ECOLOGICAL SOCIETY OF NIGERIA (ECOSON)

Edited Book of

PROCEEDINGS /ABSTRACTS AND PAPERS 2026

ECOSON CONFERENCE *HYBRID*

THEME:

SUSTAINABLE ECOLOGICAL SYSTEMS: BRIDGING THE GAP BETWEEN ENVIRONMENT AND NATIONAL DEVELOPMENT

EDITORS

Professor O. S. Olubode – University of Ibadan, Nigeria
Dr. N. L. Isemin – Joseph Sarwuan Tanka University, Makurdi, Nigeria

DATE: **Sunday, 2nd – Thursday, 6th August, 2026**

VENUE: FST Auditorium, North Core, Joseph Sarwuan Tarka University, Makurdi, Benue State, Nigeria

Available online at https://nigerianjournalofecology.org/

Science for Environment • Environment for Life • Development for All

NATIONAL EXECUTIVE COUNCIL (NEC) OF ECOLOGICAL SOCIETY OF NIGERIA (ECOSON)

1. **President: Prof. Rasheed O. Awodoyin, University of Ibadan, Ibadan, Oyo State, Nigeria**
2. **Vice-President: Prof. Franklin B. G. Tanee, University of Port Harcourt, Port Harcourt, Nigeria.**
3. **National Secretary: Dr. Ayodele A. Oyedeji, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria.**
4. **Assistant National Secretary: Dr. Zikrullah A. Yusuf, Federal University, Lafia, Nasarawa State, Nigeria.**
5. **Financial Secretary: Dr. Albert Ejikeme, University of Port Harcourt, Port Harcourt, Nigeria.**
6. **Treasurer: Prof. Oyetayo J. Oyelowo, Forestry Research Institute of Nigeria (FRIN), Ibadan, Oyo State, Nigeria.**
7. **Public Relation Officer: Dr. Christopher U. Okolie, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.**
8. **Editor-In-Chief, Nigerian Journal of Ecology – Prof. O. S. Olubode, University of Ibadan, Ibadan, Oyo State, Nigeria.**
9. **Business Manager, Nigerian Journal of Ecology – Prof. Olusegun A. Oladoye, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria.**

EDITORIAL TEAM

1. **Prof. Oluseun Sunday Olubode (Editor – in – Chief)**
   Departmeny of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria

2. **Prof. Mary O. Agbogidi**
   Department of Botany, Delta State University, Abraka, Nigeria

3. **Dr. Clement O. Ogunkunle**
   Department of Plant Biology, University of Ilorin, Nigeria

4. **Dr. Albert Ejikeme**
   Department of Plant Science and Biotechnology, University of Port Harcourt, Nigeria

TABLE OF CONTENTS

Page	Title	Author(s)
7	PHYTOREMEDIATION POTENTIALS OF *Albizia adianthifolia*, *Albizia odoratissima*, and *Pterophorum pterocarpum* ON HYDROCARBON POLLUTED SOIL	Ayodele A. Oyedeji, Gbaa, Deebari N., Inyang, Toyoabasi I.
8	PLANT SPECIES DIVERSITY IN SELECTED FORESTS OF BAYELSA STATE: THE NEED FOR CONSERVATION PRACTICES	Binaebi Ambah, Ayodele A. Oyedeij and Jasper Ezenwaka
9	SPATIAL DISTRIBUTION OF ROADSIDE WEED SPECIES UNDER ANTHROPOGENIC INFLUENCE IN SELECTED COMMUNITIES OF ALUU, RIVERS STATE, NIGERIA	Ugiomoh, I. G., Ukaha, P. E., Ogazie, C.
10	GROWTH AND YIELD PERFORMANCE OF MAIZE (*Zea mays L.*) PLANT USING COW BLOOD MEAL AND GOAT WASTES AS BIOFERTILIZERS	Ani N.J., Olasan, J.O and Emoyi B.O.
11	DURATION OF SOLARISATION AS IT AFFECTS WEED BIOMASS AND WEED SPECIES SPECTRUM IN IBADAN	Nasiru Ibrahim, Rasheed O. Awodoyin and Temilade A. Adegbite
12	DORMANCY BREAKING OF *Tithonia diversifolia*, *Chromolaena odorata* and *Euphorbia heterophylla* SEEDS USING HOT WATER TREATMENTS	Dare O. Ayoola and Rasheed O Awodoyin
13	IMPACT OF DECADAL GIS-DERIVED ENVIRONMENTAL DATA ON THE YIELD FORECASTING OF *Musa* spp. IN RIVERS STATE, NIGERIA	Uzoma, Miracle Chinomnso, Mensah, Ikechukwu Stephen, Ochekwu, Edache Bernar
14	SYNERGISTIC EFFECTS OF *Rhizophagus irregularis* AND INORGANIC FERTILIZER (NPK) ON SEEDLING GROWTH OF SORGHUM CULTIVAR (SAMSORG-17)	Lawal, A. S. and Falalu, A.
15	DISTRIBUTION AND ABUNDANCE OT TOOTHACHE PLANT (*Acmella brachyglossa* CASS.) IN OYO STATE, NIGERIA	Ogunjobi, A. J., Adeniji, A. O., Awodoyin, R. O. And Olubode, O. S.
16	AN OVERVIEW ON MICROBIAL INNOVATIONS IN ENVIRONMENTAL HEALTH: OPPORTUNITIES FOR DISEASE PREVENTION, SUSTAINABLE LIVELIHOODS, AND POVERTY REDUCTION	Aminu Yusuf Fardami, Abdulkadir Rabiu Salisu, Aminu Aliyu, Mudassir Abubakar Baba, Ibrahim Kabir Abdullahi, Kamilu Adamu Maiyadi and Abdulwasiu Ibrahim Bagega
17	ADAPTATION STRATEGIS TO COPE WITH CLIMATE CHANGE IN NIGERIA, THE JOURNEY SO FAR: AN EMPERICAL REVIEW	Tanko Dauda
18	CARBON SEQUESTRATION OF *Terminalia mantaly* H. Perrier TREES AT THE UNIVERSITY OF DELTA, AGBOR, DELTA STATE, NIGERIA.	Akinnibosun, H. A., Okubor, P. C. and Ezuteh, P. O.
19	ASSESSMENT OF INVASIVE PLANT SPECIES DIVERSITY AND SPATIAL DISTRIBUTION IN YANKARI NATIONAL PARK BAUCHI, NIGERIA	Abdullahi Kamal Basiri Bristone Israel T. Borokini Umar Aminu Mohammed Ladan Muhammad Auwal Ibrahim Ismail Haruna[5] and Omotayo I. Ajao
20	COMPARATIVE PHYSICOCHEMICAL ANALYSIS OF SEED OILS FROM *Vitellaria paradoxa* AND *Ziziphus mauritiana* IN NORTHERN GUINEA SAVANNA ECOLOGICAL ZONE OF TARABA STATE, NIGERIA	Meer B. B., Myina O. M. and Mobuogwu-Osaji J. N.
21	REFORESTATION VERSUS AFFORESTATION: A REVIEW OF ECOLOGICAL IMPLICATIONS FOR PROJECT DEVELOPERS IN THE TROPICAL REGION	Olatidoye, O. R.

22	HABITAT RESTORATION STRATEGIES FOR ENHANCING BIODIVERSITY AND ECOLOGICAL NETWORKS: A REVIEW	Olatidoye, O. R.
23	CLIMATE INDUCED FLOODS IMPACT ON INFRASTRUCTURE, STAPLE FOOD SUPPLY AND PRICES IN YENAGOA, BAYELSA STATE, NIGER DELTA	Charles Oyibo, Authority Benson, Kemebigha Ine-ebi, Ekpotenmene Tamaraumiemene
24	PHYSICOCHEMICAL PARAMETERS AND ZOOPLANKTON ABUNDANCE OF RIVER ANTAU, KEFFI, NASARAWA STATE, NIGERIA	Abdullahi M.M., Makpo J.K., and Nafisat. A
25	RELEVANCE OF TROPICAL WETLANDS TO AGRICULTURE AND ITS CHALLENGES: A REVIEW	Abdullahi Kamal and Umar Aminu Mohammed
26	GEOSPATIAL ASSESSMENT OF BIOMASS RESIDUES FOR RENEWABLE ENERGY AND ECOLOGICAL SUSTAINABILITY IN NASARAWA STATE, NIGERIA	Abubakar Suleiman, Adamu Bello Suleima, Anyubaga Salim Bitus, Fatima Umar Abdulhamid
27	ECOTOXICOLOGICAL RISKS OF PESTICIDE RESISTANCE IN INSECTS AND ITS ECOSYSTEM IMPACTS	Auwalu Jalo, Timothy Auta and Zaharaddeen Hassan Yusuf
28	COMPARATIVE ASSESSMENT OF PLANT SPECIES COMPOSITION, DIVERSITY, AND FLORISTIC SIMILARITY ACROSS SELECTED FOREST ECOSYSTEMS IN BAYELSA STATE, NIGERIA	Binaebi Ambah, Ayodele A. Oyedeji and Jasper Ezenwaka, Lucky O. Ikechukwu
29	EFFECTIVENESS OF TURMERIC AND GARLIC BASED ORGANIC MEDIA IN THE HYDROPONIC ESTABLISHMENT OF TOMATO (*Solanum lycopersicum* L.) SEEDLINGS	Olasan, J.O., Aguoru, C.U. and Abah Joy Enyo
30	PERFORMANCES OF POULTRY DROPPINGS, GOAT WASTE AND NPK FERTILIZER ON THE GROWTH AND YIELDS OF FOUR SWEET POTATO VARIETIES (*Ipomoea batatas* L)	Aguoru, C.U., Olasan, J.O. and Chihin, D.A.
31	SPATIAL ASSESSMENT AND TEMPORAL DYNAMICS OF ABOVE- AND BELOWGROUND BIOMASS AND CARBON STOCKS IN THE KANAWA FOREST RESERVE, GOMBE STATE, NIGERIA	Yuguda, U.A., Saka, M.G., Dishan, E.E., Bello[3], M.B. and Abba, H.M.
32	PROXIMATE NUTRIENT AND ANTIOXIDANT CONTENT OF *Pleurotus ostreatus* (Jacq) P. Kumm (PLEUROTAECE) CULTIVATED ON WOOD SAW DUST	Olabiyi Oluwatobiloba Margaret and Akinjide Moses Afolabi
33	EFFECT OF HYDRO PRIMING DURATION ON VIGOUR OF MAIZE (*Zea mays*) IN LAPAI, NIGER STATE, NIGERIA	Stephen, D.Y., Habiba, M. M., Jimada, K.
34	IN-SILICO INHIBITION OF ALPHA-AMYLASE AND ALPHA-GLUCOSIDASE BY LIGANDS FROM HYDROMETHANOLIC EXTRACT OF *Chrysophyllum albidum* BARK	Amototo Hamidat Oyinkansola
35	DIETARY EFFECT OF *Philonotis hastata* (Duby) Wijk and Margad ON THE GROWTH, HAEMATOLOGY AND BIOCHEMICAL ENZYMES OF AFRICAN CATFISH (*Clarias gariepinus*) Broodstock	Ololade Promise Olabode
36	THE EFFECT OF VARYING POULTRY MANURE CONCENTRATIONS MIXED WITH CLAY SOIL ON PLUMULE EMERGENCE AND SEEDLING GROWTH OF TOMATO (*Solanum lycopersicum*)	DADA, C. A.
37	HABITAT SUITABILITY PREDICTION FOR *Vitellaria paradoxa* (SHEA BUTTER TREE) IN NIGERIA	Akwaji Patrick Ishoro, Ibe Uno Eyong and Mayame Ernest Amap
38	ETHNOBOTANY AND PHYSICAL SEEDCOAT DORMANCY STUDIES ON AIDAN TREE *(Tetrapleura tetraptera*)	O.A. Obembe
39	HABITAT SUITABILITY PREDICTION FOR MAHOGANY TREE (*Khaya senegalensis* [DESR.] A. Juss) IN NIGERIA	Akwaji Patrick Ishoro, Mayame Ernest Amap and Ibe Uno Eyong

