic growth (GDP constant 2015 US\$		World Development Indicators per capita) Database
INSQ	Institutional quality	total number of sources	Computed by the author with data from the World Development Indicators Database
MHTE	Medium and hightech	% manufactured exports Database	World Development Indicators exports
FOSSIL	Energy use	kg of oil equivalent per capita	World Development Indicators Database

IMF DOTS is International Monetary Fund Direction of Trade Statistics

Econometric strategy

This study applied the autoregressive distributed lag approach to model the impact of low-carbon technologies, climate adaptation, energy consumption and institutional quality on environmental sustainability in Nigeria. The Augmented Dickey Fuller (ADF) and Phillips-Perron tests were carried out to determine the time series properties of the variables.

The implicit model of the ARDL is stated thus:

$$ECOL = f(LCTP, RENEW, ADAPT, GDP, INSQ, MHTE, FOSSIL, \epsilon_t) \quad (1)$$

Where;

LCTP	= Total trade in low carbon technology products (US Dollars)
RENEW	= Renewable energy consumption (% of total final energy consumption)
ADAPT	= Adaptation (Index)
GDP	= Economic growth (GDP per capita (constant 2015 US\$))
INSQ	= Institutional quality (total number of sources)
MHTE	= Medium and high-tech exports (% manufactured exports)
FOSSIL	= Energy use (kg of oil equivalent per capita)
ECOL	= Ecological footprint (global hectares)

It is customary to convert the observed values of the variables to their natural logarithmic values to eliminate/reduce heteroskedasticity. We converted the observed values of all the dependent and independent variables to their natural logs and used the natural log values in the final analysis. The ARDL model with the natural logarithms is presented thus:

$$\ln ECOL_t = \beta_0 + \beta_1 \ln LCTP_t + \beta_2 \ln RENEW_t + \beta_3 \ln ADAPT_t + \beta_4 \ln GDP_t + \beta_5 \ln INSQ_t + \beta_6 \ln MHTE_t + \beta_7 \ln FOSSIL_t + \epsilon_t \quad (1)$$

$$\begin{aligned} \Delta \ln ECOL_t = & \beta_0 + \beta_1 \ln ECOL_{t-1} + \beta_2 \ln LCTP_{t-1} + \beta_3 \ln RENEW_{t-1} + \beta_4 \ln ADAPT_{t-1} + \beta_5 \ln GDP_{t-1} + \beta_6 \ln INSQ_{t-1} \\ & + \beta_7 \ln MHTE_{t-1} + \beta_7 \ln FOSSIL_{t-1} + \sum_{i=1}^p \beta_{8i} \Delta \ln ECOL_{t-i} + \sum_{i=1}^p \beta_{9i} \Delta \ln LCTP_{t-i} \\ & + \sum_{i=1}^p \beta_{10i} \Delta \ln RENEW_{t-i} + \sum_{i=1}^p \beta_{11i} \Delta \ln ADAPT_{t-i} + \sum_{i=1}^p \beta_{12i} \Delta \ln GDP_{t-i} \\ & + \sum_{i=1}^p \beta_{13i} \Delta \ln INSQ_{t-i} + \sum_{i=1}^p \beta_{13i} \Delta \ln MHTE_{t-i} + \sum_{i=1}^p \beta_{14i} \Delta \ln FOSSIL_{t-i} + \epsilon_t \end{aligned} \quad (2)$$

The F-statistics and t-statistics produced in the implementation of equation 3 were used to test the presence or absence of cointegration. Our null hypothesis is that there is no cointegration among the variables. If we reject the null hypothesis, the ARDL model generates the short and long run estimates. The error correction model of the short run estimates is presented thus:

$$\begin{aligned} \Delta \ln \text{ECOL}_t = & \sum_{i=1}^p \beta_{8i} \Delta \ln \text{ECOL}_{t-i} + \sum_{i=1}^p \beta_{9i} \Delta \ln \text{LCTP}_{2t-i} + \sum_{i=1}^p \beta_{10i} \Delta \ln \text{RENEW}_{3t-1} + \sum_{i=1}^p \beta_{11i} \Delta \ln \text{ADAPT}_{4t-i} \\ & + \sum_{i=1}^p \beta_{12i} \Delta \ln \text{GDP}_{5t-i} + \sum_{i=1}^p \beta_{13i} \Delta \ln \text{INSQ}_{6t-i} + \sum_{i=1}^p \beta_{13i} \Delta \ln \text{MHTE}_{7t-i} + \sum_{i=1}^p \beta_{14i} \Delta \ln \text{FOSSIL}_{8t-i} \\ & + \lambda_1 \text{ECM}_{t-1} + \varepsilon_t \end{aligned} \quad (4)$$

RESULTS AND DISCUSSION

Summary statistics

The summary statistics of the variables are presented in Table 2. The result shows that the average total trade in low-carbon technology products was 1,266,801,504.74 US dollars with a minimum value of 121,745,418.00 US dollars. In 2021, the top five exporters of low-carbon technology products were China, Germany, the United States, Japan, and Korea, which together accounted for 55 percent of world LCT exports (see Howell et al., 2023). The top five importers of LCT products were the United States, China, Germany, the United Kingdom, and France, with a share of 41 percent of world imports (see Howell et al., 2023). Nigeria is one of the countries with the lowest comparative advantage in low-carbon technology products (see Howell et al., 2023). Renewable energy consumption constitutes about 83.92% for the period under study. The Table further shows that the average ecological footprint of Nigeria over the period under study was 157,984,180.97 global hectares, with a minimum value of 112,999,822.90 global hectares. Comparing the minimum and average values of ecological footprint in Nigeria, one could deduce substantial increase in the utilization of natural resources in the country. Growing population and increased per capita use of natural resources have increased ecological footprint in Africa (World Wide Fund and African Development Bank, 2012; Erdogan et al. 2021). Also, Sun et al. (2020) found negative links between natural resources and ecological footprints. Using advanced technology in restoring natural resources could enhance environmental quality and reduce environmental degradation (Ahmad et al. 2020).

The average global adaptation index score of Nigeria for the period under study was 40.91. This shows that Nigeria's adaptation index is low. This indicates a low adaptive capacity of the Nigeria to respond favourably to climate change and environmental degradation. In fact, in 2022, Nigeria ranked 152 out of 187 countries covered by the Notre Dame Global Adaptation Initiative (2025). The average GDP per capita was 2056.76 constant 2015. This is far below the global average in 2022 (US\$ 11,361.1 constant 2015 US\$) (World Bank Group, 2025). The average medium and high-tech exports was 45.58% of manufactured exports, while the average energy use – a proxy for fossil fuel use – was 306.96 kg of oil equivalent per capita.

Table 2: Descriptive Statistics

Variable	N	Minimum	Maximum	Mean	Std. Deviation
Total trade in low carbon technology products (US Dollars)	27	121745418.00	2928932557.00	1266801504.74	820011186.25
Renewable energy consumption (% of total final energy consumption)	27	79.90	88.10	83.92	2.51
Adaptation (Index)	27	36.21	47.02	40.91	3.56
GDP per capita (constant 2015 US\$)	27	1390.47	2585.73	2056.76	428.05
Institutional quality (total number of sources)	27	27.00	84.00	62.37	19.74
Medium and high-tech exports (% manufactured exports)	27	7.48	81.54	45.58	25.39
Energy use (kg of oil equivalent per capita)	27	260.35	376.07	306.96	31.64
Ecological Footprint (Gha)	27	112999822.90	183007117.30	157984180.97	21265744.94

Unit root tests

The results of the Augmented Dickey Fuller (ADF) and Phillips-Perron unit root tests are summarized in Table 3. According to these results, ecological footprint and institutional quality were stationary at level under the ADF while only ecological footprint was stationary at level under Phillips-Perron unit root test. All the variables – ecological footprint, total trade in low carbon technology products, renewable energy consumption, adaptation, economic growth, institutional quality, medium and high-tech exports, and fossil fuel use – were stationary at first difference under the ADF and Phillips-Perron tests. The null hypothesis of a unit root was rejected at conventional significant levels (10%, 5%, or 1%) for all the time series at first difference. These results imply that each series is non-stationary in level but stationary in the first difference.

Table 3: Stationary test from Augmented Dickey-Fuller and Phillips-Perron tests

Augmented Dickey-Fuller test			
Variable	At level		
	At level	At first difference	Decision
<i>lnLCTP</i>	-1.136	-5.456***	<i>I</i> (1)
<i>lnRENEW</i>	-1.896	-5.660***	<i>I</i> (1)
<i>lnADAPT</i>	-1.747	-4.818***	<i>I</i> (1)
<i>lnGDP</i>	-1.712	-2.693*	<i>I</i> (1)
<i>lnINSQ</i>	-2.792*	-2.786*	<i>I</i> (0)
<i>lnMHTE</i>	-2.397	-5.327***	<i>I</i> (1)
<i>lnFOSSIL</i>	-1.990	-5.706***	<i>I</i> (1)
<i>lnECOL</i>	-2.693*	-4.695***	<i>I</i> (0)

Variable

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ps-Perron test

	At level	At first difference	Decision
<i>lnLCTP</i>	-1.127	-5.458***	<i>I</i> (0)
<i>lnRENEW</i>	-1.887	-5.666***	<i>I</i> (1)
<i>lnADAPT</i>	-1.836	-4.816***	<i>I</i> (1)
<i>lnGDP</i>	-1.481	-2.697*	<i>I</i> (1)
<i>lnINSQ</i>	-2.372	-2.790*	<i>I</i> (1)
<i>lnMHTE</i>	-2.421	-5.455***	<i>I</i> (1)
<i>lnFOSSIL</i>	-1.940	-5.757***	<i>I</i> (1)
<i>lnECOL</i>	-2.728*	-4.736***	<i>I</i> (0)

*** $p < 0.01$ indicates significance at 1%

ARDL-Bounds test for cointegration

Having established that all the variables are *I*(1) (i.e. the necessary condition for cointegration is satisfied), the result of the cointegration test is reported in Table 4. The numbers in parentheses under the ARDL test are the optimal lag lengths. Since the results of the unit root tests rejected the null hypothesis of a unit root in favour of the stationary alternative, we conclude that the series are co-integrated. Hence our decision to further carry out the autoregressive distributed lag model regression. We used the ARDL Bounds test for determining whether there exists short-run and long-run relationships between the dependent and independent variables of the model. The result in Table 4 confirmed the presence of cointegrating relationships between the dependent and independent variables. The significance of the F and t-statistics confirms the presence of both long-run and short-run relationships between the dependent and independent variables in each case. This confirms the appropriateness of the autoregressive distributed lag model used in our study.

Furthermore, the diagnostics tests conducted showed that the model performed very well. White's test for homoskedasticity accepted the null hypothesis of homoskedasticity confirming the absence of heteroskedasticity in the model. The Breusch–Godfrey LM test for autocorrelation accepted the null hypothesis of no serial correlation confirming the absence of serial correlation in the model. Also, the Durbin-Watson statistic was approximately 2, indicating the absence of autocorrelation.

Table 4: Results of ARDL-bounds cointegration test

Model	Optimal lag	F-statistic	t-statistic	
ARDL(2,2,1,2,2,1,2,2) regression	AIC = 2	20.019***	5.494***	
Diagnostic Tests:	Statistic [P value]			
White's test for Homoskedasticity (H0: Homoskedasticity) +	25.00 [0.4058]			
Durbin-Watson statistic	2.33			
Breusch–Godfrey LM test for autocorrelation (H0: no serial correlation)	0.97 [0.32]			
Critical values and p-values** (H0: no levels relationship)	1%	5%	10%	P value
F test: I(0)	2.96	2.32	2.03	0.000
F test: I(1)	4.26	3.50	3.13	0.000
T test: I(0)	-3.43	-2.86	-2.57	0.000
T test: I(1)	-5.19	-4.57	-4.23	0.000

Note: *** Significant at 1% level of significance; ** Significant at 5% level of significance; * Significant at 10% level of significance. +Cameron & Trivedi's decomposition of IM-test. AIC stands for the Akaike information criterion. ** the critical values and p-values come from (Kripfganz & Schneider, 2020).

Structural stability test

We used the ordinary least squares (OLS) cumulative sum test for parameter stability to determine whether there is structural break in our model. We presented the result in Figure 2 and Table 5. The results in Figure 2 and Table 5 show that there is no structural break in our model indicating the stability of the model. This shows that our econometric model is structurally stable. This again confirms the appropriateness of the econometric model used in this paper.

Table 5: Structural stability of the model

<i>H0: No structural break</i>					
Model	Remark	Test statistic	1% level of significance	5% level of significance	10% level of significance
OLS	Accept H_0	0.13	1.63	1.36	1.22

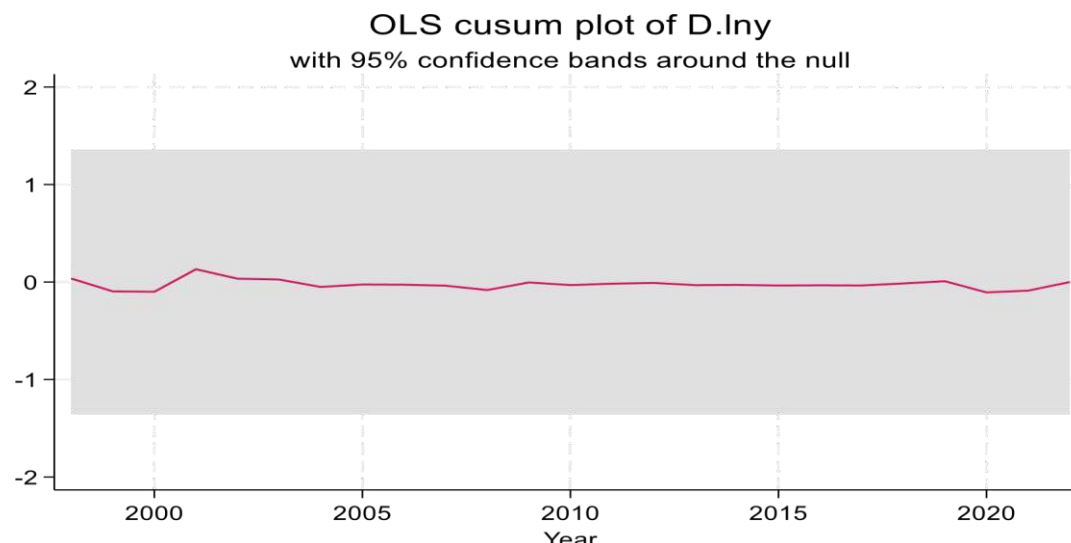


Figure 2: OLS cumulative sum test for parameter stability

Short-run and long-run impacts of technological progress, climate adaptation, energy consumption and institutional quality on environmental sustainability in Nigeria

We used the ARDL to estimate the impact of technological progress, climate adaptation, energy consumption and institutional quality on environmental sustainability in Nigeria. The long-run and short-run impacts of technological progress (total trade on low-carbon technologies and medium and high-tech exports), climate adaptation, energy consumption (renewable and non-renewable energy consumption) and institutional quality are presented in Table 6. The ECM result is negative (-0.35) and statistically significant at the 5% level of probability. This shows the degree of adjustment of the variables per year to attain long-run equilibrium. We can deduce from the result that the ECM value indicates that change in environmental sustainability (proxied by ecological footprint) from short run to long run would be corrected by 35% yearly.

The coefficients of the first difference and first lag of the first difference of total trade on low-carbon technology products were negative and statistically significant at the 1% level of probability. A 1% increase in the first difference and first lag of the first difference of total trade on low-carbon technology products would decrease Nigeria's ecological footprint by 0.37% and 0.26%, respectively in the short run. Also, in the long run, total trade in low-carbon technology products had a negative and significant relationship with ecological footprint. A 1% increase in total trade on low carbon-technology products would decrease the ecological footprint by 0.04%. This implies that total trade on low-carbon technology products decreases ecological footprint and invariably enhances/improves environmental sustainability both in the short run and long run. This finding echoes the importance of low-carbon technologies in combatting environmental degradation and climate change and by extension promoting environmental sustainability. We link this finding with similar empirical evidence elsewhere, where Okere and Fasanya (2024), Naeem et al. (2023), Sakariyahu et al. (2023) and Amari et al. (2022), found a negative effect of technological progress on carbon emissions.

Renewable energy consumption had a negative and significant impact on ecological footprint both in the short run and long run. A 1% increase in renewable energy consumption led to 5.51% and 1.94% decrease in ecological footprint in the short run and long run, respectively. These results suggest that

the relationship between renewable energy use and ecological footprint is inverse, implying that continuous use of renewable energy in Nigeria would decrease the ecological footprint of the country and, by extension, increase its environmental sustainability. Our finding is line with previous studies such as Olanipekun et al. (2019), Wang and Dong (2019), Danish et al. (2020), and Onyeneke et al. (2024), who found a negative link between renewable energy consumption and ecological footprint and carbon emissions. Renewable energy consumption helps countries save money, reduce emissions and combat climate change (Raihan et al., 2023).

The coefficients of the first difference and first lag of the first difference of adaptation in the short run were negative and statistically significant at 5% and 1% levels of probability, respectively. A 1% increase in the first difference and first lag of the first difference of adaptation was associated with 0.98% and 0.77% of reduction in ecological footprint, respectively in the short run. Also, in the long run, adaptation had a negative and significant relationship with ecological footprint. A 1% increase in adaptation decreased the ecological footprint by 0.33%. This implies that adaptation decreases ecological footprint and invariably enhances/improves environmental sustainability both in the short run and long run. Adaptation can reduce ecological footprint by enhancing resource efficiency or reducing vulnerability to climate change impacts. This finding echoes the importance of building the resilience of Nigeria in combatting environmental degradation and climate change and by extension promoting environmental sustainability. This result substantiates the finding of Khan et al. (2025), who observed that climate adaptation enhances environmental sustainability.

The coefficients of the first difference and first lag of the first difference of economic growth proxied by GDP per capita in the short run were positive and statistically significant at 5% and 1% levels of probability, respectively. A 1% increase in the first difference and first lag of the first difference of GDP per capita was associated with 0.61% and 0.89% of increase in ecological footprint, respectively in the short run. Also, in the long run, GDP per capita had a positive and significant relationship with ecological footprint. A 1% increase in GDP per capita increased ecological footprint by 0.58%. This implies that GDP per capita increases ecological footprint and invariably decreases environmental sustainability both in the short run and long run. Economic growth generally increases ecological footprint due to higher resource consumption and pollution. While economic expansion can drive improvements in living standards and technological development, these improvements can also lead to increased resource demands and environmental degradation. The pursuit for economic growth in Nigeria without appropriate environmental-friendly technologies, rate and efficiency of resource use, and policy choices, could increase the ecological footprint of the country and, by extension, contribute to environmental degradation on the continent. The positive relationship between GDP per capita and ecological footprint in Nigeria is line with the findings of Ahmed et al. (2021), Salman et al. (2022), Xu et al. (2022a) and Luo et al. (2023). This finding suggests that the pursuit for economic growth in Nigeria should be done with appropriate appropriate environmental-friendly technologies, rate and efficiency of resource use, and policy choices.

Institutional quality had a positive and significant impact on ecological footprint both in the short run and long run. A 1% increase in the number of sources for institutional quality was associated with 1.06% and 0.54% increase in ecological footprint in the short run and long run, respectively. These results suggest that the relationship between institutional quality and ecological footprint is direct, implying that institutional quality has increased the ecological footprint of the country and, by extension, decrease its environmental sustainability. This implies as the sum of the number of sources control of corruption, political stability and absence of violence/terrorism, government effectiveness, rule of law, regulatory quality, and voice and accountability increases, the ecological footprint of the country increases too. The

probable reason might be that the sources responsible for control of corruption, political stability and absence of violence/terrorism, government effectiveness, rule of law, regulatory quality, and voice and accountability make use fossil fuels to carry out their operations. The present findings are consistent with an increasing amount of empirical submission, which includes research conducted by Hussain and Dogan (2021). This research result aligns with Saba et al. (2023) Gyamfi et al. (2022) study, which presents multiple argument. First, it indicates that the institutional changes in certain African countries may not be well constructed to strengthen regulatory systems against the impacts of human activities and resource depletion on the ecosystem. Second, it suggests that there are inherent vulnerabilities and shortcomings in the institutional structure that governs resource extraction operations in some African countries. Third, it suggests that the institutions in the African region may not meet the required criteria to effectively promote structural transformation that can transition from pollution-intensive technologies to cleaner and more environmentally sustainable production methods.

The analysis of another proxy of technological advances – medium and high-tech exports – offers a fascinating approach to comprehend the environmental impact of ecological footprint in Nigeria. The coefficient estimates of the first difference of the variable – medium and high-tech exports – and the long run coefficient demonstrate statistical significance at the 5% and 10% levels, respectively. The coefficient for the lag of the first difference of medium and high-tech exports is negative and statistically significant at the 1% level. This indicates that a percentage increase in the first difference and first lag of the first difference of medium and high-tech exports leads to a corresponding increase of 0.04% and decrease of 0.06% in ecological footprint, respectively. Also, a 1% increase in medium and high-tech exports was associated with a 0.02% increase in ecological footprint in the short run. This finding suggests that environmental deterioration increases with manufacturing of medium and high-tech exports in the country. In line with this idea and considering the level of economic development in Nigeria, the process of industrialization and increasing production for exports would frequently lead to a rise in pollution and the depletion of resources. This finding also suggests that the country requires to make significant technological advancement and acquires the ability to allocate resources toward cleaner technologies and environmental conservation efforts, resulting in a reduction in environmental deterioration. Medium and high-tech exports can contribute to higher resource consumption and electronic waste, potentially increasing the ecological footprint. Wang et al. (2023) and Xu et al. (2022b) also found that medium and high-tech exports increased carbon intensity and ecological footprint.

The short run and long run coefficients of elasticity for fossil fuel are positive and statistically significant. The coefficients of the first difference and first lag of the first difference of fossil fuel use in the short run were positive and statistically significant at 5% levels of probability, respectively. This indicates that a percentage increase in the first difference and first lag of the first difference of energy intensity (specifically from fossil fuels) leads to a corresponding increase of 0.78% and 0.36% in ecological footprint, respectively. Also, a 1% increase in fossil fuel use was associated with a 0.12% increase in ecological footprint in the short run. In essence, a higher fossil fuel means that more energy is needed to produce the same economic output, which could result in increased use of resources and environmental stress. The escalated energy demand can lead to amplified ecological footprint, contamination of air and water, and exhaustion of resources.

This finding followed the collective efforts of Asongu et al. (2020) who confirmed that fossil fuels consumption contributed to environmental degradation in Africa. Okere et al. (2022), Muoneke et al. (2022) and Okere et al. (2021) attest to the fact that fossil fuels consumption in Peru, the Philippines, and Argentina.

Table 6: ARDL estimates for the impact of technological progress, climate adaptation, energy consumption and institutional quality on environmental sustainability in Nigeria

Variables	ARDL			
	Coefficient	Std. Error	t	P> t
Short-run impacts ECM(-1)				
1)	-0.35**	0.06	-5.49	0.012
$\Delta \ln ECOL(-1)$	-0.31***	0.04	-7.13	0.006
$\Delta \ln LCTP$	-0.37***	0.06	-6.39	0.008
$\Delta \ln LCTP(-1)$	-0.26***	0.04	-5.76	0.010
$\Delta \ln RENEW$	-5.51**	1.12	-4.93	0.016
$\Delta \ln ADAPT$	-0.98**	0.195	-5.03	0.015
$\Delta \ln ADAPT(-1)$	-0.77***	0.13	-6.03	0.009
$\Delta \ln GDP$	0.61**	0.12	4.96	0.016
$\Delta \ln GDP(-1)$	0.89***	0.14	6.48	0.007
$\Delta \ln INSQ$	1.06***	0.15	7.19	0.006
$\Delta \ln MHTE$	0.04**	0.01	3.76	0.033
$\Delta \ln MHTE(-1)$	-0.06***	0.007	-9.09	0.003
$\Delta \ln FOSSIL$	0.78**	0.23	3.48	0.040
$\Delta \ln FOSSIL(-1)$	0.36**	0.09	3.95	0.029
Constant	-94.20**	16.72	5.63	0.011
Long-run impacts $\ln LCTP$				
	-0.04***	0.005	-7.89	0.004
$\ln RENEW$	-1.94***	0.30	-6.46	0.008
$\ln ADAPT$	-0.33**	0.06	-5.68	0.011
$\ln GDP$	0.58***	0.04	13.24	0.001
$\ln INSQ$	0.54***	0.03	20.24	0.000
$\ln MHTE$	0.02***	0.002	10.34	0.002
$\ln FOSSIL$	0.12*	0.05	2.57	0.082
R^2	0.995			
RMSE	0.007			
Adj. R^2	0.963			

Note: RMSE is root mean square of error. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

CONCLUSIONS AND POLICY IMPLICATIONS

This study highlights the impact of technological progress, climate adaptation, energy consumption and institutional quality on environmental sustainability in Nigeria. Using time-series data obtained from six different sources and leveraging on the autoregressive distributed lag econometric framework, our findings emphasize the need to incorporate multiple factors in environmental sustainability programs. It underscores the importance of a coordinated approach to address Nigeria's environmental deterioration and carbon emissions challenge, highlighting the interconnectedness of ecological footprints, renewable and non-renewable energy consumption, adaptation, institutional quality and technological progress. We conclude from our findings that renewable energy consumption, trade in low-carbon technology products, and adaptation enhance environmental quality in Nigeria by reducing the country's ecological footprint. However, institutional quality, medium and high-tech exports, fossil fuel use, and economic growth increase the country's ecological footprint.

The results obtained from the empirical analysis offers beautiful insights to direct policymaking in Nigeria pertaining technological progress, fossil fuels, renewable energy consumption, adaptation, institutional quality and environmental sustainability. Relevant institutions in the environment and climate change sector should continue to advocate for total transition from fossil fuels to renewable energies to minimize environmental pollution, climate change and achieve environmental quality in the country. Government can redirect investments from fossil fuels to renewable energy and other solid environmental technologies that can assist the reduction of greenhouse gases. Also, there is need to install a sound watchdog system to ensure accountability and regulatory quality.

The policy implications should include suitable innovation in manufacturing medium and high-tech exports to enhance Nigeria's environmental output and performance. Significant importance in building climate resilience and sustaining trade in low-carbon products is needed in combatting climate change, carbon emissions and environmental deterioration in Nigeria.

Limitations and Future Research Direction

Some study limitations are discussed, and new research ideas are suggested. Some limitations arise from the fact that the study included only Nigeria, and the findings cannot be applied to other countries with different socioeconomic and environmental statuses. The time frame chosen for the analysis from 1996 to 2022 may also exclude current tendencies and advancements in environmental technology and policy. Hence, future research should incorporate more diverse datasets and possibly longitudinal studies capable of capturing recent trends and disruptions. Expanding the number of countries and indicators to include developed and developing countries would offer a more accurate outlook for global environmental effectiveness. In addition, future research may examine how emerging technologies, financial access and governance simultaneously use quantitative and qualitative approaches to understand better how all three interact.

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Climate Change Adaptation: A Panacea for Crop Production Proficiency in Cross River State, Nigeria

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ABSTRACT

The principal food crops grown in Cross River State include cassava, yams, maize, and cocoyams. Crop production in Cross River State, is mainly subsistence with only a small portion under irrigation where small streams are diverted seasonally for limited dry season cropping. Over time, climate change has altered precipitation leading to a rise in temperatures around the world with severe consequences on agriculture, especially food crops which are very sensitive to variation in climate condition. This study brings to bear, the usefulness of climate change adaptation strategies on food crop production efficiency (technical and profit) in Cross River State. The State has eighteen (18) Local Government Areas (LGAs) spread across 3 senatorial zones namely, Southern, Central and Northern Senatorial zones, Biase, Ikom and Yala LGAs were selected respectively to represent these zones for the study using purposeful sampling technique while Ten (10) villages were then selected from each of the selected LGAs after which I undertook random sampling of Twenty (20) farmers for interview from each of the selected villages. The study adopted a mixed-methods approach, combining both quantitative and qualitative research methods. Data analysis was done using descriptive Statistics, and multiple linear regression analysis. The study revealed that adaptation strategies such as irrigation practices, crop diversification, and off-farm employment show of lower mean scores across all locations, indicating varying levels of adoption and effectiveness in climate change adaptation strategies. Findings also showed that the most intensified climate change adaptation strategies were multiple crop types/varieties, land fragmentation, multiple planting dates, and mulching. Socio-economic factors such as age, household size, education, and access to credit negatively influenced the use of certain adaptation strategies, while sex (male-headed) and tenure security had positive effects. The researcher recommended that policies should be put in place to promote adaptation strategies to meet crop demand of the growing population.

Keywords: Climate Change, Crop Production, Adaptations, Agriculture

Introduction

The increased level of Greenhouse Gases (GHGs) has created a greenhouse effect which subsequently altered precipitation patterns and global temperatures around the world. Impacts have been witnessed in several areas due to change in precipitation and temperature. The

sectors affected include agriculture, forestry, water resources, biodiversity, human health, and ecosystems goods and services globally (Khanal, 2009; Rosegrant et al., 2008). Food crops are particularly sensitive to climate change because crop yields depend largely on prevailing climate conditions (temperature and rainfall patterns) (Palatnik & Roson, 2009), Southsouth Nigeria is not exempted. The principal food crops grown in the Southsouth geopolitical zone are cassava, yams, maize, and cocoyams, which are also sensitive to climate variability and climate change. Subsistence crop production in Cross River State is traditional and rain-fed, with very limited areas under irrigation. Small-scale traditional irrigation has been practiced for decades in areas, where small streams are diverted seasonally for limited dry season cropping. Medium and large scale schemes are very few. Although there is evidence that agriculture in temperate regions of the world has benefited in some ways from global warming, the same report states with high confidence that “agricultural production and food security, including access to food, in many African countries and regions are likely to be severely affected by climate change and climate vulnerability”. This is because African economies and the livelihoods of its population are highly dependent on agriculture which is mainly practiced in already harsh climatic conditions (e.g. high temperature, marginal environment, and considerable water stress) (IPCC, 2007a). About 60% of Nigeria’s population is employed in the agricultural sector (National Bureau of Statistics [NBS], 2021). Agriculture in Nigeria is already under significant pressure to meet the demand of rising population using finite, often degraded soil and water resources, which are now further stressed by the impact of climate change (Awotoye & Mathew, 2010). As a result, it is of interest to stakeholders in the agricultural sector to understand the kind of impact climate change will have on food and crop production. There will undoubtedly be shifts in agro-ecological conditions that will warrant changes in processes and practices in order to meet daily food requirements. In addition, climate change could become a significant constraint on economic development in developing countries that rely on agriculture for a substantial share of gross domestic production and employment (Rosegrant et al., 2008). There are two central processes for dealing with climate change, namely, mitigation and adaptation. Mitigation is a response strategy to global climate change, and can be explained as measures that reduce the amount of emissions (abatement) or enhance the absorption capacity of greenhouse gases (sequestration). Adaptation to climate change is an adjustment made to the human, ecological or physical system in response to vulnerability (Adger et al., 2007). Climate change adaptation through the modification or improvement of agricultural practices will be imperative to meet the growing food demands of modern society (Rosegrant et al., 2008). Constant evolution of crop patterns, farm management practices and land use occur across the globe, partly in response to climatic variation. Such farm-level adaptations aim at increasing productivity, improving efficiency and dealing with existing climatic conditions, and draw farmers’ current knowledge and experience (Commission of the European Communities [CEC], 2009). Although African farmers have a low capacity to adapt to changes, they have, however, survived and coped in various ways over time. A better understanding of how farmers in Africa have done this is essential for designing incentives to enhance private adaptation. Supporting the coping strategies of local farmers through appropriate public policy and investment and collective actions can help increase the adoption of adaptation measures that will reduce the negative consequences of predicted changes in future climate, with great benefits to vulnerable rural

communities in Africa (Hassan & Nhemachena, 2008), especially food crop farmers in Cross River State Nigeria. Deressa (2008) posited that farmers adapt to climate change to maximize profit by changing crop mix, planting and harvesting dates, and a host of agronomic practices. The coping strategies adopted by food crop farmers, which are mainly initiated at the farm and village-level in the southwestern Nigeria, are expected to enhance their farm productivity, efficiency and improve their profit as a producing unit.

The Research Problem

Climate change affects agriculture in several ways, one of which is its direct impact on food production. It brings about additional perspective to the national challenge of increasing agricultural production to keep pace with the rising population while keeping high standards of environmental protection. Negative effects on agricultural yields will be exacerbated by more frequent extreme weather events (CEC, 2009). Adaptation reduces the negative impact of climate change (Adger et al., 2003; Kurukulasuriya & Mendelson, 2006a). Adaptation of agronomic techniques and farm strategies is already happening (CEC, 2009). The modification of agricultural practices and production in order to cope with climate change will be imperative in order to meet and continue meeting the growing food demands of Nigerians. Evidence shows that farming systems and farming technologies within the region have been changing in response to the effects of climate change (Adebayo et al., 2011). In a study conducted in Southwest Nigeria, Adebayo et al. (2011) showed that the farmers agreed to the fact that the main climate change effect is on reduction of their personal productivity. Adapting to climate change and climate variability at the farm-level by the farmers especially through the modification of agricultural practices and farming systems have been recognised as the main coping strategies. It is believed that these strategies would help farmers improve their personal productivity and efficiency in food crop production and also raise their returns to farming as a business.

There is paucity of information on the influence of climate change adaptation strategies on efficiency of food crop farmers in Nigeria especially in Cross River State. T h u s , this study attempts to look at the effects of climate change adaptation strategies on food crop production efficiency (technical and profit) in Cross River State to fill these existing knowledge gaps.

Methodology

The study adopted the survey design. Cross River State is made up of eighteen (18) Local Government Areas and three (3) Senatorial Districts. From each of the senatorial district, one (1) Local government Area was selected. From Southern Senatorial District, Biase LGA was selected and Obubra LGA was also picked from Central Senatorial District, while Yala LGA as selected from Northern Senatorial district using purposeful sampling. Data for the study were collected from both primary and secondary sources. Structured questionnaires were used to gather information about climate change adaptation strategies used by farmers in the study area which were analyzed using both descriptive and inferential statistics, and a multivariate discrete choice model.

Research Design

This study adopted a mixed-methods approach, combining both quantitative and qualitative

research methods. The quantitative approach involved the use of survey questionnaires to collect data from farmers, while the qualitative approach involved key informant interviews with agricultural extension agents and focus group discussions with farmers. The study was conducted in Cross River State, (CRS), Nigeria. The State is located in the South-South geopolitical zone of Nigeria and has a total land area of approximately 20,156 square kilometers. CRS is known for its rich agricultural land and favorable climate, making it an ideal location for crop production.

Sampling Technique

A multi-stage sampling technique was used to select the respondents for the study. The first stage involved the selection of three local government areas (LGAs) from the 18 LGAs in Cross River State. The selected LGAs were Biase, Obubura, and Yala. The second stage was the selection of 10 villages from each of the selected LGAs while the third stage involved the random selection of 20 farmers from each of the selected villages.

Data Collection

Data were collected using the following instruments:

1. **Survey Questionnaires:** A structured questionnaire was designed to collect data from farmers on their socio-economic characteristics, crop production practices, climate change adaptation strategies, and challenges faced.
2. **Key Informant Interviews:** In-depth interviews were conducted with agricultural extension agents to gather information on the climate change adaptation strategies promoted by the government and non-governmental organizations.
3. **Focus Group Discussions:** Focus group discussions were held with farmers to gather information on their perceptions of climate change impacts on crop production and their adaptation strategies.

Data Analysis

Data were analysed using both descriptive and inferential statistics. The specific analytical techniques used include:

Descriptive Statistics: Means, frequencies, and percentages were used to summarise the socio- economic characteristics of farmers, crop production practices, climate change adaptation strategies, and challenges faced.

Inferential Statistics: Regression analysis was used to examine the relationship between climate change adaptation strategies and crop production efficiency.

Content Analysis: The qualitative data from key informant interviews and focus group discussions were analysed using content analysis to identify themes and patterns.

Model Specification

The study specified a linear regression model to examine the relationship between climate change adaptation strategies and crop production efficiency. The model is specified as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$$

Where:

Y = Crop production efficiency

X1 = Climate change adaptation strategies (dummy variable)

X2 = Socio-economic characteristics of farmers (age, education, experience) X3 = Crop production practices (use of improved seeds, fertilizers, irrigation) ε = Error term

Ethical Considerations

The study ensured that the rights and dignity of the respondents were respected. Informed consent was obtained from the respondents before the administration of the questionnaires. The respondents were also assured of confidentiality and anonymity.

RESULTS AND DISCUSSION OF FINDINGS

Table 1: Frequency Distribution of Farming Systems Practiced by Food Crop Farmers in Cross River State, Nigeria.

Farming System	Biase		Obubura		Yala	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
<i>Mono Cropping</i>	342	39.4*	74	35.6*	88	43.3*
<i>Mixed Cropping</i>	229	91.4*	212	90.0*	178	92.8*
<i>Shifting Cultivation</i>	196	82.2*	243	79.4*	253	85.0*
<i>Strip Cropping</i>	48	10.8*	8	3.9*	41	17.2*
<i>Mixed Farming</i>	80	25.0*	95	19.4	45	30.6*

Multiple Responses

Source: Researchers field work, 2025

Table 1 presents data on the frequency and percentage of different farming systems practiced by food crop farmers across three locations: Biase, Obubura, and Yala.

In Biase, Mono Cropping is practiced by 342 farmers, accounting for 39.4% of the total, while Mixed Cropping is the most common with 229 farmers (91.4%). Shifting Cultivation follows with 196 farmers (82.2%). In Obubura, Mono Cropping is practiced by 74 farmers (35.6%), with Mixed Cropping at 212 farmers (90.0%) and Shifting Cultivation at 243 farmers (79.4%). In Yala, Mono Cropping is practiced by 88 farmers (43.3%), Mixed Cropping by 178 farmers (92.8%), and Shifting Cultivation by 253 farmers (85.0%). Strip Cropping is less common, with only 48 farmers (10.8%) in Biase, 8 farmers (3.9%) in Obubura, and 41 farmers (17.2%) in Yala. Mixed Farming is practiced by 80 farmers (25.0%) in Biase, 95 farmers (19.4%) in Obubura, and 45 farmers (30.6%) in Yala.

Table 2: Farm-level Climate Change Adaptation Practices used by Food Crop Farmers in Cross River State, Nigeria

Farming System	Biase		Obubura		Yala	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Multiple crop types/varieties	355	98.6	176	97.8	179	99.4
Land fragmentation	211	76.9	130	72.2	147	81.7
Alternative fallow tillage Practices	141	39.2	54	30.0	87	48.3
Multiple Planting Dates	286	79.4	136	75.6	150	83.3
Irrigation practices	52	14.4	36	20.0	16	8.9
Crop Diversification	183	50.8	93	51.7	90	50.0
Off-farm Employment	162	45.0	84	46.7	78	43.3
Mulching	303	84.2	139	77.2	164	91.1
Cover Cropping	264	73.3	120	66.7	144	80.0
Fertilizer Application	196	54.4	99	55.0	97	53.9
Planting of Trees	61	16.9	38	21.1	23	12.8
Shading/ Sheltering	37	10.3	23	12.8	14	7.8
Change in farm size	199	55.3	91	50.6	108	60.0

* Multiple Responses

Researchers field work, 2025

Table 2 revealed that Biase with 355 farmers (98.6%) practice multiple crop types/varieties, while 211 farmers (76.9%) experience land fragmentation. Alternative fallow tillage practices are used by 141 farmers (39.2%). In Obubura, 176 farmers (97.8%) practice multiple crop types/varieties, with 130 farmers (72.2%) facing land fragmentation and 54 farmers (30.0%) using alternative fallow tillage practices. In Yala, 179 farmers (99.4%) practice multiple crop types/varieties, with 147 farmers (81.7%) experiencing land fragmentation and 87 farmers (48.3%) using alternative fallow tillage practices. Other practices include multiple planting dates, irrigation practices, crop diversification, off-farm employment, mulching, cover cropping, fertilizer application, planting of trees, shading/sheltering, and changes in farm size, with varying frequencies and percentages across the three locations.

Table 3: Distribution on Use of Farm-level Climate Change Adaptation Practices

Adaptation Strategies	Biase Mean	S.D	Obubura Mean	S.D	Mean	Yala S.D
Multiple crop types/varieties	2.65**	0.51	2.44**	0.58	2.60***	0.55
Land fragmentation	2.09***	0.59	0.02**	0.64	2.10**	0.57
Alternative fallow/tillage practices	1.96**	0.73	1.84*	0.75	2.10***	0.69
Multiple Planting Dates	2.24***	0.70	2.23***	0.73	2.14***	0.67
Irrigation practices	1.21*	0.51	1.27*	0.57	1.14*	0.44
Crop Diversification	1.70*	0.74	1.66*	0.75	1.62*	0.70
Off-farm Employment	1.65*	0.79	1.67*	0.78	1.68*	0.80
Mulching	2.17***	0.61	2.07***	0.66	2.21***	0.55
Cover Cropping	1.99***	0.65	1.88*	0.67	2.04**	0.62
Fertilizer Application	1.75*	0.74	1.73*	0.70	1.75*	0.75
Planting of Trees	1.21*	0.53	1.31*	0.63	1.14*	0.42
Shading/ Sheltering	1.12*	0.34	1.15*	0.39	1.11*	0.36
Change in farm size	1.91*	0.03	1.85*	0.79	1.91*	0.75

*** stands for very high intensification (VHI)

** stands for high intensification (HI)

* stands for low intensification (LI)

S. D. means standard deviation.

Source: Researchers field work, 2025

Table 3 revealed that Biase has the mean score for multiple crop types/varieties is 2.65 with a standard deviation of 0.51, while land fragmentation has a mean of 2.09 (S.D. 0.59). Alternative fallow/tillage practices have a mean of 1.96 (S.D. 0.73). In Obubra, the mean score for multiple crop types/varieties is 2.44 (S.D. 0.58), with land fragmentation at 0.02 (S.D. 0.64), indicating a low level of adaptation. Alternative fallow/tillage practices have a mean of 1.84 (S.D. 0.75). In Yala, the mean score for multiple crop types/varieties is 2.60 (S.D. 0.55), with land fragmentation at 2.10 (S.D. 0.57) and alternative fallow/tillage practices at 2.10 (S.D. 0.69). Overall, adaptation strategies such as irrigation practices, crop diversification, and off-farm employment show lower mean scores across all locations, indicating varying levels of adoption and effectiveness in climate change adaptation strategies.

Table 4: Frequency Distribution of Respondents by the Main Farm-level Climate Change Adaptation Practices Used

Adaptation Practices	Biase		Obubura		Yala	
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage
Multiple crop types/varieties	156	43.33	72	40.00	84	46.67
Land fragmentation	100	27.78	47	26.11	53	29.44
Multiple planting dates	44	12.22	27	15.00	17	9.44
Crop diversification	33	9.17	17	9.44	16	8.89
Off-farm employment	13	3.61	8	4.45	5	2.78
Cover cropping	14	3.89	9	5.00	5	2.78
Total	360	100	180	100	180	100

Researchers field work, 2025

Table 4 shows that Biase with 156 farmers (43.33%) use multiple crop types/varieties, while 100 farmers (27.78%) experience land fragmentation. Multiple planting dates are used by 44 farmers (12.22%). In Obubra, 72 farmers (40.00%) use multiple crop types/varieties, with 47 farmers (26.11%) facing land fragmentation and 27 farmers (15.00%) using multiple planting dates. In Yala, 84 farmers (46.67%) use multiple crop types/varieties, with 53 farmers (29.44%) experiencing land fragmentation and 17 farmers (9.44%) using multiple planting dates. Overall, multiple crop types/varieties are the most common adaptation strategy across all locations, followed by land fragmentation and multiple planting dates.

Biase has the mean score of 2.65 for multiple crop types/varieties with a standard deviation of 0.51, while land fragmentation has a mean of 2.09 (S.D. 0.59). Alternative fallow/tillage practices have a mean of 1.96 (S.D. 0.73). In Obubra, the mean score for multiple crop types/varieties is 2.44 (S.D. 0.58), with land fragmentation at 0.02 (S.D.

0.64), indicating a low level of adaptation. Alternative fallow/tillage practices have a mean of 1.84 (S.D. 0.75). In Yala, the mean score for multiple crop types/varieties is 2.60 (S.D. 0.55), with land fragmentation at 2.10 (S.D. 0.57) and alternative fallow/tillage practices at 2.10 (S.D. 0.69). Overall, adaptation strategies such as irrigation practices, crop diversification, and off-farm employment show lower mean scores across all locations, indicating varying levels of adoption and effectiveness in climate change adaptation strategies. Overall, multiple crop types/varieties are the most common adaptation strategy across all locations, followed by land fragmentation and multiple planting dates.

Conclusion

The study examined the effects of climate change adaptation strategies on food crop production efficiency in Cross River State, Nigeria. Majority of the farmers (37%) practiced mixed cropping, with an average farm size of 2 hectares. The most intensified climate change adaptation strategies were multiple crop types/varieties, land fragmentation, multiple planting dates, and mulching. Household size, age, education, and access to credit negatively influenced the use of certain adaptation strategies, while sex (male-headed) and tenure security had positive effects.

In the Rainforest zone, household size, education, and access to credit have negative impacts, while sex, extension contact, and distance have positive impacts on the use of adaptation strategies. Despite the use of various climate change adaptation strategies, the farmers are still underutilizing their resources, leading to technical and profit inefficiency. A right combination of different adaptation strategies, along with efficient use of resources at the present technology level, can help the farmers become more efficient.

Recommendations:

Government at all levels and relevant NGOs should: involve food crop farmers in adaptation policy programmes. The government should provide input-based adaptation strategies (e.g., multiple crop varieties) to enhance production and profit. They should implement proactive land use policies to encourage sustainable adaptation strategies.

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Sustainable Livelihoods Through Articulated Agri-Waste Management Practices as Adaptation Solution for Poverty Reduction in Cross River State

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ABSTRACT

Agriculture can be considered as one of the most important sectors through which Nigeria earns her livelihood. It provides food for humans, feed for livestock and raw materials for manufacturing sector. Above all, sales of cash crops provide foreign exchange earnings, from which Nigeria meets many of her needs. Consequently, many livelihoods are agro based. As a result, large volume of agri- waste lies either mismanaged or grossly neglected in Nigeria. Cross River State, is the context for this paper. Data for this study was sourced from Internet, books, journals and personal experience. Many households depend on the small, fragmented agricultural farms in their various communities. The waste generated from each of these farms, and those from post harvests, are perceived as refuse, which are discarded on site or into nearby open drains, gutter, stream or river. This behaviour of discarding waste indiscriminately contribute to the myriad of environmental issues confronting societies today, and this can undermine the sustainability of the future if there are no mitigation measures. Evidence show that waste generates wealth, therefore, these agri- waste could be useful as raw materials from which livelihood can be harnessed, supported and sustained. At the moment, in Cross River State, there is awareness and utilization of plastic wastes and metal scraps for sustenance of livelihood among community members, but most of agricultural waste generated from farms and post harvest activities are discarded as useless materials. This is caused by poor awareness and lack of capacity on its utilization or management. By encouraging Agricultural waste management, and placing it side by side crop production, a line of economic activity would be created, job opportunities will be opened up and many livelihoods supported. The environmental implication, is that these wastes (Banana waste, Palm kernels waste, cassava peels, rice husks, cocoa pods, including wastewater from fish farming.) would be utilized thus constitute lesser environmental hazards. This paper concludes that, if agri- waste management is integrated into crop production, and is established, as policy in our society, it would become a potential means to solve many issues related to environment, climate change and achievement of Sustainable Development Goals, in particular SDG 1 and 2 ,which are to end poverty and hunger. The suggestion of this paper aligns with the conference sub-theme to reduce poverty, identify

livelihood opportunities and adaptation solutions, which for this paper lies in green entrepreneurial opportunities in agri-waste management.

Keywords: *Livelihoods, agri-waste management, poverty reduction, climate change.*

Introduction

The United Nations has continued to encourage countries of the world on the need to expedite actions to achieve SDGs come 2030. Particularly affecting low and middle income countries like Nigeria is poverty, hunger and unemployment among majority of citizens. The present researchers perceive investment in agri-waste as an innovative move to sustainable livelihoods and solution to the myriad environmental issues exacerbated by climate change (Orji, Idika, Okeke, Anakwue & Ntamu, 2023; Anabaraonye et al., 2023; Anabaronye et al., 2022).

The researchers, personally has observed the negligence to agri-waste management practices among people and communities in Cross River State. This challenge to waste management practices has also been observed (Tewogbola, 2024). There is need to pay more attention in this area. The huge heap of improperly disposed agricultural wastes from these agrarian communities are not only an economic loss but constitutes solid wastes pollution, with attendant impact on the environment and human health (Anabaraonye et al., 2023). The irony is that in actual sense these wastes to a large extent are raw materials that could be in the production line for the production of a variety of useful products. But due to poor attitude, negligence, ignorance, lack of adequate awareness and knowledge, many people continue to neglect these sources of additional support to livelihood. This can be because, though there are a lot of agreements that Nigeria have gone into with United Nations with regard to environment. Many of these climate change acts, plans, policies and programmes have either remained on paper or are grossly under implemented. The challenges of poor awareness, and implementation of policies remains a problem. Hence, this negligence affects people and communities, socially and economically, amidst vulnerability to a myriad of environmental and health-related issues (Alvi & Khayyam, 2020).

The goal of this presentation is to stir up actions that would motivate concerned stakeholders; Government, Philanthropy, Funders, people and communities towards amassing support for articulated agri-waste management practices. The expectation for the present researchers is to see individuals, people, communities thrive to live sustainably, that is, getting busy with reducing, reusing and recycling agri-waste maximally, to make desired ends. But, lack of knowledge, policy support, and funding are some teething problems, against accelerating the adoption of these measures. For example, funding is needed to provide or transfer the needed knowledge, engender behaviour modifications as much as necessary, and establish model agri-waste management facilities in the communities.

Study area: Cross Rivers State. The state is an agricultural state. The Cross River State is divided into three zones: The Calabar, the Ikom, and the Ogoja.

The Cross River state's economy partially relies on crops, such as cocoyam, rubber, oil palm, yam, cocoa, cashews, and plantain crops, along with marine produce. Food crops including yams, cassava, rice, and corn (maize) are cultivated. Deep-sea fishing and shrimping along the coast provides livelihoods for coastal communities. Palm oil and kernels, timber, cocoa, and rubber are exported from Calabar seaport, which are sources of foreign revenue for the state and country at large. (Source: <https://www.britannica.com/place/Cross-River> | Nigeria, Map, & Facts - Britannica).

Conceptualizing livelihood, sustainable livelihood, articulated waste management, poverty reduction and adaptation solutions

Livelihood

Livelihood is conceived as any means of supporting one's existence, especially financially and vocationally. Livelihood comprises the capabilities, assets, and activities required to establish and function in any chosen means of living. To us human species, it is our enterprise, industry, all that we do for financial or economic gain, including to meet basic and self actualization needs. In summary, livelihood is what individuals, communities, states and countries may occupy themselves with to fend for themselves, for sustainable development, in the areas of economic, socio-political and environmental.

Sustainable livelihood

Supporting sustainable livelihood means we have to keep in mind the Sustainable Development concept.

According to the World Commission on Environment and Development, sustainable development is defined, as 'The ability of humanity to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs (Asikong, Udofia, Andy & Ubi, 2020). There is dire need for sustainable utilization, which is to keep up, maintain and perpetuate living (present and potential) uses, modifications, and developments of the environment and its living resources so that it can continue for present and future generations (Emeh, 2010). Any livelihood is deemed sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities, both now and in the future, while not undermining the natural resource base.

Articulated waste management practices

Waste management is a potential area to leverage on if a society like ours must sustain current livelihoods, and open up entrepreneurial opportunities. It is obvious, that the livelihoods of the locales have not changed, but it can be modified and made more sustainable. This can be realised with investment in transforming the agri-waste generated from livelihood activities or endeavours, (like agriculture; crop production and post harvest processing activities) into sources for another income generation. The extra monies made from these additional livelihood pathway or value added chain could become a sustainable path to solving the problem of hunger, poverty and vulnerability to environmental issues, and climate change in general.

Articulated here means a measure that brings together individuals of similar livelihood to one decision table., to enlarge and manage resources (agro wastes) to support sustainable livelihood of people and communities in what ever location they exist, at the time. It could be Cross River State, Nigeria, or any other state or country of the global south or North.

Waste management practices

Waste management can be defined as that discipline accosted with the control of generation, storage, collection, transfer, transportation, processing and disposal of solid and gaseous waste in a manner that is in accordance with the best principle of public health, economics, engineering, conservation, esthetics and other environmental considerations that is also responsible to public attitude (Asikong, Udofia, Andy, & Ubi, 2020).

Waste management deals with all types of waste, including industrial, biological, and domestic. Its process maximizes resource value and minimizes the environmental impact. The process includes the activities required to manage waste from its start to its final disposal. Four major categories of waste can be identified, municipal solid waste, industrial waste, agricultural waste and hazardous waste. However, the concern of this paper is to make case for management of agricultural waste alongside crop production activities. The researcher's motivation is based on the fact that little is being done about maximising the enormous potential that is locked in agro waste, to expand the frontiers of green entrepreneurship and agripreneurship, despite the call on Nations to transit to green economy. These are to strengthen the resilience of all towards achieving adaptation to these issues, and to mitigate many more that could arise in the course of time.

Methods of managing waste

Two hierarchical approaches to waste management systems are recognised today. The "3Rs": Reduce, Reuse, and Recycle and the "5Rs": Refuse, Reuse, Reduce, Repurpose, Recycle. Whichever framework is adopted; the focus is to minimize waste beginning at the source. These frameworks break down the life cycle of waste into stages. This enables individuals or systems to strategies effective actions to tackle waste in order to reduce pollution from the waste. These actions are explained as follows:

- i) **Refuse waste:** This refers to declining waste deliberately or intentionally, making effort to minimise waste generation.
- ii) **Reducing waste:** This refers to breaking waste into smaller sizes for easy disposal or treatment of waste to be less harmful and hazardous before disposal.
- iii) **Reusing waste:** This refers to the direct use of waste, e.g. Biogas can have generated from waste which can be used as a source of energy, most plant waste can be used as mulching materials and composting.
- iv) **Repurpose waste:** This is identifying other functional uses that the waste can be put to. For example, upcycling vehicle tires to seats, or for storage.
- v) **Recycling waste:** This is the process of minimizing the generation of waste by

recovering usable products that might otherwise become waste. Recycling is known to conserve natural resources.

Effective agricultural waste management can contribute to sustainable livelihoods by reducing waste, reusing waste, creating new income streams, and promoting environmental sustainability, by adopting the adaptation solution introduced in a community

Poverty reduction

This refers to strategies and interventions aimed at reducing poverty and improving well-being. Sustainable livelihoods through engaging in entrepreneurial opportunities in agri-waste management can contribute to poverty reduction over time. For example, individuals and communities can experience stable income sources, improvement in their socio- psycho well-being, and fostering resilience.

Adaptation solutions

This refers to several strategies and interventions aimed at helping communities adapt to climate change and other environmental challenges. Here, identifying and adopting agri-waste management practices as entrepreneurial opportunities for livelihood support, is sustainable strategy for poverty reduction.

TABLE 1: Agricultural produce in Nigeria, including Cross River State, their wastes products and the different possible uses, which provides entrepreneurial opportunities.

TABLE 1: Agricultural produce, their wastes products and the different possible uses.		
CROP	WASTE	ENTREPRENEURIAL OPPORTUNITIES
OIL PALM	EMPTY FRUIT BUNCHES PALM KERNEL SHELLS PALM PRESSED FIBRE PALM OIL MILL EFFLUENT	FUEL, FERTILIZER, CHEMICAL COMPOUNDS, FOOD AND BIOMATERIALS
COCOA	COCOA POD HUSKS, COCOA	FOOD, PAPER SUPPLIES,
	BEAN SHELLS, COCOA SWEETENING	PHARMACEUTICAL AND COSMETICS
BANANA	BANANA STEM, BANANA LEAVES, CELLULOSE	ACTIVATED CARBON, FIBRE, WASTE WATER TREATMENT AND BIO FILTER
RICE	RICE STRAW, RICE HUSK	FOOD, FEED, CELLULOSE, LIGNIN

CASSAVA	LEAVES, STEM, PEELS	ORGANIC BIOFUELS, FEEDSTOCK AND FOOD	FERTILIZER, INDUSTRIAL
POULTRY	CHICKEN DROPPINGS(FEACES), VISCERALS	FISH FEED	
FISH POND	WASTEWATER	IRRIGATION	
CROP FARM WASTES	STEMS FROM VEGGIES, PAWPAW LEAVES, BITTER LEAVES, MORINGA, ALOE VERA	FEED FOR BIRDS	

Source: Field work by Orji E. I.

Livelihood opportunities in green entrepreneurship for poverty reduction

Entrepreneurial opportunities abound in the Nigeria's agricultural sector which need to be harnessed, utilized and maximized by rural dwellers for poverty reduction and sustainable economic growth. This paper identifies the livelihood opportunities in agripreneurship and the role of green entrepreneurship in climate change mitigation and adaptation toward achieving sustainable economic growth and poverty reduction in Nigeria. Climate change, global warming and other related environmental challenges presently pose as a threat to sustainable livelihoods, exacerbating hunger in many vulnerable communities. Significantly, the growth of the agricultural sector has implications for food security, ecosystem conservation and the global yearnings to 'Stop' hunger and malnutrition in Africa. Also, from an innovate perspective, these environmental challenges have also created opportunities to develop green entrepreneurship in Nigeria, which if supported would become another measure for poverty reduction and adaptation solutions, across states in Nigeria. Through literature review and the present researcher's observation and experiences there are skill gaps, which are very obvious among the population. For example, green entrepreneurs are lacking among the rural dwellers, including the farmers. The rural communities in Nigeria, and Cross River State in particular, which are mainly agrarian are not adequately informed about how to maximize agricultural waste for reuse, or for economic gains. Therefore, it has become necessary to in addition to other poverty intervention programmes, Agricultural stakeholders and government of Nigeria to incorporate agri-waste management as adaptation solutions to reduce poverty, and thus make living sustainable for rural communities. By establishing and encouraging agri-waste management practices alongside crop production activities, the livelihood opportunities inherent in agricultural waste could be identified and harnessed. This will enhance diversification and increased productivity of farmers engaged in these waste management practices. The urban society for instance cannot function maximally in development without the support of the rural areas, particularly in food supplies. To this end, there is dire need to sensitize and provide training for farmers in rural communities

in green entrepreneurship, particularly in agri-waste management. This could have positive effect on local content knowledge by improving the already inherent natural capacity of farmers to identify the entrepreneurial opportunities within their economic space. Furthermore, knowledge in green entrepreneurship would help them realise their responsibility to conservation and climate change mitigation and adaptation. Through adopting agricultural practices that are eco-friendly, farmers would be contributing to reduction in carbon foot print, food security among other sustainable living, in the growing green economy.

Stirring up the needed action: Through Collaboration, partnership and policy influence

Various stakeholders could either collaborate, partner or influence policy to establish the agri-waste management industry in agrarian communities in order to increase livelihood opportunities for farmers and rural dwellers. Stakeholders in food security and climate change mitigation and adaptation efforts include; Government agencies and non-governmental organizations like the Food, Agricultural Organization (FAO), and relevant parastatals; Federal and State Ministeries of Environment, Forestry Commission, Nigeria Conservation Foundation, to mention some.

1. Literature Support for green business ownership as poverty reduction measure

Green entrepreneurship skill set. Training in relevant skills would empower people with the right knowledge to become green business owners, such as owning agri-waste management plants. A cassava mill can have the waste management plant that harnesses the leaves, stems and peels for onward conversion to fertilizer and biofuel. Studies aver that this action has potential to become a big part of the adaptation solution to existing environmental challenges (UN-Habitat, 2017; Orji, Idika, Okeke, Anakwue & Ntamu, 2023). Furthermore, green business if practiced is capable of reducing unemployment amongst the youth and facilitate the actualization of Sustainable Development Goals (SDGs) (Richard, Olatunji & Samuel, 2021; United Nations Environment Programme (UNEP) (2020); European Development Initiatives, 2022).

2. Spreading the transformation news to support agri-waste management

Green entrepreneurship will lead to self-employment, self-reliance, employment for others, poverty reduction and a pathway towards achieving green transition (Orji, 2023). This is further underscored with the fact from the following authors, (Richards et al, 2021; Anabaraonye, Orji, Ewa & Arinze, 2023), that there is an enormous amount of wastes being generated, especially from crop production activities. Therefore, it is of great urgency to provide the people and communities with adequate information, to direct investment towards collective action that articulate agri-waste management practices. This action is expedient to support existing livelihoods, poverty reduction measures, including new job creation for the unemployed. Waste is wealth. Therefore, supporting actions for articulated waste management practices is something synonymous to providing a community with a source of drinking water or a road, that have been craved for, for many years. Establishing agri-waste management alongside crop production activities, is a

potential means for alternative or additional livelihood.

Conceptual framework

Agri-waste management-----Sustainable Livelihoods---Poverty reduction and Adaptation solutions

Theoretical background

This paper gets theoretical support from

i) The Sustainable Livelihoods Approach. The sustainable livelihoods approach is a way of thinking about the objectives, scope, and priorities for development activities. It is based on evolving thinking about the way the poor and vulnerable (individuals, communities or countries) live their lives and the importance of policies and institutions in changing the narrative. The sustainable livelihoods approach facilitates the identification of practical priorities for actions that are based on the views and interests of those concerned. It brings attention to bear on the inherent potential of people in terms of their skills, social networks, access to physical and financial resources, and ability to influence core institutions, just as it is envisaged with the outcome of this conference. If policy is influenced in the desired direction lives of the citizens who adopt these entrepreneurial opportunities would be impacted positively, in the future.

ii) The Social cognitive theory of Bandura (2001). The theory explains that people are self regulating, proactive, self reflective, self organizing and have the power to influence their own actions to produce desired consequences. The implication of this theory applies to stirring people to adopt waste management practices (example, agri-waste management) individually, and as community. In essence, individuals can make use of their cognitive processes as a point of reference to be climate change sensitive, be conservative conscious and create wealth from waste management practices (reduce, reuse, recycle). On the other hand, individuals would know that the decision they take has outcomes. if they leave the useful-waste un-used they may face the effects of the pollution, and loss of the economic gain therein. They also lose the chance to engender other support to their livelihoods. Similarly, through information and training, individuals may gain needed knowledge and become able to self direct or regulate, thus adopt the desired behaviour (waste management practices) that would guarantee support for their livelihoods.

Conclusion

Based on the foregoing, they would be need for relevant organs of Government to understand these relationships (agri-waste management, sustainable livelihoods, poverty reduction and adaptation solutions) develop effective strategies to promote sustainable livelihoods and reduce poverty while fostering climate resilienceby promoting adoption of climate change mitigation measures. Therefore, providing information and training support to the people in the agrarian communities to adopt these waste management practices, would be a huge step in finding solutions to environmental issues, climate change and achievement of Sustainable Development Goals. in Cross River State, Nigeria, Africa, and globally.

Suggestions for adoption support and Policy actions needed include:

1. To train and create needed awareness that would encourage environment conservation attitude, behaviours, and lifestyle among individuals, and communities in Cross River State.
2. To sensitize and train individuals, on agri- waste management/ Practices.
3. Capacity development in green entrepreneurship, agripreneurship. This is expected to support livelihoods and address the problems of poverty and hunger; among other environmental issues.
4. Sell to individuals and communities, other evidence-based and economically-viable agro based business opportunities. It will serve as support to existing livelihoods, also serving as a fresh self-employment opportunity.
5. Government and policy makers should buy into this idea of integration of agri-waste management alongside crop production activities, for the purpose of supporting additional income, generating employment and enhancing environmental sustainability.

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Coping Mechanisms of IDPs Amid Boko Haram Insurgency: *Challenges and Effectiveness*

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ABSTRACT

The Boko Haram insurgency has triggered widespread displacement in Northeast Nigeria, forcing millions into overcrowded camps and host communities with inadequate access to basic services. This study examines the coping mechanisms of internally displaced persons (IDPs) in Bama, Gwoza, and Marte Local Government Areas of Borno State. Utilizing mixed methods, data was gathered through structured questionnaires, focus group discussions, and key informant interviews. The findings reveal that IDPs rely on informal livelihood activities, external assistance, and communal networks to survive, despite limited access to education, healthcare, and economic opportunities. Education is severely disrupted, with 49.86% reporting increased out-of-school children due to the use of schools as shelters. Health challenges persist, with 62.13% identifying malaria as the most prevalent disease. Livelihood disruptions have left 50.68% earning below ₦5,000 monthly. The study highlights the need for targeted interventions to strengthen resilience and improve living conditions among displaced populations.

Keywords: Boko Haram, IDPs, coping mechanisms, education disruption, healthcare challenges.

INTRODUCTION

Coping capacity or mechanism describes the ability of a system to anticipate and act effectively in response to disasters. It includes resource management and the use of absorptive capacity to recover quickly and efficiently (Parsons, 2016). This Absorptive Capacity refers to a society's ability to reduce disaster impacts by using predetermined coping mechanisms and strategies. This capacity focuses on mitigating immediate impacts through preparation and proactive measures (Cutter, 2008). Disaster Risk Reduction a conceptual framework designed to minimize vulnerabilities and risks in society to prevent (or mitigate) the adverse impacts of hazards while promoting sustainable development, encompasses preparedness, response, and recovery measures that aim to protect lives, property, and livelihoods (UNISDR (2008). According to the Sendai Framework for Disaster Risk Reduction (2015-2030), DRR also includes building resilient infrastructure and institutions, particularly in areas prone to climate-related disasters. Research are urgently needed for climate adaptation to complement mitigation efforts, particularly as climate-related disasters become more frequent and severe. Complementary adaptation measures are crucial to building resilience against disasters, safeguarding development gains, and ensuring the sustainability of communities and ecosystems (Abbas et al., 2022; Dellmuth & Gustafsson, 2021).

For Nigeria's National Emergency Management Agency (NEMA), integrating climate adaptation into its disaster management framework is essential to address the increasing risks of climate-induced disasters. By enhancing adaptive, absorptive, and coping capacities at institutional and community levels, NEMA can build a proactive and sustainable disaster management system that addresses both current and future risks.

Disaster Risk Reduction (DRR) can minimize the adverse impacts of disasters by reducing vulnerabilities and building resilience. Since its inception during the International Decade of Natural Disaster Reduction (IDNDR: 1990–1999), the focus has shifted from hazard reduction to risk reduction and resilience building. Furthermore, the term "natural disaster" has been replaced with "natural hazard," recognizing that disasters are the consequences of unaddressed vulnerabilities rather than the hazards themselves. Modern DRR frameworks also emphasize systemic risks and cascading disasters, reflecting the interconnected nature of contemporary challenges (Rajib Shaw et al., 2022).

STUDY AREA

North East Zone, Maiduguri, Borno State

1.2.1 Location

Borno State is situated between latitudes 10°30' and 14°30'N and longitudes 11°30' and 14°45' E. The State occupies a significant portion of the Chad Basin and shares international borders with the Republic of Niger to the north, Chad to the northeast, and Cameroon to the east (See Figure 3.1). Domestically, it is bordered by Adamawa state to the South, Yobe state to the West, and Gombe state to the Southwest (Ijere and Daura, 2000). The study was conducted at the National Emergency Management (NEMA) North East Zonal Office in Borno State, located in the northeastern region of Nigeria with Coordinates: Latitude 11.8464° N, Longitude 13.1571° E. Maiduguri, the capital of Borno State, serves as the headquarters of the North-East Zonal Office of NEMA. It is strategically located in northeastern Nigeria and coordinates disaster management for states including Yobe, Adamawa, Gombe, Bauchi, and Taraba. The region experiences severe challenges such as drought, desertification, and flooding, compounded by socio-economic vulnerabilities and conflict-induced displacement. Studying in this area would highlight the role of climate resilience and adaptation strategies in managing both climatic risks and the resulting humanitarian crises (e.g displacement and food insecurity).

Study Area Information

1.2.2 Climate

The region has a Sahelian climate, characterized by high temperatures (35–45°C), low annual rainfall (400–600 mm), and long dry seasons. Borno State experiences hot and dry conditions for most of the year, although the southern part of the state enjoys slightly milder weather. The state has an annual mean minimum temperature of 21.7°C and an annual mean maximum temperature of 36.0°C (National Bureau of Statistics (NBS), 2012).

The number of rainy days, decreases from south to north, varying between 80 days in the south and fewer than 40 days in the north. For example, in 2004, Biu recorded 60 rainy days with a total rainfall of 951 mm, while Ngala recorded only 20 rainy days with 499 mm of rainfall (Statistical Year Book, 2006).

1.2.3 Relief and Drainage

Borno State features two primary relief formations: the highlands of the Biu Plateau and Mandara Mountains in the southern part, which rise to about 650 meters above sea level, and the expansive Lake Chad plains in the northern part of the state, with an average elevation of 300 meters above sea level. The highlands dominate the southern and southeastern regions of the state, covering approximately one-third of Borno's total land area. The remaining two-thirds are comprised of plains generally less than 300 meters above sea level (Kogbe, 1989).

The terrain is largely flat and semi-arid, with poor drainage systems due to minimal surface water. The Komadugu-Yobe river is one of the few significant water bodies in the area, the drainage system in Borno State is divided into two main groups of rivers: one draining southward into the Benue River system, and the other flowing towards Lake Chad. The state's rivers are predominantly seasonal, with peak flows occurring during the rainy season in July and August. The Biu Plateau, located in the southern part of the state, is primarily drained by the Hawul River, which flows southward into the Gongola River (Ijere & Daura, 2000).

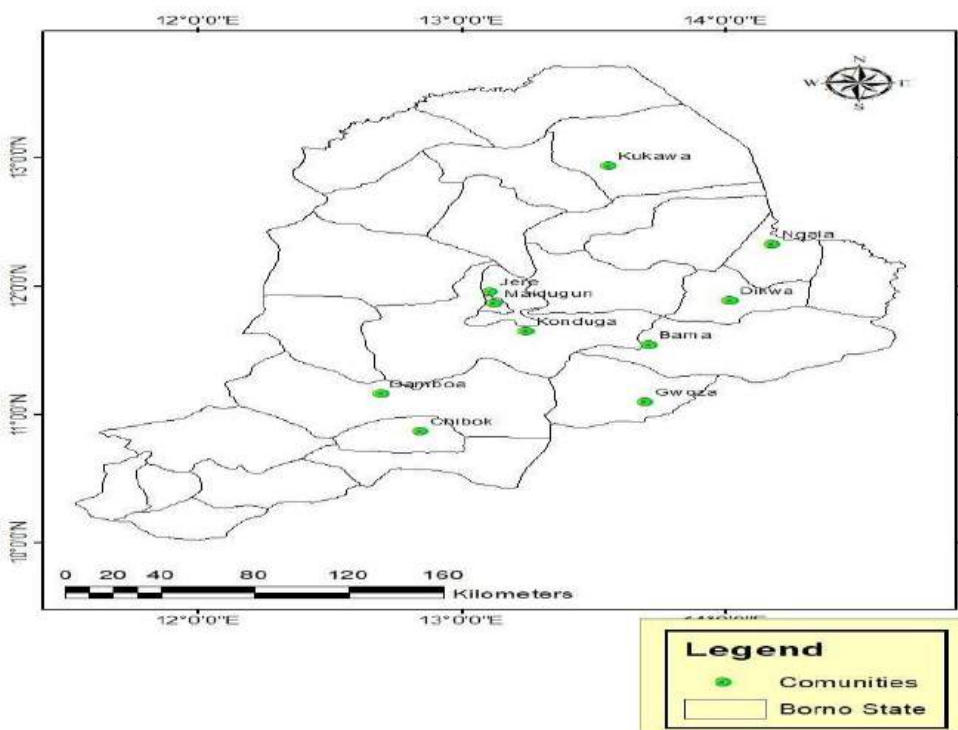


Figure 1: Map of the Study Area

Source: Cartography Laboratory, Bayero University Kano (2024).