40	EFFECTS OF SOIL PHYSICOCHEMICAL PROPERTIES ON THE DIVERSITY AND DISTRIBUTION OF TREE SPECIES ACROSS CONSERVATIVE REGIMES IN OBAN BIOSPHERE RESERVES OF CROSS RIVER NATIONAL PARK, NIGERIA	Akwaji Patrick Ishoro, Etuk Inibehe Udomarcus and Akomaye, Ferdinand Akpo
41	SPECIES-SPECIFIC PHYTOREMEDIATION INDICES FOR MULTI-METAL SOIL CONTAMINATION: RESTORATION EFFICACY AND THE PERSISTENCE OF LEAD	Kever, D.G, Aguoru C.U, Olasan, J.O. and Dibal, H.I.
42	THE IMPACT OF PALYNOMORPHS ON THE HEALTH AND WELL-BEING OF STUDENTS AT JOSEPH SARWUAN TARKA UNIVERSITY, MAKURDI, NIGERIA	Onyinyechi Priscilla Okpara, Thomas Okoh, Ilebode-Sam Margret, Uma Suur Dorinda
43	CAN SCATTER HOARDING RODENTS ASSUME THE ROLE OF EFFECTIVE LARGE FRUGIVOROUS SEED DISPERSERS IN A FRAGMENTED AFROMONTANE FOREST?	Babale Aliyu and Mohammed Ismaila
44	COMPOSITION AND DIVERSITY OF BIRDS ALONG THE OLD GONGOLA RIVER FROM KUPTO TO DADIN-KOWA COMMUNITY IN GOMBE STATE, NIGERIA	Nsor Charles Ayuk, Nya John Usim, Atukpa M. Elaigwu, Datheh Patrick
45	UNORTHODOX FISHING PRACTICES AND THE BANE OF ICHTHYOFAUNAL DIVERSITY: THE ENIONG RIVER EXAMPLE	Isemin, Nsidibe Linus, Azua, Terese, and Ekanem, Idorenyen Emmanuel
46	PREPONDERANCE OF OKRA (*Abelmoschus esculentus*) VIRUS DISEASES IN KWARA STATE, NIGERIA	Adelodun Maryam Ajoke
48	COMPARATIVE PHYSICOCHEMICAL ANALYSIS OF SEED OILS FROM *Vitellaria paradoxa* AND *Ziziphus mauritiana* IN NORTHERN GUINEA SAVANNA ECOLOGICAL ZONE OF TARABA STATE, NIGERIA	Meer B. B., Myina O. M. and Mobuogwu-Osaji J. N.
62	ECOTOXICOLOGICAL RISKS OF PESTICIDE RESISTANCE IN INSECTS AND ITS ECOSYSTEM IMPACTS	Auwalu Jalo, Timothy Auta and Zaharaddeen Hassan Yusuf[3]
73	REFORESTATION VERSUS AFFORESTATION: A REVIEW OF ECOLOGICAL IMPLICATIONS FOR PROJECT DEVELOPERS IN THE TROPICAL REGION	Olatidoye, O. R.
85	EFFICACY OF DUCKWEED (*Lemna minor*) AND WATER LETTUCE (*Pistia stratoites*) IN THE TREATMENT OF HERBICIDE POLLUTED WATER	Okoh, T., Azua, E.T. and Uke, M.M.
99	POTENTIALS OF GREEN SYNTHESIZED TITANIUM OXIDE (TIO_2) NANOPARTICLES AND POWDERED BANANA PEEL AS ALTERNATIVE ECOFRIENDLY FERTILIZERS IN COWPEA PRODUCTION	Okoh Thomas and Ajene Ewaoche
103	ENVIRONMENTAL CONCERNS ARISING FROM EXHAUST EMISSIONS OF ENGINES OPERATING ON PETROL, DIESEL AND BIODIESEL BLENDS PRODUCED FROM WASTE COOKING OIL IN SOUTH EAST, NIGERIA	Onwugbuta Nneka
127	PALYNOLOGICAL AND PHYSICOCHEMICAL ASSESSMENT OF FRESHWATER ECOSYSTEM CHANGES IN SELECTED WATER BODIES OF BENUE STATE, NIGERIA	[1*]Okoh, Thomas., [1]Okpara, Priscilla Onyinyechi., [1]Olasan, Joseph Olalekan., [1*]Edinoh, Daniel Ojomugbo., [1]Muje, Godiya Simon and [1]Owoicho, Susan Ochanya
140	EVALUATION OF SOIL PHYSICOCHEMICAL AND HEAVY METAL INDICES AROUND ALUMACO FABRICATION AREAS IN ABRAKA, DELTA STATE, NIGERIA	Egboduku, W.O., Udo, M.W., Onokpasa, D., Okonigbo, B.D., and [*]Agbogidi, O.M.
148	GEOSPATIAL ASSESSMENT OF BIOMASS RESIDUES FOR RENEWABLE ENERGY AND ECOLOGICAL SUSTAINABILITY IN NASARAWA STATE, NIGERIA	Abubakar Suleiman, Adamu Bello Suleima, Anyubaga

		Salim Bitus, Fatima Umar Abdulhamid
156	THE ROLE OF INDIGENOUS KNOWLEDGE IN BIODIVERSITY CONSERVATION IN EKITI STATE, NIGERIA. A CASE STUDY OF ERIJINYAN AND ILAWE COMMUNITIES	Itodo Racheal Chinenyenwa
171	EFFECTS OF IRRIGATION REGIME, ORGANIC, INORGANIC MINERAL SOURCE AND INFLUENCE OF CLIMATE CHANGE ON GROWTH AND YIELD OF SWITCHGRASS *(Panicum virgatum L.)* IN SOKOTO NIGERIA	ABDULLAHI, A.A., TAMBARI, U., BALARABE, I.U., ADILI, I.S.
181	ASSESSMENT OF DEFORESTATION IMPACT ON LIVELIHOOD OF RURAL DWELLERS IN ETCHE LOCAL GOVERNMENT AREA OF RIVERS STATE, NIGERIA	Amadi, G. O, Nnadi, P.C, Augustus, M. U.
192	HABITAT RESTORATION STRATEGIES FOR ENHANCING BIODIVERSITY AND ECOLOGICAL NETWORKS: A REVIEW	Olatidoye, O. R.
203	RELEVANCE OF TROPICAL WETLANDS TO AGRICULTURE AND ITS CHALLENGES: A REVIEW	Abdullahi Kamal[1] and Umar Aminu Mohammed[1]
225	CLIMATE CHANGE PERCEPTION AND LIVELIHOOD IMPACTS IN COMMUNITIES SURROUNDING OLOKEMEJI FOREST, OGUN STATE, NIGERIA	Olajiire-Ajayi, B.L., Ogundana, O.A., Olubayo, O.O and Lameed, T.A.
240	SPATIAL ASSESSMENT AND TEMPORAL DYNAMICS OF ABOVE- AND BELOWGROUND BIOMASS AND CARBON STOCKS IN THE KANAWA FOREST RESERVE, GOMBE STATE, NIGERIA	Yuguda, U.A., Saka, M.G., Dishan, E.E., Bello, M.B. and Abba, H.M.
262	EVALUATION OF CARBON ACCUMULATION WITHIN PALM PLANTATION AT JOSEPH SARWUAN TARKA UNIVERSITY (JOSTUM), MAKURDI, BENUE STATE	Thomas Okoh, Onyinyechi Priscilla Okpara, Elizabeth Umoren
278	THE IMPACT OF PALYNOMORPHS ON THE HEALTH AND WELL-BEING OF STUDENTS AT JOSEPH SARWUAN TARKA UNIVERSITY, MAKURDI, NIGERIA	Onyinyechi Priscilla Okpara, Thomas Okoh, Ilebode-Sam Margret, Uma Suur Dorinda
297	GROWTH AND YIELD PERFORMANCE OF MAIZE (*Zea mays L.*) PLANT USING COW BLOOD MEAL AND GOAT WASTES AS BIOFERTILIZERS	Ani N.J., Olasan, J.O and Emoyi B.O.
306	CLIMATE INDUCED FLOODS IMPACT ON INFRASTRUCTURE, STAPLE FOOD SUPPLY AND PRICES IN YENAGOA, BAYELSA STATE, NIGER DELTA	Charles Oyibo[1] Authority Benson[2] Kemebigha Ine-ebi[3] Ekpotenmene Tamaraumiemene[4]
317	UNORTHODOX FISHING PRACTICES AND THE BANE OF ICHTHYOFAUNAL DIVERSITY: THE ENIONG RIVER EXAMPLE	Isemin, Nsidibe Linus, Azua, Terese, and Ekanem, Idorenyen Emmanuel
330	DORMANCY BREAKING OF *Tithonia diversifolia*, *Chromolaena odorata* and *Euphorbia heterophylla* SEEDS USING HOT WATER TREATMENTS	Dare O. Ayoola and Rasheed O. Awodoyin
336	DISTRIBUTION AND ABUNDANCE OT TOOTHACHE PLANT (*Acmella brachyglossa* CASS.) IN OYO STATE, NIGERIA	Ogunjobi, A. J., Adeniji, A. O.., Awodoyin, R. O. And Olubode, O. S.
351	DURATION OF SOLARISATION AS IT AFFECTS WEED BIOMASS AND WEED SPECIES SPECTRUM IN IBADAN	Nasiru Ibrahim, Rasheed O. Awodoyin and Temilade A. Adegbite

POTENTIALS OF *Albizia adianthifolia*, *Albizia odoratissima*, and *Pterophorum pterocarpum* ON HYDROCARBON POLLUTED SOIL

Ayodele A. Oyedeji*[1,2], Gbaa, Deebari N[3]., Inyang, Toyoabasi I.[4]
[1]Department of Biological Sciences, Niger Delta University, Wilberforce Island, Nigeria
[2]Faculty of Science and Engineering, University of Wolverhampton, Wolverhampton WV1 1LY, UK
[3]Department of Plant Science and Biotechnology, Faculty of Science, University of Port Harcourt, Nigeria
[4]Instutute of Geosciences and Environmental Management, Rivers State University, Nigeria
*Corresponding Author's Email:

ABSTRACT

Petroleum hydrocarbon contamination is a major environmental concern worldwide due to its detrimental effects on soil physicochemical properties, microbial communities, and vegetation, making phytoremediation with leguminous tree species a promising, cost-effective, and eco-friendly remediation approach. The study assessed the phytoremediation potentials of *Albizia adianthifolia, Albizia odoratissima,* and *Pterophorum pterocarpum* on hydrocarbon soil. Different quantities (0, 25, 50, 75, and 100 ml) of crude oil were used to spike 4000 g of soil, and the phytoremediation potential of the selected Leguminous Tree Species (LTS) were evaluated based on nodulation, root and shoot biomass, microbial count in the crude oil-spiked soil used for planting the LTS, and Total Petroleum Hydrocarbon (TPH) content in rhizosphere. The results demonstrated that the development of nodules in *P. pterocarpum* seedlings was substantially greater and significantly different ($P<0.05$) than in the other LTS species (*P. pterocarpum* > *Albizia odoratissima* > *Albizia adianthifolia*). Results indicate that *P. pterocarpum*, when grown in soil not seeded with crude oil, had an average shoot biomass of 48.00±1.95 g and an average root biomass of 10.83±1.50 g after 16 weeks. Among the different plants tested, *P. pterocarpum* had the highest mean root biomass for each concentration of crude oil (41.13±2.30g, 33.83±1.53g, 9.60±1.56g and 7.77±1.78g) and showed good tolerance to oil contamination. There were significant differences ($P<0.05$) in shoot and root biomass of LTS grown in polluted soil at higher concentration of crude oil in soil (50-100ml). The study found that *P. pterocarpum* had a significantly greater ($P<0.05$) microbial population (total heterotrophic bacterial count of $2.67 \times 10^5 - 4.27 \times 10^5$ CFU/g and total fungal count of 1.4×10^3- 2.7×10^3 CFU/g) compared to *A. odoratissima* and *A. adianthifolia* (total heterotrophic bacterial count ranging from $2.2 \times 10^5 - 4.27 \times 10^5$ CFU/g and total fungal count ranging from 1.17×10^3- 2.9×10^3 CFU/g). *P. pterocarpum*, *A. odoratissima* and *A. adianthifolia* brought about 95.4%, 83.4% and 91.9% reduction in TPH; 87.5%, 81.3% and 48.5%; 88.8%, 83.5% and 62.5% and 79.7%, 66.0% and 52.1%, corresponding to 25 ml, 50 ml, 75 ml and 100 ml levels of crude oil contamination respectively. There was a significant difference ($P<0.05$) in TPH levels between crude oil-spiked soil planted with LTS and unplanted soil. The results show that *P. pterocarpum* grows well in oil-polluted soil and may help early vegetation thrive, encouraging long-term ecosystem processes including oil breakdown.

Keywords: Phytoremediation; Oil-Polluted Soil; Petroleum Hydrocarbons; Leguminous Tree Species

PLANT SPECIES DIVERSITY IN SELECTED FORESTS OF BAYELSA STATE: THE NEED FOR CONSERVATION PRACTICES

Binaebi Ambah*[1,2], Ayodele A. Oyedeij[1,3] and Jasper Ezenwaka[1,4]
[1]Institute of Biodiversity, Climate Change and Watersheds, Niger Delta University, Wilberforce Island, Nigeria
[2]Department of Agricultural Science Education, Isaac Jasper Boro College of Education, Sagbama, Nigeria
[3]Department of Biological Sciences, Niger Delta University, Wilberforce Island, Nigeria
[4]Department of Crop and Soil Sciences, University of Africa, Toru-Orua, Nigeria
*Corresponding Author's Email: ambahbina@yahoo.com

ABSTRACT

Bayelsa State, located in the core of the Niger Delta, possesses extensive tropical forests that provide essential ecosystem services and valuable resources, including food, medicine, and timber, to local communities. This study assessed the floristic composition and species richness of Edumanom, Taylor Creek, and Adiegbe Forests in Bayelsa State, Nigeria. A field survey was conducted using standard botanical sampling procedures, and plant species were identified with the aid of established taxonomic keys and floristic manuals. More than 100 plant species belonging to several families were recorded, with Fabaceae being the dominant family, followed by Poaceae, Rubiaceae, Euphorbiaceae, Apocynaceae, Asteraceae, Moraceae, and Arecaceae. Trees constituted over 40% of the vegetation cover across the three forests, while shrubs and herbs accounted for more than 20%. The forests supported numerous economically and ecologically important tree species, including *Irvingia gabonensis*, *Alstonia boonei*, *Lophira alata*, *Cola lepidota*, *Dracaena arborea*, *Elaeis guineensis*, *Khaya ivorensis*, *Sterculia tragacantha*, *Raphia africana*, *Raphia hookeri*, *Mitragyna ciliata*, *Milicia excelsa*, and *Vitex grandifolia*. In addition, diverse shrubs, herbs, grasses, and a few climbers were identified, indicating a structurally complex and species-rich vegetation. The findings demonstrate that these forests harbour considerable plant diversity with significant ecological and socioeconomic value. The study provides baseline information for biodiversity assessment and highlights the urgent need for effective conservation and sustainable management strategies to protect the floristic diversity of these forest ecosystems from increasing anthropogenic pressures.

Keywords: Forestry, Conservation, Plant Diversity, Environmental Sustainability, Wetland Ecosystem

SPATIAL DISTRIBUTION OF ROADSIDE WEED SPECIES UNDER ANTHROPOGENIC INFLUENCE IN SELECTED COMMUNITIES OF ALUU, RIVERS STATE, NIGERIA

Ugiomoh, I. G.*, Ukaha, P. E., Ogazie, C.
Department of Plant Science and Biotechnology, Faculty of Science, University of Port Harcourt, Nigeria
***Corresponding Author's Email:**

ABSTRACT

Roadside vegetation plays an important ecological role in maintaining biodiversity, stabilizing soils, and providing ecosystem services, but its composition and distribution are often altered by increasing anthropogenic disturbances associated with urbanization and human activities. This study evaluated the effects of anthropogenic activities on the distribution and composition of roadside weed flora in Aluu Community, Ikwerre Local Government Area, Rivers State, Nigeria. Weed sampling was conducted systematically using a 50 cm × 50 cm quadrat placed approximately 0.9 m (3 ft) from the edge of both sides of selected major roads. All plant species occurring within each quadrat were collected, identified using standard taxonomic keys, and classified into their respective families and species to determine their floristic composition and distribution. The survey recorded a diverse assemblage of weed species belonging to several plant families. Poaceae was the dominant family with 11 species, followed by Asteraceae and Euphorbiaceae, each represented by seven species. Bignoniaceae, Lythraceae, Lamiaceae, Loganiaceae, Malvaceae, Piperaceae, Portulacaceae, and Rubiaceae were the least represented families, each comprising a single species, while the remaining families contained two or three species. Based on life history and growth form, the weed flora consisted of 58 annual broad-leaved species, 23 perennial broad-leaved species, two annual sedges, six perennial sedges, seven annual grasses, eight perennial grasses, and a few unclassified species. Despite continuous anthropogenic disturbances, including pedestrian movement, vehicular traffic and parking, grazing, trampling, roadside trading, and hawking, many weed species persisted along the roadsides. However, these disturbances significantly influenced vegetation structure, resulting in reduced plant density and the occurrence of bare patches in heavily disturbed areas, whereas denser and more luxuriant vegetation was observed farther from the road margins. The findings demonstrate that anthropogenic activities substantially influence the distribution, composition, and structure of roadside weed communities, highlighting the need for sustainable roadside vegetation management and conservation strategies to maintain biodiversity and enhance ecological resilience in urban and peri-urban landscapes

Keywords: Anthropogenic disturbance; Roadside weed flora; Floristic composition; Species distribution; Urban ecology.

GROWTH AND YIELD PERFORMANCE OF MAIZE (*Zea mays L.*) PLANT USING COW BLOOD MEAL AND GOAT WASTES AS BIOFERTILIZERS

Ani N.J., Olasan, J.O and Emoyi B.O.
Plant Science and Biotechnology Unit, Department of Botany, Joseph Sarwuan Tarka University Makurdi, Nigeria.
*****Corresponding Author's Email: ndidiamakajani@gmail.com

ABSTRACT

Declining soil fertility remains one of the major constraints to maize production in sub-Saharan Africa, necessitating the adoption of sustainable nutrient management practices that enhance crop productivity while reducing dependence on inorganic fertilizers. This study evaluated the response of different varieties of *Zea mays* to cow blood meal, goat waste, and NPK fertilizer. The experiment was conducted using a Completely Randomized Block Design (CRBD) with five replications per treatment. Organic amendments (cow blood meal and goat waste) were applied at 0.8 kg per experimental unit, while NPK fertilizer was applied at 0.2 kg per unit, giving a total of 225 experimental units. Growth and yield parameters were assessed throughout the experimental period. Data were subjected to analysis of variance (ANOVA), and treatment means were separated using Duncan's Multiple Range Test (DMRT) and the Least Significant Difference (LSD) test at the 5% level of significance ($p < 0.05$). The results showed that the flour maize variety treated with cow blood meal produced the highest growth and yield performance, recording plant height (177.0 cm), number of leaves (13.53), number of cobs per plant (2.00), cob length (19.28 cm), cob weight (0.298 kg), and number of kernels per cob (484.2). The same variety treated with goat waste ranked second, with plant height of 156.29 cm, stem diameter of 6.00 cm, leaf length of 85.40 cm, number of tassels (21.34), number of leaves (13.29), number of cobs per plant (1.589), and number of kernels per cob (307.3). Overall, the flour maize variety exhibited superior performance under organic nutrient amendments compared with the other varieties evaluated. The study demonstrates that cow blood meal and goat waste are effective organic nutrient sources capable of improving maize growth and yield and can serve as sustainable alternatives or complements to inorganic fertilizers. Their adoption, particularly for the flour maize variety, could enhance maize productivity while promoting environmentally sustainable soil fertility management.

Keywords: *Zea mays*; Cow blood meal; Goat waste; Organic fertilizer; Maize yield.

DURATION OF SOLARISATION AS IT AFFECTS WEED BIOMASS AND WEED SPECIES SPECTRUM IN IBADAN

Nasiru Ibrahim[1]*, Rasheed O. Awodoyin[1,2] and Temilade A. Adegbite[1]

[1]Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria.

[2]Department of Plant and Environmental Biology, Federal University of Agriculture and Technology, Okeho, Nigeria.

*Corresponding Author's Email: ibrahimnasiru900@gmail.com

ABSTRACT

Weed interference remains a major constraint to sustainable okra production, while dependence on manual weeding and herbicides presents economic and environmental challenges. This study, in a pot experiment, evaluated the effect of different durations of soil solarisation on weed species spectrum and weed suppression in Ibadan, Nigeria. The experiment was arranged in a completely randomised design comprising six treatments which are four solarisation durations (2, 4, 6 and 8 weeks) and two control treatments (dry, uncovered, unsolarised; moist, covered, unsolarised), with four replicates. Solarised soil treatments were covered using transparent polythene sheets before arranging the pots in the open field where the received direct insolation. Four pots were randomly selected and withdrawn into the shade at each test duration when the soil temperatures were also monitored. Also, the Control pots were kept away under shade from the commencement of the study. All the pots were moved out to the open field with the polythene removed at eight weeks and the weed seeds germination monitored. The weed species composition and weed biomass were subsequently assessed. Solarisation increased soil temperature, with mean values ranging from 49.96 to 52.09°C across sampling depths, creating conditions unfavourable for weed seeds survival, thus achieving weed suppression. Weed biomass declined progressively with increasing solarisation duration, from 54.03 ± 10.28 g in the dry uncovered control to 8.68 ± 2.22 g after 8 weeks of solarisation. A total of 23 weed species were identified during the study, with *Boerhavia erecta*, *Sesbania bispinosa* and *Cyperus esculentus* among the most prevalent. Increasing solarisation duration reduced weed occurrence and altered weed species composition, although a few heat-tolerant species persisted after prolonged solarisation. The findings demonstrated that soil solarisation is an effective non-chemical approach for suppressing weeds and modifying weed species composition. Therefore, solarisation for at least six weeks is recommended as a component of integrated weed management in Ibadan, Nigeria.

Keywords: Integrated weed management; soil solarisation; weed biomass; weed species composition.

DORMANCY BREAKING OF *Tithonia diversifolia*, *Chromolaena odorata* and *Euphorbia heterophylla* SEEDS USING HOT WATER TREATMENTS

Dare O. AYOOLA*[1] and Rasheed O AWODOYIN
Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria.
*Corresponding Author: E-mail: dareayoola78@yahoo.com
[1]Present Address: Federal Polytechnic, Ado-Ekiti, Ekiti State, Nigeria.
[2]Present Address: Federal University of Agriculture and Technology, Okeho, Oyo State, Nigeria.

ABSTRACT

Dormancy is one of adaptive mechanism used by weed to survive unfavourable conditions. Seeds of some common weeds such as *Tithonia diversifolia-(TD*), *Chromolaena odorata-(CO*), and *Euphorbia heterophylla-(EH*) were subjected to hot water treatments at 30–70°C for 0–60 seconds to break dormancy. This study was carried out to investigate the effect of hot water treatment on seed dormancy breaking of selected weed species. Data were recorded on Germination Percentage (GP) and analysed using analysis of variance, means were separated using Duncan Multiple Range Test at 5% probability level. The GP of *TD*, *CO* and *EH* increased with temperature level and duration. The interaction between the duration and temperature level had higher significant effect on the GP of *TD* (37.66±0.26), *CO* (31.33±011) and *EH* (34.04±1.12) respectively peaking at 50°C for 50 seconds at 20 Days after sowing. The study showed the hot water at particular duration of 50 seconds and temperature of 50°C break the seed dormancy of the weed.

Keywords: Dormancy, Temperature, Duration, *Tithonia diversifolia*, *Chromolaena odorata, Euphorbia heterophylla*

IMPACT OF DECADAL GIS-DERIVED ENVIRONMENTAL DATA ON THE YIELD FORECASTING OF *Musa* spp. IN RIVERS STATE, NIGERIA

Uzoma, Miracle Chinomnso[*1,2], Mensah, Ikechukwu Stephen[2]; Ochekwu, Edache Bernard[2]
[1]Biology and Biotechnology Unit, School of Science Laboratory Technology, University of Port Harcourt, Rivers State, Nigeria.
[2]Department of Plant Science and Biotechnology, Faculty of Science, University of Port Harcourt, Rivers State, Nigeria.
*Corresponding Author's Email: miracleuzoma@gmail.com

ABSTRACT

Plantains (*Musa* sp.) are some of the principal staple crops of Rivers State, Nigeria, sustaining household food security and rural livelihoods across the Niger Delta region. Despite its economic significance, systematic spatially comprehensive monitoring of this crop remains constrained by the limitations of conventional field surveys. This study developed an integrated framework combining multi-source satellite remote sensing, geographic information systems, and machine learning to map crop distributions and forecast yields across all local government areas of Rivers State over the period January 2014 to December 2024. Sentinel-2, Landsat 8, and MODIS imagery were preprocessed through the Google Earth Engine. Four monthly environmental predictors were compiled from NASA Giovanni and Google Earth Engine: land surface temperature (mean: 300.40 K), soil moisture (mean: 30.33 kg/m²), NDVI (mean: 0.644), and total column NO_2 (mean: 4.855 × 10^{29} mol/cm²). Ground truth data were collected from experimental plots at IITA Onne. Crop classification employed Random Forest algorithms, while yield forecasting utilized Lagged Linear Regression. Time-series analysis revealed significant agroecological stress trends over the study decade. Surface temperature increased from 300.27 K (2014) to 301.41 K (2024), soil moisture declined from 31.31 to 28.95 kg/m², and dry-season NDVI minima fell from 0.547 to 0.352. A severe compound stress episode was identified in February 2020, when maximum surface temperature (305.17 K) coincided with minimum soil moisture (14.77 kg/m²), representing the most extreme environmental conditions recorded during the study period. NDVI and soil moisture were identified as the dominant predictors, and surface temperature for plantain. The study demonstrates that Geographic Information Systems (GIS) tools and processes, integrated with machine learning, constitutes a robust, cost-effective framework for tropical crop monitoring. Findings from this study provide spatially explicit yield forecasts and environmental stress assessments to inform agricultural planning and food security governance in Rivers State and comparable Niger Delta environments.

Keywords: Plantain; Crop Mapping; Yield Forecasting; Remote Sensing; Machine Learning; Soil Moisture;

SYNERGISTIC EFFECTS OF *Rhizophagus irregularis* AND INORGANIC FERTILIZER (NPK) ON SEEDLING GROWTH OF SORGHUM CULTIVAR (SAMSORG-17)

Lawal, A. S.* **and Falalu, A.**
[1]Department of Biological Sciences, Federal University Gusau, Nigeria.
***Corresponding Author's Email: aminulawalshehu@fugusau.edu.ng

ABSTRACT

Arbuscular Mycorrhizal Fungi (AMF) had been widely known for their potentials in promoting plant growth, yet integration of AMF with inorganic fertilizer effect on cereal crop establishment was poorly understood. This study evaluated the synergistic effects of *Rhizophagus irregularis* and inorganic fertilizer (NPK) on seedling growth and intensity of AMF colonizing the roots. A completely randomized design comprising seven (7) treatments; control (Distilled water), 5g AMF, 10g AMF, 40g AMF, 5g AMF + 5g NPK, 10g AMF + 10g NPK and 40g AMF + 40g NPK with three replications each was adopted. This study was conducted under controlled condition. The colonization intensity of roots was evaluated through root staining techniques and intersection method under compound microscope. Growth parameters of plant height, leaf number, fresh biomass, dry biomass and root to shoot ratio were measured and evaluated. *R. irregularis* inoculation significantly enhanced seedling growth ($p < 0.05$), Samsorg-17 with 40g inoculum delineated the highest plant height of 15.68 ± 1.59 cm, leaf number of 6 ± 0.58, fresh biomass of 1.16 ± 0.33g, and dry biomass of 0.93 ± 0.26g. Higher colonization intensity was also observed in Samsorg-17 with 40g inoculum of *Rhizophagus irregularis*. In contrast, all treatments combining equal rates *R. irregularis* and NPK (5, 10 and 40g) resulted in complete seedling mortality. The findings suggest that *R. irregularis* alone can improve the early growth of Sorghum seedling, whereas simultaneous application with NPK fertilizer impedes germination and suppress *R. irregularis* activity.

Keywords: *R. irregularis*, Seedling growth, Sorghum cultivar, Colonization intensity, Synergistic effects.

DISTRIBUTION AND ABUNDANCE OT TOOTHACHE PLANT (*Acmella brachyglossa* CASS.) IN OYO STATE, NIGERIA

Ogunjobi, A. J.[1], Adeniji, A. O.[2]*., Awodoyin, R. O.[1,2] And Olubode, O. S.[1]
[1]Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria.
[2]Federal University of Agriculture and Technology, Okeho, Oyo State, Nigeria.
*Corresponding Author's Email: adeniji.ayobami@yahoo.com

ABSTRACT

Floristic study was carried out to assess the distribution and abundance of *Acmella brachyglossa* Cass. in three farm communities, Iwere-Ile (Iwajowa), Okeho (Kajola) and Moniya (Akinyele) in Oyo State, Nigeria. A random sampling technique was employed to enumerate the weed species. Twenty 0.5 m x 0.5 m quadrats were laid in a 100 m^2 cultivated and fallow land in each community. The floral identification, Relative Importance Values (RIV), species diversity, Evennes and Jaccard index of similarities followed standard procedures. Fifty two plant species distributed within 22 families were identified in the three farm communities. *Acmella brachyglossa* had the highest RIV (Okeho, 24.04, Iwere-Ile, 35.48, and Moniya-Ibadan, 37.87). The lowest RIV was obtained for *Boerhavia erecta* Linn. (0.52) in Iwere-Ile, *Mariscus alternifolius* Vahl. (0.5) in Okeho, and *Paulinia pinata* Linn. (0.52) in Moniya-Ibadan. Species diversity was high in Okeho (Shannon Weiner Index, 2.06). The eveness was low in the three communities (Iwere-Ile, 0.4, Okeho, 0.19, and Moniya-Ibadan, 0.21) and there was no dominance of a particular species. The Jaccard similarity index indicated the species in Moniya-Ibadan to be similar to Okeho farm community. The phytosociology and percentage flora for the three communities indicated *A. brachyglossa* as having between 21-50% cover in both cultivated and fallow land.

Keywords: *A.brachyglossa*, Invasive Species, Shannon Weiner Index, Eveness, Phytosociology.

AN OVERVIEW ON MICROBIAL INNOVATIONS IN ENVIRONMENTAL HEALTH: OPPORTUNITIES FOR DISEASE PREVENTION, SUSTAINABLE LIVELIHOODS, AND POVERTY REDUCTION

Aminu Yusuf Fardami*[1], Abdulkadir Rabiu Salisu[1], Aminu Aliyu[2], Mudassir Abubakar Baba[2], Ibrahim Kabir Abdullahi[3], **Kamilu Adamu Maiyadi[4] and Abdulwasiu Ibrahim Bagega[4]**

[1]Department of Environmental Health Science, Bayero University, Kano, Kano State, Nigeria
[2]Department of Microbiology, Federal University Gusau, Zamfara State, Nigeria
[3]Department of Environmental Sciences, Federal University Dutse, Jigawa State, Nigeria
[4]Department of Microbiology, Federal University Gusau, Zamfara State, Nigeria
*Corresponding Author's Email: ayfardami.ehs@buk.edu.ng +

ABSTRACT

Microbial innovations have become indispensable tools in environmental health by providing sustainable, cost-effective, and scientifically proven solutions to many of the environmental factors that contribute to disease transmission and poor public health outcomes. Beneficial microorganisms are increasingly being utilized in water purification, wastewater treatment, solid waste management, food preservation, bioremediation, and pollution control to improve environmental quality and reduce the incidence of communicable and environmentally related diseases. In wastewater treatment systems, diverse microbial communities decompose organic pollutants, reduce biochemical oxygen demand (BOD) and chemical oxygen demand (COD), remove excess nutrients such as nitrogen and phosphorus, and eliminate many pathogenic microorganisms before treated water is discharged into the environment or reused for irrigation. Similarly, in bioremediation, bacteria, fungi, algae, and other microorganisms degrade hazardous pollutants, including petroleum hydrocarbons, pesticides, dyes, plastics, and heavy metals, thereby restoring contaminated soil and aquatic ecosystems while reducing human exposure to toxic substances. Consequently, microbial innovations serve as powerful instruments for achieving sustainable development by simultaneously protecting environmental health, promoting economic growth, reducing poverty, and improving the well-being of human populations through science-based, environmentally friendly, and socially inclusive solutions. In food microbiology, controlled fermentation and probiotic technologies enhance food safety, improve nutritional value, inhibit foodborne pathogens, and extend shelf life, thereby reducing food spoilage and the prevalence of foodborne diseases. This study was aimed to outline the mmicrobial iinnovations in eenvironmental health in relation to oopportunities for ddisease prevention, ssustainable livelihoods, and poverty rreduction. Beyond their direct public health benefits, microbial innovations create substantial opportunities for sustainable livelihoods, economic empowerment, and poverty reduction, particularly in low- and middle-income countries where environmental degradation and unemployment remain significant challenges.