METHODOLOGY

This section presents and discusses the various procedures adopted in conducting this research including the various steps adopted while in the field work. It also presents the types of data, sources and methods of data collection, research design, population of the study, sampling and sampling technique, data processing and analysis.

1.1 Data Types and Sources

The study employed both primary and secondary data sources and utilized a quantitative approach, and the quantitative data were gathered through surveys using questionnaires. The data collected and their Sources and Purpose are presented on Table 1 below.

Table 1: Types and Sources of Data Required for the Study

S/N	Types of Data Purpose of Data	Source of Data	
1.	Data on the Socio-economic Variables	Questionnaire Survey	Characterization
2.	Data on benefits of establishing a coping mechanisms of IDPs amid any insurgency Department at NEMA	Questionnaire Survey	Examine benefits
3.	Improve NEMA's preparedness and response to a coping mechanisms in IDPs amid any insurgency	Questionnaire Survey	Analyze how to incorporate into the proposed department
4.	Aligning NEMA's operations with Nigeria's commitments under international agreements such as the Paris Agreement and the Sendai Framework.	Questionnaire Survey	Assess the role of the proposed department
5.	Integrating coping mechanism measures amid any insurgency into NEMA's framework	Questionnaire Survey	Identify the challenges and opportunities involved

Source: Author Compilation (2024)

1.2 Data Collection Instruments

Data were as collected using a structured questionnaire, the structured questionnaire provided respondents with a set of alternative responses, from which they selected the most appropriate option.

1.2.1 Questionnaire survey

A structured questionnaire was designed using an electronic mobile application called Kobo Collect, which was downloaded from the Google Play Store on an Android operating system. The application was used to collect data and automatically sync it into the Kobo Toolbox account. The survey aimed to gather information from respondents on the Socio-economic variables, respondents' opinion about the existing gaps in NEMA's disaster management and coping mechanism framework amid any insurgency.

1.2.2 Sample size and Sampling Technique

The population for this study consists of staff from Maiduguri Zonal office of NEMA. The office was chosen as the study area is due to their strategically aligned with the need to comprehensively evaluate the relevance of coping mechanism and adaptation strategies for enhancing disaster management at the National Emergency Management Agency (NEMA). The location represents a distinct geographical, socio-economic, and disaster-prone context within Nigeria, providing diverse perspectives on effect of coping mechanisms and its challenges within NEMAs response capacity.

RESULTS AND DISCUSSION

This section presents and discusses the detailed results and responses obtained during the study, offering an overview of the research analysis conducted using various statistical methods. In total, Three Hundred and Sixty-Seven (367) questionnaires were administered; hence, the discussion is based on the responses of these 367 participants.

1.3 Demographic and Socio-economic characteristics of the respondents:

The demographic analysis provides insights into the characteristics of respondents and how socio-economic factors shape their perceptions, experiences, and vulnerabilities related to disaster management, effect and challenges of coping mechanism amid any insurgency. The findings are compared with existing studies for supporting evidence and criticism where applicable.

Table 2 provides a summary of the demographic and socio-economic characteristics of the respondents involved in the study. It details variables such as sex, education level and occupation of the respondents. The table presents both the frequency and percentage distribution of these variables, offering a comprehensive overview of the demographic and socio-economic profile of the respondents, which is crucial for understanding the context of the study and analyzing the relevance of proving an effective coping mechanism amid any insurgency for enhancing disaster management at the national emergency management agency (NEMA), Nigeria.

Table 2: Frequency distribution of respondents' demographic and Socio-economic characteristic variables.

Variable	Frequency	Percentage
Sex		
<i>Female</i>	176	48.0%
<i>Male</i>	191	52.0%
Education		
<i>Non-Formal</i>	170	21.3%
<i>Primary</i>	78	21.3%
<i>Secondary</i>	87	23.7%
<i>Tertiary</i>	32	46.73%
Occupation		
<i>Farming</i>	200	45.50%
<i>Business/Trading</i>	103	15.07%
<i>Civil Service</i>	64	17.44%

Source: Authors estimates from survey data (2022)

Male (58%) and Female (42%) respondents participated in the study, showing a relatively balanced gender representation but with a slight male dominance. Specifically, 52.0% of the respondents were male headed, while 4.08% were female headed. The percentage of the female headed households was 4.08% lower than that of the male headed households. This is consistent with Ogunmefun and Achike (2015), who observed a higher male participation rate in disaster and socio-economic studies, particularly in northern Nigeria, where cultural norms influence women's participation in surveys. Studies such as Dazé (2019) argue that underrepresentation of women in data collection may obscure their unique vulnerabilities, particularly in disaster contexts where women and children are disproportionately affected.

Tertiary education (46.73%) and Secondary (23.7%) were the dominant levels of education, while Primary (21.3%) and non-formal education (8.3%) accounted for the remaining respondents. The lower levels of education reflect the socio-economic realities of communities in conflict- and climate-affected regions like Borno and rural Kano.

This aligns with Aliyu et al. (2021), who found that education levels directly influence awareness effect of any coping mechanism amid any form of insurgency and disaster preparedness. Dazé (2019) argues that limited education contributes to poor understanding and a coping mechanism amid any form of insurgency adaptation strategies. Education disparities must be addressed through training programs to build awareness and technical capacity for disaster management.

Farming (45%) and business/trading (30%) were the dominant occupations, followed by civil service (15%) and artisans (10%). Unemployment was notably high in conflict-affected areas, particularly among youth. The dependence on agriculture highlights the vulnerability of respondents to climate change and insurgency impacts such as droughts, floods, desertification and conflicts.

Similar patterns were observed in IPCC (2022), which reported that agricultural-dependent communities in sub-Saharan Africa are at greater risk of climate-induced disasters.

Overrepresentation of agricultural workers may limit insights into the vulnerabilities of other occupational groups such as professionals or service providers. UNDRR (2024) suggests diversifying occupational categories to understand the broader economic impacts of disasters.

1.4 Aligning NEMA's operations with Nigeria's commitments under international agreements such as the Paris Agreement and the Sendai Framework.

To assess the role of the department in aligning NEMA's operations with Nigeria's commitments under international agreements such as the Paris Agreement, Figure 3 below illustrates the impact of improving preparedness and response to a coping mechanisms in IDPs amid any insurgency shows that 70% agreed that the proposed department would help align NEMA's operations with Nigeria's Nationally Determined Contributions (NDCs) under the Paris Agreement. Also, 65% indicated that the department would facilitate improved monitoring, evaluation, and reporting on a coping mechanisms in IDPs amid any insurgency initiatives in line with global commitments.

Moreover, 60% highlighted that alignment with international frameworks would enable NEMA to access technical and financial support from global organizations and also 55% suggested that the department could create platforms for collaboration and knowledge sharing with international partners. This alignment could enhance resource mobilization. However, reliance on external funding may introduce dependencies that hinder self-reliance

Table 3: Role in Aligning with Frameworks

S/N	Role	Frequency (%)
1	NDC Alignment	70
2	Monitoring and Reporting	65
3	International Support	60
4	Collaboration Platforms	55

1.5 Integrating coping mechanism measures amid any insurgency into NEMA's framework:

To identify the challenges and opportunities involved in establishing a section in the proposed department within NEMA's organizational structure, findings as observed from table4 shows that 67% agreed that insufficient budget allocation may hinder the establishment of the section within the proposed department while, 55% of respondents believed that organizational inertia and internal resistance might slow down implementation. Meanwhile, 60% highlighted a lack of

trained personnel to effectively manage coping mechanisms in IDPs amid any insurgency projects.

On the Opportunities aspects 70% identified opportunities for securing international funding and technical assistance and 65% noted that the department would address current gaps in disaster management frameworks. Meanwhile, 58% suggested that the department would facilitate targeted community-based adaptation strategies to reduce vulnerabilities. While challenges such as budget constraints are significant, opportunities like international funding could bridge resource gaps.

Table: Challenges and Opportunities

S/N	Category	Frequency (%)
1	Insufficient Budget	67
2	Organizational Inertia	55
3	International Funding	70
4	Policy Gap Solutions	58
5	Trained Personnel	60
6	Community Adaptation	58

CONCLUSION

For Nigeria's National Emergency Management Agency (NEMA), integrating climate adaptation into its disaster management framework is essential to address the increasing risks of climate-induced disasters. By enhancing adaptive, absorptive, and coping capacities at institutional and community levels, NEMA can build a proactive and sustainable disaster management system that addresses both current and future risks.

Disaster Risk Reduction (DRR) can minimize the adverse impacts of disasters by reducing vulnerabilities and building resilience. Since its inception during the International Decade of Natural Disaster Reduction (IDNDR: 1990–1999), the focus has shifted from hazard reduction to risk reduction and resilience building. Furthermore, the term "natural disaster" has been replaced with "natural hazard," recognizing that disasters are the consequences of unaddressed vulnerabilities rather than the hazards themselves. Modern DRR frameworks also emphasize systemic risks and cascading disasters, reflecting the interconnected nature of contemporary challenges (Rajib Shaw et al., 2022). From the general findings it noted that establishing a dedicated Climate Resilience and Adaptation Department at NEMA has the potential to close significant gaps in the agency's disaster management framework. The department can: Improve preparedness and response to climate-related disasters, Align NEMA's operations with Nigeria's commitments under international agreements, Enhance resource mobilization, technical capacity, and community engagement.

However, challenges such as insufficient funding, limited technical expertise, and resistance to change need to be addressed. Targeted recommendations, including capacity building, policy revisions, and international partnerships, are critical for successfully strategic coping mechanism amid any insurgency into NEMA's operations.

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Building Climate Resilience Among Tomato (*Lycopersicon Esculentum* L. Var) Farmers Using Local Organic Fertilizers

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ABSTRACT

The field experiment assesses effects of six locally manufactured legume-based organic fertilizers on tomato plant. The six legume-based organic fertilizers produced by composting vegetal matter of *Centrosema pubescens*, *Mucuna bracteata*, *Calopogonium mucunoides*, *Mucuna pruriens*, *Lablab purpureus*, and *Stylosanthes capitata* respectively with rice husk, poultry waste and swine waste in a ratio 5:4:4:4 dry weight, NPK 15:15:15 and no-fertilizer (Control) treatments were the eight treatments of the experiment applied respectively on 10kg topsoil containerized in 35cm x 30cm poly-pots on which tomatoes were grown. Six 10kg soils were mixed to 10t/ha of each of the six organic fertilizer before the tomatoes were transplanted-in, while one 10kg soil was treated to 800kg/ha NPK 15:15:15 fertilizer two weeks before, and one 10kg soil has neither manure nor NPK. Tomato seedlings were transplanted from germination box into the poly-pots at two weeks old. A sample size of 4 tomato plants made up 32 plants per block, and total 96 plants were used for the experiment arranged in RCBD with 3 replications. Data collected weekly for 9 WAP on plant height, girth and number of leaves were subjected to ANOVA using SPSS 20. Means separation was by Duncan Multiple Range Test at $P < 0.05$. The result shows significant differences across treatments in the height, girth and number of leaves of the tomato plants. Compounded organic fertilizers recorded higher plant height, girth and number of leaves than the NPK and the control treatments. The legume-based organic fertilizers demonstrated potentials to enhancing soil fertility, growth and productivity of crops; and should be recommended.

Keywords: Soil fertility, legume-based organic fertilizers, tomato plant growth and productivity

INTRODUCTION

Tomato (*Lycopersicon esculentum* L. var) is an important vegetable crops worldwide with a total production of around 141 million tons on a cultivated area of 5 million

hectares (Shantha *et al.*, 2012). It is ranking 1st in the world for vegetables and accounts for 14% of world vegetable production (over 100 million metric tons/year \$ 1.6 billion market; (Bauchet and Causse, 2012). Tomato production in Nigeria is ranked 6th globally, representing 10.8% of Africa's and 1.2% of the world's production of tomato (Afolabi *et al.*, 2017). The fruit is green in colour when not fully ripe and contains other carotenoid along with lycopene but in fully ripe stage lycopene is the only carotenoid present in tomato (Singh *et al.*, 2012; Collins *et al.*, 2022). Lycopene is important not only because of the color it imparts but also because of the recognized health benefits associated with its presence (Hasturk *et al.*, 2011). Tomato is particularly a good source of carotenoids/phenols which protects against cardiovascular disease, diabetes and stroke (Scalbert and Williams, 2000; Collins *et al.*, 2022). It is a rich source of minerals, vitamins, organic acid and dietary fiber; and have been reported to decrease risk for prostate, lung, and stomach cancer (Bramley, 2000; Rajkumar *et al.*, 2006; Collins *et al.*, 2022). In fact, the plant has very many well documented benefits. These enormous benefits notwithstanding, the production of tomatoes in southeastern Nigeria as with many other crops, is bedeviled by the characteristic low soil fertility of the region as reported by several authors (Omotayo and Chukwuka, 2009; Nwosu *et al.*, 2011; Omenihu *et al.*, 2011; Ngome *et al.*, 2011; Osodeke, 2017 Nwajiobi *et al.*, 2020b). This being worsened by the global climate change phenomenon (Nwajiobi *et al.*, 2013; Arunima *et al.*, 2023). Though inorganic fertilizers are the quickest way of nutrient supply to soil, there are serious challenges with the continuous use of inorganic fertilizers which include increasing soil acidity, eutrophication of nearby water bodies, damage to soil structure, contamination of underground water, and the growing unavailability and high cost of inorganic fertilizers (Nwosu *et al.*, 2011, Mbah *et al.*, 2012; Uka *et al.*, 2013; Moyin-Jesu, 2015). These challenges cannot be ignored and some of them can worsen with climate change. The use of organic fertilizers such as cow dung has its own limitations such as not being sufficiently available at the recommended rates, it is bulky and labour intensive for transportation and application, and it is often of poor quality (Ngome *et al.*, 2011). Notwithstanding, organic manures are increasingly preferable to inorganic fertilizers because it not only replenishes lost soil nutrients, but also improves the physical, chemical and biological properties of such soils (Omotayo and Chukwuka, 2009).

Legumes which are known for their high crude protein content; and are useful for many purposes such as food for humans, feed for animals including for grazing livestock, as ground cover for suppression of weeds and for protection of soil from flooding and erosion; are very useful in soil nutrient and fertility management (Nwosu *et al.*, 2011, Ambika *et al.*, 2023; Nwajiobi *et al.* 2018, 2020a, b and c). Arunima *et al.* (2023) reported that biofertilizers significantly improved the performance of tomato, while Nwajiobi *et al.* (2018 and 2020c) reported that the legume-based organic fertilizers enhanced the growth performances of maize and *Amaranthus* respectively. This research is a field trial to comparatively evaluate the effects of the legume-based organic fertilizers on tomato plant growth.

MATERIALS AND METHOD STUDY AREA

The experiment was carried out at the Nursery Unit of the Department of Forestry and Environmental Management (FOREM), Michael Okpara University of Agriculture Umudike, Abia State at onset of the rainy season. Umudike is situated within 50° 30'N and 70° 31'E on the lowland rain forest of Nigeria, at an elevation of 122 meters above sea level (Nwosu *et al.*, 2011, Chukwu *et al.*, 2024) (Fig. 1). Annual rainfall ranges from 1800mm to 2200mm with the intensity reaching up to 100mmhr⁻¹. Temperature is high throughout the year with a range of 33°C -35°C as the maximum and 28°C to 29°C as minimum (Nwosu *et al.*, 2011), while relative humidity varies from 51% to 87%. The soil is acid sandy loam in the ultisol group with pedosite within Ahiara soil series (normal) in soils of Ikwuano, underlain by Coastal Plain Sands as the geology and parent material (Omenihu *et al.*, 2011, Chukwu *et al.*, 2024).

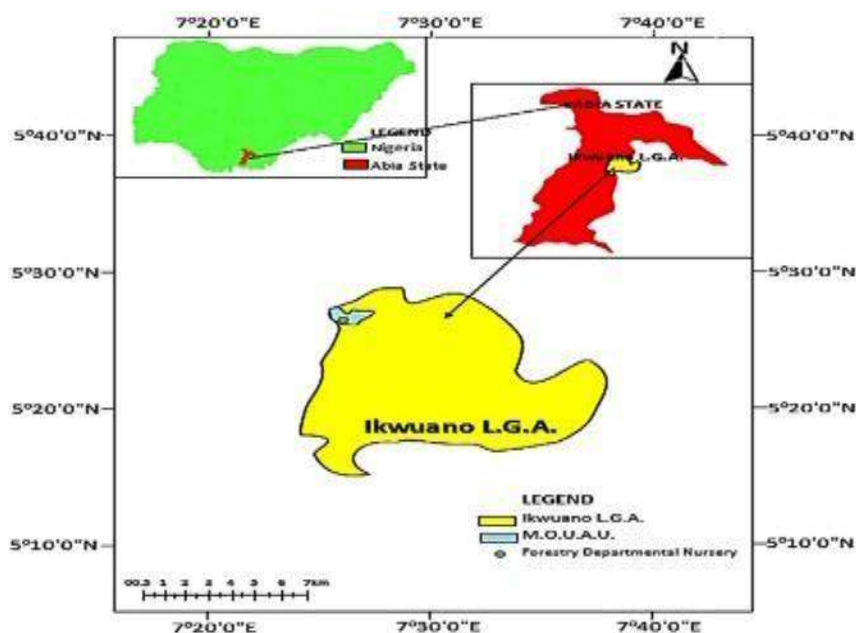


Fig. 1. Map of Ikwuano LGA, Abia State showing FOREM Nursery in MOUAU, Ikwuano LGA, Abia State

Seeds: Tomato seeds used for the experiment were obtained from the National Seeds Service, Umudike Centre. The seeds were broadcasted and germinated in germination boxes measuring 50cm x50cm x 10cm, and transplanted at two weeks old.

Fertilizers: Fertilizers used were the NPK 15:15:15, the various legumes-based organic fertilizers which was produced from composting a mixture of vegetal matters of *Centrosema pubescens*, *Mucuna bracteata*, *Calopogonium mucunoides*, *Mucuna pruriens*, *Lablab purpureus*, and *Stylosanthes capitata* respectively with rice husk, poultry manure and swine dung in the ratio 5:4:4:4. The nutrient composition of the legume-based fertilizers have been reported (Nwajiobi *et al.*, 2020b).

Top soil and poly pots: Top soils collected from a fallow farm land besides the nursery unit of the FOREM was bulked, properly mixed and sieved to remove large particles, roots and debris. The composite soil sample was analyzed for physico-chemical properties at the Soil Laboratory of the National Root Crop Research Institute (NRCRI), Umudike, and analyzed using standard methods of soil analysis described by Udo, *et al.* (2001). Ten kilograms (10kg) of the soil was collected into poly pots measuring 35cm × 30cm for the experiment. A total of ninety-eight (98) poly pots measuring 35cm × 30cm were used for planting for the experiment

Experimental Layout: The experimental site was cleared manually. Poly pots containing top soil were subsequently arranged on the plot in a Randomized Complete Block Design in three replications (Plate 1). The poly pots containing the composite soils were treated to 10t/ha of the respective organic fertilizers before the tomato plants were transplanted-in. For the NPK 15:15:15 treatments, poly pots containing top soil were treated to 800kg/ha NPK 15:15:15 fertilization and the tomato planted after two weeks. Single tomato seedling was planted per pot. The experimental treatments are summarized in Table 1.

Table 1: Experimental treatments

Treatment	Description
1.	10t/ha <i>Centrosema pubescens</i> based organic fertilizer
2.	10t/ha <i>Mucuna bracteata</i> based organic fertilizer
3.	10t/ha <i>Calopogonium mucunoides</i> based organic fertilizer
4.	10t/ha <i>Mucuna pruriens</i> based organic fertilizer
5.	10t/ha <i>Lablab purpureus</i> based organic fertilizer
6.	10t/ha <i>Stylosanthes capitata</i> based organic fertilizer
7.	800kg/ha NPK15:15:15 inorganic fertilizer
8.	Top Soil Only (Control) no fertilizer



Plate 1(a and b). Experimental Plot at start and at end of the experiment.

Planting: The tomato seeds were broadcasted in germination boxes measuring 50cm x 50cm x 6cm filled with the experimental topsoil. Germinated and vigorous seedlings were transplanted into poly-pot containing 10kg of soil at two weeks old.

Cultural Practices: Watering was done once, in the evenings, daily. Weeds were hand-picked from the pots, while the space between the blocks and treatments were weeded with hoe.

Data Collection: Data on plant growth parameters such as plant height, girth (collar diameter), and number of leaves were collected weekly during the period of the experiment. Plants heights (cm) were measured using measuring tape from soil level in the poly pot to the apical meristem of the tomato plant. The plant girth or collar diameter (cm) was determined using veneer caliper at the collar region. Plant number of leaves were determined by counting the number of leaves per plant.

Data Analysis: Data collected were analyzed using Analyses of Variance (ANOVA) using SPSS 20. statistical tool. Significant differences were separated using DMIR at $p \leq 0.05$.

RESULTS AND DISCUSSION

Table 2. Effect of Fertilizers on Tomato height (cm).

TREATMENTS	4WAP	5WAP	6WAP	7WAP	8WAP	9WAP
T1 (<i>C. pubescens</i>)	14.20 ^a ±0.71	18.83 ^{ab} ±0.87	24.49 ^{ab} ±1.23	33.73 ^a ±1.27	42.75 ^a ±1.42	54.22 ^a ±0.89
T2 (<i>M. bracteata</i>)	11.64 ^{abc} ±0.76	16.49 ^{ab} ±1.03	21.07 ^{ab} ±1.40	27.07 ^a ±2.80	33.57 ^{ab} ±4.21	39.12 ^{ab} ±5.49
T3 (<i>C. mucunoides</i>)	11.32 ^{abc} ±0.51	15.63 ^{ab} ±0.43	19.66 ^b ±0.67	27.20 ^a ±1.99	34.80 ^{ab} ±2.33	44.20 ^{ab} ±3.63
T4 (<i>M. pruriens</i>)	12.94 ^{ab} ±1.01	18.59 ^a ±1.38	24.53 ^{ab} ±2.20	32.42 ^a ±3.30	40.63 ^{ab} ±4.67	48.97 ^{ab} ±6.08
T5 (<i>L. purpureus</i>)	13.08 ^{ab} ±1.73	18.33 ^a ±1.95	26.78 ^a ±4.36	34.98 ^a ±5.09	42.35 ^{ab} ±6.10	50.11 ^{ab} ±7.24
T6 (<i>S. capitata</i>)	10.80 ^{bc} ±1.03	14.68 ^b ±1.65	19.41 ^b ±2.12	27.46 ^b ±3.11	30.30 ^b ±5.78	37.00 ^b ±7.67
T7 (NPK 15:15:15)	9.54 ^c ±0.69	10.18 ^c ±0.62	11.31 ^c ±0.53	12.06 ^b ±0.64	12.98 ^c ±0.81	15.24 ^c ±0.76
T8 (Control)	6.38 ^d ±0.57	6.51 ^d ±0.57	6.58 ^c ±0.57	6.71 ^b ±0.59	7.45 ^c ±0.60	8.58 ^c ±0.34

abcde Means ± SE with similar superscripts in the same column are not significantly different ($P > 0.05$)

Effect of Fertilizers on Tomato height (cm)

The results (Table 2) show that the tomatoes height varied with treatment in the various weeks of data collection. At 4WAP, tomatoes treated with *C. pubescence* compost recorded highest height growth (14.20±0.71). Although height growth of *C. pubescence* compost treated tomatoes is not significantly different from the height growth of *M. bracteata*, *C. mucunoides*, *M. pruriens* and *L. purpureus* compost treated tomatoes, it is significantly different ($P < 0.05$) from height growth of tomatoes treated with NPK 15:15:15 and the control. At 7WAP plant height of all tomatoes treated with the various legumes compost were significantly higher ($P < 0.05$) than the tomatoes treated with NPK 15:15:15 and Control. Same trend was observed in the 8th and 9th WAP thereby indicating that the organic fertilizers encouraged plant height growth better than the NPK 15:15:15 and control. The result supported the findings of Akanbi *et al.* (2010), Louisa and Taguiling (2013), Chukwuka *et al.* (2014) that organic fertilizers supply the essential plant nutrients that enhance growth, development and optimum productivity of crops. It also supported Arunima *et al.* (2023) who reported that biofertilizers improved the performance of tomato as well as Nwajiobi *et al.* (2018) report that the legume-based organic fertilizers enhanced maize growth.

Table 3. Effect of Fertilizers on Tomato girth (cm)

TREATMENTS	4WAP	5WAP	6WAP	7WAP	8WAP	9WAP
T1 (<i>C. pubescens</i>)	1.59 ^a ±0.17	1.80 ^a ±0.17	2.02 ^a ±0.16	2.18 ^{ab} ±0.16	2.34 ^a ±0.14	2.85 ^a ±0.12
T2 (<i>M. bracteata</i>)	0.83 ^{cd} ±0.14	1.09 ^{cd} ±0.19	1.26 ^{bc} ±0.22	1.45 ^c ±0.22	1.62 ^{bc} ±0.23	2.08 ^b ±0.21
T3 (<i>C. mucunoides</i>)	0.78 ^{cd} ±0.14	1.00 ^{cd} ±0.20	1.19 ^{bc} ±0.24	1.55 ^c ±0.21	1.66 ^{bc} ±0.20	2.23 ^b ±0.20
T4 (<i>M. pruriens</i>)	0.62 ^d ±0.19	0.92 ^{cd} ±0.19	1.35 ^{bc} ±0.23	1.38 ^c ±0.25	1.84 ^b ±0.21	2.40 ^b ±0.20
T5 (<i>L. purpureus</i>)	1.30 ^{ab} ±0.19	1.61 ^{ab} ±0.17	1.90 ^a ±0.19	2.32 ^a ±0.20	2.45 ^a ±0.20	2.98 ^a ±0.08
T6 (<i>S. capitata</i>)	1.16 ^{bc} ±0.12	1.33 ^{bc} ±0.11	1.62 ^{ab} ±0.14	1.78 ^{bc} ±0.13	2.10 ^{ab} ±0.08	2.25 ^b ±0.09
T7 (NPK 15:15:15)	0.93 ^{cd} ±0.12	1.08 ^{cd} ±0.08	1.23 ^{bc} ±0.06	1.29 ^{cd} ±0.05	1.32 ^c ±0.05	1.35 ^c ±0.06
T8 (Control)	0.74 ^{cd} ±0.02	0.78 ^d ±0.02	0.81 ^c ±0.02	0.83 ^d ±0.02	0.84 ^d ±0.03	0.84 ^d ±0.03

abcde Means ± SE with similar superscripts in the same column are not significantly different (P > 0.05)

Effect of the Fertilizers on Tomato girth (cm)

Table 3 shows the effect of the fertilizers on the growth in girth of tomato plant. The result show that at 4WAP, only girths of tomato plants treated with compost of *C. pubescens*, *M. pruriens* and *L. purpureus* were significantly greater (P<0.05) than girths of plants treated with NPK 15:15:15 and the untreated (control). However, at 7WAP, all the legumes compost treated tomatoes plant's girth were significantly greater (P<0.05) than the tomato plants treated with NPK 15:15:15 and the untreated (control). Thus the fertilizers appear to increase growth of tomato plant's girth as it did the height. Similar trend was observed at 8WAP and 9WAP. All organic fertilizer treated tomatoes recorded significant girth increase than the control and the NPK 15:15:15 fertilizer. This further demonstrated that organic fertilizers enhanced tomato growth than the inorganic fertilizers and the untreated (Control) soil. The findings support report of Nwajiobi *et al.* (2020a) that the legumes vegetal matter are rich in mineral elements which are available to plants when composted. It also supported Moyin-Jesu (2015) who reported lower values of cabbage head yield and growth parameters with NPK 15:15:15 compared to poultry manure treatment. Many authors have indeed reported that organic fertilizers enhance growth, development and optimum productivity of crops (Akanbi *et al.*, 2010; Louisa and Taguiling, 2013; Chukwuka *et al.*, 2014 and Arunima *et al.*, 2023).

Table 4. Effect of Fertilizers on Number of leaves of Tomato Plant

TREATMENTS	4WAP	5WAP	6WAP	7WAP	8WAP	9WAP
T1 (<i>C. pubescens</i>)	3.50 ^b ±0.22	6.83 ^{ab} ±0.40	8.83 ^{ab} ±0.40	10.67 ^a ±0.49	11.67 ^{ab} ±0.49	14.00 ^a ±0.89
T2 (<i>M. bracteata</i>)	4.00 ^a ±0.00	5.17 ^b ±0.48	6.50 ^b ±0.76	7.83 ^a ±0.91	8.67 ^b ±1.02	10.17 ^a ±1.17
T3 (<i>C. mucunoides</i>)	4.00 ^a ±0.00	6.17 ^{ab} ±0.48	7.83 ^{ab} ±0.65	9.33 ^a ±0.95	10.33 ^{ab} ±0.95	11.50 ^a ±1.06
T4 (<i>M. pruriens</i>)	3.83 ^{ab} ±0.17	7.83 ^a ±0.83	9.50 ^a ±1.09	10.67 ^a ±1.45	11.83 ^{ab} ±1.45	12.67 ^a ±1.45
T5 (<i>L. purpureus</i>)	4.00 ^a ±0.00	6.83 ^{ab} ±0.60	8.50 ^{ab} ±0.81	10.67 ^a ±1.20	12.50 ^a ±1.57	13.67 ^a ±1.89
T6 (<i>S. capitata</i>)	3.83 ^{ab} ±0.17	5.50 ^b ±0.67	7.67 ^{ab} ±1.23	9.50 ^a ±1.61	10.33 ^{ab} ±1.87	11.33 ^a ±2.32
T7 (NPK 15:15:15)	3.00 ^c ±0.00	3.50 ^c ±0.50	2.17 ^c ±0.31	2.50 ^b ±0.34	1.67 ^c ±0.33	1.17 ^b ±0.54
T8 (Control)	2.83 ^c ±0.17	2.83 ^c ±0.48	1.50 ^c ±0.22	1.67 ^b ±0.21	1.50 ^c ±0.22	0.00 ^b ±0.00

abcde Means ± SE with similar superscripts in the same column are not significantly different (P > 0.05)

Effect of Fertilizers on Number of leaves of Tomato Plant

The result (Table 4) shows that the number of leaves of the legume-compost treated tomatoes were significantly higher than the number of leaves on the tomatoes treated with NPK 15:15:15 and the control from 4WAP to 9WAP. Beyond 7WAP, the leaves of the NPK 15:15:15 and the control treatments were dying off the plants probably due to exhaustion of the nutrient elements in its growth media. Generally, the organic fertilizers treated tomatoes show better and healthier growth and development than the NPK 15:15:15 and the control treatments respectively. The findings agree with Akanbi *et al.* (2010), Louisa and Taguiling (2013) and Chukwuka *et al.* (2014) that organic fertilizers supply the essential plant nutrients that enhances growth, development and optimum productivity of crops. The findings also supported Arunima *et al.* (2023) report that biofertilizers improve the performance of tomato, as well as Nwajiobi *et al.* (2018 and 2020c) reports of enhanced growth performance of maize and Amaranthus with the legume-based organic fertilizers.

The least values of number of leaves; as well as least values of plant height and girth discussed earlier; obtained under the control treatment compared to other treatments could be as a result of low soil fertility status that characterize soils of southeastern Nigeria. This finding was supported by Moyin-Jesu (2015) who worked on use of various organic fertilizers on soil fertility improvement, growth and head yield parameters of cabbage (*Brassica oleraceae* L), and reported that the various organic fertilizers (poultry manure, wood ash and rice bran) applied increased the growth, head yield of cabbage and soil N, P, K, Ca, Mg, pH and organic matter (O.M).

Conclusion and Recommendation

Nigeria is endowed with numerous underutilized leguminous species, many of which grow in the wild as weeds. Vegetal matter of these leguminous plants, as well as other agricultural wastes are rich in minerals which can be made available as nutrient to crops through composting. The use of these relatively abundant organic materials for compounded organic fertilizer production has enormous potentials in soil management, biodiversity conservation, agro-ecosystem stabilization and climate change adaptation/mitigation. The locally produced legume-based organic fertilizers significantly improved tomato growth. This is in addition to well-known ecological and biodiversity conservation advantages of such organic fertilizers. *L. purpureus*, *M. bracteata* and *M. pruriens* based organic fertilizers have higher adaptability based on the growth attributes of the tomato plants assessed, should be recommended. Farmers are also encouraged to identify and utilize locally abundant agricultural wastes applying similar technology to manage soil fertility rather than sole reliance on inorganic fertilization. Further research with other legumes species of which their uses are relatively unknown is recommended, as it will also enhance the conservation status of these species based on the theory that use enhances species conservation. Large scale production and use of the improved organic fertilization technologies should be encouraged and promoted through provision of grants and subsidies. Agricultural and forestry extension agents should publicize improved technologies and the research findings to especially rural farmers, to encourage and facilitate its adoption.

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Antibacterial Potential of Saponin- And Flavonoid-Enriched Extracts from Clove (*Syzygium Aromaticum*) Against Foodborne Pathogens

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Abstract

This study examines the antibacterial potential of saponin- and flavonoid-enriched fractions extracted from the clove plant (*Syzygium aromaticum*) against some foodborne bacterial pathogens, including *Escherichia coli*, *Streptococcus* spp., and *Corynebacterium* spp. Using optimized extraction techniques, high yields of bioactive compounds were obtained, with saponins yielding 2.30 g/100 g and flavonoids 1.30 g/100 g. The antibacterial activity of these fractions was assessed using standard sensitivity tests. The minimum inhibitory concentrations (MICs) for *E. coli* were 62.5 µg/mL (saponins) and 250 µg/mL (flavonoids), while the minimum bactericidal concentrations (MBCs) were 125 µg/mL and 500 µg/mL, respectively. For *Streptococcus* spp., the MIC values were 125 µg/mL (saponins) and 500 µg/mL (flavonoids), with corresponding MBCs of 250 µg/mL and >500 µg/mL. A chi-square test revealed no significant difference in the antibacterial effects of saponins and flavonoids against *E. coli* ($\chi^2 = 1.049$) and *Streptococcus* spp. ($\chi^2 = 0.407$). However, a significant difference was observed for *Corynebacterium* spp. ($\chi^2 = 9.549$). These findings suggest that saponin- and flavonoid-enriched fractions effectively inhibit bacterial growth, highlighting their potential application in food safety and antimicrobial therapy.

Keywords: Antibacterial, Saponin, Flavonoid, Clove, foodborne pathogens, *Syzygium aromaticum*

INTRODUCTION

Clove (*Syzygium aromaticum*) has long been recognized for its rich array of bioactive compounds, notably flavonoids and saponins, which contribute to its traditional medicinal uses. Recent studies have highlighted the antibacterial properties of these phytochemicals. For instance, flavonoids are known to disrupt bacterial cell walls and inhibit biofilm formation, while saponins exhibit membrane-permeabilizing effects that can lead to bacterial cell lysis (Shehu *et al.*, 2023; Aji and Azizah, 2023).