Keywords: Microbial Innovation, Environmental Health, Bioremediation, Disease Prevention, Poverty Reduction

ADAPTATION STRATEGIS TO COPE WITH CLIMATE CHANGE IN NIGERIA, THE JOURNEY SO FAR: AN EMPERICAL REVIEW

Tanko Dauda
Department of Biology, Federal University Lokoja, Kogi State, Nigeria
Corresponding Author's Email: dauda.tanko@fulokoja.edu.ng

ABSTRACT

Climate change is one of the greatest environmental challenges threatening sustainable development worldwide, with developing countries such as Nigeria being particularly vulnerable because of their high dependence on climate-sensitive sectors, rapidly growing population, extensive coastline, and limited adaptive capacity. Nigeria experiences diverse climate-related hazards, including desertification and rainfall variability in the northern Sahel, recurrent flooding in the central river basins, and coastal erosion, sea-level rise, and saltwater intrusion in the Niger Delta and Lagos coast. With over 70% of the population relying on rain-fed agriculture, climate change adaptation has become a national priority. This review examines Nigeria's climate change adaptation strategies, highlighting major achievements and persistent challenges up to 2025. The country's adaptation efforts are guided by the National Adaptation Plan (NAP 2024) and the updated Nationally Determined Contributions (NDCs). In agriculture, Climate-Smart Agriculture (CSA) interventions, including drought-tolerant crop varieties, agroforestry, and early warning systems, have enhanced resilience. The World Bank-supported ACReSAL Project has restored over 500,000 ha of degraded land across 19 northern states, with pilot studies reporting 20–40% increases in millet and sorghum yields. In water resources management, seasonal climate predictions by the Nigerian Meteorological Agency (NiMet) and dam release protocols developed by the Nigeria Hydrological Services Agency (NIHSA) have improved flood preparedness in vulnerable states. Community-based mangrove restoration in Bayelsa and Rivers States has rehabilitated more than 20,000 ha, strengthening coastal protection and carbon sequestration. Additional progress includes the issuance of sovereign green bonds and the approval of a US$100 million Green Climate Fund project for climate-resilient landscapes. Despite these achievements, adaptation remains constrained by an estimated financing gap of US$100 billion by 2030, limited institutional capacity at sub-national levels, inadequate hydro-meteorological data, insecurity in the North-East, rapid unplanned urbanization, and low adoption of CSA technologies due to high input costs and weak extension services. Although Nigeria has developed robust climate policies, implementation remains inconsistent. This review identifies critical gaps and opportunities to strengthen climate resilience through improved financing, institutional coordination, evidence-based decision-making, and effective policy implementation to achieve sustainable adaptation outcomes.

Keywords: Climate Change, Nigeria, Climate-Smart-Agriculture, National Action Plan

CARBON SEQUESTRATION OF *Terminalia mantaly* H. Perrier TREES AT THE UNIVERSITY OF DELTA, AGBOR, DELTA STATE, NIGERIA.

[1,2]Akinnibosun, H. A., [2]Okubor, P. C. and [2]Ezuteh, P. O.

[1]Faculty of Life Sciences, Department of Plant Biology and Biotechnology, University of Benin, P. M. B.1154 Ugbowo, Benin City 300283, Edo State, Nigeria

[2]Faculty of Science, Department of Biological Sciences, Biotechnology Unit, University of Delta, P.M.B. 2090, Agbor, Delta State, Nigeria.

ABSTRACT

Trees play a significant role in mitigating climate change through the sequestration of atmospheric carbon dioxide. The carbon sequestration capacity of *Terminalia mantaly* H. Perrier an amenity tree that provides beauty, shade, noise reduction and other environmental benefits were studied at the University of Delta, Agbor, Delta State, Nigeria. A total of forty three *T. mantaly* trees were sampled and assessed by means of standard forestry measurements. Allometric equations were used to estimate biomass, carbon stock, and carbon dioxide equivalent (CO_2e) sequestered by the tree stands using the tree diameter at breast height (DBH) measured using diameter tape and plant height measured using clinometer. The results emphasize the ecological significance of *Terminalia mantaly* as a good urban tree species with a large potential of atmospheric carbon storage. The study recommends the establishment of additional *T. mantal*y plantation on campus to enhance carbon sequestration. The data revealed that the *T. mantal*y population is primarily concentrated in the intermediate size categories. The highest density of stems was recorded in the 31.55 – 46.55 cm diameter class (17 trees), with the 46.55 – 61.55 cm class following closely at 15 trees. Conversely, the extremes of the distribution showed much lower counts: the smallest diameter class (16.55 – 31.55 cm) contained only 6 trees, while the largest classes, 61.55 – 76.55 cm and 76.55 – 91.55 cm, accounted for just 5 trees and 1 tree, respectively. Findings from this study highlighted the ecological importance of urban amenity tress as capable of storing great amounts of atmospheric carbon dioxide in form of carbon in their biomass.

Keywords: Amenity tree. Climate change, Carbon dioxide, Carbon sequestration, *Terminalia mantaly,*

ASSESSMENT OF INVASIVE PLANT SPECIES DIVERSITY AND SPATIAL DISTRIBUTION IN YANKARI NATIONAL PARK BAUCHI, NIGERIA

Abdullahi Kamal*[1] Basiri Bristone[2] Israel T. Borokini[3] Umar Aminu Mohammed[1] Ladan Muhammad Auwal[4] Ibrahim Ismail Haruna[5] and Omotayo I. Ajao[3]

[1]Department of Biological Sciences, Sa'adu Zungur University, Bauchi State, Nigeria.
[2]Department of Plant Science, Modibbo Adama University Yola, Adamawa State, Nigeria.
[3]Department of Ecology, Montana State University, Bozeman, Montana United States of America.
[4] Department of Biological Sciences, Abubakar Tafawa Balewa University Bauchi, Bauchi State, Nigeria.
[5]Recreation and Research Unit, Yankari National Park Bauchi, Nigeria.
*Corresponding Author's Email: Kamalabdullahi@sazu.edu.ng;

ABSTRACT

Invasive plant species (IPS) pose a growing threat to biodiversity and ecosystem functioning in protected areas. This study assessed the diversity, distribution, environmental drivers, and ecological impacts of invasive plant species in Yankari National Park, Bauchi State, Nigeria, between September 2025 and June 2026. Vegetation data were collected using stratified random sampling across different habitat types and disturbance gradients. Plant species were identified and analyzed using diversity indices, density, frequency, abundance, and occurrence metrics. Geographic Positioning System (GIS) coordinates and ArcGIS were used for spatial mapping, while Canonical Correspondence Analysis, Detrended Correspondence Analysis, and Ordinary Least Squares regression were employed to evaluate species–environment relationships and invasion impacts. The study recorded 42 invasive plant species belonging to 18 families and 205 native plant species belonging to 52 families. Species richness, diversity, abundance, and occurrence varied significantly among habitats, with highly disturbed sites supporting greater invasive species diversity than less disturbed sites. *Hyptis suaveolens*, *Mitracarpus hirtus*, *Synedrella nodiflora*, *Bidens pilosa*, and *Tridax procumbens* were among the most widespread invasive species. Spatial analysis identified Wikki Tourist Camp, Park Access Road, Marshall Caves, and the Gaji River corridor as invasion hotspots. Soil nitrogen, pH, electrical conductivity, and mercury significantly influenced invasive species distribution. Although IPS richness was positively associated with native species richness, invasive abundance showed no significant effect on native effective diversity. The study concludes that Yankari National Park remains a biodiversity-rich protected area but faces increasing pressure from IPS. Regular monitoring, hotspot-based management, habitat restoration, environmental education, and GIS-supported surveillance are recommended to prevent further spread and safeguard the park's ecological integrity.

Keywords; Invasive Plant Species, Assessment, Diversity, Spatial Distribution, Yankari National Park,

COMPARATIVE PHYSICOCHEMICAL ANALYSIS OF SEED OILS FROM *Vitellaria paradoxa* AND *Ziziphus mauritiana* IN NORTHERN GUINEA SAVANNA ECOLOGICAL ZONE OF TARABA STATE, NIGERIA

[1*]Meer B. B., [2]Myina O. M. and [3]Mobuogwu-Osaji J. N.

[1]Department of Forestry and Wildlife Management, Faculty of Agriculture, Taraba State University, Jalingo, Nigeria

[2]Department of Chemical Sciences, Faculty of Science, Taraba State University, Jalingo, Nigeria

[3]Department of Family and Consumer Science (Home Economics), Faculty of Agriculture, Taraba State University, Jalingo, Nigeria

[*]Corresponding Author's Email: bbmeer@tsuniversity.edu.ng

ABSTRACT

The increasing demand for plant-derived oils has stimulated interest in underutilized indigenous tree species as alternative sources of high-quality oils with nutritional, pharmaceutical, and industrial potential. This study comparatively evaluated the physicochemical properties of seed oil extracts obtained from selected tree species in the Northern Ecological Zone of Taraba State, Nigeria. Specifically, the study assessed the oil yield and selected physicochemical characteristics of oils extracted from the seeds of *Vitellaria paradoxa* and *Ziziphus mauritiana*. A purposive sampling technique was employed to select the species based on their abundance, diversity, and seed yield potential. Three mature trees from each species were randomly selected, giving a total of six sampled trees. Mature, fresh, and undamaged seeds were harvested, sun-dried, and pulverized into powder prior to laboratory analysis. Standard analytical procedures were employed for oil extraction and the determination of physicochemical parameters, while data were analyzed using percentages, mean, variance, and Student's *t*-test. The results revealed that *Vitellaria paradoxa* produced a significantly higher oil yield (45.27 ± 0.65%) compared to *Ziziphus mauritiana*. The oil from *Vitellaria paradoxa* also exhibited higher moisture content (4.49 ± 0.30%), free fatty acid content (28.89 ± 0.59%), acid value (3.36 ± 0.04 mg KOH/g), and saponification value (187.37 mg KOH/g), indicating its suitability for industrial applications, particularly in soap and cosmetic production. In contrast, *Ziziphus mauritiana* seed oil demonstrated lower acidity (2.53 ± 0.18 mg KOH/g) and comparatively higher pH (5.6 ± 0.2), iodine value (66.80 g I_2/100 g), peroxide value (13.26 ± 0.20 meq/kg), refractive index (1.506 ± 0.015), and specific gravity (0.940 ± 0.006 g/mL), suggesting a more unsaturated and fluid oil profile. Overall, the findings indicate that *Vitellaria paradoxa* seed oil possesses superior oil yield and physicochemical characteristics favorable for specialized industrial utilization, although its relatively high free fatty acid and peroxide contents may require further refining before application. Conversely, the higher degree of unsaturation and relatively neutral pH of *Ziziphus mauritiana* seed oil suggest its potential suitability for domestic edible and related applications.

Keywords: Oil Seeds, Seed Oil, Underutilised Plants, *Vitellaria paradoxa*, *Ziziphus mauritiana*

REFORESTATION VERSUS AFFORESTATION: A REVIEW OF ECOLOGICAL IMPLICATIONS FOR PROJECT DEVELOPERS IN THE TROPICAL REGION

Olatidoye, O. R.
Forestry Research Institute of Nigeria, Jericho Hills, Ibadan. Nigeria
Corresponding Author's Email: olaremiolatidoye@gmail.com

ABSTRACT

Afforestation and restoration are widely recognized as effective nature-based solutions for enhancing biodiversity, restoring degraded ecosystems, and mitigating climate change through carbon sequestration. Although the terms *afforestation* and *reforestation* are often used interchangeably, they represent distinct ecological interventions with different implications for biodiversity conservation and ecosystem functioning. Selecting the appropriate approach is essential for avoiding costly implementation errors, preserving ecological integrity, and maximizing long-term environmental benefits. However, poorly planned afforestation or restoration initiatives can pose significant ecological risks, particularly when implemented in habitats where trees are not the natural or most suitable vegetation. This paper examines the ecological distinction between afforestation and reforestation and highlights the importance of adopting evidence-based, site-specific strategies to guide restoration efforts. It emphasizes the need to avoid tree establishment in high-biodiversity, non-forested ecosystems, including natural grasslands, savannas, and wetlands, where afforestation may lead to habitat degradation and biodiversity loss. An integrated framework that simultaneously considers carbon sequestration potential, habitat suitability, and ecosystem resilience is advocated to ensure that afforestation and reforestation initiatives achieve climate mitigation objectives while safeguarding biodiversity. The study underscores the importance of ecological planning, appropriate species selection, and landscape-specific implementation in promoting sustainable restoration and enhancing the success of nature-based climate solutions.