Food-borne pathogens have become serious social issues that have drawn a lot of attention from consumers and food safety regulatory authorities globally as a result of

these frequent outbreaks of microbial infections (Usman *et al.*, 2022).

The rise of antibiotic-resistant bacteria, such as *Escherichia coli*, *Streptococcus* spp., and *Corynebacterium* spp., also poses a significant challenge to public health. These pathogens are responsible for a range of foodborne infections, urinary tract infections and respiratory illnesses, and their increasing resistance to conventional antibiotics necessitates the exploration of alternative antimicrobial agents (Pulzova *et al.*, 2019; Saderi *et al.*, 2020; Koirala *et al.*, 2021).

In this context, natural compounds derived from plants offer a promising avenue for the development of new antibacterial therapies. Clove extracts, rich in flavonoids and saponins, have demonstrated efficacy against various bacterial strains, including multidrug-resistant ones. For example, studies have shown that clove essential oil and its main component, eugenol, exhibit strong antibacterial activity against foodborne pathogens by disrupting cell membranes and inducing oxidative stress (Liu *et al.*, 2025).

Therefore, this study aims to extract flavonoids and saponins from clove and evaluate their antibacterial activity against some foodborne pathogens such as *E. coli*, *Streptococcus* spp., and *Corynebacterium* spp. By investigating the potential of these natural compounds, we hope to contribute to the development of effective strategies for combating bacterial infections and addressing the growing issue of antibiotic resistance.

MATERIAL AND METHODS

Collection and preparation of Aqueous extract from *Syzygium aromaticum*

Fresh clove buds (*Syzygium aromaticum*) were obtained from Yankaba Market in Kano State, Nigeria. The buds were thoroughly washed with distilled water, sliced, and air-dried. Once completely dried, they were ground into a fine powder and sieved. A total of 100 grams of the powdered sample was mixed with 1500 mL of distilled water and left at room temperature for two hours. The mixture was then vortexed for 4 minutes and allowed to settle. It was filtered, and the resulting aqueous extract was collected for further analysis (Bharadwaj *et al.*, 2019).

Qualitative screening for Phytochemicals (flavonoids and saponins)

Saponin Test:

An aliquot of 500 µl of the extract was mixed with 7 ml of distilled water. The formation of persistent froth upon shaking indicated the presence of saponins (Bharadwaj *et al.*, 2019).

Flavonoid Test:

To 100 µl of the extract, 1 ml of 0.1M sodium hydroxide (NaOH) was added. The appearance of a strong yellow color that turned colorless upon the addition of dilute acid confirmed the presence of flavonoids (Bharadwaj *et al.*, 2019).

Following confirmation, the aqueous extract was evaporated to dryness to obtain powdered forms of the active constituents for accurate measurement and downstream applications.

Extraction of saponins and flavonoids

The extraction of saponin- and flavonoid-enriched fractions followed the cold maceration and solvent partitioning method described by Woo *et al.* (1980) and recently adapted by Phuc *et al.* (2024). The powdered clove material was first partitioned with diethyl ether to separate non-polar components. The aqueous layer was further partitioned with ethyl acetate, followed by n-butanol. The remaining aqueous layer was treated with 1% potassium hydroxide to isolate saponins. Subsequently, the remaining portion was acidified with hydrochloric acid and again partitioned with n-butanol to extract flavonoids.

This stepwise partitioning strategy allowed the isolation of targeted bioactive constituents. Diethyl ether removed lipophilic compounds, ethyl acetate isolated semi-polar compounds, while n-butanol and acid/base treatments enriched the extract with polar compounds such as saponins and flavonoids (Woo *et al.*, 1980).

Isolation of bacterial Pathogens

Foodborne pathogens, including *E. coli*, *Streptococcus spp.*, and *Corynebacterium spp.*, were isolated from spoiled tomatoes collected from a rural irrigation farm in Kano State, following the procedure of Bashir and Usman (2021). Twenty-five grams of homogenized tomato sample was suspended in 225 ml of sterile buffered peptone water to achieve a 1:10 dilution. A 1 ml aliquot of this homogenate was serially diluted in test tubes up to 10^{-5} . Using the pour plate method, 1 ml from dilutions 10^{-3} to 10^{-5} was inoculated into sterile Petri dishes in duplicates. Sterile molten agar was poured over the inoculum and swirled for even distribution. Plates were incubated at 37°C for 24 hours (Mbajiuka *et al.*, 2014).

Viable plate count

Colony-forming units (CFUs) were enumerated using a colony counter to determine the total viable aerobic bacterial load per plate (Mbajiuka *et al.*, 2014).

Gram staining technique

Smear of each isolate was made on the slide and heat fixed. Primary stain (crystal violet) was applied for 45 second and washed with gentle running water. Lugol's iodine was added for 45 seconds and was decolorized with acetone - alcohol and washed with clean water. The slides were counter stained with 30% safranin for 30 second and washed. It was then air dried and examined at under oil immersion lens of the microscope used (Cheesbrough, 2006).

Biochemical Characterization

The bacterial isolates were further identified using standard biochemical tests, including catalase, coagulase, oxidase, indole, urease, methyl red, Voges-Proskauer, and citrate utilization tests (Cheesbrough, 2006).

Preparation of plant extract Concentrations

A stock solution (2000 µg/ml) was prepared by dissolving 2 grams of the powdered extract in 1 ml of dimethyl sulfoxide (DMSO), as outlined by Cheesbrough (2006). Serial dilutions were then performed to obtain concentrations of 1000, 500, 250, and 125µg/ml.

Standardization of Inoculum

Bacterial suspensions were standardized to a 0.5 McFarland standard (approximately 1.5×10^8 CFU/ml) using sterile saline. The 0.5 McFarland standard was prepared by mixing 0.05 ml of 1.17% $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ with 9.95 ml of 1% sulfuric acid (H_2SO_4) with constant stirring. Turbidity was compared visually against a white background with a black line (Kalpana *et al.*, 2013).

Antimicrobial Susceptibility Testing

The antimicrobial activity of the extracts was evaluated using the agar well diffusion method (Cheesbrough, 2006). Mueller-Hinton Agar plates were inoculated with 0.1 ml of the standardized inoculum and spread using a sterile swab. Wells (6 mm) were made in the agar, and 0.1 ml of each extract concentration (1000, 500, 250, and 125 $\mu\text{g/ml}$) was dispensed into respective wells. Sodium benzoate (250 $\mu\text{g/ml}$) was used as the positive control. After 30 minutes of pre-diffusion, plates were incubated at 37°C for 24 hours. Zones of inhibition were measured in millimeters using a Vernier caliper. All assays were conducted in duplicates, and mean values were recorded.

Determination of Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal concentration (MBC)

The MIC was determined using the broth microdilution method (Andrews and Hammack, 2011). Two milliliters of 1000 $\mu\text{g/ml}$ extract was added to 2 ml of sterile Mueller Hinton broth and serially diluted across nine test tubes to achieve concentrations from 1000 to 62.5 $\mu\text{g/ml}$. Each tube was inoculated with 0.1 ml of standardized bacterial culture. After incubation at 37°C for 24 hours, the MIC was recorded as the lowest concentration showing no visible growth.

For the MBC, 0.1 ml from the tubes with no visible growth was sub-cultured onto Mueller Hinton Agar and incubated for 24 hours at 37°C . The lowest concentration that produced no bacterial growth was recorded as the MBC (Andrews and Hammack, 2011).

RESULTS

The physicochemical characteristics of the flavonoid- and saponin-enriched extracts derived from clove are summarized in Table 1. The flavonoid extract exhibited a reddish-brown coloration with a fine, granular texture, yielding 1.30 g. In contrast, the saponin extract appeared light yellow with a slightly coarse consistency and produced a yield of 2.30 g.

The antibacterial effects of these extracts on *Streptococcus spp.* are presented in Table 2. Zones of inhibition were measured and compared with those of streptomycin, a standard antibiotic, to evaluate the degree of resistance, intermediate sensitivity, or susceptibility. A Chi-square Test of Independence was used to assess the relationship between the presence of flavonoid and saponin. The calculated chi-square value was approximately 0.407, which is below the critical value of 6.635 at a 0.01 significance level with 1 degree of freedom. Consequently, the null hypothesis was accepted, indicating no statistically significant association between flavonoid and saponin effects against *Streptococcus* at the stated significance level.

In the case of *Escherichia coli* (Table 3), both flavonoid and saponin extracts demonstrated antibacterial activity across all tested concentrations, suggesting susceptibility when compared to streptomycin. The chi-square statistic was approximately 1.049, which also falls below the critical threshold of 6.635 at the 0.01 significance level. Hence, the null hypothesis was accepted once again, indicating no significant relationship between the effects of the two phytochemicals against *E. coli*.

For *Corynebacterium spp.*, the results are presented in Table 4. The bacterium showed resistance to all concentrations of both flavonoid and saponin extracts when compared to the standard antibiotic. Here, the chi-square statistic was approximately 9.549, which exceeds the critical value of 6.635 at the 0.01 significance level. Thus, the null hypothesis was rejected, and it was concluded that a statistically significant relationship exists between the presence of flavonoid and saponin in their activity against *Corynebacterium spp.*

The Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC) are presented in Table 5. The result of the flavonoid and saponin extracts is for *E. coli* and *Streptococcus spp.* *Corynebacterium spp.* was excluded from this table due to its complete resistance to both extracts, rendering MIC and MBC assessments irrelevant for this bacterium.

The result shows that flavonoid extract was found to have MIC of 250µg/ml on *E. coli* and 500µg/ml on *Streptococcus spp.* While the MBC values were 500µg/ml and > 500µg/ml against *E. coli* and *Streptococcus spp.* respectively. The saponin extract had MIC value of 62.5µg/ml on *E. coli* and 125µg/ml on *streptococcus spp.* The MBC values on *E. coli* and *Streptococcus* were 125µg/ml and 250µg/ml respectively.

Table 1. Physiochemical appearance of the flavonoid and saponins constituent of the clove plant.

<u>Physiochemical appearance of the clove constituent</u>			
	Color	Weight (g)	Texture
Flavonoid	Reddish brown	1.3	Fine and granular
Saponin	Light yellow	2.3	Slightly coarse constituent

Table 2. Antibacterial activity of saponin and flavonoid on the isolated food borne pathogens. (*Streptococcus spp*)

Control antibiotics	Antibiotic sensitivity readings (mm)	Flavonoid and sensitivity readings (mm) (µg/ml)	Saponins and sensitivity readings (mm) (µg/ml)
S	33	1000 (22) 500 (19) 250 (16) 125 (14)	1000 (28) 500 (25) 250 (22) 125 (14)
Chi square (χ^2) = 0.407			

Table 3. Antibacterial activity of saponin and flavonoid on the isolated food borne pathogens (*E. coli*).

Control antibiotics	Antibiotic sensitivity readings (mm)	Flavonoid and sensitivity readings (mm) (µg/ml)	Saponins and sensitivity readings (mm) (µg/ml)
S	23	1000 (18) 500 (17) 250 (15) 125 (13)	1000 (24) 500 (23) 250 (22) 125 (20)
Chi square (χ^2) = 1.049			

Table 4. Antibacterial activity of saponin and flavonoid on the isolated food borne pathogens (*Corynebacterium spp*)

Control antibiotics	Antibiotic sensitivity readings (mm)	Flavonoid and sensitivity readings (mm) (µg/ml)	Saponin and sensitivity readings (mm) (µg/ml)
S	10	1000 (10) 500 (9) 250 (9) 125 (9)	1000 (10) 500 (9) 250 (9) 125 (9)

Chi square (χ^2) = 9.549

Key: S is Streptomycin

Table 5. MIC and MBC values of flavonoid and saponin on *E. coli* and strep bacteria.

	Flavonoid (µg/ml)	Saponin (µg/ml)
MIC for <i>E. coli</i>	250	62.5
MBC for <i>E. coli</i>	500	125
MIC for Strep	500	125
MBC for Strep	>500	250

Key; MIC= Minimum Inhibitory Concentration, MBC= Minimum Bactericidal Concentration, *E. coli*= *Escherichia Coli*, Strep = *Streptococcus spp*

DISCUSSION

This study highlights the antimicrobial potential of flavonoids and saponins against foodborne pathogens, specifically *Streptococcus*, *Escherichia coli*, and *Corynebacterium* species, in comparison to the antibiotic streptomycin. Notably, *Streptococcus* demonstrated sensitivity to both flavonoids and saponins across all tested concentrations, indicating their promise as alternative antimicrobial agents. This observation aligns with recent findings that emphasize the broad-spectrum antibacterial activity of flavonoids, including their efficacy against drug-resistant strains (Amaha *et al.*, 2022).

However, *E. coli* exhibited differential responses: it was susceptible to saponins but resistant to flavonoids. This suggests distinct mechanisms of action or varying bacterial susceptibilities between these phytochemicals. Recent studies have shown that saponins can enhance the effectiveness of traditional antibiotics against *E. coli*, indicating potential synergistic effects (Amaha *et al.*, 2022). However, the resistance of *E. coli* to flavonoids observed in this study contrasts with the work of Frlan *et al.* (2023), their research on flavonoids (like baicalein) found that, except for baicalein, most flavonoids had *little to no inhibitory effect* on *E. coli* growth (e.g., MICs above test concentrations), even though some were active against *S. aureus*, possibly due to differences in bacterial strains or flavonoid structures (Hamid *et al.*, 2024).

Similarly, *Corynebacterium* species displayed resistance to both flavonoids and saponins at all concentrations tested, mirroring standard antibiotic susceptibility patterns. This resistance suggests that these phytochemicals may not be effective against infections caused by *Corynebacterium* spp. The variability in bacterial responses could be attributed to species-specific differences, as previously reported (MDPI, 2023).

Future research should explore the potential synergistic effects of combining flavonoids and saponins, as well as their interactions with conventional antibiotics. Such combinations may enhance antimicrobial efficacy and help overcome resistance mechanisms (MDPI, 2023). The current findings suggest that while flavonoids and saponins show promise, particularly against *Streptococcus* infections, their effectiveness against other bacterial strains requires further investigation.

Statistical analyses support these observations. The chi-square statistic of approximately 0.407 (Table 1) is below the critical value of 6.635 at the 0.01 significance level, leading to the acceptance of the null hypothesis that there is no significant relationship between the presence of flavonoids and saponins (Pikhtirova *et al.*, 2023). Similarly, Table 2 shows a chi-square statistic of approximately 1.049, which also supports the null hypothesis. These findings contrast with earlier reports suggesting a significant relationship, possibly due to differences in *E. coli* strains or extract concentrations used (Hamid *et al.*, 2024).

In contrast, Table 3 presents a chi-square statistic of approximately 9.549, exceeding the critical value at the 0.01 significance level. This result leads to the rejection of the null hypothesis, indicating a significant relationship between the presence of flavonoids and saponins, consistent with recent studies (MDPI, 2023).

CONCLUSION

Flavonoids and saponins exhibit varying inhibitory effect against different bacterial strains. While both compounds showed potential as alternative antimicrobial agents, their effectiveness differs significantly depending on the bacterial strain, higher activity was demonstrated against *Streptococcus*, suggesting their potential against foodborne infections caused by this bacterium. However, their efficacy against *E. coli* and *Corynebacterium spp* was limited, with *E. coli* showing susceptibility to saponins but resistance to flavonoids, and *Corynebacterium spp* exhibiting resistance to both compounds. These findings suggest that saponin- and flavonoid-enriched fractions effectively inhibit bacterial growth, highlighting their potential application in food safety and antimicrobial therapy.

Further researches on specific mechanisms of action of these phytochemicals and their interactions with different bacterial strains is important.

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Launching GovOptix-NG App: Optimizing Governance Costs for a Brighter Future in Nigeria

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ABSTRACT

Nigeria's governance system suffers from high administrative costs and systemic inefficiencies that hinder socio-economic progress. GovOptix-NG, a revolutionary governance optimization platform, offers a transformative solution by integrating advanced technologies-mathematical modeling, optimization techniques, artificial intelligence, and blockchain-to enhance transparency, accountability, and cost-efficiency. This paper presents the conceptual design, methodology, implementation strategy, and expected socio-economic impact of GovOptix-NG. The NEST2025 Conference provides an opportunity to launch this innovation, gather stakeholder feedback, and foster collaborative efforts for scalable governance reforms across Nigeria and potentially Africa.

Keywords: Governance Optimization, Artificial Intelligence, Blockchain, Public Sector Efficiency, Nigeria

Introduction

Nigeria's governance landscape has long been plagued by deeply rooted challenges that include high administrative costs, bloated bureaucracies, and inadequate transparency. These inefficiencies have not only led to misallocation of resources but have also weakened public trust in institutions, stalled economic development, and undermined democratic governance. According to Olaniyan and Badejo (2020), the persistent failure of government systems to deliver public goods and services efficiently has created a developmental bottleneck. These failures are compounded by the complexity of Nigeria's federal structure, which often results in duplicated efforts and inconsistencies in policy implementation across different tiers of government.

In 2022, the World Bank highlighted that Nigeria's recurrent expenditure consumed over 60% of the national budget, leaving little room for capital projects that could drive long-term development. In many Ministries, Departments, and Agencies (MDAs), inefficiencies manifest in the form of redundant processes, overlapping responsibilities, and a lack of

integrated systems for monitoring and evaluation. Moreover, the opacity in financial management, delays in budget implementation, and limited citizen participation in governance decisions further exacerbate these systemic problems (Transparency International, 2021).

Despite multiple reform initiatives such as SERVICOM, IPPIS, and TSA, progress has been incremental and often hampered by resistance to change, institutional inertia, and a lack of real-time data to support evidence-based decision-making. Most existing digital governance solutions are fragmented and reactive, addressing symptoms rather than root causes.

GovOptix-NG introduces a paradigm shift in how governance can be conceived and operationalized. The platform is built on four technological pillars: mathematical modeling, optimization algorithms, artificial intelligence, and blockchain. These technologies collectively enable dynamic policy simulations, predictive governance, and immutable audit trails, thereby providing decision-makers with the tools necessary to improve performance while minimizing costs. In essence, GovOptix-NG transitions governance from a reactive model to a predictive and adaptive system capable of evolving in response to real-world data.

The launch of GovOptix-NG at the NEST2025 Conference is a timely intervention aligned with Nigeria's broader digital transformation goals. The platform serves as both a policy support tool and a collaborative environment that facilitates real-time engagement among stakeholders. The participatory design of GovOptix-NG ensures that it is not only technologically sound but also socially embedded and contextually relevant. This paper aims to detail the design, methodology, and pilot outcomes of GovOptix-NG, demonstrating its potential to catalyze meaningful governance reforms in Nigeria and across the African continent.

Materials and Methods

1 Platform Architecture and Development Methodology: GovOptix-NG was developed using an agile methodology involving multiple iterations of stakeholder feedback, prototyping, and system validation. The development process followed a modular architecture approach, allowing seamless integration of various technological components such as AI engines, blockchain ledgers, and optimization models. Each module was independently tested for functionality and interoperability before system-wide simulations were conducted.

The artificial intelligence component was developed using supervised machine learning models, particularly regression and classification algorithms, trained on a historical dataset of government expenditures, procurement records, policy outcomes, and citizen satisfaction indices. Data preprocessing involved data cleaning, normalization, and feature engineering to ensure accuracy and reliability of the predictive models.

2 Optimization Models: To identify the most cost-effective governance strategies, linear and non-linear optimization models were developed using Python and MATLAB. These models focused on minimizing administrative costs while maximizing service delivery

outputs. Key performance indicators (KPIs) such as cost-per-citizen served, time-to-service delivery, and budget utilization efficiency were incorporated as constraints in the optimization framework.

3 Blockchain Integration: Blockchain was utilized to ensure transparency, traceability, and accountability in public financial management. A permissioned blockchain architecture was implemented using Hyperledger Fabric, allowing only verified government actors to participate in the ledger while maintaining an immutable record of all financial transactions and governance decisions. Smart contracts were employed to automate compliance with procurement guidelines and service-level agreements.

4 Stakeholder Engagement and Participatory Design: Stakeholder engagement was central to the design and refinement of GovOptix-NG. Over 150 stakeholders, including policymakers, academia, civil society groups, and citizens, participated in co-creation workshops, focus group discussions, and usability tests. Feedback was collected through digital surveys and analyzed using qualitative coding techniques to inform design modifications.

5 Pilot Testing and Evaluation Framework: The platform was piloted in three MDAs covering health, education, and infrastructure. A mixed-methods evaluation framework was employed, combining quantitative metrics (cost reduction, time saved) and qualitative assessments (user satisfaction, perceived transparency). Data from the pilots were used to calibrate the AI models and validate the optimization algorithms. Pilot feedback was also instrumental in improving the user interface and dashboard features.

Results and Discussion

1 Pilot Results: The pilot implementation of GovOptix-NG demonstrated its transformative potential. MDAs reported an average of 17% reduction in redundant administrative costs and a 26% improvement in resource allocation efficiency. Real-time dashboards enhanced decision-making capabilities, while blockchain-based audit trails significantly improved trust among stakeholders.

2 Stakeholder Perceptions: Feedback from users revealed a high degree of satisfaction with the platform's usability and the clarity of visualizations. Policymakers appreciated the predictive analytics that allowed them to anticipate policy impacts before implementation. Civil society participants commended the increased transparency and auditability of government transactions.

3 Strategic Conference Launch: The NEST2025 Conference offers a unique opportunity to showcase GovOptix-NG to a broader audience. Live demos, panel discussions, and breakout sessions will facilitate stakeholder interaction and feedback collection. This event also provides a springboard for regional scalability, as interest in digital governance grows across West Africa.

Conclusion

GovOptix-NG represents a groundbreaking advancement in Nigeria's quest for efficient, transparent, and accountable governance. By integrating cutting-edge technologies such

as artificial intelligence, blockchain, and optimization science, the platform provides a comprehensive solution to long-standing governance challenges. The results from pilot testing affirm its potential to deliver measurable improvements in cost efficiency and service delivery.

The upcoming NEST2025 Conference will serve as a strategic launchpad for GovOptix-NG, enabling multi-stakeholder engagement, real-time feedback, and advocacy for national adoption. In doing so, the platform not only addresses Nigeria's immediate governance inefficiencies but also positions the country as a digital governance pioneer in Africa. With sustained political will, strategic partnerships, and continued innovation, GovOptix-NG can contribute to building a governance ecosystem that is data-driven, citizen-centric, and future-ready.

Acknowledgements

We gratefully acknowledge National Mathematical Centre Research Grant and the contributions of all stakeholders, particularly the pilot participants, researchers, and the planning committee of the NEST2025 Conference. We also thank the Sarcouncil Journal of Entrepreneurship and Business Management and Sarcouncil Journal of Economics and Business Management for publishing our prior foundational research.

Partnership Opportunities: Showcasing TopneunetAI's Climate Modelling Innovation

We would be honored to showcase TopneunetAI, our groundbreaking AI-driven climate modelling and forecasting solution. TopneunetAI represents a significant advancement in environmental technology, currently delivering an impressive 95% prediction accuracy in climate forecasts. As a revolutionary tool, it is designed to support data-driven environmental planning and policy-making in Nigeria and beyond.

We are keen to collaborate with the Nigerian Environmental Study Action Team (NEST) and other relevant agencies to deepen the impact of AI in addressing climate challenges. We look forward to the opportunity to contribute meaningfully to the conference and engage with key stakeholders in environmental sustainability.

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Determination of Protein, Lipid and Carbohydrate Content in *Chlorella sorokinana* under Autotrophic and Heterotrophic Cultivation

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ABSTRACT

Microalgae are a wide range of single-cell photosynthetic organisms, both eukaryotic and prokaryotes, which generally grow in a variety of habitats. This study evaluated the biochemical composition - specifically protein, lipid, and carbohydrate content of Chlorella vulgaris cultivated under autotrophic and heterotrophic conditions over a 30-day period. Growth rate, absorbance, and macromolecular content were analyzed to understand how different cultivation strategies influence biomass and metabolite accumulation. The Biuret method by sigma Aldrich for protein quantification revealed that autotrophic cultures yielded significantly higher protein concentrations (0.739 g/dL) compared to heterotrophic cultures (0.217 g/dL), reflecting the role of photosynthesis in promoting nitrogen assimilation and protein biosynthesis. Conversely, heterotrophic conditions favored lipid accumulation, which was quantified using the sulfo-phosphate-vanillin colorimetric method, thus revealing the lipid concentration to be 135.849 mg/L, approximately doubling that of autotrophic cultures (67.923 mg/L). Carbohydrate quantification using the Anthrone method showed that heterotrophic cultures also accumulated slightly higher sugar levels (2.67 mg/dL) compared to autotrophic ones (2.25 mg/dL), likely due to metabolic shifts favoring carbon storage in non-photosynthetic environments. The results indicated the existence of distinct growth patterns between the two growth conditions. Autotrophic cultures demonstrated gradual and sustained biomass accumulation, consistent with photosynthetic activity, whereas heterotrophic cultures exhibited rapid initial growth followed by a decline, likely due to substrate depletion and accumulation of metabolic byproducts. Absorbance measurements supported these trends, with higher early optical density values in heterotrophic conditions but greater stability in autotrophic systems over time. These findings highlight the metabolic flexibility of Chlorella vulgaris and the impact of cultivation conditions on biochemical profiles. Autotrophic cultivation was observed to be more suitable for high-protein production, relevant to food and feed applications, while heterotrophic growth is advantageous for lipid and carbohydrate accumulation, aligning with biofuel and bioproduct development. Optimization of growth parameters tailored to desired end-products can significantly enhance the commercial viability of microalga biotechnology.

Keywords: Micro-algae; *Chlorella vulgaris*; Growth conditions; Autotrophic; Heterotrophic

Introduction

Microalgae have attracted increasing attention in recent years due to their promising potential applications in food, energy, and high-value compound production, as well as in environmental fields Chen *et al.*, (2022). The abundant production of algal biomass is necessary to support its

wide application. Microalgae can grow via various trophic modes. Among them, autotrophic and heterotrophic cultivation are the main approaches used in the commercial production of microalgae (Ruiz *et al.*, 2022).

Materials and Methods Study Area

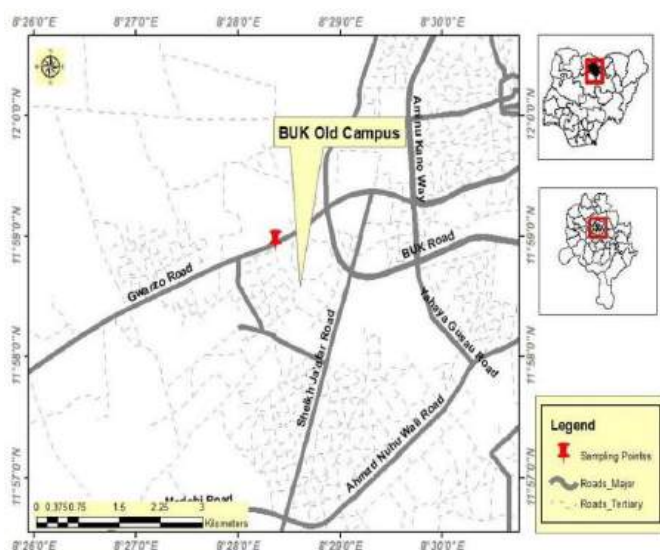


Figure 1: Sampling area map for the collection of microalgae in Kabuga, Kano State.

The samples were collected from a ditch used for irrigation purposes in a garden located along Kabuga, Gwarzo Road, Kano, Nigeria. The sampling site was chosen due to its potential for diverse micro-algal species. The geographical coordinates of the site were 11.98384748°N, 8.4758066°E.

Water Sample Collection

Water samples were obtained from three different locations within the ditch to ensure a broad representation of microalgae. Water samples were collected using a dark bottle container as described by Indabawa (2014).

Preparation of Algae Sample Using BG11 Medium

The collected water samples were filtered through a sterile filter paper to remove large debris. The filtrates containing micro-algal cells were then centrifuged at 3,000–5,000 rpm for 10–15 minutes to separate the biomass from the surrounding water. After centrifugation, the supernatant was discarded, and the algal pellet was washed twice with sterile distilled water to remove impurities and possible contaminants. The resulting pellet was re-suspended in a small volume of sterile BG11 medium to maintain viability before inoculation. This procedure follows the microalgae isolation protocols described by Converti (2019).

Media Preparation

The preparation of TAP media followed a standardized protocol, beginning with the addition of 5 mL of TAP Salt, 0.075 mL of phosphate buffer, and 0.2 mL of trace elements into a sterile bottle

and finally 0.484 g of Tris base and 200 mL of distilled water were introduced into the mixture according to the protocol of Hirano *et al.*, (2010).

Identification and Isolation of Microalgae

Agar plating was used for the isolation of individual species, for isolation the inoculation loop loaded with natural water sample were streaked across the agar surface, similar to the microbiological method used for bacteria. After incubation for few days, the colonies originating on the surface of agar plates were removed with a wire loop and inoculated into the liquid media. The microalgae were subjected to microscopic observation for proper identification using compound digital microscope. Species were identified according to the key provided by Edward and David (2010).

Growth and Maintenance of Microalgae

Phototropic and heterotrophic cultivation conditions were established for inoculation; in the autotrophic setup, the prepared and sterilized TAP media was inoculated with 5 mL of the *Chlorella vulgaris*. The inoculated flask was then placed in an illuminated environment with continuous exposure to sunlight to support autotrophic growth. For the heterotrophic cultivation, 0.2grams of glucose was weighed using a digital weighing balance and was poured into 100 mL of liquid medium. The medium was autoclaved at 121°C for 30 minutes, 5 mL of *Chlorella vulgaris* culture was introduced into the glucose-containing medium. This setup was then placed in a dark environment to promote heterotrophic growth, relying solely on the supplied organic carbon source for metabolism and proliferation. Perez-Garcia *et al.*, (2011).

Determination of specific growth rate

The specific growth rate (μ_{max} , day⁻¹) was calculated using the protocol of Mata and Martins, (2012): $\mu_{max} = \frac{1}{t_2 - t_1} \ln \left(\frac{N_2}{N_1} \right)$, where N1 and N2 are the cell concentration at the beginning (t1) and end (t2) of the exponential growth phase, respectively.

Microalgae Cell Counting

The hemocytometer's grids were covered with a cover slip, and its chamber was filled with a pipette. The sample enters the chamber through capillary action once the pipette is positioned at the tip of the hemocytometer. After settling, the cells were examined under a microscope to ensure that they were distributed satisfactorily. There were nine large squares in the grid, twenty-five medium squares in each large square, and sixteen little squares in each medium square.

The process was repeated twice to count the normal number of cells in the centre large square for important measures. The average number of cells for each species is multiplied by the

Neubauer conversion factor ($\times 10^4$) to determine the cell density. The cells were counted using the X40 objective lens. The mean quantity of cells was tallied. Santos Ballardo *et al.*, (2005).

Protein measurement

Protein was determined using Biuret method provided by Sigma Aldrich protocol (2023). Algal samples were centrifuged to extract soluble proteins. A blank (Biuret reagent + distilled water), standard (Biuret reagent + standard protein), and (Biuret reagent + algal extract) were prepared. Absorbance was measured at 550nm, and protein concentration was calculated using the absorbance ratio method.

Determination of Lipid Content

The lipid content was determined using the SPV method, lipid quantification was based on the reaction of lipids with sulfuric acid (H_2SO_4) and phosphovanillin reagent, which produces a pink-purple color and is measured at 500 nm using a spectrophotometer Bligh and Dyer (1959).

Determination of Carbohydrate Content

1mL pellet were diluted in 1mL distilled water, 1mL of 5% aqueous phenol in water was added, and then 5mL concentrated sulphuric acid was applied immediately to the surface of the solution according to the procedure described by Chaplin, (1986). The absorbance was measured at 490nm in a spectrophotometer after 20mins. 5mL of concentrated sulphuric acid was applied immediately to the surface of a blank solution made with 1mL of purified water and 1mL of 5% aqueous phenol solution.

Results

Fig 1.0: Growth Rate of *Chlorella vulgaris* under Autotrophic and Heterotrophic Conditions over 30 days

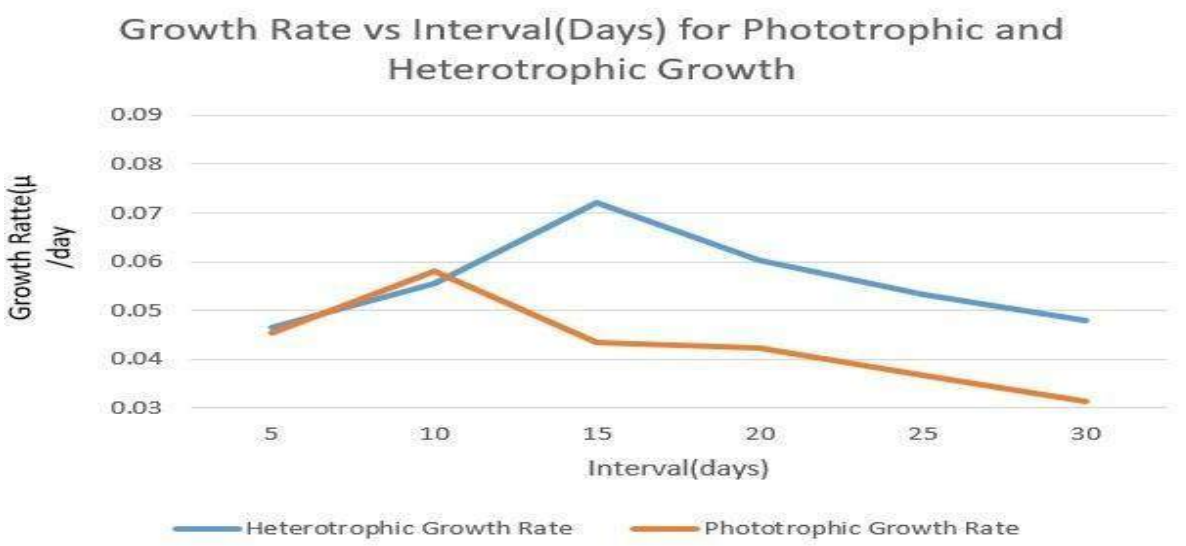


Table 1.1: Absorbance readings of autotrophic and heterotrophic growth of *Chlorella vulgaris*

Concentration of Protein (μg/mL)	
Autotrophic Condition	Heterotrophic Condition
0.739	0.217
Concentration of Lipid (μg/mL)	
Autotrophic Condition	Heterotrophic Condition
135.849	67.923
Concentration of Carbohydrate (μg/mL)	
Autotrophic Condition	Heterotrophic Condition
1.523	5.456

Discussion

In this research, *Chlorella vulgaris* was identified and found to be versatile in utilizing different cultivation methods. The growth performance and biochemical composition of *Chlorella vulgaris* under autotrophic and heterotrophic conditions over a 30-day cultivation period revealed distinct physiological behaviors. Autotrophic growth, driven by light and inorganic carbon (CO₂), showed a gradual yet sustained increase in biomass and optical density (OD), whereas heterotrophic growth, reliant on organic carbon sources like glucose, exhibited rapid initial growth followed by a marked decline Becker, (2013); Richmond, (2004).

Under autotrophic conditions, the OD at 680 nm rose steadily from 0.109 at day 0 to 0.885 by day 30, with the highest specific growth rate (0.1478) recorded between days 0–5. This growth trajectory reflects the efficiency of photosynthetic activity in the early stages when nutrients and light are abundant Barta *et al.*, (2021); Wang *et al.*, (2013). However, from day 10 onwards, a significant decrease in growth rate was observed, likely due to self-shading, nutrient depletion (particularly nitrogen and phosphorus), and oxygen accumulation, which collectively impair photosynthesis Markou & Nerantzis, (2013); Bhatnagar *et al.*, (2011).