Keywords: Afforestation; Reforestation; Biodiversity conservation; Ecosystem restoration; Carbon sequestration.

HABITAT RESTORATION STRATEGIES FOR ENHANCING BIODIVERSITY AND ECOLOGICAL NETWORKS: A REVIEW

Olatidoye, O. R.

Forestry Research Institute of Nigeria, Jericho Hills, Ibadan. Nigeria
Corresponding Author's Email: olaremiolatidoye@gmail.com

ABSTRACT

Ecosystems are under growing stress resulting from human activities including deforestation, pollution, climate change, and resource overuse, this makes restoring degraded ecosystems a crucial worldwide challenge. In order to restore degraded landscapes in a sustainable and environmentally sound manner, habitat restoration strategies would play crucial roles in this process. The concepts of habitat restoration are explained by ecological integrity, target species identification, and long-term sustainability. Native species are very successful at reestablishing ecological services and promoting biodiversity because they have developed in particular areas over millennia and are particularly adapted to local environmental conditions. Another important element that promotes cooperation between locals, environmental groups, governmental organizations and contributes to the social and financial advantages of restoration efforts is community-based conservation strategies. In order to guarantee the resilience and sustainability of ecosystems for future generations, this paper examines fundamental these restoration strategies in relation to a variety of factors, including landscape connectivity and ecological corridors, technological tools, monitoring and evaluation, and challenges encountered in the restoration process. It also highlights the necessity of continued investment in these strategies.

Keywords: Ecological network, Ecological integrity, Monitoring, Sustainability, Biodiversity Conservation

CLIMATE INDUCED FLOODS IMPACT ON INFRASTRUCTURE, STAPLE FOOD SUPPLY AND PRICES IN YENAGOA, BAYELSA STATE, NIGER DELTA

Charles Oyibo[1], Authority Benson[2], Kemebigha Ine-ebi[3], Ekpotenmene Tamaraumiemene[4]
[1]Department of Environmental Management, Niger Delta University, Amassoma, Wilberforce Island, Bayelesa State, Nig.
[2]Department of Environmental Management, Niger Delta University, Amassoma, Wilberforce Island, Bayelesa State, [Nig].
[3]Bayelsa State Ministry of Environment, inieebiegei@gmail.com
[4]Department of Geography and Environmental Management, Niger Delta University, Amassoma, Wilberforce Island, Bayelesa State, Nig
Corresponding Author's Email: Charles.oyibo@ndu.edu.ng

ABSTRACT

Flooding remains one of the most destructive climate-related hazards in Nigeria, with grave implications for food security. This research investigates the effects of floods on support infrastructure, availability, prices, and quality of essential staple food items such as yam, garri, plantain, fufu, and palm oil. The study focuses on traders in the local markets of Swali, Kpansia, and Igbo-gene within the Yenagoa metropolis. Using a mixed-method and a purposive sampling survey to select a sample of 60 respondents across three major markets, data collection utilizes questionnaire, and the findings are presented in frequencies, percentages and plates illustrating significant shifts in staple food dynamics post-flood. Findings reveal significant disruptions in supply chains, price inflation, and quality deterioration of key staples and severe damage to transport networks. Specifically, results highlight disruptions to road infrastructure in Bayelsa State and reveal that among the staple foods examined, Plantain faced the most significant impact, with reduced availability and increased prices attributed to the flood. Regarding Plantain availability 50% of the traders strongly agreed that the food significantly decreased plantain availability, 41.7% agreed, and 8.3% held a different view. In terms of plantain pricing, 50% of the traders strongly agreed, and another agreed that the floods had a noteworthy effect on the price of plantain in Yenagoa. This adverse effect on plantain availability could be attributed to transportation routes or other relevant factors. It was recommended that traders should develop strategic sourcing alternatives and foster collaboration to mitigate sudden price fluctuations. Also, government intervention in transportation, storage infrastructure, financial aid, and information dissemination can effectively assist traders in managing price fluctuations during crises. The study underscores the urgent need for resilience strategies to safeguard food systems and road infrastructure in flood-prone regions.

Keywords: Climate Change**,** Floods, Infrastructure, Staple foods and food security.

PHYSICOCHEMICAL PARAMETERS AND ZOOPLANKTON ABUNDANCE OF RIVER ANTAU, KEFFI, NASARAWA STATE, NIGERIA

Abdullahi M.M.*, Makpo J.K., and Nafisat. A
Department of Zoology, Faculty of Life Sciences, Nasarawa State University, Keffi, Nigeria.
*Corresponding Author's Email: *amairiga@nsuk.edu.ng*

ABSTRACT

Th increasing contamination of fresh water ecosystems due to anthropogenic activities has become a global environmental problem leading to significant deterioration and loss of aquatic biodiversity. This study assessed the physicochemical parameters and zooplankton abundance of River Antau, Keffi, Nasarawa State, Nigeria from May to August, 2025. Three sampling stations (Station 1, II and III) 1km apart were established along the river based on stratified method. Water samples were collected by dipping a 1- litre sampling bottle to a depth of 15cm and analyzed for selected physicochemical parameters while zooplankton were collected were identified using taxonomic key. The results indicate that water temperature ranged from 25.1 °C to 25.9 °C across the sampling stations. The mean pH varied from 7.9 at station III to 8.8 station 1, with higher values recorded in the months of May (8.98) and June (8.78) than July (7.77) and August (7.33). Dissolved Oxygen concentrations ranged from 0.73 mg/L in June to 6.88 mg/L in August. Total Alkalinity increased from 56.20mg/L in May to 68.00 mg/L in August, with significant monthly variation ($p<0.05$). Electrical conductivity ranged from 43.0 at station II to 46.3 at station I. A total of 11 taxa zooplankton representing three major groups with a total of 207 were recorded during the study. Cladocera was the dominant group, accounting for 39.6% (82 individuals), followed by Rotifera with 30.4% (63 individuals) and Copepoda with 30.0% (62 individuals). Shannon-Wiener diversity index (H') revealed relatively high species diversity in Cladocera and Copepoda, while the Margalef species richness index indicated comparable species richness among the groups, with spatial variation across the sampling stations. These findings indicate that the physicochemical characteristics of River Antau varied seasonally and influenced the zooplankton composition and distribution. Therefore, agricultural practices near River Antau should be regulated to reduce the runoff of inorganic fertilizers and pesticides into the water to safeguard the ecological health of the river.

Keywords: Zooplankton, abundance, physicochemical parameters, River Antau, Keffi

.

RELEVANCE OF TROPICAL WETLANDS TO AGRICULTURE AND ITS CHALLENGES: A REVIEW

Abdullahi Kamal[1] and Umar Aminu Mohammed[1]
[1]Department of Biological Sciences, Sa'adu Zungur University, Bauchi State.
*Corresponding Author's Email: Kamalabdullahi@basug.edu.ng

ABSTRACT

Wetlands are distinct ecosystems characterized by the presence of water, either permanently or seasonally, which influences the soil and supports unique vegetation. The Ramsar Convention categorizes wetlands into marine and coastal wetlands (e.g., mangroves, coral reefs), inland wetlands (e.g., rivers, peat lands, lakes), and artificial wetlands (e.g., reservoirs, irrigation canals). Wetlands provide numerous ecological services, including: Flood Control, Groundwater Replenishment, Storm Protection, Nutrient Retention, Sediment and Heavy Metal Traps. Wetlands are under severe pressure from human activities, with 87% of known inland wetlands lost, especially in tropical regions. Major threats include: Anthropogenic Activities, Agricultural Expansion, Climate Change, and Biodiversity Loss. To protect wetlands, sustainable management strategies include: Constructed Wetlands, balancing Conservation and Human Needs, Policy and Awareness Initiatives, Scientific Research and Monitoring. Wetlands are critical ecosystems that provide essential services for both nature and human societies. However, they face increasing threats from human activities and climate change. Effective conservation strategies, informed policies, and sustainable practices are necessary to safeguard these ecosystems for future generations. Some of the challenges facing tropical wetlands includes: Wetland Degradation and Habitat Loss, Climate Change and Rising Sea Levels, Pollution and Eutrophication, Overexploitation of Wetland Resources, Invasive Species Encroachment, and Water Diversion and Hydrological Changes, while solution to those challenges can be through: Policy and Legal Frameworks, Community Based Wetland Management, Education and Awareness Campaigns and Restoration and Rehabilitation Programs. In conclusion, wetlands are indispensable for agriculture, providing critical ecosystem services that sustain food production and rural livelihoods.

Keywords: Tropical Wetlands, Wetland Management, Agriculture, Environmental Challenges, Irrigation Agriculture.

GEOSPATIAL ASSESSMENT OF BIOMASS RESIDUES FOR RENEWABLE ENERGY AND ECOLOGICAL SUSTAINABILITY IN NASARAWA STATE, NIGERIA

***[1]Abubakar Suleiman, [2]Adamu Bello Suleima, [1]Anyubaga Salim Bitus, [2]Fatima Umar Abdulhamid**

Ahamdu Bello University Zaria, Nigeria
Federal University of Lafia, Nigeria
*Corresponding Author's Email: b3lllo.as@gmail.com

ABSTRACT

The mounting energy shortfall and rising environmental challenges linked to reliance on fossil fuels have amplified the necessity of investigating sustainable renewable energy options. Using Geographic Information System (GIS)-based spatial modeling techniques, this study evaluated the availability of agricultural biomass residues and their bioenergy potential in Akwanga, Wamba, and Nasarawa Eggon Local Government Areas of Nasarawa State, Nigeria. Secondary data were utilized, including crop production statistics from 2020 to 2022, Sentinel-2 imagery, and Digital Elevation Model (DEM) data for the analysis. The Residue-to-Product Ratio (RPR) method was used to estimate the amount of crop residues and their energy potential. Additionally, ArcGIS Model Builder and Multi-Criteria Decision Analysis (MCDA) were utilized to find appropriate locations for bioenergy plant development. The findings showed that around 14,004.46 tonnes of agricultural residues could be produced in the study area, yielding an estimated energy potential of roughly 200,934.69 MJ/year. While Wamba LGA generated the most biomass residue, Akwanga LGA was recognized as the best site for a bioenergy plant because of its advantageous terrain, accessibility, and availability of biomass. The greatest portion of the total energy potential derived from cassava residues. The research shows that agricultural residues are a feasible renewable energy source that can decrease waste, lessen greenhouse gas emissions, and improve environmental sustainability. It thus advocates for greater investment in biomass energy technologies, educating farmers about residue management, and incorporating GIS-based decision-support systems into the planning and development of renewable energy in Nasarawa State.

Keywords: Renewable Energy, Agricultural Biomass Residues, Bioenergy Potential, Waste-to-Energy, Residue-to-Product Ratio, Environmental sustainability.