In contrast, heterotrophic cultures, starting with a higher initial OD (0.284), peaked early (OD = 0.872 at day 5) but declined sharply to 0.204 by day 30. The specific growth rate reached its maximum (0.0990) between days 10–15, reflecting efficient nutrient uptake during metabolic adaptation Liang *et al.*, (2009). The subsequent decline was attributed to glucose depletion and the accumulation of inhibitory byproducts such as organic acids Liu *et al.*, (2013). These results confirm findings by Wang *et al.*, (2014) and Smith *et al.*, (2022), who noted the limitations of heterotrophic systems due to substrate exhaustion and reduced long-term sustainability.

Lipid accumulation was significantly higher in heterotrophic cultures (135.849 mg/L) compared to autotrophic ones (67.923 mg/L), which aligns with previous studies indicating enhanced lipid biosynthesis when microalgae are exposed to excess organic carbon Wan *et al.*, (2012; Li *et al.*, (2014). Wan *et al.*, (2012) reported lipid content reaching up to 50% of dry weight in glucose-supplemented cultures, while Chai *et al.* (2018) found autotrophic cultures generally capped at 8–18%. The elevated lipid yield under heterotrophic growth makes it favorable for biofuel applications despite the challenges in maintaining biomass Chisti, (2007).

Conversely, autotrophic growth favored protein synthesis, with a protein concentration of 0.739 g/dL compared to 0.217 g/dL in heterotrophic cultures. This can be attributed to the availability of light and inorganic nitrogen, both essential for protein and chlorophyll synthesis in photosynthetic organisms Bhatnagar *et al.*, (2011). These findings are consistent with studies highlighting the role of cultivation mode in determining the biochemical output of *C. vulgaris* Nouri *et al.*, 2021; Becker, (2013).

Carbohydrate content also varied with growth conditions. Heterotrophic cultures showed slightly higher carbohydrate concentrations (1.98–2.67 mg/dL) than autotrophic ones 2.17–2.25 (mg/dL), suggesting a metabolic shift toward carbohydrate storage under glucose-rich conditions Liang *et al.*, (2009). The accumulation of polysaccharides in heterotrophic cells may serve as an energy reserve in response to reduced photosynthetic activity (Richmond, (2004). The Anthrone method effectively quantified total sugars, and the results are in agreement with previous reports that link carbon source availability to carbohydrate biosynthesis in microalgae Wang *et al.*, (2013).

Overall, *C. vulgaris* displayed a clear physiological distinction between autotrophic and

heterotrophic cultivation. While heterotrophic growth enables rapid biomass and lipid accumulation suitable for industrial lipid extraction, it suffers from substrate dependency and metabolic inhibition. On the other hand, autotrophic growth offers more sustainable biomass production with superior protein yield, albeit at lower lipid productivity. These insights support the idea of mixed cultivation systems to optimize both biomass and metabolite output, as proposed by Markou & Nerantzis (2013).

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Evaluating Seed Germination and Seedlings Growth of Three Moist Forest Tree Species for Conservation and Climate Mitigation at Umudike, Nigeria

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ABSTRACT

Climate change is having significant impact on forest species capacity for regeneration and establishment making studies on seed germination and seedling growth increasing exigent to conservation efforts. This study investigated seed germination and seedling growth of three moist forest tree species - *Irvingia gabonensis*, *Cola acuminata*, and *Cola nitida* under four (0g, 1g, 2g, and 3g) of NPK fertilizer treatment levels at the nursery unit of Department of Forestry and Environmental Management (FOREM), Michael Okpara University of Agriculture, Umudike. The experiment was a two-factor scheme (3 x 4) in Randomized Complete Block Design (RCBD) with five replicates. Fresh fruits of the tree species were collected from Forestry Research Institute of Nigeria, Ahiaeke while topsoil used for the experiment were collected from an abandoned farmland besides FOREM nursery. Data collected over 16 weeks after planting (WAP) were subjected to ANOVA using the Statistical Analysis System. The result showed significantly earlier germination (14 ± 0.33 DAP) and higher percentage germination ($87.00\% \pm 2.71\%$) of *I. gabonensis* to *C. nitida* (40 ± 0.35 DAP and $71.33\% \pm 2.30\%$ respectively) and *C. acuminata* (42 ± 0.37 DAP and $75.33\% \pm 2.21\%$ respectively). The result also shows significant increase in seedling growth from week 2 to 14, with the 3g of NPK treatment having the best results for the three species. The findings have implications for forestry and environmental management practices. Further research can build upon these results to optimize fertilizer application and enhance species production and conservation. Precision use of fertilizers in the nursery practice for the three species should be recommended.

Key words: Seed germination, seedling growth, tree species conservation

INTRODUCTION

The environment is the foster parent of every plant and plays an indispensable role in its development so also is climate change having significant impact on forest (Nwoboshi, 1982; Okali and Isichei, 2014; Nwajiobi et al., 2023). The impacts of climate change on tropical forest include adverse effect on the provision of ecosystem products and services with loss of biodiversity (Okali and Isichei, 2014; Nwajiobi et al., 2023). This decrease in forest productivity and utility will, according to the authors, further escalate deforestation as more forest land will be converted into agricultural land thus weakening forest resilience and worsening climate situation, especially in developing economies of the tropical regions. Such dramatic changes

could adversely affect natural forest with species dieback and biodiversity losses. In areas with high anthropogenic pressure, forest expansion is levelled out by regional common land-use practices, including deforestation for plantation establishment, grazing and logging, and the forest-savanna ecotone could disappear if no urgent preventative measures are undertaken (Koutouan-Kontchoi *et al*, 2020; Myster, 2012; Oliveras and Malhi, 2016).

It is in the light of the foregoing that the phenomenon of seed dormancy (the failure of perfectly sound and uninjured seeds to germinate even in the presence of favourable environmental condition), which is common with many tropical forest tree species (Nwoboshi, 1982; Olajide *et al.*, 2014) portends a significant setback to forest tree species conservation.

Seed is a mature ovule containing a unit of plant with a state of development having seed coats, food-storage tissue, and embryo. It is a key element in plant production that it exercises a very great influence on the success and failures of both natural and artificial regeneration (Nwoboshi, 1982). Seed germination is a process in which the metabolism of plant seeds is stimulated after hydration, and the radicle breaks through the seed covering (Nonogaki, 2017). Seed germination and growth are influenced by various factors, including temperature, water, seed attributes (weight, shape, and size), physiological characteristics, and seed predation. The complexity of these factors can affect seed viability and germination ability, making it challenging to achieve optimal germination rates. As mentioned earlier, there are situations however where seeds known to be perfectly sound will fail to germinate under favourable environmental conditions; a phenomenon known as seed dormancy.

Irvingia gabonensis, also known as African bush mango or wild mango, is a tree species native to the humid forest zone of West and Central Africa. Its fruit is a broadly ellipsoid drupe with a juicy fibrous pulp and a stony nut that encases an oil-rich dicotyledonous kernel (Ogunsina *et al.*, 2008). The kernel is rich in nutrients and has been reported to have potential uses in food products development, confectioneries, edible fats, soaps, and cosmetics (Ainge and Brown, 2001; Agbor, 1994). *Cola acuminata* and *Cola nitida* also known as kola nut, are tree species native to tropical Africa. The seeds contain caffeine and are used as a stimulant in many West African cultures (Gebissa, 2006). The kola nut has a strong cultural significance in West and Central Africa and is used in traditional ceremonies and as a symbol of hospitality (Asogwa *et al.*, 2012b). The nut is also used in traditional medicine to treat various ailments, including digestive disorders, asthma, and inflammation (Odebunmi *et al.*, 2009; Warner, 2007). Understanding the properties and uses of these plant species can provide valuable insights into their potential applications in food products development, traditional medicine, and cultural practices. Despite their well-known economic benefits, *Irvingia gabonensis*, *Cola acuminata*, and *Cola nitida* seeds exhibit some degree of dormancy, leading to slow or failed germination even under favorable environmental conditions. A good knowledge of the specific requirements for their seed germination and growth is crucial for the successful propagation of these species. This study aims to investigate seed germination and seedling growth of the three different moist forest tree species (*Irvingia gabonensis*, *Cola acuminata* and *Cola nitida*) with a focus on fertilizer rate that enhances growth to facilitate the conservation and sustainable utilization of these valuable tree species.

MATERIALS AND METHOD

Study Area

The study was conducted at the Nursery Unit of the Department of Forestry and Environmental Management, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria. Umudike

is located between latitude 5°27' and 5°32'N and longitude 7°32' and 7°33'E, with an annual rainfall of approximately 2180mm, average relative humidity of 72% and monthly temperature ranging from 20°C to 36°C (Nwosu *et al.*, 2011).

Source of Planting Materials

The fruits of *Irvingia gabonensis*, *Cola acuminata*, and *Cola nitida* (Plate 1 – 4) were collected from the Forestry Research Institute of Nigeria, located in Umuahia North Local Government Area of Abia State. The choice of *Irvingia gabonensis*, *Cola acuminata* and *Cola nitida* was based on the availability of their seeds in the moist forest area. The three species are denoted by the letters

X, Y and Z as follows:

X = *Irvingia gabonensis*

Y = *Cola acuminata*

Z = *Cola nitida*



X. *Irvingia gabonensis*



Y. *Cola acuminata*



Z. *Cola nitida*

Plate 1. Seeds of the three tree species

Methodology

The seeds of the species were processed from the fruits and tested for viability using a combination of methods. Eighty viable seeds from each plant species were broadcast into germination boxes, and watering was done daily. After germination, 50 seedlings from each plant species were selected and transplanted into polythene pots filled with 4kg of top soil. The experiment was arranged in a 3 x 4 factorial in Randomized Complete Block Design with three levels of moist forest species (*I. gabonensis*, *C. acuminata*, and *C. nitida*) and four levels of fertilizer treatment. (A, B, C, and D indicated below) in five replications:

A: 4kg of top soil (control)

B: 4kg of top soil + 1g of NPK 15:15:15 fertilizer

C: 4kg of top soil + 2g of NPK 15:15:15 fertilizer

D: 4kg of top soil + 3g of NPK 15:15:15 fertilizer

Germination

Seeds were considered germinated when the plumule emerged above the soil surface. The number of days to first germination were recorded for all three species. Germination of the species were monitored and counted daily for a period of 14 weeks. Time to first germination was recorded and the germination per day recorded for a period of four weeks. Percentage germination and germination rate were calculated using method of Ranal and Santana (2006).

Percentage germination for each tree species was determined from the ratio of the number of seeds that germinated for each species at 28 Days After Planting (DAP) to the total number of seeds planted.

$$\text{Germination (\%)} = \frac{\text{Ratio of the total number of germination} \times 100}{\text{Total number of seeds planted}}$$

Soil Collection and Analysis

Top soil was collected from abandoned farmland besides the FOREM Nursery. The surface vegetation was cleared and the top soil collected at 3-10cm depth was bulked and the debris which included stones plant roots and litters were sieved away. The soil was filled into the germination boxes wherein the seeds were broadcasted for germination. Four kilogrammes (4kg) of the same composite soil were filled into each of the poly pots wherein the germinated seedlings were transplanted into for further growth evaluation. The composite soil samples were taken to the Soil Analysis laboratory of the National root crop research Institute (NRCRI) for analysis of the physicochemical properties.

Data Collection and Analysis

The research data were collected over a period of 14 weeks after planting (14 WAP) which is 98 days) for each plant species:

Growth Parameters

The species growth parameters were measured every 7 days (1 week). Growth parameters measured included:

Time to first germination: The time between seed broadcast to first germination of each of the species were noted and recorded.

Plant height (cm): measured from the soil surface to the tip of the terminal bud using a fibreglass measuring tape

Seedling Collar Diameter (mm): measured using a digital calliper at the region of the seedling stem above the cotyledon (epicotyl)

Number of Leaf or Leaf count: determined by counting the leaves in each seedling

Statistical Analysis

All data collected were subjected to analysis of variance (ANOVA) using the general linear model procedure of the Statistical Analysis System (SAS Institute, 2003). Means were compared using the least significant difference at $P < 0.05$.



a. *Irvingia gabonensis*



b. *Cola acuminata*



c. *Cola nitida*

Plate 2. Seedlings of the tree species at 1 WAP



a. *Irvingia gabonensis*



c. *Cola acuminata*



d. *Cola nitida*

Plate 3. Seedlings of the tree species at 14 WAP

RESULTS AND DISCUSSION

Physico-Chemical Properties of Experimental Soil

Table 1: Initial status of soil before experiment.

Soil properties	Value
Clay (g/kg)	10.80
Silt (g/kg)	20.48
Sand (g/kg)	59.31
Texture	Sandy loam
PH	6.9
Total nitrogen (g/kg)	1.04
Organic carbon (g/kg)	4.10
Available P(g/kg)	6.08
Exchangeable K(cmol/kg)	0.10
Exchangeable Ca(cmol/kg)	3.9
Exchangeable Mg(cmol/kg)	4.3

Table 1. shows that the soil is relatively poor in mineral (N 1.04g/kg, P 20g/kg, K 0.10 cmol⁻¹), The soil reaction is almost neutral (pH. 6.9). The findings support reported low nutrient status of soils in the southeast resulting from deforestation and intensification of crop production which causes soil erosion and excessive leaching of the soil nutrients (Osodeke, 2017). The soil is largely sandy (59.31g/kg) which may have conferred the slightly acidic nature. It supported Nwoboshi (1982) that acidic soils are common where rainfall is high and the soil is permeable enough to permit the leaching of appreciable amounts of exchangeable bases from the upper horizons of the soil. The findings also supported reports that soil fertility is a crucial problem facing agricultural development and food security in Sub-Saharan Africa (SSA) (Omotayo and Chukwuka, 2009).

Table 2: Seed Germination of the Three Tree Species

Tree Species	No. of Days to 1 st Germination (DAP)	Percentage Germination (%)
<i>Irvingia gabonensis</i> (X)	14±0.33 ^a	87.00%±2.71 ^b
<i>Cola acuminata</i> (Y)	42±0.37 ^b	75.33%±2.21 ^a
<i>Cola nitida</i> (Z)	40±0.35 ^b	71.33%±2.30 ^a
F	197.600***	58.750**

Values are means of replicates±Standard Error. Values with similar letters across the rows are not significantly different (p<0.5). DAP=Days After Planting

Seed Germination the Three Tree Species

The three tree species varied in their mean time to first germination and percentage germination (Table 2). Germination of *I. gabonensis* occurred quicker (14±0.33 DAP) than *Cola acuminata* (42±0.37 DAP) and *C. nitida* (40.00±0.35 DAP). Germination percentage was also highest for *I. gabonensis* (87.00%±2.71), followed by *Cola acuminata* (75.33%±2.21), while the least was recorded with *Cola nitida* (71.33%±2.30). The variations in the time of seed germination of the species is likely a genetic predisposition since the genes contain specific information for regulating the chains of morphological and physiological events that determine the expression of specific traits and characteristics of the phenotype including the duration of seed dormancy (Hartmann *et al.*, 2007). The relatively lengthy days to first germination of the species supported Nwoboshi (1982) and Olajide *et al.* (2014) that seed dormancy occurs in many tropical tree species and to varying degrees. As early germination is a desirable characteristic for fast establishment in the forest gaps (Burslem and Miller, 2001), *I. gabonensis* is likely to gain early dominance of a new canopy gap amongst the three species.

The Plants Growth in Height (cm)

Table 3, 4 and 5 show the mean growth and optimum levels of NPK fertilizer treatments on the plant height (cm) of the seedlings at weekly intervals. At week 1, the mean plant height (cm) of *I. gabonensis* were A 18.30cm, B 16.17cm, C 18.76cm and D 16.31cm; mean plant height (cm) of *C. acuminata* were A 2.26cm, B 2.87cm, C 4.70cm and D 9.80cm; and mean plant height (cm) of *C. nitida* were A 2.39cm, B 2.97cm, C 3.32cm and D 3.40cm. At week 14, the mean plant height (cm) of *I. gabonensis* results were A 29.97cm, B 31.89cm, C 36.69cm and D 43.86cm; mean plant height (cm) of *Cola acuminata* were A 6.41cm, B 7.61cm, C 10.39cm and D 16.29cm; and mean plant height (cm) of *Cola nitida* were A 6.07cm, B 6.54cm, C 7.72cm and D 8.82cm. It indicated that the species seedlings differed significantly (P<0.05) among the different fertilizer treatment. Although there were no significant differences in the growth of the various species at Week 1, the seedlings raised from treatment D (3g of NPK 15:15:15 fertilizer) had

significantly the highest mean growth performance in height at 14 weeks after treatment application (WATA) followed by treatment C (2g of NPK 15:15:15 fertilizer) and also treatment B (1g of NPK 15:15:15 fertilizer), the least mean height performance was recorded with seedlings of the control (treatment A). The results are in agreement with Choudhary and Yaday (2011) who reported enhanced cowpea growth with fertilizer application. There is significant interaction effect of fertilizer and species on the plant height of the three different moist forest tree species and this increased over the weeks

Table 3: Height Growth (cm) of *Irvingia gabonensis*, *Cola acuminata* and *Cola nitida*

Treatment	Species	WEEKS AFTER TREATMENT APPLICATION (WATA)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	X	18.3 0	19.2 5	20.0 7	23.81	24.4 7	26.1 0	27.1 1	28.2 2	28.75 ab	28.92 b	29.6 6 ^c	29.7 6 ^c	29.8 6 ^c	29.9 7 ^c
A	Y	2.26 c	2.45 b	2.75 ^c	3.13 ^c	3.55 ^c	3.92 ^c	4.28 b	4.59 ^c	4.91 ^c	5.17 ^c	5.48 ^c	5.77 ^c	6.02 ^c	6.41 ^c
A	Z	2.39 c	2.61 ^c	2.96 b	3.91 ^a b	3.97 b	4.01 ^c	4.07 ^c	4.12 ^c	4.17 ^c	4.21 ^c	4.26 ^c	4.37 ^c	5.07 d	6.07 d
B	X	16.1 7	18.0 3	20.6 8	22.67	23.9 3	25.4 9	26.5 7	27.4 8	27.82 b	29.31 b	31.3 2 ^c	31.4 8 ^c	31.6 8 ^c	31.8 9 ^c
B	Y	2.87 c	3.08 b	3.38 bc	3.74 ^c	4.05 ^c	4.49 ^c	4.94 b	5.34 ^c	5.74 ^c	6.14 ^c	6.41 ^c	6.81 ^c	7.21 ^c	7.61 ^c
B	Z	2.97 b	3.24 b	3.26 ab	3.66 ^b	3.76 b	3.73 d	3.83 d	3.97 ^c	4.07 ^c	4.17 ^c	4.27 ^c	4.51 ^c	5.31 ^c	6.54 ^c
C	X	18.7 6	20.6 9	22.8 4	24.61	23.6 9	25.7 6	27.1 9	29.0 5	29.92 ab	32.88 ab	35.8 g ^b	36.1 g ^b	36.5 g ^b	36.6 g ^b
C	Y	4.70 b	4.91 b	5.20 b	5.59 ^b	6.01 b	6.47 b	6.89 b	7.39 b	7.89 ^b	8.39 ^b	8.88 b	9.38 b	9.88 b	10.3 g ^b
C	Z	3.32 ab	3.61 a	3.72 a	4.04 ^a	4.24 a	4.44 b	4.64 b	4.84 b	5.04 ^b	5.22 ^b	5.44 b	5.84 b	6.77 b	7.72 b
D	X	16.3 1	18.2 5	20.2 5	23.02	23.3 5	25.8 9	28.3 6	30.9 7	32.94 a	36.70 a	40.6 7 ^a	41.7 2 ^a	42.7 9 ^a	43.8 6 ^a
D	Y	9.80 a	10.0 1 ^a	10.2 9 ^a	10.65 a	11.1 5 ^a	11.6 7 ^a	12.1 6 ^a	12.7 6 ^a	13.20 a	13.87 a	14.4 7 ^a	15.0 6 ^a	15.6 8 ^a	16.2 9 ^a
D	Z	3.40 a	3.66 a	3.74 a	4.15 ^a	4.44 a	4.88 a	5.04 a	5.34 a	5.64 ^a	5.91 ^a	6.19 a	6.79 a	7.81 a	8.82 a
Mean		8.48				11.3	12.2	12.9	13.6			16.0	16.4	17.0	17.6
LSD _{0.05} F.S		8.93 ab	9.14 a	9.92 g ^a	11.08 ab	8 8 ^b	3 3 ^a	2 1 ^b	7 6 ^b	14.17 b	15.07 b	8 4 ^b	7 4 ^b	5 4 ^b	8 7 ^b

abcd means within the same WATA having different superscripts are significantly different (P<0.05).

Diameter Growth of the Three Species

Table 6, 7 and 8 shown the mean growth and optimum level of NPK treatment on plant diameter (mm) of this selected seedlings and statistics within weekly intervals. At week 1, mean plant diameter (mm) of *I. gabonensis* result were A 1.48mm, B 1.40mm, C 1.60mm and D 1.86mm; mean plant diameter (mm) of *Cola acuminata* were A 1.22mm, B 1.96mm, C 1.94mm and D 2.47mm; and mean plant diameter (mm) of *Cola nitida* were A 1.94mm, B 2.56mm C 2.60mm and D 2.20mm. At week 14, mean plant diameter (mm) of *I. gabonensis* result were A 3.26mm, B 3.50mm, C 4.14mm and D 4.84mm; mean plant diameter (mm) of *C. acuminata* were A 2.40mm, B 3.05mm, C 3.29mm and D 4.27; and mean plant diameter (mm) of *Cola nitida* were A 2.82mm, B 3.34mm, C 3.84mm and D 4.74mm. The result indicated significant difference between the three tree species at the various fertilizer levels. The collar diameter increased with increasing level of NPK 15:15:15 fertilizer with the 3g treatment giving the highest result. The findings supported Choudhary and Yaday (2011) who reported enhanced cowpea growth with fertilizer

application. The interaction between fertilizer and species is significant for collar diameter growth of the three different moist forest tree species.

Table 4: Mean plant diameter (mm) of *Irvingia gabonensis*, *Cola acuminata* and *Cola nitida*

Treatment	Species	WEEKS AFTER TREATMENT APPLICATION (WATA)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
A	X	1.48	1.65	2.04	2.46 ^{ab}	2.61 ^{ab}	2.76 ^{ab}	2.71 ^b	2.81 ^b	2.86 ^c	3.04 ^b	3.09 ^c	3.14 ^c	3.19 ^d	3.26 ^d
A	Y	1.22 ^b	1.23 ^b	1.26 ^c	1.30 ^c	1.62 ^c	1.73 ^c	1.93 ^d	1.98 ^c	2.03 ^d	2.08 ^c	2.12 ^c	2.17 ^c	2.22 ^d	2.40 ^c
A	Z	1.94 ^b	1.98 ^b	1.92 ^b	2.11 ^b	2.13 ^b	2.17 ^c	2.20 ^c	2.23 ^c	2.26 ^c	2.29 ^d	2.32 ^d	2.38 ^d	2.43 ^d	2.82 ^d
B	X	1.40	1.58	1.88	2.06 ^b	2.19 ^b	2.42 ^b	2.30 ^c	2.41 ^c	2.72 ^c	3.08 ^b	3.18 ^c	3.29 ^c	3.39 ^c	3.50 ^c
B	Y	1.96 ^a	1.98 ^a	2.01 ^b	2.05 ^b	2.34 ^b	2.45 ^b	2.54 ^c	2.61 ^b	2.68 ^c	2.74 ^b	2.79 ^b	2.85 ^b	2.91 ^c	3.05 ^b
B	Z	2.56 ^a	2.58 ^a	2.42 ^a	2.52 ^a	2.57 ^a	2.62 ^b	2.67 ^b	2.73 ^b	2.78 ^b	2.85 ^c	2.89 ^c	2.99 ^c	3.18 ^c	3.34 ^c
C	X	1.60	1.86	2.12	2.67 ^a	2.31 ^{ab}	2.69 ^{ab}	2.93 ^{ab}	3.18 ^a	3.39 ^b	3.59 ^b	3.73 ^b	3.91 ^b	4.03 ^b	4.14 ^b
C	Y	1.96 ^a	1.98 ^a	2.01 ^b	2.05 ^b	2.34 ^b	2.45 ^b	2.54 ^c	2.61 ^b	2.68 ^c	2.74 ^b	2.79 ^b	2.85 ^b	2.91 ^c	3.05 ^b
C	Z	2.60 ^a	2.61 ^a	2.60 ^a	2.77 ^a	2.87 ^a	2.97 ^a	3.07 ^a	3.19 ^a	3.32 ^a	3.42 ^b	3.53 ^b	3.72 ^b	3.82 ^b	3.84 ^b
D	X	1.86	1.83	3.14	2.49 ^{ab}	2.76 ^a	2.90 ^a	3.19 ^a	3.45 ^a	3.73 ^a	4.07 ^a	4.27 ^a	4.57 ^a	4.69 ^a	4.84 ^a
D	Y	2.47 ^a	2.49 ^a	2.62 ^a	2.67 ^a	3.24 ^a	3.23 ^a	3.69 ^a	3.77 ^a	3.85 ^a	3.94 ^a	4.05 ^a	4.11 ^a	4.18 ^a	4.27 ^a
D	Z	2.20 ^b	2.24 ^b	2.29 ^{ab}	2.61 ^a	2.81 ^a	3.03 ^a	3.23 ^a	3.43 ^a	3.63 ^a	3.83 ^a	4.04 ^a	4.43 ^a	4.62 ^a	4.74 ^a
Mean		1.93	2.00	2.19	2.31	2.48	2.62	2.75	2.87	3.00	3.14	3.23	3.37	3.46	3.60
LSD _{0.05} F.S		2.04 ^a	2.14 ^a	2.24 ^{ab}	2.49 ^a	2.49 ^b	2.61 ^b	3.01 ^b	3.10 ^b	3.24 ^b	3.34 ^b	3.44 ^b	3.59 ^b	3.68 ^b	3.76 ^b

abcd means within the same WATA having different superscripts are significantly different ($P < 0.05$).

Mean Number of Leaves of the Species

Table 10, 11 and 12 shown the mean growth composition and optimum level of NPK treatment on leaves of the selected seedlings and statistical composition within weekly intervals. At week 1, mean number of leaves of *I. gabonensis* results were A 5.80, B 5.00, C 5.20 and D 5.60; mean number of leaves of *Cola acuminata* A 1.40, B 2.00, C 2.00 and D 5.00; and mean number of *Cola nitida* A 1.80, B 2.80, C 4.00 and D 4.00. At week 14, mean number of leaves of *I. gabonensis* results were A 12.80, B 13.60, C 14.60, and D 16.80; mean number of leaves of *Cola acuminata* were A 14.00, B 14.40, C 14.40 and D 18.40; and mean number of *Cola nitida* were A 14.40, B 15.40, C 17.60 and D 18.60. There is significant difference between the number of leaves of three tree species and at the various fertilizer treatment levels. The number of leaves on the various species seedlings increased with increasing level of NPK 15:15:15 fertilizer with the 3g treatment giving the highest values for the three species at 14 weeks after treatment application (WATA) while the Control had the least values. Significant interaction effect exists between fertilizer and species on the number of leaves of the three different moist forest tree species.

Table 9: Mean Number of leaves of *Irvingia gabonensis*, *Cola acuminata* and *Cola nitida*

		WEEKS AFTER TREATMENT APPLICATION (WATA)														
Treat		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
A	X	5.8	6.4	6.8	7.0	7.2	7.6	7.6	8.6	8.8	9.80	10.	11.2	11.8	12.8	
		0	0	0	0	0	0	0 ^{ab}	0 ^{ab}	0 ^b	b	20 ^b	0 ^b	0 ^c	0 ^c	
A	Y	1.4	2.2	3.2	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	
A	Z	0 ^b 1.8	0 ^b 2.0	0 ^b 3.2	0 ^b 3.8	0 ^b 4.8	0 ^b 5.8	0 ^b 6.8	0 ^b 7.8	0 ^b 8.8	0 ^b 9.80	0 ^b 10.	0 ^b 11.8	0 ^b 13.2	0 ^b 14.4	
B	X	0 ^c 5.0	0 ^c 5.4	0 ^b 6.0	0 ^c 6.2	0 ^c 6.0	0 ^c 6.4	0 ^c 6.6	0 ^c 7.8	0 ^c 8.8	c 9.80	80 ^d 10.	0 ^d 11.8	0 ^d 12.6	0 ^b 13.6	
		0	0	0	0	0	0	0 ^b	0 ^b	0 ^b	b	80 ^b	0 ^b	0 ^{bc}	0 ^{bc}	
B	Y	2.0	2.6	3.2	4.2	5.2	6.2	7.2	8.2	9.2	10.2	11.2	12.2	13.4	14.4	
B	Z	0 ^b 2.8	0 ^b 3.2	0 ^b 4.0	0 ^b 5.0	0 ^b 6.0	0 ^b 7.0	0 ^b 8.0	0 ^b 9.0	0 ^b 10.	0 ^b 11.0	0 ^b 12.	0 ^b 13.0	0 ^b 14.8	0 ^b 15.4	
C	X	0 ^b 5.2	0 ^b 5.6	0 ^b 5.6	0 ^b 6.0	0 ^b 6.4	0 ^b 6.6	0 ^b 7.2	0 ^b 8.6	00 ^b 9.6	0 ^b 10.6	00 ^c 11.6	0 ^c 12.6	0 ^c 13.6	0 ^b 14.6	
		0	0	0	0	0	0	0 ^{ab}	0 ^{ab}	0 ^{ab}	0 ^{ab}	0 ^{ab}	0 ^{ab}	0 ^{ab}	0 ^b	
C	Y	2.0	2.8	3.4	4.4	5.4	6.6	7.4	8.4	9.4	10.4	11.4	12.4	13.4	14.4	
C	Z	0 ^b 4.0	0 ^b 4.6	0 ^b 5.2	0 ^b 5.6	0 ^b 6.8	0 ^b 7.6	0 ^b 8.8	0 ^b 9.8	0 ^b 10.	0 ^b 11.8	0 ^b 12.	0 ^b 14.0	0 ^b 16.2	0 ^b 17.6	
D	X	0 ^a 5.6	0 ^a 6.4	0 ^a 7.0	0 ^b 7.0	0 ^a 7.4	0 ^b 8.0	0 ^a 8.8	0 ^a 9.8	80 ^a 10.	0 ^a 11.8	80 ^b 12.	0 ^b 13.8	0 ^b 14.8	0 ^a 16.8	
		0	0	0	0	0	0	0 ^a	0 ^a	80 ^a	0 ^a	80 ^a	0 ^a	0 ^a	0 ^a	
D	Y	5.0	6.2	7.0	8.0	9.4	10.	11.	12.	13.	14.4	15.	16.4	17.4	18.4	
D	Z	0 ^a 4.0	0 ^a 4.6	0 ^a 5.4	0 ^a 6.4	0 ^a 7.4	40 ^a 8.4	40 ^a 9.4	40 ^a 10.	00 ^a 11.	0 ^a 12.4	40 ^a 14.	0 ^a 15.2	0 ^a 17.6	0 ^a 18.6	
		0 ^a	0 ^a	0 ^a	0 ^a	0 ^a	0 ^a	0 ^a	40 ^a	40 ^a	0 ^a	00 ^a	0 ^a	0 ^a	0 ^a	
Mean		3.7	4.3			5.6	6.4	7.2	8.0	9.0	9.9			13.0	14.3	15.4
LSD _{0.05} F.		2	3	5		3	2	2	2	7	7	11	12	3	2	2
S		3.7	4.3	4.7		5.3	6.2	6.6	7.8	8.9	9.9	10.9	11.9	13.0	14.4	15.5
		3 ^b	3 ^b	3 ^b		3 ^b	0 ^b	0 ^b	0 ^b	3 ^b	3 ^b	3 ^b	3 ^b	0 ^b	0 ^b	3 ^b

abcd means within the same WATA having different superscripts are significantly different ($P < 0.05$).

CONCLUSION AND RECOMMENDATIONS

Conclusion

The time to seed germination vary significantly amongst forest tree species and has enormous significance in the planning and execution of afforestation and reforestation programmes for species and environmental conservation. Similarly, nutrient availability and supply impacts on tree seedlings growth to very large extent. At onset of data collection (week 1) the fertilizer treatments effect on the seedlings of the three tree species were not significant. However, treatment effects gradually increased across weeks to become significantly different at the later weeks. The seedlings height, collar diameter and leave number were significantly influenced by

the NPK 15:15:15 fertilizer application with the 3g of NPK 15:15:15 fertilizer (treatment D) showing significantly better performance for all growth parameters. The fertilizer enhanced seedlings growth rate evidenced in higher values for all three growth parameters of the three forest tree species.

Recommendations

Accurate records of forest species germination characteristics are crucial for tropical forest species management and conservation. Although there is increasing disinterest in inorganic fertilizers use in farms due to mirages of associated negative environmental issues, it should be recommended for use in the nursery to enable species grow faster to required planting girth in the field. Based on the findings of this study, it is clear that up to the level of 3g of NPK 15:15:15 fertilizer should be recommended for best results in the nursery practice of *Irvingia gabonensis*, *Cola acuminata* and *Cola nitida* seedlings.

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Carbon Sequestration in Selected Soils and Landuse Types of Omo Forest Reserve, Southwest Nigeria

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ABSTRACT

Carbon sequestration improves soil health and mitigates climate change. However, indiscriminate land use and forest exploitation have destabilized carbon storage in Omo Forest Reserve (OFR). Vegetation decline from human activities persists, yet past studies overlook the roles of soil and land use. This study estimates carbon stocks across soil horizons under selected soil and land use types in OFR. A reconnaissance survey of Omo Forest Reserve identified two soil types (Alfisol, Inceptisol) and three land use types (Arable Land (AL), Natural Forest (NF), Teak Plantation (TP)). Soil samples from surface horizons (SH) and sub-surface horizons (SSH) were analyzed for physical, chemical, and morphological properties. Carbon sequestration was estimated using Batjes method, and data were analyzed using descriptive statistics, regression, and ANOVA. The Alfisols and Inceptisols were mainly at middle and lower physiographic positions; with soil pH of 5.4 ± 2.2 and 5.6 ± 2.3 ; and texture of sandy loam and loamy sand, respectively. The Alfisols and Inceptisols corresponded with Lixisols and Cambisols; Egbeda and Apomu Series in the WRB and Local Series systems, respectively. Within soil horizons of AL, NF and TP, soil organic carbon varied widely with CV of 0.89, 1.04 and 0.78, respectively in OFR. The sequestered carbon by SH and SSH of Alfisol and Inceptisol, respectively in OFR were [(365.07 $\pm$ 89.66, 1410.68 $\pm$ 166.00), (1020.31 $\pm$ 411.22, 1177.67 $\pm$ 396.72) (AL)]; [(804.13 $\pm$ 150.04, 1387.18 $\pm$ 385.94), (1067.71 $\pm$ 418.07, 1210.86 $\pm$ 675.10) (NF)] and [(348.81 $\pm$ 87.59, 1492.67 $\pm$ 69.55), (568.37 $\pm$ 333.66, 573.91 $\pm$ 190.70) (TP)]. The high CV by AL, NF and TP in both soil types showed that sequestered carbon was highly variable with values 92.55, 103.67 and 74.65% for Alfisols and 85.69, 104.88 and 83.24% for Inceptisols. The sequestered carbon in soil types, landuse and horizons were not significantly different. Organic carbon ($\beta=0.93$), horizon thickness ($\beta=0.34$) and bulk density ($\beta=0.16$), were main predictors of sequestered carbon in OFR. Bulk density and horizon thickness enhanced carbon sequestration in sub-surface horizons, particularly in teak plantations. However, high variability in soil nutrients and sequestered carbon suggests instability. Thus, proper management to minimize soil disturbance and enhance soil organic carbon is strongly recommended.

Keywords: Soil types, Landuse types, Carbon sequestration, Omo Forest Reserve

INTRODUCTION

Carbon (C) is an important element in the earth's ecosystem as it forms the major building block

of cellular structures for most living organisms existing on earth (Komalirani and Sharma, 2012; Hannah and Max, 2020). As plants and animals grow and die, their remains are decomposed by micro-organisms which deposit some organic complexes of variable proportions and chemical compositions in the soil. Under favourable environmental condition, soil organisms present in the soil break down these organic complexes, integrating quite an appreciable amount into new chemical complexes within their individual biomass while expelling others back into the soil or respiring it into the atmosphere as CO₂ (Olson *et al.*, 2014).

Carbon in the soil exists in two forms: as soil inorganic carbon (in form of carbonate minerals) and soil organic carbon (as soil organic matter) (Jobbagy and Jackson, 2000). The soil inorganic carbon consists of mineral forms of carbon, either from disintegration of parent material, or from reaction of minerals present in the soil with atmospheric CO₂. Soil organic matter is the form in which SOC exist and it also comprises relatively accessible carbon in the form of fresh plant remains and relatively inert carbon in products obtained from plant remains, such as humus and charcoal (Lal, 2007). Several factors such as climate, landuse, vegetation type, disturbance, nutrient availability and management techniques may cause changes in soil organic matter either to increase or decrease (Six and Jastrow, 2002; Baker *et al.*, 2007).

Agricultural activities such as the conversion of native grasslands and forest lands into agricultural land, are one of the most extensive landuse that contribute to the production of greenhouse gases (GHGs) (Hartemink, 2010; HLPE, 2012). It also leads to carbon stock reduction, resulting from the removal of above-ground biomass during harvest, subsequent burning, decomposition and losses of soil carbon through processes such as erosion and leaching (Lal, 1999). Carbon sequestration which involves the trapping or capturing of atmospheric CO₂ majorly by plants and storing them as soil organic matter, aids as one technique of increasing SOC concentration in the soil, enhance its distribution in the various depths of the soil profile and maintain it in a stable soil micro-aggregates by protecting it from the activities of microbes where it stores as recalcitrant carbon having a long turnover time (Lal, 2007).

Variability in soil carbon was reported to exist among landuse and soil type, with mineral components changing the structure of the soil depending on the fractions of the components of the soil: sand, silt and clay (Reynaldo *et al.*, 2012). Soil organic carbon as well as the characteristics of the relationship of organic carbon with depth in the soil profile have been found to vary strongly with vegetation type and landuse (Jobbagy and Jackson, 2000). These variations have been attributed to climate, clay content and vertical and spatial distribution of plant roots (Reynaldo *et al.*, 2012). The general assumption of these variations in organic carbon has been that the more diverse the vegetation and number of plant species present in tropical forests, the more efficiently carbon can be sequestered (Nield, 2020).

Although, previous studies on carbon sequestration by other researchers, centered largely on carbon captured and stored by vegetation with little attention paid on the role of soil as carbon sink in the proposed study location. There is however little or no information on the estimation of carbon sequestered in the surface and sub-surface horizons of the landuse types and the different soil types in Omo forest reserve. This study was conducted therefore, to estimate the amount of carbon sequestered in soil horizons of two soil types and three landuse types of Omo

Forest Reserve. The specific objectives of this research therefore, were to: characterize and classify the soils of the study area; quantify the amount of carbon sequestered in the soils of the different landuse types and in the vegetation of both forest reserves; ascertain the variations in soil carbon sequestered by the soil horizons of the different soils and landuse types.

METHODOLOGY

Description and Location of the Study Area

This research was carried out in Omo Forest Reserve, known to be the largest forest reserve in Ogun State and one of the few remaining large blocks of high forests in Nigeria. It covers an area of about 130,500 hectares (Oyinloye *et al.*, 2010) and is situated in the Ijebu East Local Government Area (LGA) of Ogun State. Omo Forest Reserve is located within Latitudes 06° 35' 09.90'' N - 07° 06' 04.94'' N, and Longitudes 04° 04' 27.28'' E - 04° 35' 22.16'' E, and is administratively divided into six Jungles denoted as: J1, J2, J3, J4, J5 and J6.

The study location possesses two main rock types and these includes: the basement complex rocks of the Pre-Cambrian age made up of the older and younger granites in the northern parts of the State. The second are the younger and older sedimentary rocks of both tertiary and secondary ages in the southern parts. The topography of this study area is characterised mainly by an undulating terrain with slopes reaching up to 15%, with an altitude of 90-150 m (Iveren and Osho, 2018).

The River Omo is the major River that drains the reserve with River Owena and several other tributaries traversing it; while the eastern and southern boundaries of the reserve is lined by River Oni. The geological make-up of the reserve showed that it lies basically on a crystalline rock of homogeneous basement complex overlain by the Eocene deposits of sand, clay and gravel at the southern part of the reserve (Isichei, 1995).

The study area is situated in the moderately hot, humid tropical lowland rainforest zone of South-West Nigeria, there are two distinct seasons in the Omo Forest Reserve viz; the rainy season which lasts from March/April to October/November and the dry season which lasts for the rest of the year, October/November till March/April. Temperature is relatively high during the dry season with mean temperature of around 30°C, while Harmattan, brought in by the North-Easterly trade winds from December-February, has ameliorating effects on the dry period high temperatures. The mean annual rainfall ranges from 1600 to 2000 mm (Iveren and Osho, 2018). The reserve is characterized majorly by vegetation suggesting a mixed moist semi-evergreen rainforest and it has the most complex and productive vegetation type in the country. It is estimated that the forest supports about 8000 species of plants (Isichei, 1995). Due to selective exploitation in the past, the forest is largely a mature secondary forest, with pockets of riparian forest along the river courses and in other areas where log extraction is difficult. Both timber and non-timber products (such as fuel-wood, sponge, snails, leave and ropes) are being exploited in this forest reserve (Lowe, 1993). Hunting, farming, saw milling, fishing and trading are other socio-economic activities practiced in the reserve. The Omo Forest has also been known to be a center for tourism, research, and several educational activities.

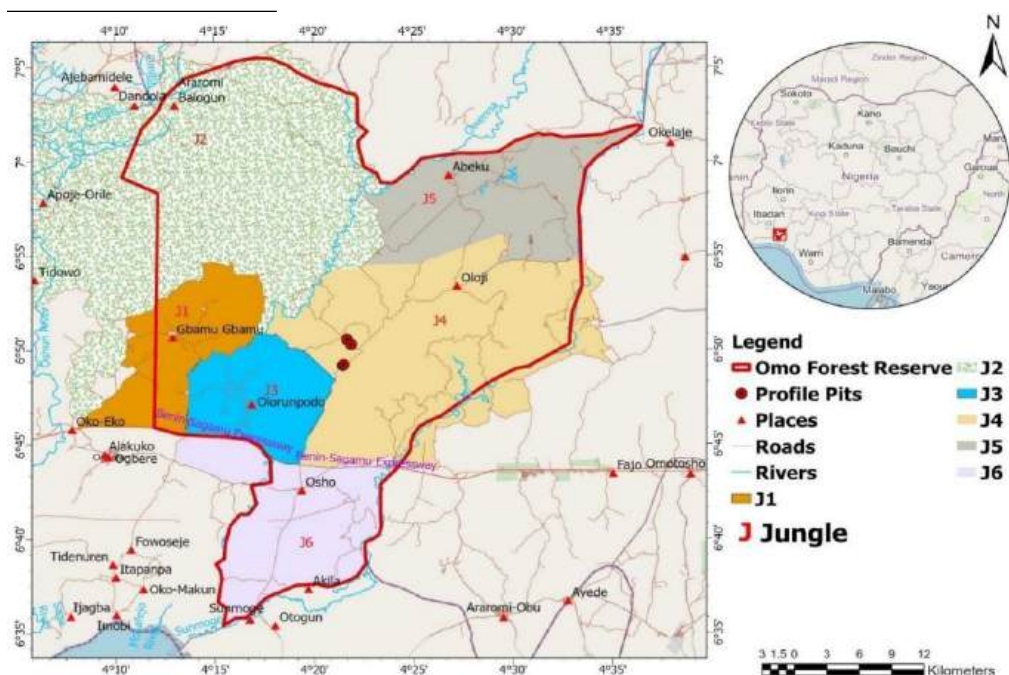


Figure 1: Map of Omo Forest Reserve

Field Survey

An initial (reconnaissance) tour was made to the study location for a general appraisal of the terrain to be surveyed, as well as seek permission from appropriate authorities, to gain easy access into the reserve. The co-ordinates of the sampling points were obtained using the Global Positioning System (GPS) device and a semi-detailed survey approach was adopted for the main field work.

Identification of Soil Types and Landuse Types

Series of auger observations were made randomly at several spots and at varying depths (15, 30, 45, 60 90 and 120 cm where possible) at different physiographic positions (upper slope, middle slope and lower slope) all within the landuse types investigated. Soil observation (morphological and physical properties) including: texture (by hand feel), consistency, colour (using the Munsell colour chart), mottles, structure etc. were made. Soils with similar properties were noted and profile pits were dug to further examine the soils for identification of distinct properties.

Several landuse types ranging from arable land, planted forests, natural forest, fallow etc. exists in Omo forest reserve. Amongst the arable land were soils cropped to cassava. Planted forests include Teak, Gmelina, Oak, Tea etc. The natural forest is divided into strips: the strict natural forest, which is being protected to maintain its natural state and to safeguard especially endangered species of both plants and animals. This area of the forest reserve is not accessible for research purposes; though, the other strip of natural forests is dedicated for research purposes and thus accessible. Nevertheless, there were however, substantial evidence of anthropogenic activities in this part of the forest reserve.

Soil Profile Pit Establishment and Soil Sampling

One profile pit each measuring about 1.5×1.5×1.5, was dug on the two soil types identified within a landuse. Then two other profile pits sited about 40-70 m, away from the main profile pit were sunk alongside (serving as replicates to the main profile pit) to further ascertain that the soil types were similar. Consequently, three profile pits were sunk on each of the soil type (Alfisol and Inceptisol) identified, all within a landuse type, giving a total of six profile pits on each landuse type which amounted to 18 profile pits in the study location. The profile pits were described using standard procedures of FAO guidelines (FAO, 2006). Composite soil samples were collected from each horizon with the aid of a hand trowel for routine chemical and physical analyses. Undisturbed soil samples were also collected from each horizon using a cylindrical metal core sampler (of known volume) for bulk density determination. The soils were analysed for morphological properties (colour, consistency, mottles, stoniness, roots, boundary forms etc.) in-situ.

Laboratory Analysis

A set of soil samples collected were air-dried and processed by passing them through a 2 mm mesh for particle size distribution, and other chemical properties. A little quantity of the 2 mm sieved soil was again passed through a 0.5 mm mesh to analyze for total nitrogen and organic carbon. The soils were analyzed using standard methods as described by Udo *et al.* (2009).

Soil Characterization and Classification

Soil characterization was carried out by examining the data from the morphological, physical and chemical properties derived from the soil analysis. The data derived from the soil characterization were then used to classify the soil using three different soil classification systems: Soil Taxonomy 12th Edition (USDA, 2014); World Reference Base (WRB) for Soil Resources (FAO, 2014); and the Local series classification using Smyth and Montgomery (1962).

Determination of Soil Organic Carbon (SOC) Sequestered by Soil

Soil organic carbon sequestration was calculated on soil horizon basis using the method by Batjes (1996) and Ahukaemere *et al* (2016).

$$\text{Soil Organic Carbon Sequestration (g C/m}^2\text{)} = \text{BD}_i(\text{g/cm}^3) \times \text{OC}_i(\text{g/kg}) \times \text{D}_i(\text{cm})$$

Where: BD_i = bulk density of individual horizon (g/cm^3);

OC_i = organic carbon of individual horizon (g/kg);

D_i = thickness of individual horizon layer (cm).

RESULTS AND DISCUSSION

Morphological Properties of the Soils of the Study Area

The Alfisols had a yellowish brown to strong brown soil colour mainly at the surface horizons and a reddish brown to red at the sub-surface horizons with a Bt horizon showing evidence of clay accumulation as a result of clay illuviation from adjoining horizon. The Alfisols existed more at the upper slope and middle slope physiographic positions.

The Inceptisols had a greyish brown to brown soil colour at the surface horizons and pinkish grey to light brown at the sub-surface horizons. They were found majorly at the lower slope physiographic positions with just a few existing at the middle slope.

Soil Organic Carbon (SOC) Sequestered in the Different Soil Horizons of Alfisols and Inceptisol

The soil organic carbon (SOC) of the arable land ranged from 208.85 to 2935.50 g C/m^2 having

a grand mean of 1013.58 g C/m² with horizon thickness ranging from 10 to 45 cm. The natural forest had its soil organic carbon to range from 300 to 4352.29 g C/m² having a grand mean of 1335.67 g C/m² and a horizon thickness ranging from 12 to 45 cm. The SOC of the teak plantation ranged from 134 to 3079.44 g C/m² having a grand mean of 1269.11 g C/m² and horizon thickness ranging from 13 to 50 cm. Table 3 refers.

In the case of the Inceptisols, the arable land had their soil organic carbon to range from 281.70 to 3950.43 g C/m² having a grand mean of 1368.88 g C/m² and a horizon thickness ranging from 12 to 40 cm. The SOC of the natural forest ranged from 47.10 to 2858.40 g C/m² having a grand mean of 827.83 g C/m² and horizon thickness ranging from 13 to 28 cm. The teak plantation had their soil organic carbon stock to range from 69.54 to 1688.01 g C/m² having a grand mean of 579.54 g C/m² and horizon thickness ranging from 10 to 62 cm. Table 4 refers.

Sequestered Carbon in Surface and Sub-Surface Horizons of the Soil and Landuse Types in Omo Forest Reserve

The carbon sequestered in the different horizons were put into two groups or categories of horizons: surface horizons and sub-surface horizons. All the mineral horizons (O, OA, A, Ap, etc. horizons) were grouped as surface horizon while the deeper horizons and transitional horizons (B, Bt, C, Cr etc. horizons) beyond the mineral horizons were grouped as sub-surface horizons. The sequestered carbon by surface and sub-surface horizons (g C/m²) of Alfisols were 365.07±89.66 and 1410.68±166.00 in the Arable land; 804.13±150.04 and 1387.18±385.94 in the Natural forest and; 348.81±87.59 and 1492.67±69.55 in the Teak plantation, while the sequestered carbon by surface and sub-surface horizons of Inceptisols were 1020.31±411.22 and 1177.67±396.72 in the Arable land; 1067.71±418.07 and 1210.86±675.10 in the Natural forest and; 568.37±333.66 and 573.91±190.70 in the Teak Plantation. Table 6 refers.

Variation in Carbon Sequestered by Soil Types and Landuse Types in Omo Forest Reserve

In the Alfisols of the Omo forest reserve, the highest SOC stock was recorded in the natural forest with value 1335.67 g C/m² and a coefficient of variation of 103.67%, followed by teak plantation with value 1269.11 g C/m² and a coefficient of variation of 74.65% and lastly the arable land with value 1013.58 g C/m² with a coefficient of variation of 92.55%. However, for the Inceptisols, the highest SOC stock was recorded in the arable land with value 1368.88 g C/m² with a coefficient of variation of 85.69% and this was followed by the natural forest with value 827.83 g C/m² and a coefficient of variation of 104.88% and then the teak plantation recorded a SOC stock of 579.54 g C/m² with a coefficient of variation of 83.24%. Table 7 refers.

Characterisation and Classification of the Soils of Omo Forest Reserve

The Alfisols were characterised mainly by a brown soil colour at the surface horizons and red soil colour at the sub-surface horizons and existed primarily at the middle physiographic position. The Inceptisols were characterised majorly by a light brown colouration at the surface horizons and a greyish colouration at the sub-surface horizons and existed primarily at the lower physiographic position. The gray colouration of these soils may be due to the oxidation reaction or anaerobic condition in which the soil has been subjected or exposed to. Customarily, the colour of the soil is determined and greatly influenced by the physical and chemical properties of the parent materials on which they are derived; the quantity of organic matter present in the soil; not ruling out the presence of the iron (Fe) existing in the soil. More so, soil colour may also be associated with how well-drained and aerated a soil is, which usually gives a rich brown hue colouration.

Brightly coloured soils are characteristics of a well-drained and well aerated soils.

Soil with poorly drain characteristics, formed under the absence of oxygen where most of the soil pore spaces have been occupied with water usually results in a greyish or blue-grey colouration. This agrees with the findings of Esu (2010), who stated that the grayish coloration of soils is an indication that the soil is imperfectly or poorly drained arising from prolonged anaerobic condition and iron oxide influence on the soils.

The Alfisols and Inceptisols of arable land, natural forest and teak plantation in Omo forest reserve were noted to be strongly acidic. The pH values recorded were observed to fluctuate irregularly with depth in all the horizons of the profile pits. The strongly acidic nature of these soils could be attributed to the high precipitation (rainfall) usually associated with the tropics. Another reason could be attributed to the prevailing characteristic acidic nature of Alfisols and Inceptisols which are often-times a consequence of the nature and property of the parent materials from which the soils are derived coupled with the influence of the leached horizons through the process of illuviation and eluviation. Eshett *et al.* (1990) and Onweremadu *et al.* (2007) reported that leaching enhances soil acidity under high annual rainfall condition which is a major characteristic of the tropics.

The coefficient of variation of the pH of the soils of the arable land, natural forest and teak plantation of both Alfisols and Inceptisols in Omo forest reserve were all observed to be within the low variability range. This implies that the acidity levels of this soils are quite stable suggesting that the acid levels of the soil horizons of both Alfisols and Inceptisols varied less among one another. These further confirms a strong trend in the acidic nature of the soils of the Omo forest reserve.

Organic carbon content was noted to be very high in the Alfisols and Inceptisols of arable land, natural forest and teak plantation in Omo forest reserve. Although, the organic carbon was observed to follow an irregular pattern and thus, vary significantly within the horizons of the different landuse types. Low to high coefficient of variation of organic carbon content recorded in the arable land, natural forest and teak plantation of both Alfisols and Inceptisols is in line with the findings of Ahukaemere *et al.* (2016), who recorded moderate to high variation in the organic carbon contents of the soil horizons in all the soil profile pit of the soils of some forest reserves in Nigeria.

Generally, the sub-surface horizons of the arable land, natural forest and teak plantation of both Alfisols and Inceptisols recorded the highest amount of organic carbon content when compared with the surface horizons. This shows the characteristic nature and innate capacity of the sub-surface horizons to store more carbon in relation to the surface horizons. This discovery is in line with those of Eswaran *et al.*, (1993), Batjes (1996), Mbah and Idike (2011), Abebayehu (2013), and Ahukaemere *et al.* (2016), who reported high carbon concentration in the deeper soil horizons. However, the high organic carbon content recorded at the surface horizons of especially the Inceptisols of the arable land and natural forest could be due to decomposing organic material input from plant litters existing on the soil surface or probably some fluvic materials transported from upper slope, and being deposited at the lower slope or valley bottom where the Inceptisols existed majorly. Ahukaemere (2016) also reported high organic matter content in few surface horizons.

Total nitrogen ranged from moderately low to medium and moderate in the Alfisols and Inceptisols of the Omo forest reserve. The moderately low nitrogen content recorded in the arable land could be due to leaching and loss of nitrogen through volatilisation caused as a result of land clearing

and repeated tillage and burning of the soil surface exposing the soil to harsh environmental condition associated with the tropics. However, the medium and moderate levels of nitrogen recorded at the natural forest and teak plantations could be due to the effect of the vegetation or canopy cover which tends to form a shed preventing direct sun rays on the surface of the soil and the kinetic energy in which rain droplets hit the surface of the soil causing dislodgment of the soil particles is reduced. By this, the surface soils are protected from harsh environmental conditions which ordinarily may enhance the rate of decomposition of organic materials thereby, increasing the rate of volatilisation of nitrogen present on the soil surface. The coefficient of variation of total nitrogen were all observed to be high in both Alfisols and Inceptisols in Omo forest reserve. This is an indication that total nitrogen is highly variable in these soils.

The textural class of the soils of Omo forest reserve traversed from sand to loamy sand at the surface horizons and sandy loam to sandy clay loam at the sub-surface horizons. This finding is at par with those of Chude *et al.* (2012) who noted that Alfisols and Inceptisols of basement complex rocks under rain forest vegetation have a characteristic loamy sand surface layers over more clayey subsoil and that soil texture vary greatly according to the rapid changes in rock lithology.

The clay fractions of the Alfisols and Inceptisols of Omo forest reserve were observed to be generally low at the surface horizons when compared with the relatively higher values obtained in the sub-surface horizons. Again, clay was observed to increase irregularly in the horizons but were higher at the sub-surface horizons and this may probably be due to the pedological process of illuviation and eluviation of clay particles in the contiguous top or lower horizons of the soil profile. This finding is also in line with those of Akinbola *et al.* (2009) who noted that high sand content of some soils in Nigeria are partly attributed to sandy nature of the parent material as well as clay movement through the process of eluviation and illuviation or through surface erosion by runoff. The high coefficient of variation of clay recorded in the horizons of both the Alfisols and Inceptisols is an indication that the clay fractions of these soils are highly variable and unstable.

Similarly, the silt fraction of the Alfisols and Inceptisols are higher at the sub-surface horizons than in the surface horizons of Omo forest reserve. Silt was also observed to increase irregularly in the various horizons and this may be due to the leaching of silt and other fine earth materials down the profile or washing away of these materials through the process of run-off or erosion. This observation is in line with that of Onweremadu *et al.* (2007) who reported that the low clay and silt fraction of the soils of an area are as a result of increase in the rainfall pattern which causes leaching thereby influencing the pedogenic feature of translocation of clay and silt fractions down the soil profile. The high coefficient of variation of silt recorded across board implies that silt is highly variable in some areas of the study location.

The sand (coarse and fine) fractions of the Alfisols and Inceptisols are higher at the surface horizons than the sub-surface horizons in Omo forest reserve. The high sand fraction observed here have its major contributions from the coarse sand fraction. This finding is at par with that of Olowolafe (2008) who discovered a higher percentage of sand in the fine earth fraction of most of the soils in Nigeria. Again, the concentration of sand fraction on the surface horizons of these soils could be due to the deposition of coarse sand materials carried by wind and run-off from the upper slope, down to the lower slope with the aid of slope and gravity. Esu (1982) and Chude *et al.* (2012) attributed the relatively higher fine sand fraction on the surface horizons of some of the soils in Nigeria to the aeolian deposits on the surface horizons of the soils and described Alfisols and Inceptisols to be mainly coarse textured. This discovery also corresponds with that of Ndukwu

et al. (2015), who affirmed that the sandy nature of soils can be linked to the sandy quality of the geological formation of parent materials. Again, Usman (2008), also noted that soils on geological sediments in Nigeria have appreciable amount of sand and are therefore erosion prone.

Low coefficient of variation in sand, noted at the arable land of the Inceptisols in Omo forest reserve shows that the coarse sand fraction of this soil is stable. The moderate coefficient of variation observed at the arable land, natural forest and teak plantation of the Alfisols and Inceptisols in Omo forest reserve suggests that the coarse sand fraction of these soils are moderately stable, although, this moderate stability can be maintained with proper soil management. Nevertheless, the high coefficient of variation noted in the Alfisols and Inceptisols of the arable land, natural forest and teak plantation in Omo forest reserve, indicates that the fine sand fraction of these soils is highly variable.

The bulk density values recorded in both Alfisols and Inceptisols in Omo forest reserve, showed that the soils are within the ideal bulk density range for plant growth and would not impede root penetration. Although, the bulk density values based on horizons were observed to increase regularly with depth in all the profile pits of the arable land, natural forest and teak plantation and this could probably be as a result of changes in clay and organic matter distribution in the horizons. However, the low bulk density values recorded at the surface horizons of most of the Alfisols and Inceptisols were observed to have relatively high organic carbon contents revealing the influence of organic matter on soil compaction. Ahukaemere *et al.* (2016) in his findings, reported that organic matter has significant positive influence on soil bulk density. Although, Chude *et al.* (2012) noted that Alfisols are generally poorly structured at the plough layer and so, the bulk density tends to rise rather rapidly after cultivation thereby impeding root development. Generally, the bulk density values recorded in the Alfisols and Inceptisols of the Omo reserve were found to be less than the critical limits for root restriction (1.75 – 1.85 mg/kg) (Soil Survey Staff, 2003).

Low coefficient of variation in bulk density was recorded in the Alfisols of Omo forest reserve indicating that the bulk densities of these soils are quite stable. In like manner, low coefficients of variation were also recorded in the arable land and teak plantation of the Inceptisols in Omo forest reserve. The low coefficient of variation recorded in these landuse types above could be as a result of the tillage activities being carried out on the arable land and the high organic matter accumulation on the surface soils of the teak plantation. However, the highest coefficient of variation of bulk density recorded could be as a result of pedological processes taking place within the horizons of the profile pits.

Following the description and analysis of the soil characterisation given above, the soils of Omo forest reserve were classified as Alfisols and Inceptisols in the USDA soil classification systems; Lixisols and Cambisols in the WRB classification system; and Egbeda and Apomu at the local series level.

Carbon Sequestered in the Soil and Landuse Types of Omo Forest Reserve

The highest soil organic carbon stock was recorded in the natural forest of Alfisols in Omo forest reserve and this was closely followed by the teak plantation and lastly, arable land. The high soil organic carbon value observed in the natural forest were majorly contributions of carbon sequestered in the sub-surface horizons and few contributions from the surface horizons. The high value recorded in the natural forest could be as a result of the partially decomposed supplementary organic material from litters and faunas which accumulated on the surface of the soil and gradually undergoing decomposition and pedoturbation with time. Or may probably be

due to the deep rooting systems associated with trees where the activities of micro-organisms are relatively high following their interaction with tree roots through the process of rhizo-deposition. This finding is in line with those of Weintraub *et al.* (2007) and Strand *et al.* (2008) who reported a significant contribution of plant roots to Soil Organic Carbon (SOC) through accumulation of microbes in the root zone and by their decomposition, thereafter, supply carbon to the soil through the process known as rhizo-deposition. Again, this finding is at par with those of Six *et al.* (2002), that forest soils sequester more than 80% of all terrestrial above-ground carbon and more than 70% of all soil organic carbon than the grass land.

In contrast, the arable land of the Inceptisols in Omo forest reserve, recorded the highest soil organic carbon stock when compared to the natural forest and teak plantation. The high SOC value noticed in the arable land of the Inceptisols in Omo forest reserve had the highest contribution also from the soil organic carbon sequestered at the sub-surface horizons of the arable land. The high value of soil organic carbon recorded in this landuse type especially at the sub-surface horizons, could be attributed to the physiographic position of this landuse, which is located at the valley bottom. It therefore has every tendency to receive some fluvic and organic materials removed or carried away by water and or gravity from the adjoining upper and middle slope positions. These materials are deposited on the immediate surface of the soil and the process continues, leading to some kind of buried horizon as a consequent of series of depositions. This finding is in line with those of Mbah and Idike (2011), who reported that soil organic carbon has the tendency of decomposing rapidly at the surface soil thus, liberating CO₂ to the atmosphere while a good amount of carbon is captured, stored and becomes stabilised especially in the sub-surface horizons of the soil profile.

The high values of soil organic carbon stock recorded in the natural forest of the Alfisol in Omo forest reserve are noted from both the soil organic carbon sequestered at the surface and sub-surface horizons. The reasons also could be as a result of the partially decomposed organic materials on the surface of the soil and the stable nature of the soils of the forest ecosystem as compared to the arable lands or teak plantation.

The high soil organic carbon observed in the sub-surface horizons is evidence that clay protects soil organic carbon by forming stable-clay organic complexes (Six *et al.*, 2002). Again, this reason could be attributed to the fact that there is less disturbance deep down there in the sub-surface horizons thereby making the sequestered soil carbon more stable for the time being. Depending on the rooting depth of plants, a substantial quantity of carbon is sequestered below the plough layer where it is protected from disturbance and consequently, leads to lengthier residence time in the soil. Clay forms some complexes with which it uses to protect carbon in the sub-soils. The relationship between carbon and clay does not occur often and most time fluctuates.

Conclusion

The Alfisols and Inceptisols (USDA), corresponded with Lixisols and Cambisols; Egbeda and Apomu series in the WRB and Local Series systems respectively. The sub-surface horizons have more innate ability to store more carbon than the surface horizons. Organic carbon, bulk density and horizon thickness proved significant in predicting the quantity of carbon sequestered by soils. Therefore, the improvement of these predictors (including organic carbon, bulk density and horizon thickness) are very important management aspects that can lead to increase in carbon sequestration ability and capacity of a soil. Most of the soil nutrients as well as sequestered carbon in the soils of the study areas were highly variable indicating they are very much unstable.

Farmers therefore, need to concentrate or pay more attention to management practices that will improve these soil characteristics (such as organic carbon and bulk density) with the aim of improving the quantity and quality of carbon sequestered by the soils as this would help to improve soil health and fertility (thereby enhancing crop and pasture yields), as well as aid to mitigate climate change.

Proper management geared towards reducing soil disturbance and increasing soil organic carbon is encouraged. Hence, intensive soil tillage, bush burning, and deforestation in these areas should be circumvented as they can enhance the rapid decomposition of organic materials thereby, releasing already sequestered carbon back into the atmosphere.

Table 1: Mean values and Variability in Selected Chemical Properties of the Landuse Types on Alfisols in Omo Forest Reserve

Landuse	Parameters	Alfisols	
		Mean	CV
Arable Land	pH (H ₂ O)	4.9	7.77
	OC (g per kg)	26.94	80.44
	Total N (g per kg)	1.68	80.36
	Avail. P (mg per kg)	21	78.62
	K (cmol per kg)	0.2	72.73
	ECEC (cmol per kg)	4.51	46.78
	B/Sat (%)	82.94	19.82
Natural Forest	pH (H ₂ O)	5.0	12.57
	OC (g per kg)	35.91	98.72
	Total N (g per kg)	2.24	99.11
	Avail P (mg per kg)	28	144.86
	K (cmol per kg)	0.3	75.00
	ECEC (cmol per kg)	3.95	50.38
	B/Sat (%)	79.58	24.54
Teak Plantation	pH (H ₂ O)	5.0	7.34
	OC (g per kg)	29.43	77.88
	Total N (g per kg)	1.84	77.72
	Avail P (mg per kg)	14	103.59
	K (cmol per kg)	0.2	68.18
	ECEC (cmol per kg)	4.52	76.11
	B/Sat (%)	90.49	6.4

CV: Coefficient of variation; n = 18

Table 2: Mean values and Variability in Selected Chemical Properties of the Landuse Types on Inceptisols in Omo Forest Reserve

Landuse	Parameters	Inceptisols	
		Mean	CV
Arable Land	pH (H ₂ O)	5.4	6.48
	OC (g per kg)	34.30	78.92
	Total N (g per kg)	2.14	78.97
	Avail P (mg per kg)	2	62.9
	K (cmol per kg)	0.3	112.12
	ECEC (cmol per kg)	3.33	48.05
	B/Sat (%)	81.21	22.47
Natural Forest	pH (H ₂ O)	5.0	9.92
	OC (g per kg)	27.48	107.82
	Total N (g per kg)	1.72	107.56
	Avail P (mg per kg)	2	115.3
	K (cmol per kg)	0.3	40.0
	ECEC (cmol per kg)	4.51	58.5
	B/Sat (%)	89.27	13.32
Teak Plantation	pH (H ₂ O)	5.2	12.21
	OC (g per kg)	17.37	116.29
	Total N (g per kg)	1.55	125.16
	Avail P (mg per kg)	2	102.55
	K (cmol per kg)	0.3	92.59
	ECEC (cmol per kg)	4.04	56.44
	B/Sat (%)	79.01	21.85

CV: Coefficient of variation; n = 18

Table 3: Soil Organic Carbon Sequestered in the Horizons of the Landuse Types in Alfisols in Omo Forest Reserve

Landuse	Profile No	Horizon	Depth (cm)	BD mg kg ⁻¹	OC g kg ⁻¹	HT Cm	CS (g C/m ²)
Arable Land	OMO A1 (1)	Ap	0-12	1.36	12.18	12	198.78
		B	12-30	1.48	19.32	18	514.68
		Bt1	30-55	1.53	5.46	25	208.85
		Bt2	55-83	1.56	67.2	28	2935.30
		Bt3	83-128	1.62	13.02	45	949.16
		BC	128-170	1.83	13.86	42	1065.28
Natural Forest	OMO F1 (1)	A	0-16	1.48	19.74	16	467.44
		Bt1	16-45	1.74	23.10	29	1165.63
		Bt2	45-73	1.59	15.96	28	710.54
		BCt1	73-106	1.52	33.6	33	1685.38
		BCt2	106-140	1.45	34.86	34	1718.60
		BCt3	140-180	1.42	78.96	40	4484.93
Teak Plantation	OMO P1 (1)	A	0-15	1.63	18.9	15	462.11
		Bts1	15-37	1.62	64.26	22	2290.23
		Bts2	37-68	1.66	21.42	31	1102.27
		Bct	68-94	1.50	78.96	26	3079.44
		BC	94-142	1.49	8.82	48	630.81
		Cr	142-192	1.55	15.54	50	1204.35

HT: Horizon thickness; BD- Bulk Density; CS: Carbon sequestered

Table 4: Soil Organic Carbon Sequestered in the Horizons of the Landuse Types on Inceptisols in Omo Forest Reserve

Landuse	Profile No	Horizon	Depth (cm)	BD mg kg ⁻¹	OC g kg ⁻¹	HT Cm	CS (g C/m ²)
Arable Land	OMO A2 (1)	AP	0-18	1.41	79.71	18	2023.04
		AB	18-44	1.45	36.46	26	1374.54
		Bw	44-70	1.42	7.63	26	281.70
Natural Forest	OMO F2 (1)	A	0-16	1.28	74.20	16	1519.62
		AB	16-31	1.70	7.63	15	194.57
		Bw1	31-53	1.79	7.63	22	300.47
		Bw2	53-80	1.69	5.94	27	271.04
Teak Plantation	OMO P2 (1)	A	0-10	1.64	4.24	10	69.54
		AB	10-35	1.80	10.06	25	452.70
		Bw1	35-58	1.71	9.75	23	383.47
		Bw2	58-120	1.69	16.11	62	1688.01

HT: Horizon thickness; BD- Bulk Density; CS: Carbon sequestered

Table 5: Taxonomic Classification of Alfisols and Inceptisols in Omo Forest Reserves

Forest Reserve	Landuse	Profile No	USDA	WRB	SERIES
ALFISOLS					
Omo	Arable Land	OMO A1 (1)	Arenic Kandiuustalf	Chromic Lixisol	Egbeda
	Natural Forest	OMO F1 (1)	Typic Kandiuustalf	Ferric Lixisol	Egbeda
	Teak Plantation	OMO P1 (1)	Typic Kandiuustalf	Ferric Lixisol	Egbeda
INCEPTISOLS					
	Arable Land	OMO A2 (1)	Fluvic Dystrustept	Gleyic Cambisol	Apomu
	Natural Forest	OMO F2 (1)	Typic Dystrustept	Chromic Cambisol	Apomu
	Teak Plantation	OMO P2 (1)	Typic Haplustept	Eutric Fluvisol	Apomu

Table 6: Sequestered Carbon in Surface and Sub-Surface Horizons of the Soil and Landuse Types in Omo Forest Reserves

Location	Landuse	Sequestered carbon (g C/m ²) in Soil Type/Horizon			
		Alfisol		Inceptisol	
		Surface	Sub-Surface	Surface	Sub-Surface
Omo	Arable Land	365.07	1410.68	1020.31	1177.67
	Natural Forest	804.13	1387.18	1067.71	1210.86
	Teak	348.81	1492.67	568.37	573.91
	Plantation				

Table 7: Variabilities in Soil Organic Carbon Sequestered in the Landuse Types on Alfisols and Inceptisols in Omo and Gambari Forest Reserves

Location	Landuse	Soil type			
		Alfisol		Inceptisol	
		SOC (g C m ²)	CV (%)	SOC (g C m ²)	CV (%)
Omo	Arable Land	1013.58	92.55	1368.88	85.69
	Natural Forest	1335.67	103.67	827.83	104.88
	Teak Plantation	1269.11	74.65	579.54	83.24

SOC- Soil organic carbon; CV- Coefficient of variation

Table 8: Effect of Soil Types, Landuse Types and their Interaction on Carbon Sequestered by Horizon (Surface and Sub-Surface) Basis.