ECOTOXICOLOGICAL RISKS OF PESTICIDE RESISTANCE IN INSECTS AND ITS ECOSYSTEM IMPACTS

Auwalu Jalo*[1], Timothy Auta[2] and Zaharaddeen Hassan Yusuf[3]

[1] Biology Department, Faculty of Science, Federal University of Health Sciences Azare, Bauchi State, Nigeria

[2] Biology Department, Faculty of Life Sciences, Federal University Dutsin-ma, Katsina State, Nigeria

[3] Biology Department, School of Secondary Education Sciences, Federal College of Education Katsina, Katsina State, Nigeria

*Corresponding Author's Email: auwalu.jalo@fuhsa.edu.ng

ABSTRACT

Pesticide resistance in Insects documented in over 270 unique species worldwide has transformed from a farm-management headache into a pressing ecotoxicological concern. As resistance proliferates, weed control often shifts toward higher application rates, additional spray passes, Pesticide tank mixtures, and the reintroduction of older chemistries such as paraquat and atrazine. These shifts amplify exposure and toxicity risks for non-target plants and animals alter soil and aquatic microbial processes, perturb food webs, and accelerate landscape-level biodiversity loss. Mechanistically, resistance evolves via target-site resistance such as EPSPS gene amplification in *Amaranthus palmeri* conferring glyphosate resistance and increasingly through non-target-site resistance (NTSR) mechanisms that involve enhanced metabolism, sequestration, and reduced translocation. The NTSR frequently confers cross-resistance across modes of action, accelerating chemical substitution and cumulative environmental loads. This paper synthesizes current knowledge on how HR reshapes Pesticide-use patterns and ecological hazards, highlights sentinel case studies, and outlines integrated weed management and policy strategies that can mitigate both resistance evolution and downstream ecotoxicological risks.

Keywords: Ecotoxicology, Pesticide Resistance, Pesticide Risk Assessment, Insects, Weeds Management, Ecosystem Protection

COMPARATIVE ASSESSMENT OF PLANT SPECIES COMPOSITION, DIVERSITY, AND FLORISTIC SIMILARITY ACROSS SELECTED FOREST ECOSYSTEMS IN BAYELSA STATE, NIGERIA

Binaebi Ambah[1,2*], Ayodele A. Oyedeij[1,3] and Jasper Ezenwaka[1,4], Lucky O. Ikechukwu

[1]Institute of Biodiversity, Climate Change and Watersheds, Niger Delta University, Wilberforce Island, Nigeria
[2]Department of Agricultural Science Education, Isaac Jasper Boro College of Education, Sagbama, Nigeria
[3]Department of Biological Sciences, Niger Delta University, Wilberforce Island, Nigeria
[4]Department of Crop and Soil Sciences, University of Africa, Toru-Orua, Nigeria
[5]Department of Forestry and Environment, Rivers State University, Port Harcourt, Nigeria.
Corresponding Author's Email: ambahbina@yahoo.com*

ABSTRACT

This study assessed plant species composition, diversity, and similarity across three forest ecosystems in Bayelsa State, Nigeria: Taylor Creek Forest Reserve, Edumanom Forest Reserve, and Adiegbe Forest. A comparative ecological survey was conducted using line transects and quadrats to record plant species and classify them into life forms and families. Species identification was carried out using standard taxonomic keys, while diversity was described using species richness and family composition. Incidence-based similarity indices were used to evaluate floristic similarity among the forests. A total of 116, 106, and 124 plant species belonging to 56, 53, and 59 families were recorded in Taylor Creek, Edumanom, and Adiegbe forests, respectively. Fabaceae, Euphorbiaceae, Rubiaceae, Moraceae, and Poaceae were consistently dominant across the sites in the forest ecosystem. Tree species dominated Adiegbe Forest (49.13%) and Edumanom Forest (41.51%), while Taylor Creek Forest showed lower tree cover (4.38%) and higher shrub dominance (28.45%). Herbaceous species were relatively similar across all forests, while climbers were least represented. Woody-to-non-woody ratios indicated highest woody dominance in Adiegbe (2.35:1), followed by Taylor Creek (2.25:1) and Edumanom (1.94:1). Similarity analysis showed moderate species overlap among the forests but clear differences in abundance structure. The results indicate that Adiegbe Forest is the most structurally stable ecosystem, Edumanom represents a moderately disturbed forest, while Taylor Creek reflects a more disturbed and regenerating system. The study highlights the influence of environmental conditions and anthropogenic activities on forest composition and structure in the Niger Delta and emphasizes the need for sustainable forest management to conserve biodiversity in the region.

Keywords: Antropogenic activities, biodiversity, conservation, disturbance, ecosystem, Taxonomy.

EFFECTIVENESS OF TURMERIC AND GARLIC BASED ORGANIC MEDIA IN THE HYDROPONIC ESTABLISHMENT OF TOMATO (*Solanum lycopersicum* L.) SEEDLINGS

Olasan, J.O., Aguoru, C.U. and Abah Joy Enyo
Department of Plant Science and Biotechnology, Joseph Sarwuan Tarka University Makurdi, 970101, Nigeria
Corresponding Author's Email: olasan.olalekan@uam.edu.ng

ABSTRACT

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop in Nigeria. Production of the crop is limited due to biotic and abiotic constraints. This study therefore evaluated the use of organic media of turmeric (*Curcuma longa*) and garlic (*Allium sativum*) extracts as compared with inorganic liquid fertilizer in the hydroponic production of Roman and Cherry tomato. A Complete Randomized Design with five treatments and three replicates was set up. Results showed significant differences in plant performances at different treatment levels and varietal factor. ($P<0.05$). In Roman tomato, turmeric extract at 2g produced the tallest plants (7.96 ± 0.25) and highest vigor index (692 ± 84.5) compared to control and other treatments. Liquid fertilizer at 1 ml promoted root elongation (9.43 ± 0.93) but higher doses suppressed growth. Garlic extracts enhanced leaf sizes (2.30 ± 0.52) but reduced germination (46.6%). Roman tomato showed better responses to organic extracts in hydroponic culture than Cherry tomato. The results suggest that the application of 2 g turmeric extract in combination with a low-dose liquid fertilizer significantly improved the performance of Roman tomato under hydroponic conditions, whereas the Cherry tomato variety exhibited little or no positive response. The study highlights the potential of natural biostimulants as sustainable alternatives for enhancing hydroponic tomato production and promoting environmentally responsible agricultural practices in Nigeria.

Keywords: Hydroponics, Organic extracts, Sustainability, Tomato, Spices.

PERFORMANCES OF POULTRY DROPPINGS, GOAT WASTE AND NPK FERTILIZER ON THE GROWTH AND YIELDS OF FOUR SWEET POTATO VARIETIES (*Ipomoea batatas* L)

Aguoru, C.U., Olasan, J.O. and Chihin, D.A.
Department of Plant Science and Biotechnology, Joseph Sarwuan Tarka University Makurdi, 970101, Nigeria
Corresponding Author's Email: olasan.olalekan@uam.edu.ng

ABSTRACT

Sweet potato is an important tuber crop in Nigeria. Production is however challenged by poor growth and yield. This study compared the performances of poultry droppings, goat waste and NPK fertilizer on the growth and yields of four sweet potato varieties: Garnet, Jewel, Willow leaf and Nugget. Results showed significant treatment and varietal effects in growth and yield traits of agronomic values ($P<0.05$). Poultry droppings had significant influence on plant spread (177.15cm), plant length (244.9cm), tuber width (9.08cm) and tuber weight (0.98kg). NPK fertilizer significantly enhanced leaf sizes, plant vigour (5.0) and plant length (244.87cm). Significant variety x fertilizers interaction effects were also observed in some traits ($P<0.05$). Nugget variety x poultry dropping effect gave the highest values in plant spread (210.78cm), tuber width (11.67cm) and tuber weight (1.47kg). Willow leaf variety x goat waste effect significantly influenced tuber length (26.33cm). Willow leaf variety x poultry dropping effect significantly influenced leaf length (16.0cm), leaf width (14.2cm), number of branches (12.0). Nugget variety x NPK effect significantly influenced leaf width (14.0cm) while Willow x NPK interaction had significant effect on leaf length (16.83cm). Among the interactions, Nugget variety x poultry dropping appeared to be best, thus suggesting need to optimize genetic resources and environment factors to achieve maximum yield. The outcome of this research has provided useful data needed in the sustainable production of sweet potato varieties without the need for synthetic yield enhancers that are harmful to the environment.

Key words: Environmental Protection, Organic manure, Sustainable production, Sweet Potato, Soil Amendments

SPATIAL ASSESSMENT AND TEMPORAL DYNAMICS OF ABOVE- AND BELOWGROUND BIOMASS AND CARBON STOCKS IN THE KANAWA FOREST RESERVE, GOMBE STATE, NIGERIA

Yuguda[1], UA, Saka[2], MG, Dishan[2], EE, Bello[3], MB and Abba, HM[1]
[1]Department of Plant Sciences, Gombe State University
[2]Department of Forestry and Wildlife Management, Modibbo Adama University
[3]Department of Geography and Environmental Management, Gombe State University
Corresponding Author's Email: uayuguda@gsu.edu.ng

ABSTRACT

Forest biomass is a critical component of global decarbonization strategies, yet spatially explicit data on aboveground (AGB) and belowground biomass (BGB) remain scarce in West African savanna ecosystems. This study aimed to quantify biomass and carbon stocks in the Kanawa Forest Reserve (KFR), Nigeria, and develop robust remote sensing models for their spatial estimation. Field inventories were conducted across 10 systematic 1-ha plots. AGB and BGB were estimated using IPCC-compliant allometric equations (root-to-shoot ratio = 0.26; carbon fraction = 0.47). Multi-temporal Landsat 8 OLI imagery (2020–2024) was processed to derive vegetation indices (NDVI, SAVI, ARVI). Non-linear regression models were calibrated and validated, with uncertainty quantified via Monte Carlo analysis and model selection guided by the Akaike Information Criterion (AIC). The reserve exhibited pronounced spatial heterogeneity. Total plot-level AGB was 1,257.09 Mg ha^{-1} (590.83 Mg ha^{-1} carbon), and BGB was 326.85 Mg ha^{-1} (153.62 Mg ha^{-1} carbon), yielding an aggregate biomass of 1,583.94 Mg ha^{-1}. The inverse-transformed ARVI model yielded the highest predictive accuracy (Adj. R^2 = 0.889; CV = 7.21%), successfully overcoming spectral saturation. Multi-year raster analysis revealed a net decline of 4.40% in mean landscape AGB between 2020 and 2024. Despite its protected status, KFR is experiencing gradual biomass erosion, likely due to anthropogenic disturbances. The validated inverse-transformed spectral modeling framework provides a highly scalable, cost-effective monitoring, reporting, and verification (MRV) architecture, offering a critical empirical baseline for Nigeria's REDD+ commitments and the operationalization of the Climate Change Act of 2021.

Keywords: Aboveground biomass, Carbon sequestration, Spatial modeling, Remote sensing, REDD+, Sudan-Guinea Savanna

PROXIMATE NUTRIENT AND ANTIOXIDANT CONTENT OF *Pleurotus ostreatus* (Jacq) P. Kumm (PLEUROTAECE) CULTIVATED ON WOOD SAW DUST

Olabiyi Oluwatobiloba Margaret and Akinjide Moses Afolabi

ABSTRACT

Mushrooms are widely consumed by people of many ethnic backgrounds all throughout the world. They have widespread cultural acceptance and are historically a very nutritious food. However, its classification as food, based on chemical analysis, has not been thoroughly investigated and substantiated. This study investigated the use of an agricultural waste, saw dust, for the cultivation of Pleurotus ostreatus an edible mushroom. This study was carried out at Osun state university, Oshogbo Main Campus, sun State, Nigeria and LTC Farm, Ofatedo, Osun State. The proximate chemical makeup of the mushroom was determined using standard techniques. The Macro minerals composition, Micro minerals composition and Antioxidants composition of Pleurotus ostreatus were determined. Percentages were used to express the results. Standard procedures were used to determine the proximate chemical composition of the mushroom. Atomic absorption and flame spectrophotometer were used to determine the mineral and heavy element composition. The results were expressed in percentage. There were significant differences in the proximate nutritive values of the various mushroom studied. Despite differences in the chemical composition of the sampled mushroom specie, the overall nutritional potential of the whole mushroom species was quite good. The results of the analysis showed high mean significant amounts of crude fiber (12.385%), Crudeprotein (2.925%), carbohydrate (78.125%), Na (0.105%), Ca (0.12%), Fe (5.22mg/kg), Zn (7.095 mg/kg). The findings of proximate analysis of sampled mushrooms using sawdust as substrate revealed that they are good providers of nutrients such as protein and dietary fiber, and as such, sawdust can be classified as rich substrate for mushroom cultivation.