Variate	Sequestered carbon (g C/m ²)
Landuse Types (LUT)	
Arable Land	903
Natural Forest	941
Teak Plantation	792
LSD (0.05)	Ns
Soil Types (ST)	
Alfisols	956
Inceptisols	802
LSD (0.05)	Ns
Horizons (H)	
A	741
B	1017
LSD (0.05)	Ns

H-Horizon; LUT-Landuse type; L-Location; ST-Soil type

Table 9: Stepwise Regression Analysis with Carbon Sequestered as Dependent Variable in Omo Forest Reserve

Predictors	Forest Reserves	
	Omo	
	Unstandardised coefficients (β)	Standardised coefficients (β)
OC	35.67	0.93
HT	32.01	0.34
BD	1177.95	0.16
Cu	76.95	0.81
Mn	-0.83	0.82
Avail. P	-	-

OC – Organic carbon; HT – Horizon thickness; BD – Bulk density; Cu - Copper; Mn - Manganese

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Environmental Consequences of New Road Infrastructure within Kano Metropolis

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ABSTRACT

The construction of road pavements requires a significant quantity of natural resources and energy there by causing various indirect and direct environmental impacts. The various human activities and development works have adverse impacts on environment causing climate change, which is recognized as one of the most critical environmental concerns confronting the world. This study aims to evaluate the environmental implications of road infrastructure in Kano Metropolis, providing insight into how road development affects ecological sustainability and urban quality of life. The study employed a descriptive type of survey design using a sample size of 384 drawn from Krejcie and Morgan sampling table. A well-structured questionnaire alongside focus group discussion and key in-depth interviews were used for data collection. The results revealed that 88.2% of respondents confirmed that the road infrastructure is in good condition. However, 65.7% strongly agreed that the areas surrounding the roads have been turned into dumpsites, and 61.3% strongly agreed that poor waste management has made road infrastructure a significant issue. The study concludes that while road infrastructure in Kano metropolis has significantly increased over the past decade, it faces serious threats from improper waste disposal and flood management, which, if not addressed, could lead to road damage in the near future. The need for user education and incorporating safety measures is emphasized to reduce accidents. The study recommends more frequent monitoring and evaluation of the roads, intensified environmental sanitation, public education, and regular impact assessments.

KEYWORDS: Road Infrastructure, waste and flood management, Environmental monitoring.

INTRODUCTION

The presence of an adequate, reliable and efficient transport system is a critical factor in local economic development. A well-developed transportation infrastructure provides adequate access to local communities, which in turn is a necessary condition for the efficient operation of manufacturing, retail, labour and housing market (Olubemehin, 2012). Kano as one of the fastest growing city in Sub-Saharan Africa is undergoing massive transformation in past 20 years. This leads to growing establishment of more roads, bridges, underpass and overhead all with sole aim of easy flow of goods, services and human. This new development may have its own side of problems especially the issue of perennial flooding as well as solid waste disposal (Usman et al, 2016).

Air pollution caused by road construction harms the environment, degrading the region's air quality (Guita 2020). The degraded air resulting from road construction mainly contains silica, among other compounds (Guo et, al., 2023, Harrison et, al., 2016). When inhaled into the

human body, silica can lead to lung cancer and other respiratory tract infections such as silicosis, cough, cold, etc. (Guo et al., 2023, Gharpure et al., 2021). These diseases impact human health greatly and can have even worsening effects on people with underlying health conditions such as asthma, which may lead to the loss of life (Tan et al., 2021). Road construction is linked to environmental pollution and risks, which impact people's health and well-being in urban and rural areas (Gharpure et al., 2021)

The loss of carbon sink services offered by tree cover due to deforestation during road construction is an important factor and needs to be accounted in any Life Cycle Assessment (LCA) studies of road pavements. Road construction sector can play a significant part in achieving the Nationally Determined Contribution (NDC) as pavement life cycle have significant impacts on the environment. All over the world, the impacts of product, process and system on ecosystem are being performed using the life cycle approach. Life cycle assessment (LCA) is a tool to assess the environmental impacts of any activity, product or system by translating the environmental burdens to environmental impacts based on quantification of inputs and outputs (Butt et al., 2014).

STUDY AREA

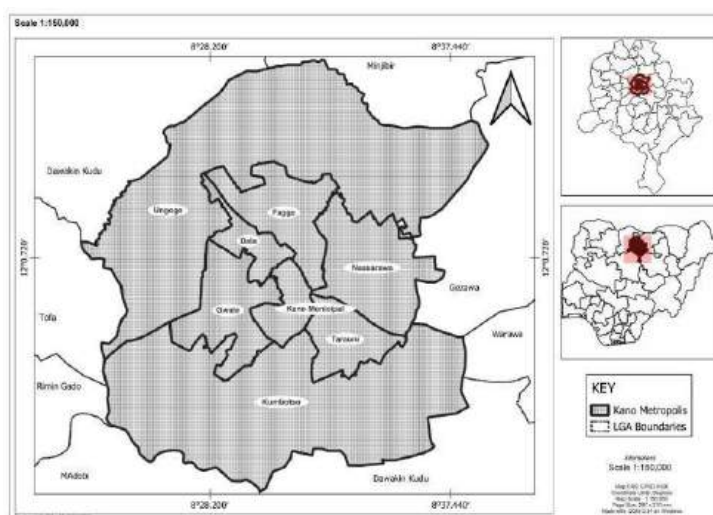


Figure1.1 Map of Kano showing Study Area

Source: GIS Lab Department of Geography Bayero University Kano (2024)

STUDY DESIGN

Location and Extent

This study adopted descriptive type of survey research design. Assessing the conditions and environmental impact of road infrastructures such as bridges, flyovers and underpasses was more appropriate with surveyed research design. Opinions from inhabitants of the study location were sought through interaction in order to provide insight into the subject under study.

The study employed proportionate sampling method for allocation of questionnaires based on the distribution of the infrastructure then availability sampling method was used to select the respondents while stratified sampling method was used to select the infrastructure, road

infrastructure such as bridges, flyovers and underpasses were stratified into class A, B, C and D. However, systematic sampling was used to distribute the research instrument at a periodic of five intervals to the respondents at the time of data collection until the requirement of responses are achieved.

RESULTS AND DISCUSSIONS

1.1 Environmental Effects of Road Infrastructural Development in Kano Metropolis

The development of infrastructure especially road has a way of affecting the environment either positive or negative, from an interview conducted at Kano State Ministry of Works, Housing and Infrastructural Development it was confirmed that environmental impact assessment has been carried out before the commencement of construction of the bridges. The officer confirmed that all environmental factors have been given due consideration even though he made it clear that it is not the responsibility of the ministry to take care of the roads upon completion because all roads ones completed are handed over to agencies vested with the responsibility of maintaining them. He said agencies like KNUPDA, REMASAB, FERMA and other sister agencies are responsible for taking care of roads upon completion.

1.2 Environmental Consequences of Waste Disposal management on the Road infrastructures within Kano metropolis

The distribution of responses where 33.5% strongly agreed that the surrounding of the flyovers has been turned into dumpsite, 32.2% agreed with the statement above on the other hand 25.2% disagreed while 7.3% strongly disagreed too. This result means that since 65.7% of the respondents agreed and strongly agreed that the surrounding of the road infrastructures has been turned into dumpsite, the need to take serious actions is essential as seen in figure 2 and plate 1A, B.

Bridges around Hotoro, Sabon Gari and Gadan Lado have the highest percentage of these occurrences, indicating that there is high number of dumping activities taking place in such locations.

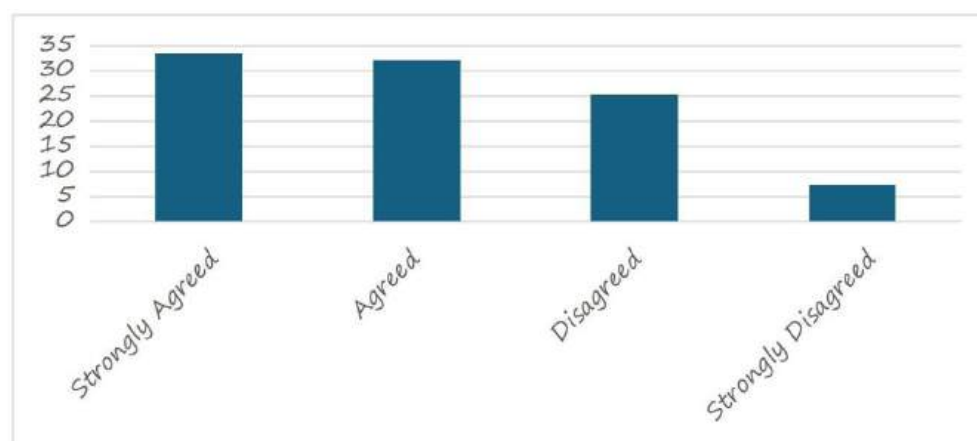


Figure 2: People's Behaviour in Handling Waste around the Roads

Source: Fieldwork 2024



Plate 1: Sabon Gari Dumpsite
Dumpsite



Plate 2: Sabon titi Dumpsite



Plate 3: Kofar Ruwa

Source: Fieldwork 2024

1.3 : Problems of Waste Management along Flyovers

The surrounding of flyovers has been in serious problem due to poor waste management. This result as seen in table 4.8 above, 32.8% of respondents strongly agreed that the surrounding of the road infrastructures has become a serious problem due to waste management, 28.5% of the respondents agreed, 29.4% disagreed to the above statement and 7.3% strongly disagreed to it. This result shows that the surrounding of the road infrastructure has serious problem of waste management as agreed and strongly agreed makes 61.4% of the total responses.

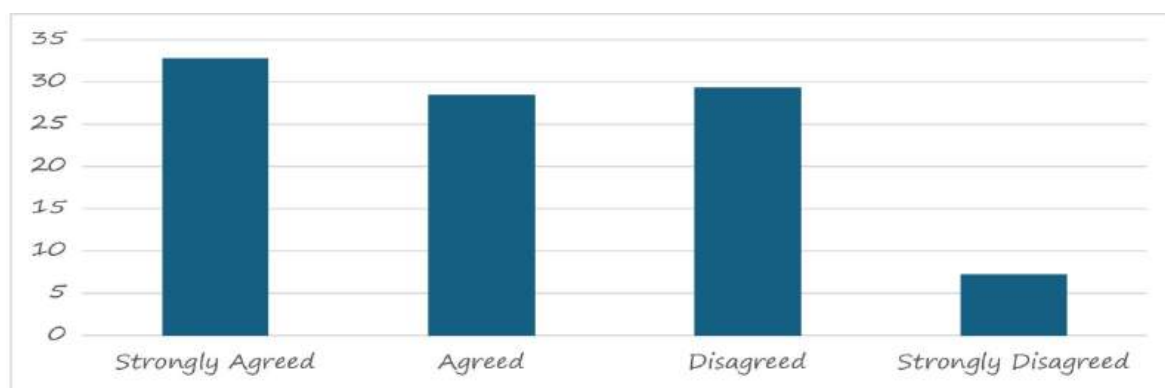


Figure 3: Road infrastructures and waste management Problems

Source: Fieldwork 2024

1.4 Environmental Consequences due to Flooding along Road infrastructures within Kano Metropolis

Flooding in itself can be natural or manmade but for the sake of this research work, manmade factors especially construction of road infrastructures are considered.

Findings as recorded in table 4.10 above shows that 35.9% of the respondents agreed that there are adequate drainage facilities, 28.3% said its very adequate, 21.0% complained it is inadequate because the road infrastructure causes flooding during raining season and 12.9% says it poor. This result shows that 64.2% confirm adequacy and very adequate of the drainage systems along road infrastructure in Kano Metropolis.

Nevertheless, from the distribution it is clear that bridges located in Naibawa, has a serious drainage problem, one (1) respondent said the drainage is adequate, one (1) respondent said the drainage is very adequate, one (1) respondent said the drainage is inadequate while

seventeen (17) said the drainages are poor that makes eighteen respondents out of twenty. Likewise, a similar problem is observed along Sabon Titi were out thirty-five respondents, eighteen said its inadequate, two said its poor making a total of nineteen (19) respondents affirming the need to recheck the drainages along the said bridges.

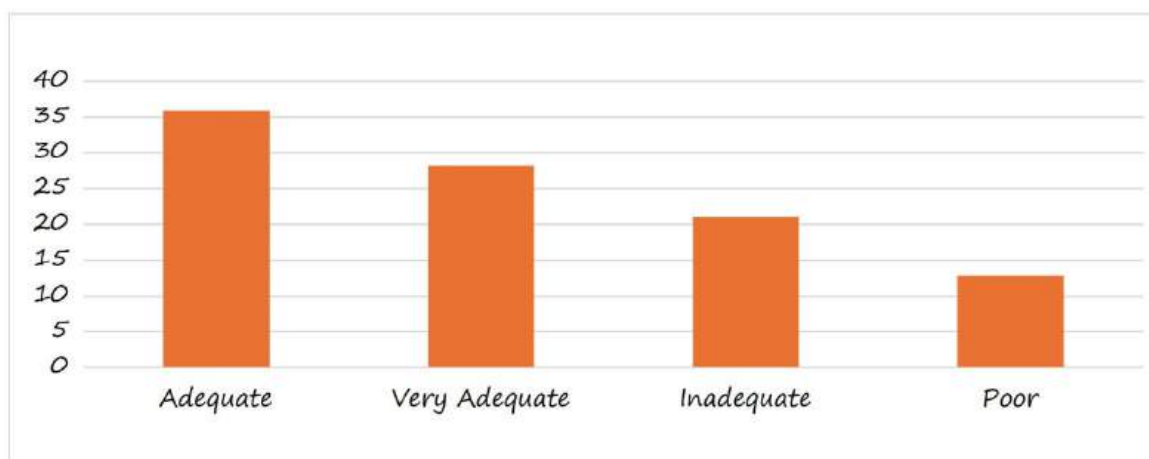


Figure 4: Adequacy of Drainage Systems

Source: Fieldwork 2024

1.5 Presence of Structural Defaults along Road Infrastructure.

Figure 5 below shows that 52.9% of the respondent affirms to the presence of structural defaults on the road infrastructure within kano metropolis especially those constructed in the last one (1) decade while 45.1% said there are no structural defaults on the road infrastructure. When carefully studying the result, its shows that there is serious level of structural default on bridges along Sabon Titi and Naibawa as seen in plate.

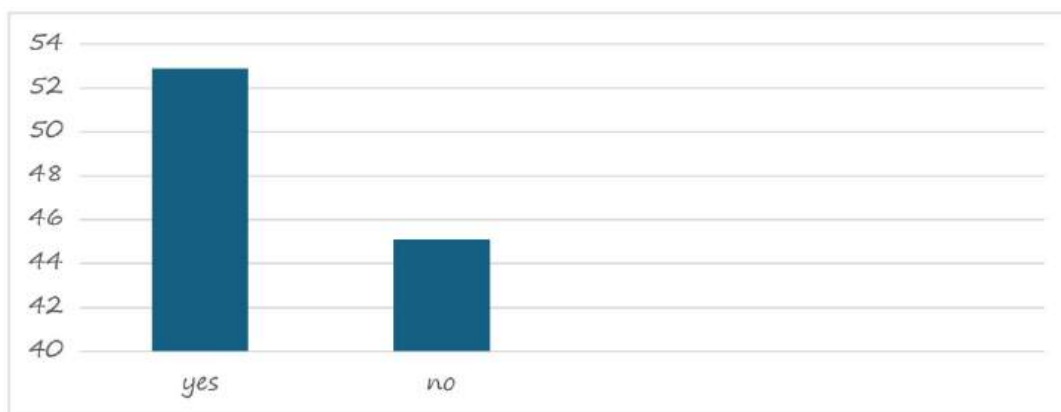


Figure 5: Structural Defaults on Road Infrastructure Source: Fieldwork 2024



Plate 4: Structural Default along Kofar Ruwa
Source: Fieldwork 2024



Plate 5: Structural Default along Kofar Ruwa
Source: Fieldwork (2024)

Conclusions and Recommendations

The new roads infrastructures constructed in the last decade are under serious threat from improper waste disposal and inadequate flood management, which, if not addressed by the authorities, could lead to substantial damage through flooding, structural default, pollution from waste and social bias in the near future. Additionally, educating road users is essential, along with incorporating safety measures, as these steps will greatly help reduce accidents along the road networks.

5.4 Recommendations

Findings from this study has outline the critical need for safety and waste management. The study from the conclusions made has the following recommendations;

- Regular monitoring and evaluation of all available road infrastructure should be intensified by the Government agencies responsible for managing the roads after their completion.
- Environmental sanitation by commercial owners along the road infrastructure should be encourage to clear waterways.
- Public enlightenments should be encouraged so that people should know the value of clean environment and avoid indiscriminate refuse dumping especially along drainage systems.
- Policies should be promulgated by government all level on waste disposal management and flood control.
- Structural default on roads infrastructures should be given serious consideration as living it linger can lead to loss of lives of users.

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Meat Singeing Methods in Southern Nigeria: Potential Health Risks and Implications for Climate Change Mitigation

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ABSTRACT

This study assessed the impact of different meat processing methods on heavy metal contamination, nutritional composition, and associated health risks, with a focus on singeing practices commonly employed in Nigeria. The aim was to evaluate concentrations of heavy metals—lead (Pb), mercury (Hg), manganese (Mn), nickel (Ni), copper (Cu), zinc (Zn), and iron (Fe)—in beef processed using four methods: scrap tyre singeing, gas flame singeing, firewood singeing, and hot water immersion. Standard analytical procedures were used to determine heavy metal concentrations, proximate composition, mineral and vitamin levels. Carcinogenic risk (CR) assessments were performed for lead and nickel based on oral exposure models. The results revealed that meats singed with scrap tyres and gas flames had significantly higher levels of Pb (up to 0.098 ± 0.004 mg/kg), Hg (up to 0.033 ± 0.006 mg/kg), and Mn (up to 0.084 ± 0.005 mg/kg), exceeding safe limits in several cases. Nickel-driven carcinogenic risk values ranged from 5.80×10^{-5} to 9.25×10^{-5} , with scrap tyre-singed meat presenting the highest CR. Nutritionally, hot water-treated meat retained more vitamins and less fat, while LPG singeing preserved protein and phosphorus content. In contrast, elevated Zn and Fe in tyre- and firewood-singed meat likely reflected exogenous contamination. The findings underscore the public health risks posed by unsafe singeing practices and reinforce the need for regulatory interventions. Safer alternatives such as hot water immersion and controlled gas-based methods are recommended to reduce toxic metal exposure and protect consumer health.

Keywords: Singeing practices, nutritional/heavy metal composition, health and environmental implications

INTRODUCTION:

In Southern Nigeria, singed meat, particularly processed hides (pomo or kanda), is a widely consumed delicacy across diverse socio-economic and cultural groups. The process of singeing—burning off animal fur—is an essential preliminary stage in preparing this meat. Traditionally, firewood has been the primary fuel for this process, favoured for its availability, affordability, and ability to impart a characteristic smoky flavour. However, rapid urbanization, deforestation, and escalating energy demands have rendered firewood increasingly scarce and expensive, leading processors to adopt alternative, often hazardous methods.

Emerging trends indicate a worrying shift toward the use of non-conventional fuels such as scrap tyres, plastics, petroleum products, and other combustible wastes. These materials are easily accessible and generate high-intensity flames suitable for hair removal, but their combustion releases huge carbon dioxide in addition to a complex mixture of pollutants—including heavy metals, polycyclic aromatic hydrocarbons (PAHs), dioxins, and furans—

many of which are classified as carcinogenic or toxic by international health agencies. When these compounds are deposited onto the meat or released into the surrounding environment, they pose serious public health threats to both consumers and processors (Obiri-Danso et al., 2008; Duruibe et al., 2017).

This process negates the efforts which the government of Nigeria is making to reduce GHG emission into the atmosphere and meet its international obligations (Nzegbule and Udoka, 2023). Nigeria pledged to reduce GHG emissions by 20% voluntarily and 47% with support through the nationally determined contributions (FME, 2021).

The toxicological risks associated with these unconventional singeing methods are substantial. Scrap tyres, for example, contain zinc oxide, lead, cadmium, and carbon black—components that are non-biodegradable, bioaccumulative, and capable of inducing systemic toxicity in vital organs over time. Inhalation of smoke from such combustion processes can result in respiratory ailments, while consumption of contaminated meat may lead to chronic diseases, reproductive disorders, and developmental impairments. Even wood fuel, when combusted under suboptimal conditions, releases harmful by-products such as phenols, fly ash, and particulate matter that contribute to environmental degradation and human health concerns (Shakya et al., 2006).

Despite these known risks, empirical data on singeing practices in Southern Nigeria remain sparse. There is limited documentation on the types of fuels currently in use, their prevalence across communities, and the level of awareness among meat processors and consumers regarding associated health hazards. Moreover, regulatory oversight is often weak or absent, allowing dangerous practices to persist unchecked in both urban and rural settings.

This study was therefore designed to bridge this knowledge gap by systematically assessing the methods and materials used for meat singeing in selected locations across Southern Nigeria. Specifically, the research aimed to evaluate the toxicological profiles of meat singed using different fuel sources and to identify the potential health risks posed to consumers. The main goal was to generate evidence that can inform safer food processing practices, guide policy formulation, and raise public health awareness in Nigeria.

MATERIALS AND METHODS

Study Area and Site Selection

The study was conducted in Southern Nigeria, comprising of the South-west, South-east, and South-South geopolitical zones. Study sites were selected based on population and commercial activity, and included: Calabar (Ikot Enebong abattoir), Aba (Ogbor Hill abattoir, Waterside), Benin City (Ikpoba - Okha abattoir), and Lagos (Odo Eran abattoir, Lagos Mainland). Reconnaissance visits were made to identify major abattoirs and observe singeing methods used. Common singeing practices observed included the use of LPG, hot water, scrap tyres and fuel wood.

Sample Collection

Cow meat samples were collected from singeing sites. Four samples, each weighing 10g, were taken from eviscerated carcasses at each site.

Proximate Analysis of Meat Samples

Proximate analysis was conducted on the meat samples to determine their nutritional composition. The parameters analyzed included: moisture content, crude protein, crude fat, and ash content. Standard procedures were employed for these analyses. Gravimetric oven drying method was used to determine moisture content (APHA, 2005). Protein content was determined following using the Kjeldhal titrimetric method (Chang, 2003). Fat content was determined using Soxhlet extraction gravimetric method (Thiex, 2003), while furnace

incineration gravimetric method was followed to determine ash content (Harbers and Nielsen, 2003).

Determination of Heavy Metals in Meat Samples

Heavy metal content in meat samples was determined using Atomic Absorption Spectrophotometry (AAS). Meat samples were incinerated in a muffle furnace, and the resulting ash was dissolved in 10ml of molar HCl solution, diluted to 100ml, filtered, and analyzed (Amfo-Otu et al., 2014).

Health Risk Assessment

1. Estimated Daily Intake (EDI)

EDI = (C × IR) / BW, Where:

- C = concentration of the metal in meat (mg/kg)
- IR = ingestion rate (kg/day)
- BW = body weight (kg)

2. Target Hazard Quotient (THQ)

THQ = EDI / RfD, Where:

- EDI = Estimated Daily Intake (mg/kg-day)
- RfD = Reference dose for the metal (mg/kg-day)

If **THQ > 1**, there's a potential **non-carcinogenic health risk**.

3. Hazard Index (HI)

The sum of THQs for all metals: $HI = THQ_1 + THQ_2 + \dots + THQ_n$

Where:

- THQ_1 to THQ_n = Target Hazard Quotients for individual metals

If **HI > 1**, there is a **cumulative health concern**.

4. Cancer Risk (CR)

CR = EDI × CSF

Where:

- EDI = Estimated Daily Intake (mg/kg-day)
- CSF = Cancer Slope Factor (mg/kg-day)⁻¹

Reference Doses (RfD) and Cancer Slope Factors (CSF)

Heavy Metal	RfD (mg/kg/day)	CSF (mg/kg/day) ⁻¹
Manganese (Mn)	0.14	-
Copper (Cu)	0.04	-
Zinc (Zn)	0.3	-
Nickel (Ni)	0.02	0.91
Lead (Pb)	N/A	0.0085
Mercury (Hg)	0.0003	1.0 (for methylmercury)

Note: Carcinogenic risk (CR) was typically calculated only for metals classified as carcinogenic (e.g., Ni, Pb, and Hg).

An average daily meat consumption of 50 g/day (0.05 kg/day) was adopted for risk estimation, based on global dietary exposure models (FAO/WHO, 2009).

Statistical Analysis

The data obtained from this study were summarised using mean and standard deviation and presented in tables. One-way Analysis of Variance (ANOVA) was used to determine the significant variation in proximate composition and heavy metal in meat singed using different methods. The Duncan multiple range post-hoc test was used to detect specific significant differences at $p < 0.05$. All statistical analyses were performed using Statistical Package of Social Sciences (SPSS) version 25.

RESULTS

Table 1 presents the concentration of seven heavy metals—manganese (Mn), copper (Cu), zinc (Zn), nickel (Ni), lead (Pb), iron (Fe), and mercury (Hg)—in meat samples singed using different processing methods across four urban centers in Southern Nigeria: Calabar, Aba, Benin, and Lagos.

Statistically significant differences in heavy metal concentrations were observed across locations and singeing methods. The gas flame method in Benin yielded the highest concentrations of manganese (2.750 ± 0.021 mg/kg), copper (3.427 ± 0.031 mg/kg), and zinc (10.453 ± 0.458 mg/kg), all significantly higher than those found in other treatments. In contrast, scrap tyre singeing in Aba produced the highest levels of nickel (3.073 ± 0.070 mg/kg), lead (0.287 ± 0.031 mg/kg), iron (8.327 ± 0.042 mg/kg), and mercury (0.033 ± 0.006 mg/kg), underscoring its potential to introduce multiple contaminants into meat. Comparatively, wood flame-singed meat showed moderate levels of metals across all locations, while hot water-treated samples (Calabar and Lagos) generally exhibited the lowest concentrations of toxicants, particularly for Mn, Zn, and Pb.

When grouped by the singeing method, distinct patterns emerged. Scrap tyre singeing consistently resulted in elevated concentrations of all measured heavy metals, posing the highest toxicological risk among all methods. Gas flame singeing also led to significantly elevated levels of Zn (10.453 ± 0.458 mg/kg) and Cu (3.427 ± 0.031 mg/kg), which may be attributed to fuel combustion residues or metal components of the burner. Wood flame singeing, though less severe, still produced moderate concentrations of Fe (up to 4.103 ± 0.021 mg/kg), Zn (up to 5.173 ± 0.042 mg/kg), and Cu (up to 2.103 ± 0.021 mg/kg), likely due to incomplete combustion and contact with contaminated surfaces. Hot water processing, in both Calabar and Lagos, yielded the lowest heavy metal burdens, suggesting it as the safest method from a contaminant exposure perspective.

Table 1: Heavy metal content of singed meat

Location	Singeing method	Mn ²⁺ (mg/kg)	Cu ²⁺ (mg/kg)	Zn ²⁺ (mg/kg)	Ni ²⁺ (mg/kg)	Pb ²⁺ (mg/kg)	Fe ²⁺ (mg/kg)	Hg ²⁺ (mg/kg)
Calabar	Water	0.117±0.012 ^e	0.840±0.020 ^f	3.013±0.012 ^d	0.720±0.080 ^d	0.027±0.006 ^d	2.773±0.042 ^e	0.010±0.000 ^c
	Wood	0.348±0.012 ^c	0.982±0.020 ^{ef}	4.112±0.042 ^{bc}	0.600±0.012 ^c	0.011±0.007 ^c	2.166±0.031 ^f	0.018±0.006 ^{bc}
Aba	scrap tyres	1.947±0.023 ^b	2.103±0.021 ^{bc}	5.173±0.042 ^b	3.073±0.070 ^a	0.287±0.031 ^a	8.327±0.042 ^a	0.033±0.006 ^a
	Wood	0.360±0.017 ^c	1.940±0.020 ^e	3.840±0.069 ^c	0.807±0.012 ^d	0.017±0.012 ^c	3.913±0.031 ^c	0.023±0.006 ^b
Benin	Wood	0.273±0.031 ^d	1.820±0.060 ^d	3.853±0.070 ^e	0.727±0.012 ^d	0.033±0.006 ^d	4.103±0.021 ^b	0.020±0.000 ^b
	Gas	2.750±0.021 ^a	3.427±0.031 ^a	10.453±0.458 ^a	1.393±0.042 ^c	0.133±0.012 ^b	3.687±0.061 ^d	0.023±0.006
Lagos	Water	0.067±0.012 ^f	1.337±0.021 ^e	2.707±0.061 ^d	1.647±0.023 ^b	0.040±0.000 ^d	2.827±0.031 ^e	0.027±0.006 ^{ab}

The proximate composition, mineral, and vitamin contents of meats singed using different methods—hot water (HW), firewood (FW), liquefied petroleum gas (LPG), and scrap tyre (TYRE) is presented in Table 2. Protein content was highest in meat singed with LPG ($10.75 \pm 0.21\%$), significantly greater ($p < 0.05$) than in meat treated with FW ($8.48 \pm 1.42\%$). Conversely, HW-treated meat had the lowest fat content ($1.37 \pm 0.08\%$), significantly different ($p < 0.05$) from LPG and TYRE methods, which yielded higher fat values ($3.53 \pm 0.37\%$ and $2.71 \pm 0.09\%$, respectively). Although crude fiber was absent in all samples, ash content differed significantly, with HW-singeing resulting in the highest ash level ($1.22 \pm 0.18\%$) compared to TYRE ($0.75 \pm 0.07\%$) and LPG ($0.94 \pm 0.04\%$) methods. Moisture content was significantly highest in LPG-singeing ($58.62 \pm 1.47\%$), while TYRE-treated meat showed the lowest ($52.89 \pm 0.37\%$).

Carbohydrate content varied significantly among the treatments, with FW-singeing yielding the highest value ($34.99 \pm 2.65\%$), while LPG-treated samples had the lowest ($26.12 \pm 0.86\%$). Mineral analysis showed that TYRE- and FW-treated meats had significantly higher iron content (12.38 ± 0.50 and 12.31 ± 0.59 mg/100 g, respectively) compared to HW-singeing (6.45 ± 0.00 mg/100 g). The highest phosphorus content was observed in LPG-treated meat (456.92 ± 0.97 mg/100 g), which differed significantly ($p < 0.05$) from all other treatments. Zinc content peaked in TYRE-singeing (5.02 ± 0.25 mg/100 g) and was lowest in LPG-singeing (3.37 ± 0.30 mg/100 g). Vitamin concentrations also displayed notable differences; HW-singeing preserved the highest vitamin level (78.20 ± 0.04 mg/100 g), followed closely by TYRE (76.82 ± 0.33 mg/100 g), both significantly higher than FW (6.47 ± 0.12 mg/100 g) and LPG (23.72 ± 0.33 mg/100 g). These findings suggest that while LPG-singeing may be optimal for retaining protein and phosphorus, HW-singeing is superior in preserving vitamins and minimizing fat content. However, the apparent nutrient advantages of TYRE-singeing must be interpreted with caution due to potential contamination from toxic residues.

Table 2: Proximate Composition, Mineral and Vitamin Contents of Meats Singed with Various Methods

Singeing Methods	Protein	Fat (%)	Fibre (%)	Ash (%)	Moisture (%)	CHO (%)	Fe (mg/100g)	P (mg/100g)	Zn (mg/100g)	Vitamins (mg/100g)
HW	9.51±1.18	1.37±0.0	0	1.22±0.1	55.76±1.88 ^a	32.15±	6.45±0.00	418±3.12	4.68±0.24 ^a	78.20±
	a	8 ^c		8 ^a		0.32 ab	b	b		0.04 ^a
				b						
FW	8.48±1.42	2.32±0.0	0	0.87±0.0	53.36±1.24 ^b	34.99±	12.31±0.5	344.16±1	3.64±1.95 ^b	6.47±0.
	a	5 ^b		1 ^b		2.65 ^b	9 ^a	.95 ^d		12 ^d
LPG	10.75±0.2	3.53±0.3	0	0.94±0.0	58.62±1.47 ^a	26.12±	11.24±1.7	456.92±0	3.37±0.30 ^b	23.72±
	1 ^a	7 ^a		4 ^b		0.86 ^a	7 ^a	.97 ^a		0.33 ^c
TYRE	9.06±1.27	2.71±0.0	0	0.75±0.0	52.89±0.37 ^a	34.60±	12.38±0.5	363.17±1	5.02±0.25 ^a	76.82±
	a	9 ^a		7 ^b		0.36 ^a	0 ^a	.02 ^c		0.33 ^b

Hot water (HW), firewood (FW), liquefied petroleum gas (LPG), and scrap tyre (TYRE)

Table 3 shows the Estimated Daily Intake (EDI) values for various heavy metals in meat processed through different singeing methods. Hot water immersion showed the lowest levels of contamination across all metals. The values for manganese (Mn), copper (Cu), and iron (Fe) were particularly low, indicating that this method did not introduce significant contamination compared to the others. While zinc (Zn) and nickel (Ni) levels were relatively moderate, they still remained on the lower end of the spectrum compared to other methods. Furthermore, mercury (Hg) concentration was also the lowest in this method, making it a safer choice with respect to this particularly toxic metal. Overall, hot water immersion proved to be the cleanest method in terms of heavy metal contamination.

In contrast, scrap tyre singeing resulted in higher levels of contamination across all metals compared to hot water immersion. Zinc (Zn) showed the highest concentration at 1.58×10^{-3} mg/kg, indicating that scrap tyres contributed significantly to zinc contamination in meat. Lead (Pb) also stood out with a concentration of 4.07×10^{-4} mg/kg, which was considerably higher than in other methods, raising concerns about the potential health risks associated with lead exposure. The mercury (Hg) level in scrap tyre singeing was 2.21×10^{-5} mg/kg, which was still relatively low, but higher than in hot water immersion, further suggesting that scrap tyres may have introduced hazardous contaminants into meat.

The gas flame method produced contamination levels that were generally higher than hot water immersion but slightly lower than scrap tyre singeing. Zinc (Zn) levels remained relatively high at 1.43×10^{-3} mg/kg, and nickel (Ni) and iron (Fe) were also present in moderate amounts. However, gas flame singeing did not significantly differ from scrap tyre singeing in terms of contamination. Lead (Pb) and mercury (Hg) concentrations in this method were also comparable to those seen with scrap tyre singeing, suggesting that while gas flame may have been slightly cleaner, it still posed a risk due to the introduction of heavy metals.

The wood singeing method generally had lower contamination levels than both scrap tyre and gas flame methods, particularly in terms of manganese (Mn), copper (Cu), and zinc (Zn). However, it still introduced moderate levels of nickel (Ni), lead (Pb), and iron (Fe), with lead being higher than in hot water immersion at 1.79×10^{-4} mg/kg. Mercury (Hg) levels were also moderate in wood singeing, falling between the concentrations seen in hot water immersion and scrap tyre singeing. While wood singeing may have been cleaner than scrap tyre and gas flame methods, it still presented some risks, particularly with respect to lead and mercury.

Table 4 presents the Target Hazard Quotients (THQs) for individual metals and the corresponding Hazard Index (HI) for meat processed using four different singeing methods. Hot water immersion exhibited the lowest overall risk, with an HI value of 0.0993. All individual THQs under this method were well below the safety threshold of 1, indicating minimal concern for adverse health effects. Among the metals, lead (THQ = 0.05857) and mercury (THQ = 0.03097) were the major contributors to the overall risk, though still within acceptable limits. This indicated that hot water immersion was the safest processing method evaluated in this study.

In contrast, the use of scrap tyres for singeing posed the highest health risk, with an HI of 0.2021. This elevated value was largely due to high THQs for lead (0.11629) and mercury (0.07367), suggesting an increased likelihood of chronic health effects with prolonged consumption of meat processed using this method. Although the THQs remained below 1, the cumulative exposure from multiple metals raised serious public health concerns.

Gas flame singeing showed an intermediate level of risk, with an HI of 0.1311. Similar to the scrap tyre method, lead (THQ = 0.06057) and mercury (THQ = 0.05967) were the dominant contributors. While gas flame singeing was safer than the scrap tyre method, it still represented a notable source of metal exposure compared to hot water immersion.

Wood singeing presented a hazard index of 0.1024, slightly higher than hot water immersion but lower than the other fuel-based methods. The main contributors to the risk were lead (THQ = 0.05114) and mercury (THQ = 0.043), yet all individual THQs remained below critical thresholds. Although relatively safer than scrap tyre and gas flame singeing, the wood method still introduced measurable levels of contamination.

The carcinogenic risk (CR) assessment (Table 5) revealed that all meat samples subjected to different singeing methods posed some degree of potential lifetime cancer risk, particularly due to exposure to nickel (Ni) and lead (Pb). Among the methods analyzed, meat singed with scrap tyres exhibited the highest total carcinogenic risk (9.25×10^{-5}), primarily driven by elevated levels of nickel. This value approaches the upper bound of the U.S. Environmental Protection Agency's (USEPA) acceptable risk range (1.0×10^{-6} to 1.0×10^{-4}), indicating a potentially significant long-term health concern for consumers regularly exposed to such meat.

Gas flame-singed meat also demonstrated a relatively high CR (8.04×10^{-5}), again largely influenced by nickel exposure. Hot water immersion and wood singeing methods resulted in lower cumulative CRs— 7.59×10^{-5} and 5.80×10^{-5} respectively—remaining within the permissible threshold but still suggesting a non-negligible risk, particularly with frequent consumption. While none of the methods exceeded the critical carcinogenic risk threshold, the trend clearly showed that singeing with scrap tyres and gas flames substantially increased potential cancer risks compared to more traditional or safer methods like hot water immersion or wood singeing. This emphasizes the importance of regulating meat processing practices to protect public health.

Table 3: **Estimated Daily Intake (EDI)** values for each metal based on the different singeing methods

Singeing Method	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Fe (mg/kg)	Hg (mg/kg)
Hot Water Immersion	4.14×10^{-5}	4.5×10^{-5}	1.26×10^{-3}	8.14×10^{-5}	2.05×10^{-4}	7.36×10^{-5}	9.29×10^{-5}
Scrap Tyre	5.21×10^{-5}	5.86×10^{-5}	1.58×10^{-3}	9.79×10^{-5}	4.07×10^{-4}	1.28×10^{-4}	2.21×10^{-5}
Gas Flame	4.64×10^{-5}	5.29×10^{-5}	1.43×10^{-3}	8.64×10^{-5}	2.12×10^{-4}	1.06×10^{-4}	1.79×10^{-5}
Wood	3.57×10^{-5}	4.36×10^{-5}	1.09×10^{-3}	6.21×10^{-5}	1.79×10^{-4}	9.29×10^{-5}	1.29×10^{-5}

Table 4: **Target Hazard Quotients (THQs) and Hazard Index by Singeing Method**

Singeing Method	Target Hazard Quotients (THQs)							Hazard Index (HI)
	Manganese (Mn)	Copper (Cu)	Zinc (Zn)	Nickel (Ni)	Lead (Pb)	Iron (Fe)	Mercury (Hg)	
Hot Water Immersion	0.0003	0.00113	0.0042	0.00407	0.05857	0.00011	0.03097	0.0993
Scrap Tyre	0.00037	0.00147	0.00527	0.0049	0.11629	0.00018	0.07367	0.2021
Gas Flame	0.00033	0.00132	0.00477	0.00432	0.06057	0.00015	0.05967	0.1311
Wood	0.00025	0.00109	0.00363	0.00311	0.05114	0.00013	0.043	0.1024

All individual THQs < 1, indicating **no immediate non-carcinogenic health risk** per metal. Hazard Index (HI) is also < 1, suggesting **low cumulative risk** from combined exposure.

Table 5: **Carcinogenic Risk (CR) by Singeing Method**

Singeing Method	CR (Pb)	CR (Ni)	Total CR (Pb + Ni)
Hot Water Immersion	1.74×10^{-6}	7.41×10^{-5}	7.59×10^{-5}
Scrap Tyre	3.46×10^{-6}	8.90×10^{-5}	9.25×10^{-5}
Gas Flame	1.80×10^{-6}	7.86×10^{-5}	8.04×10^{-5}
Wood	1.52×10^{-6}	5.65×10^{-5}	5.80×10^{-5}

CR acceptable range of 1.0×10^{-6} to 1.0×10^{-4} .

DISCUSSION

This study reinforces the critical role of meat processing methods in determining both heavy metal contamination and nutritional quality, raising serious public health concerns over common singeing practices such as scrap tyre and gas flame combustion. Lead (Pb) levels exceeded permissible limits in several samples, particularly those singed with scrap tyres and gas flames, consistent with findings by Ekenma et al., (2015) and Buhari et al., (2023) who linked elevated Pb to leaching from tyre-derived residues. Mercury (Hg) concentrations were also elevated in scrap tyre-treated samples, supporting the observations of Nwude et al. (2011) that hazardous materials used during singeing contribute to mercury accumulation in meat. Given mercury's neurotoxicity and

bioaccumulative nature, even the relatively low levels detected (0.033 ± 0.006 mg/kg) warrant concern in populations with high meat intake. Manganese (Mn) concentrations were elevated in most processed meat samples, particularly those singed with scrap tyres and gas, while samples treated with hot water showed comparatively lower levels. This pattern is consistent with observations by Odoh et al., (2017), who linked increased Mn concentrations to both environmental deposition and contamination from processing equipment. Zinc (Zn) and copper (Cu) were also present at relatively high concentrations across all samples. As essential micronutrients, Zn and Cu are vital for immune function, enzyme activity, and cellular metabolism.

Beyond heavy metals, the study also revealed significant variations in the proximate composition, mineral profile, and vitamin content of meat processed using different methods. The higher protein and phosphorus contents found in LPG-singeing-treated meat align with observations by Adeyemi et al. (2014), who reported that controlled, uniform heating with gas flames helped preserve protein structure and essential minerals. Likewise, the reduced fat content and enhanced vitamin retention in hot water-treated samples corroborate the findings of Omojola et al. (2013), who demonstrated that hot water scalding effectively limits oxidative degradation and nutrient loss. Conversely, the relatively high iron and zinc concentrations in tyre- and firewood-singeing methods—while appearing nutritionally beneficial—may be the result of exogenous contamination from ash and metallic residues, as previously suggested by Onoja et al. (2017) and Okareh et al. (2021). These studies also warned of the potential health hazards posed by polycyclic aromatic hydrocarbons (PAHs) and heavy metals introduced during unsafe meat processing.

The observed variations in proximate, mineral, and vitamin compositions of meats subjected to different singeing methods are consistent with earlier reports on the effects of processing techniques on meat quality. The significantly higher protein and phosphorus contents observed in LPG-singeing align with the findings of Adeyemi et al. (2014), who reported that gas-based processing preserved more essential nutrients due to uniform and controlled heat application. Similarly, the low fat and high vitamin retention seen in HW-treated samples is corroborated by Omojola et al. (2013), who noted that hot water scalding minimized nutrient loss and oxidative degradation, thus better preserving vitamins.

Conversely, the relatively high iron and zinc content in TYRE- and FW-singeing, though nutritionally appealing at face value, may be attributable to exogenous contamination from metallic residues in burnt tyres and wood ash, as previously noted by Onoja et al. (2017) and Okareh et al. (2021). These studies also cautioned against the health risks associated with heavy metal accumulation and polycyclic aromatic hydrocarbons (PAHs) in meat processed using unsafe materials like scrap tyres. The elevated vitamin levels in HW- and TYRE-singeing in the current study partially support Okiei et al. (2009), who observed that moderate heat exposure retains thermolabile nutrients, though the high vitamin values in TYRE-singeing could also reflect analytical interference or surface contamination rather than true biological retention.

An important toxicological aspect of this study was the assessment of carcinogenic risk (CR) from nickel and lead exposure in processed meat. CR values ranged from 5.80×10^{-5} to 9.25×10^{-5} , with scrap tyre-singed meat posing the highest risk, largely due to elevated nickel concentrations. Nickel, classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC, 2012), contributed similarly to high CR values in gas flame-singed meat (8.04×10^{-5}). In contrast, meats singed with firewood (5.80×10^{-5}) and hot water (7.59×10^{-5}) showed comparatively lower but still notable risks. These findings align with previous report by Njoga et al. (2021), which highlighted the influence of contaminated fuel sources on carcinogenic risk in thermally processed meats.

Implication on Climate Change Mitigation

Singeing of meat is a notable pathway through which carbon dioxide (CO₂) and other greenhouse gases are released into the atmosphere, contributing to climate change. Traditionally, firewood has served as the primary fuel source for singeing, but there is a growing reliance on non-conventional materials such as scrap tyres, plastics, and petroleum products due to their ability to generate intense heat for burning off animal fur. The use of fuelwood contributes to deforestation, one of the primary human activities driving elevated atmospheric carbon concentrations. This ongoing depletion of forest cover compromises the capacity of ecosystems to provide critical services, including the regulation of CO₂ levels through carbon sequestration. Additionally, the combustion of these materials releases oxygen-depleting compounds and soot into the atmosphere, further exacerbating environmental degradation. As reported by Aremu and Babatunde, the energy released from burning 3.95 kg of firewood ranges between 42.2–45.42 MJ/kg, while burning carcasses required up to 61.42 MJ/kg over 38.6 minutes—highlighting the intensity of emissions from such practices.

The findings from this study also highlight the critical role of meat processing methods in determining contamination levels, with scrap tyre and gas flame treatments yielding the highest concentrations of toxic metals such as lead, mercury, and manganese. These results align with prior research (Buhari et al., 2012) and underscore the continued public health risks posed by unsafe meat singeing practices. Beyond reaffirming known hazards, this study emphasizes the urgent need for regulatory enforcement to eliminate hazardous materials from food processing. Promoting safer alternatives—such as hot water immersion—alongside targeted public education campaigns is essential to reducing dietary exposure to heavy metals, protecting consumer health, and supporting broader climate change mitigation efforts.

CONCLUSION

In conclusion, hot water immersion proved to be the safest singeing method when it came to heavy metal contamination, with the lowest concentrations of all metals, making it a preferable choice for ensuring food safety. On the other hand, scrap tyre singeing resulted in the highest contamination levels, especially for zinc and lead, which were of concern due to their toxicity. Gas flame singeing and wood singeing presented intermediate levels of contamination, with gas flame being slightly cleaner than wood but still posing health risks due to the presence of heavy metals. Singeing of meat with fuel wood and scrap tyres contribute to the volume GHG in the atmosphere, Singeing using LNG and Hot water appear to be cleaner methods judging by the relatively less quantity emissions released.

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Influence of Micro Climatic Variables on Insect Diversity in Selected Tropical Agroecosystems of Kano State

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ABSTRACT

This study investigates the relationship between insect diversity indices such as Species Richness, Evenness, Abundance, Shannon and Dominance and Ecological/Climatic parameters across three distinct agricultural systems; Rainfed, Irrigated and Fallow farms in Kano State, Nigeria over a 12-month period (January-December, 2023). Insect sampling was conducted regularly using standard entomological techniques and diversity indices were analyzed. Concurrently, key climatic variables such as: temperature, precipitation, relative humidity, cloud cover, and windspeed were recorded. Using linear regression analysis, the study identified a significant positive correlation between species richness and cloudcover, indicating that increased cloudiness may enhance habitat sustainability or insect activity. Additionally, abundance was positively correlated with relative humidity, suggesting moisture availability as a potential driver of insect population dynamics. These findings highlight the sensitivity of insect communities to microclimatic variables and underscores the importance of ecological monitoring for sustainable agricultural and biodiversity conservation strategies in tropical ecosystems.

Key words: Ecological, Diversity, Farms, Insects.

INTRODUCTION

Insects are involved in a variety of roles in the ecosystem such as pollination and maintenance of plant community composition and structure through phytophagy (Costa-Neto, 2015). The total value of pollination services rendered by all insects globally, has been estimated to be in excess of \$57 billion annually (Melbourne 1999). The main vital crop pollinators are bees for both social and solitary species, albeit also include some flower visitors i.e., beetles, butterflies, and other flies. Several crucial pollinating insect species are related to different insect orders such as Hymenoptera (included wasp, bees, and ants), Lepidoptera (included butterflies and moths) Diptera (flies), and the order Coleoptera (beetles) (Costa-Neto, 2015).

Insects aid in soil fertility and structuring (Currie, 2004). Some insects are termed as 'keystones' because the loss of their critical ecological functions could collapse the wider ecosystem. Keystones refers to species that has a disproportionately large effect on its ecosystem relative to its abundance and they perform essential ecological functions such as: Pollination, decomposition, pest control, food source e.t.c. For example, termites convert cellulose in tropical soils, suggesting that they are keystones in tropical soil structuring (Currie, 2004)). Also, in aquatic ecosystem, a comparable service is provided by the guild of mostly larval insects that break down and release

the nutrients from wood and leaves derived from the surrounding terrestrial environment (Dainese *et al.*, 2019).

Thus, insects emerge as essential components of healthy ecosystems, playing a pivotal role in decomposition processes crucial for waste prevention and nutrient cycling. Their absence would have devastating consequences for the environment, affecting biodiversity, nutrient availability, and potentially contributing to climate change. Therefore, conservation efforts aimed at protecting insect populations are imperative for maintaining a healthy and balanced planet. (Forrister *et al.*, 2019). Population Dynamics is a study of changes in species composition and their number with reference to time interval (Maestre *et al.*, 2016).

Studying insect diversity in relation to climatic factors helps us to understand the population dynamics of insects and factors responsible for the changes across the different habitats. This study delves into the impact of climate change and habitat loss, changes in land use and agriculture practices, pollution and chemical contamination, invasive species and pathogens, as well as interactions with other species. Understanding these factors is essential for assessing the health of ecosystems, addressing biodiversity loss, promoting sustainable agriculture, and preserving the intricate balance of nature (Jimoh, 2012). These primarily climatic factors such as temperature, precipitation, relative humidity, cloudcover and windspeed are closely linked with broader environmental conditions and together, they play a pivotal role in determining insect distribution, as they directly influence ecosystem health, habitat suitability, and availability of essential resources. (Maria, 2012). Current estimates of changes in climate indicate an increase in global mean annual temperatures of 1°C by 2025 and 3°C by the end of the twenty-first century. The amounts of CO₂ have been projected to double between 2025 and 2070, depending on the level of emission of greenhouse gasses (UNFCCC, 2007). Mean annual temperature changes between 3°C and 6°C are estimated to occur (Smith, 2011)

The changes of insect's population are influenced by a combination of biotic and abiotic factors and their complex interactions. To survive and thrive in challenging environments, insects have developed unique adaptations and flexible responses. Among the various abiotic factors, temperature and humidity play a significant role in determining the abundance and distribution of insects. Temperature has been extensively studied and found to have a profound influence on the ecological dynamics of insect communities (Hillerbrand, 2004).

3.0 MATERIALS AND METHODS

3.1 Study Areas: Three study sites/habitats was used for the purpose of this study:

Habitat A: Irrigated Farm located at Kura Local Govt Area.,

Habitat B: Rainfed farm located at Madobi, Kumbotso Local Govt Area and.

Habitat C: Fallow land in Bayero University Kano.

Irrigated farm is located in Kura which is a town in one of the 44 Local Government in Kano State and lies Southwards of Kano city. Kura lies between latitude 11° 41'70"N and 11.77139°N and Longitude 825° 49'0"E and 8.4302° E (Nipost 2006). Over 70% of the population in this area are engaged directly or indirectly in agricultural activities including possessing both rainfed and irrigated farm lands (Mohammad, 2011).

Vegetation Types: Kura lies within the Sudan Savannah zone of Northern Nigeria, which is characterized by pen woodlands, scattered trees and grasslands. The vegetation is significantly influenced by agriculture, seasonal rainfall, and human settlements. As they contribute to reduced vegetation, change in species composition, degradation of ecosystem services and promotion of

Environmental stress (Lambin and Geist 2006).

Tree Types: The common tree species found includes: *Azadirachta indica* (Neem), *Parkia biglobosa* (African locust bean), *Mangifera indica* (Mango), *Faidherbia albida* (Winter thorn) and *Eucalyptus camaldulensis* (Eucalyptus). The trees are mostly found around homesteads, farms, and along roads serving purposes such as shade, fuel wood, fodder and soil enrichment (Akinyele 2010).

Shrub types: The common shrub species include: *Guiera senegalensis*, *Calotropis procera*, *Ziziphus mauritania* and *Cassia obtusifolia*.

Ground Vegetation: The ground vegetation includes: Grasses such as *Pennisetum pedicellatum*, *Hyparrhenia rufa*, *Andropogon gayanus* and also, Herbaceous plants such as: *Amaranthus spp.*, *Commelina spp.*, *Cleome viscosa*. (Yusuf and Ologe, 2017).

Rainfed farm is located at Madobi is also one among the 44 Local Areas in Kano State. Towns and villages that make up Madobi LGA include Chinkoso, Agalawa, Ningawa, Yakun, Ruga, Kanwa, Gora, and Gazana. The estimated population of Madobi LGA is estimated to be about 273,449 inhabitants with the vast majority of the area's dwellers being members of the Hausa and Fulani ethnic affiliations. (Manpower Nigeria, 2024).

Vegetation Types: Madobi is located in the Sudan savannah ecological zone of Nigeria, characterized by seasonal tropical grassland with scattered trees and shrubs. The vegetation is shaped by climatic conditions, human activities and agricultural practices.

Trees: Common trees species found in the area include: *Azadirachta Indica* (Neem), *Parkia biglobosa* (African locust bean), *Mangifera indica* (Mango), *Faidherbia albida* (Winter thorn) and *Vitellaria paradoxa* (Shea butter tree). These trees are important for shade, fuelwood, traditional medicine and agroforestry (Jimoh *et al.*, (2012).

Ground vegetation: The ground vegetation in Madobi consists mainly of: Grasses such as *Andropogon gayanus*, *Hyparrhenia spp.*, *Pennisetum pedicellatum* *e.t.c.* Also, seasonal herbaceous plants dominate during the rainy season (Yusuf and Ologe, 2017).

Fallow farm is located at Bayero University Kano which is situated at Ungogo Local Government. Area which is about 204km² and it is characterized with an average rainfall of 200mm-350mm per annum with highest rainfall during the months of August and lowest in May, the vegetation type is mainly savanna which is characterized by shrubs during raining season and few trees. But the vegetation cover is now altered as a result of human activities.

The Fallow farm is located at Bayero University Kano which is situated at Ungogo Local Government Area, which covers about 204km². This area receives an average annual rainfall of 200mm-350 mm with the peak in August and lowest in May, the natural vegetation is primarily savanna dominated by shrubs in the raining season and few trees. However, human activities have significantly altered the vegetation cover (Jimoh *et al.*, 2012).

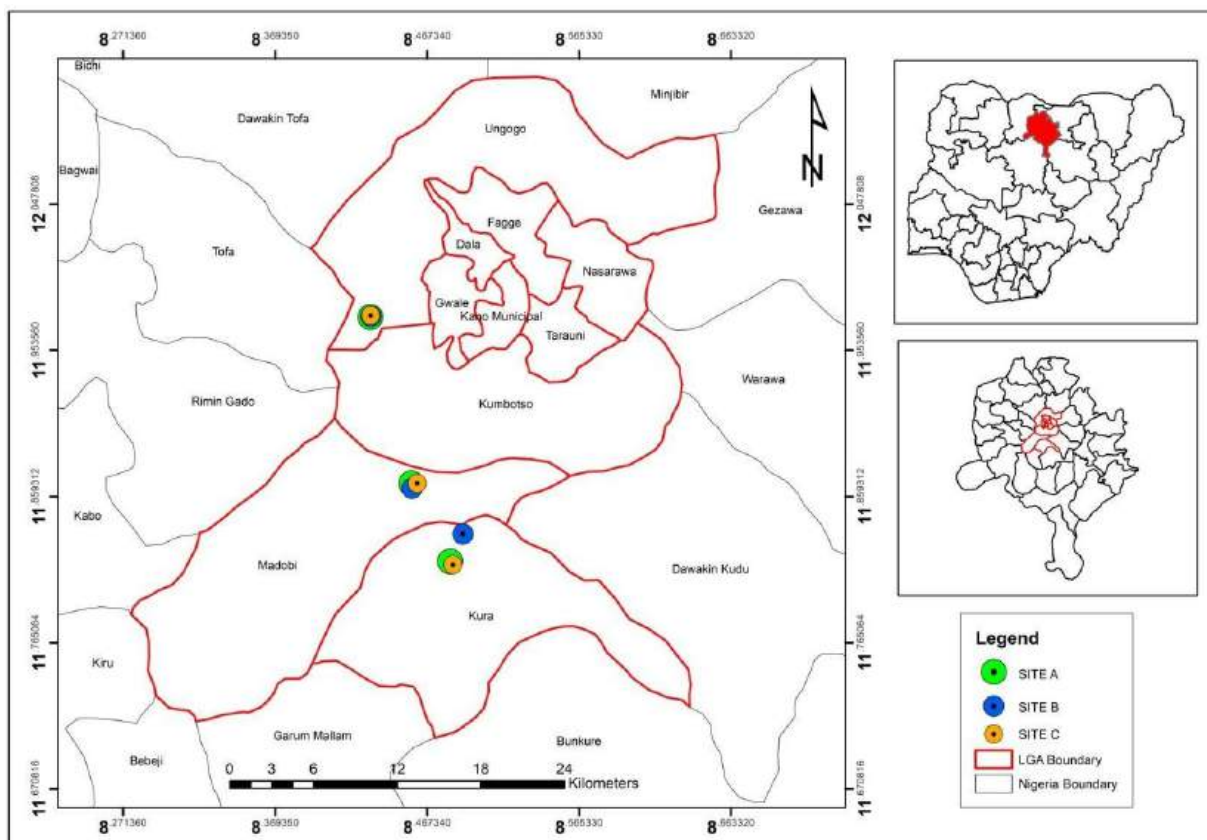


Figure1: Kano State showing Sampling Points (Source: Cartography Lab, Bayero University Kano).

Survey Method

Sampling was carried out for a period of January- December 2023. Samples were collected once a week from 8:00am-12:00noon so as to match the activity pattern of the insects and avoid extreme midday heat. Insects were collected using Pitfall traps, sweep net and handpicking methods.

Duration of Sampling: Insects sampling was collected once in a week. i.e four times in a month

Design & Layout of Pitfall Traps Method

The design of the pitfall trap is in line with the method described by Triplehorn and Johnson 2005. This method consists of using eight traps per site spaced along a transect. This gave a total of 24 traps three sites. A plastic container each of 15cm diameter used (This is because pitfall traps with a large diameter has the highest number of catches and dug 20cm deep (Morris *et al.*, 2002). Cups were inserted into the ground together so that the top of the trap of the trap was flushed with the soil surface. Traps were filled with ethylene glycol/ methanol to preserve the insects collected and were emptied on a daily basis

Field Design of Sweep Net Method

Two transects of about 100m was used. Distance between the transects was about 100m. There were 10 Sampling points on each transect. A total of 20 sampling points were used. At each point, a sweep net with a diameter of 38cm diameter was swept once over the field to collect flying insects.

The net handle was 0.90m, also net opening was 0.19m radius. The net was swung in a 180° arc counts as one sweep. A total of 5 sweeps were taken as described by Ryan and Christopher (2013).

Hand Picking Method

Hand picking of insects was done for about 1 hour at each site. Insects caught were put inside a killing jar and appropriately labeled for an onward delivery to the lab. Insects collected were transported to the laboratory inside the killing jars and identification was made using the appropriate taxonomic keys.

Methodology for Climatic Data

To assess the influence of climatic factors on insect diversity in Kano State, Nigeria, climatic data was recorded systematically throughout the period of sampling.

Climatic Parameter Measured and tools for Recording Climatic Data

The climatic variables measured and instruments includes:

1. Temperature: A digital thermometer was used for measuring air temperature and Humidity
2. Relative Humidity: This was measured using thermo-Hygrometer.
3. Rainfall: A standard Rain Gauge was installed at each study site to collect rainfall data during the raining seasons
4. Windspeed: A portable Anemometer was used to record the windspeed in the study sites.
5. Cloud cover: Visual observation and okta Scale was used for estimating cloud cover.

GPS devices was used to mark coordinates of each sampling point and Field note notebook or data sheets was used for logging daily climatic readings and observations.

Data Analysis

Diversity related issues such as Specie Richness, Evenness, Abundance, Shanon and Dominance were done using Shanon weiner indices and variations according to habitats was done using two-way ANOVA followed by Duncan's test. However, all the observed specimens were arranged in a tabular form following their morphological and taxonomic characteristics. Linear regression was used to test if there is correlation between diversity indices and ecological/climatic parameters. All tests were analyzed at the level of significance of $\alpha = 0.05$.

RESULTS AND DISCUSSIONS

Table 1: Shows the mean variation of insect diversity indices in the various habitats in year 2023 where there was significant difference in Abundance, Richness, Shanon and Dominance in Rainfed and Irrigated farms but a significant difference was observed in fallow farm.

TABLE 1: Mean Variation of Insect diversity indices across the various habitats in year 2023

Indices	Habitat Types		
	Irrigated Farm	Rainfed Farm	Fallow Farm
ABUNDANCE	0.842±0.0416 ^b	0.831±0.032 ^b	0.864±0.026 ^a
RICHNESS	1.536±0.322 ^b	1.455±0.197 ^b	1.709±0.287 ^a
EVENNESS	0.959±0.01 ^a	0.945±0.029 ^a	0.951±0.027 ^a
SHANON	1.921±0.244 ^b	1.851±177 ^b	2.057±0.192 ^a
DOMINANCE	0.159±0.0473 ^a	0.166±0.033 ^a	0.135±0.026 ^b

Note: Mean followed by different superscripts across rows are significant $p < 0.05$ using Duncan test

Table 2: Frequency and Relative Abundance of Insects in the various Habitats (2023)

Habitats Orders	IF N.I	R.A(%)	RF N.A	R.A(%)	FF N.I	R.A(%)
Blattodea	37	3.375%	52	3.88%	75	4.40%
Coleoptera	252	17.834%	93	6.95%	98	5.75%
Diptera	91	6.440%	51	3.81%	113	6.63%
Hemiptera	45	3.184%	28	2.087%	72	4.22%
Homoptera	13	0.920%	20	1.49%	34	2.17%
Hymenoptera	215	15.215%	194	14.49%	260	15.26%
Isoptera	177	12.526%	265	19.76%	215	12.62%
Lepidoptera	197	13.941%	198	14.76%	230	13.50%
Neuroptera	54	3.821%	52	3.87%	90	5.28%
Odonata	202	14.295%	174	13.49%	269	15.79%
Orthoptera	110	7.784%	189	14.09%	247	14.50%
Mantodea	20	1.415%	25	1.86%	-	-
	1413		1341		1703	

Table 2: Shows the frequency and relative abundance of insects in the various habitats in the year 2023 where irrigated farm recorded 1413 individual insects with Hymenoptera having the highest relative abundance of 15.21%. Rainfed farm recorded 1341 individual insects with Isoptera having the highest relative abundance of 19.76%. Fallow farm recorded 1703 individual insects with Odonata having the highest relative abundance of 15.79%.

Table 3: Shows a linear regression result between Specie Richness and ecological parameters 2023

The Result shows that in Fallow farm, Specie Richness has a positive correlation with cloud cover at $P=0.034838^{**}$ and Relative Humidity at $P=0.001331^{*}$

Table 3: Linear Regression Result Between Specie Richness and Ecological Parameters in 2023

HABITAT Parameters	IF Estimated slope	T.value	P.value	RF Estimated slope	T.value	P.value	FF Estimated slope	T
Intercept	0.0813306	2.348	0.0305*	1.2116874	5.643	2.36e-05***	1.008729	
Temperature	0.016275	1.692	0.1078	0.0047233	0.644	0.527	0.002883	
Wind speed	-0.007477	-0.166	0.8699	-0.0139993	-0.339	0.739	0.045708	
Precipitation	0.242447	1.623	0.1221	0.1930513	0.539	0.597	0.391606	
Cloud Cover	0.002424	1.463	0.1608	0.0019019	1.048	0.309	0.002590	
R.Humidity	0.003304	1.158	0.2621	0.0003025	0.112	0.912	0.006505	
Adjusted R ²	0.335			-0.02166			0.5425	
P.Value	0.02684			0.5008			0.001333	

Table 4: Shows the result of the Linear Regression between specie Evenness and ecological parameters in 2023 in Irrigated, Rainfed and Fallow farms. The result shows that in Fallow farm, Specie Evenness has a positive correlation with cloud cover at P=0.034838** and Relative Humidity at P=0.001331*

Table 4: Linear Regression Result Between Specie Evenness and Ecological Parameters 2023

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Cloud Cover	0.002424	1.463	0.1608	0.0019019	1.048	0.309	0.002590
R.Humidity	0.003304	1.158	0.2621		0.112	0.912	0.006505

Adjusted R ²	0.335	-0.02166	0.5425
P.Value	0.02684	0.5008	0.001333

Table 5: Shows the result of the Linear Regression between Abundance and ecological/climatic parameters in 2023 in Irrigated, Rainfed and Fallow farms. The Result shows that in Fallow farm, Abundance has a positive correlation with Relative Humidity at P=0.00281**

Table 5: Linear Regression Result Between Abundance and Ecological Parameters 2023

Parameters	Estimated slope	T.value	P.value	Estimated slope	T.value	P.value
HABITAT	IF			RF		
Intercept	0.7639208	15.857	5.07e-12***	7.861e-01	23.255	7.03e-15***
Temperature	0.0015700	1.174	0.256	1.351e-03	1.171	0.257
Wind speed	- 0.0025631	-0.140	0.687	-5.381e-03	-0.827	0.419
Precipitation	0.0159487	0.767	0.453	7.592e-02	1.345	0.195
Cloud Cover	0.0003243	1.407	0.177	3.063e-04	1.072	0.298
R.Humidity	0.00055551	1.398	0.179	3.291e-05	0.078	0.939
Adjusted R ²	0.23			0.1241		
P.Value	0.08048					

Discussions

From the results of the study, Table 1 shows a significant difference between the means of only fallow farm in the year 2023.

However, the significant difference observed in the fallow farm may be attributed to the distinct insect diversity and community structure present, which is likely influenced by variations in vegetation type, level of disturbance, and availability of resources. This study is in line with the studies of: Khan *et al.*, (2013), Baldi & Batary (2011).

The result of the findings of table 2 revealed that irrigated farm(IF), rainfed farm(RF) and fallow farm(FF) recorded a number of insect species but fallow farm recorded the highest number. This implies that a less disturbed habitat or those left to regenerate naturally like fallow land supports a richer and more diverse insect community. This might likely be due to the presence of more heterogenous vegetation, reduced pesticide use, and improved microhabitat conditions which provide shelter, food, and breeding grounds for a wider range of insect species. Rainfed and Irrigated farm typically involve more intensive agricultural practices example; tilling, monoculture cropping, use of agrochemicals, which can negatively impact insect populations by reducing habitat complexity and increasing mortality.

The higher insect diversity in fallow farms is beneficial for ecosystem services such as: Pollination, Biological Pest control and Nutrient recycling. This study is in line with the studies of Akomah *et al.*, (2010), Saha *et al* 2023,

Temporal & spatial Variations in Insects Species Abundance

Year 2023 recorded Isoptera as the insects with the highest relative abundance in rainfed farm. This could be as a result of the fact that isopterans are attracted to moist environments making rainfed farms with high moisture content more conducive to their population growth.

Also, rainfed farms often involve less intensive agricultural practices compared to irrigated farms, allowing soil-dwelling insects like termites to thrive. Also, high termite presence indicates a functioning detritivore community, essential for sustainable ecosystem services like organic matter break down. The organic matter present in rainfed farms also provides a food source for termites to feed on thereby, increasing their populations.

This study is in line with the studies of Oyedele *et al* 2023 in which he reported that isopteran (termites) dominated the soil macro-invertebrate community in less intensively managed farmlands such as the rainfed farms, highlighting their importance in soil ecology and resilience. The high relative abundance of Odonata in Fallow farm in the year 2023 could be as a result of the following:

This could be as a result of the fact that Odonata are predatory insects that feed on other insects, as such, this makes fallow farm a suitable farm for them. Fallow farm that has been left uncultivated for a period of time, may have a higher presence of insect prey for dragons to feed on. This factors will lead to higher population of odonates.

Also, Since Odonates are semi-aquatic, their larvae develop in water, and adults are usually found near wet or moist areas. High numbers suggests that the fallow farm may have seasonal pools, wet patches or nearby water bodies, thereby supporting breeding.

Fallow farms are typically less disturbed, with diverse vegetation and minimal pesticide use, which creates suitable microhabitats and food sources for adult odonata.

Linear Corelation between Specie Richness and diversity indices 2023

The result of linear correlation between insect diversity indices and ecological parameters revealed no correlation between the indices and all the ecological parmeters measured in rainfed and irrigated farm. But a positive correlation between specie richness and cloud cover and also with relative humidity in fallow farm only throughout 2023. This could be as a result of the following:

Insect communities in rainfed and irrigated farms may be more influenced by agricultural practices (e.g tillage, pesticide use, monoculture) than by natural ecological conditions. This may buffer or mask the effects of weather variables on diversity.

Whereas, in fallow farms where there are minimal human disturbance insects may respond more naturally to environmental changes.

Higher relative humidity and cloud cover could support more diverse insect communities by: reducing dessication stress, supporting richer vegetation or microhabitats, providing more favorable conditions for insect activity and reproduction. This is in line with the studies of Chen & Zhang (2021) which found that relative humidity and cloud cover significantly affected insect abundance and diversity in non-cultivated fields. And also, the research of Menzel & Greggers (2015) where he reported that insect activity and diversity are positively related to relative humidity in natural and semi-natural habitats.

Conclusion

It can be concluded that fallow farm recorded the highest number of insects orders and species respectively. This Research has shown that irrigated and rainfed farms is a disturbed habitat and agricultural activities and/or fertilizer application have influence on their population. This will have a negative impact in insect's biodiversity.

The positive and negative correlations that exists between insect diversity indices and climatic/ecological parameters measured such as temperature, precipitation, relative humidity, cloud cover and windspeed indicated that environmental conditions play a role in shaping insect community structure and they are the factors that cause the changes in the population of insects.

Recommendations

Preservation of Fallow Farms: Incorporating or maintaining fallow lands within agricultural systems is recommended to enhance insect biodiversity and support ecological balance. Also, leaving fallow land can significantly enhance insect density, potentially benefitting ecosystem services like pollination and pest control.

Climate-Awareness Management: To effectively manage insect populations under changing climate conditions in Kano State, farmers should adopt climate-resilient practices such as: integrated pest management (IPM), the use of pest-and drought-resistant crop varieties, conservation of native vegetation to support beneficial insects, and adjusting planting times based on local weather patterns.

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