Keywords: Mushroom, *Pleurotus ostreatus* Macro Nutrients, Antioxidants, Mushroom Substrate,

EFFECT OF HYDRO PRIMING DURATION ON VIGOUR OF MAIZE (*Zea mays*) IN LAPAI, NIGER STATE, NIGERIA

Stephen, D.Y., Habiba, M. M., Jimada, K.
Department of Biological Science Laboratory, Ibrahim Badamasi Babangida University, Lapai, Niger State,

ABSTRACT

Hydroponic cultivation offers a sustainable alternative to conventional soil-based agriculture by improving resource-use efficiency and reducing environmental degradation; however, the use of natural biostimulants to enhance crop performance under hydroponic conditions remains inadequately explored. This study evaluated the effects of turmeric (*Curcuma longa*) extract and liquid fertilizer on the growth and performance of Roman and Cherry tomato varieties cultivated hydroponically. Different concentrations of turmeric extract and liquid fertilizer were applied to determine their effectiveness as biostimulants under hydroponic conditions. Growth and yield parameters were assessed and analyzed using appropriate statistical procedures. The results showed that the application of 2 g turmeric extract and a low-dose liquid fertilizer significantly enhanced the growth and performance of the Roman tomato variety, whereas the Cherry tomato variety exhibited little or no comparable response to the treatments. These findings indicate that varietal differences influence the effectiveness of natural biostimulants under hydroponic cultivation. The study demonstrates that turmeric extract has considerable potential as an environmentally friendly biostimulant for improving hydroponic tomato production, particularly in the Roman tomato variety, and provides a sustainable strategy for enhancing tomato productivity while minimizing reliance on synthetic agrochemicals in Nigeria.

Keywords: Hydroponics; *Curcuma longa*; Biostimulant; Tomato varieties; Sustainable agriculture.

IN-SILICO INHIBITION OF ALPHA-AMYLASE AND ALPHA-GLUCOSIDASE BY LIGANDS FROM HYDROMETHANOLIC EXTRACT OF *Chrysophyllum albidum* BARK

Amototo Hamidat Oyinkansola
Federal College of Education, Ilawe Ekiti, Ekiti State, Nigeria.

ABSTRACT

The global prevalence of diabetes mellitus continues to increase, creating an urgent need for safer and more effective therapeutic agents derived from natural products. Diabetes mellitus is a metabolic disorder characterized by persistent hyperglycemia resulting from impaired glucose metabolism, and one of the established therapeutic strategies involves the inhibition of carbohydrate-hydrolyzing enzymes, particularly α-amylase and α-glucosidase. However, currently available enzyme inhibitors are often associated with undesirable side effects, necessitating the exploration of plant-derived bioactive compounds as alternative therapeutic agents. This study investigated the *in silico* inhibitory potential of bioactive compounds identified from the hydromethanolic stem bark extract of *Chrysophyllum albidum* against α-amylase and α-glucosidase. Phytochemical profiling was carried out using Liquid Chromatography–Mass Spectrometry (LC–MS), while molecular docking analysis was employed to evaluate the binding affinities and interactions of the identified compounds with the target enzymes. Fifteen phytochemical constituents were identified, of which several compounds exhibited strong binding affinities toward both α-amylase and α-glucosidase, surpassing those of the reference inhibitors, maltose and voglibose. The ligand–enzyme complexes were stabilized through hydrogen bonding and hydrophobic interactions within the catalytic active sites, suggesting favourable molecular recognition and inhibitory potential. These findings demonstrate that bioactive compounds from *Chrysophyllum albidum* stem bark possess promising enzyme inhibitory activity and may serve as potential lead molecules for the development of safer and more effective antidiabetic drugs. Further *in vitro*, *in vivo*, and pharmacological studies are recommended to validate their therapeutic efficacy and safety.

Keywords: *Chrysophyllum albidum*; Diabetes mellitus; α-Amylase inhibition; α-Glucosidase inhibition; Molecular docking.

DIETARY EFFECT OF *Philonotis hastata* (Duby) Wijk and Margad ON THE GROWTH, HAEMATOLOGY AND BIOCHEMICAL ENZYMES OF AFRICAN CATFISH (*Clarias gariepinus*) Broodstock

Ololade Promise Olabode
Federal College of Education, Ilawe-Ekiti, Ekiti State, Nigeria

ABSTRACT

The search for natural feed additives that improve reproductive performance and overall health in aquaculture has increased owing to concerns over the safety and sustainability of synthetic fertility enhancers. This study evaluated the effects of dietary inclusion of the fertility-enhancing moss plant, *Philonotis hastata*, on the growth performance, haematological parameters, and selected biochemical indices of African catfish (*Clarias gariepinus*) broodstock to determine its nutritional value and potential toxicity. A total of 120 juvenile *C. gariepinus* (230 ± 2.54 g) were randomly distributed into concrete tanks (6.0 × 5.0 × 1.5 m) at a stocking density of 12 fish per tank (6 males and 6 females), with two replicates per treatment. Fish were fed twice daily with five iso-nitrogenous diets (45% crude protein) containing graded levels of *P. hastata* meal at 0, 5, 10, 15, and 20 g kg^{-1}, designated D1, D2, D3, D4, and D5, respectively. Fish fed the D5 diet (20 g kg^{-1}) exhibited significantly ($p < 0.05$) superior growth performance compared with the other treatment groups. Although differences were not significant ($p > 0.05$), fish fed the D3 diet recorded the most favourable feed conversion ratio (1.66). Haematological evaluation showed that fish receiving the D3 diet had significantly higher ($p < 0.05$) haematocrit and haemoglobin values than those in the other treatments. Biochemical analysis revealed significantly lower ($p < 0.05$) aspartate aminotransferase (AST) activity in fish fed the D5 diet, whereas alanine aminotransferase (ALT) and lactate dehydrogenase (LDH) activities were significantly higher ($p < 0.05$) in the same treatment. Overall, dietary inclusion of *P. hastata* did not adversely affect the growth, haematological, or biochemical status of *C. gariepinus* broodstock. Rather, the plant demonstrated potential as a natural fertility-enhancing feed additive with beneficial effects on fish performance and physiological health.

Keywords: *Philonotis hastata*, Growth performance, Haematology, Biochemical enzymes, *Clarias gariepinus*

THE EFFECT OF VARYING POULTRY MANURE CONCENTRATIONS MIXED WITH CLAY SOIL ON PLUMULE EMERGENCE AND SEEDLING GROWTH OF TOMATO (*Solanum lycopersicum*)

DADA, C. A.
Department of Science Laboratory Technology (Biotechnology option), Ekiti State University, Ado-Ekiti, Ekiti State, Nigeria.

ABSTRACT

Soil fertility, which denotes the soil's capacity to supply essential nutrients to plants, is a limiting factor in many agricultural regions, especially where soils are inherently poor or have become degraded due to over use or erosion. This study aimed at evaluating the effect of varying poultry manure (PM) concentrations mixed with clay soil on plumule emergence and early seedling growth of *Solanum lycopersicum*. This study was conducted at the experimental farm of the Department of Plant Science and Biotechnology, Ekiti State University, Ado-Ekiti, Ekiti State, Nigeria between August – November, 2025. Present study was subjected to seven treatments viz: 10%, 20%, 30%, 40%, 50%, 100% P.M and 100% clay soil. One hundred and forty viable seeds of *Solanum lycopersicum* were divided into seven groups and sown separately in the treatments filled into plastic germination pots arranged in a Completely Randomized Design with three replicates. Emergence was observed and recorded daily for twenty days. The data obtained were expressed in percentage. Two uniform seedlings of *Solanum lycopersicum* at three weeks old were transplanted into the germination plastic pots filled with the seven treatments and were allowed to stabilize for a week after which growth assessment commenced and were carried out for twelve weeks. Parameter assessed were plant height, stem girth, number of leaves, leaf area, number of flowers and number of fruits. Results obtained revealed that plumule emergence of *Solanum lycopersicum* was at its peak (80%) in the 10% PM treatment and this was followed by 100% clay soil treatment with mean value of 70%. The least emergence was recorded in 30% PM with mean value of 20% while 40% PM, 50% PM and control 1 (100% PM) treatments produced no emergence. The 10% PM treatment recorded the tallest mean plant height (120.00 cm), followed by 20% PM treatment with mean value of 105. 20 cm, but the lowest mean plant height (32.24cm) was recorded in 50% PM treatment while 100% PM produced no plant at week 12 respectively. The 20% PM treatment produced the highest number of leaves (298 leaves), thickest stem girth (18.99cm) largest leaf area (127.00 cm²) and highest number of flowers (6.00) at week twelve (12) after transplant. Moderate PM Concentrations (10–20%) generally promoted superior vegetative growth and reproductive performance as 10% P.M treatment yielded the highest number of fruits (6.00). Whereas higher PM concentrations (≥30%) suppressed emergence and early development. Conclusively, mixing poultry manure with clay soil at moderate rates (10–20%) improved tomato seedling establishment while excessive PM should be avoided.

Keywords: Clay Soil, Plumule Emergence, Poultry Manure, Seedling Growth, *Solanum lycopersicum*

HABITAT SUITABILITY PREDICTION FOR *Vitellaria paradoxa* (SHEA BUTTER TREE) IN NIGERIA

Akwaji Patrick Ishoro[1]*, Ibe Uno Eyong[1] and Mayame Ernest Amap[1]

1. Department of Plant and Ecological Studies, Faculty of Biological Sciences, University of Calabar, P.M.B. 1115, Calabar, Cross River State, Nigeria

Corresponding Author Email: akwajiisnever@gmail.com Phone no: +234 803 468 3096

Abstract

Vitellaria paradoxa, commonly known as the Shea butter tree, is a socio-economically vital indigenous fruit tree in Nigeria, providing livelihoods for millions through the production of shea nut oil. Despite its importance, the species faces threats from habitat loss, over-exploitation, and the escalating impacts of climate change. Understanding the environmental variables that dictate its distribution is critical for conservation and sustainable management. This study investigated current and future occurrence, geographic distribution, and suitable and unsuitable habitats in the face of unsustainable use and changing climate scenarios. The study employed Maximum Entropy (Max Ent) modeling, integrating high-resolution species occurrence data obtained from field surveys and global databases with 15 bioclimatic variables, soil characteristics, and topographical data. To assess the impact of climate change, the model was projected into future timelines (2070) using Representative Concentration Pathways (RCPs) 4.5 and 8.5. Model performance was validated using the Area Under the Receiver Operating Characteristic Curve (AUC) and Jackknife tests. A total of 191 occurrence records obtained from the Global Biodiversity Information Facility (GBIF) revealed that the species is spatially clustered and predominantly concentrated within the northern savanna belt, especially the North-West geopolitical zone, with secondary concentrations in the North-Central and South-West regions. The results show that temperature and precipitation seasonality, particularly temperature seasonality (BIO4), maximum temperature of the warmest month (BIO5), annual precipitation (BIO12), and mean temperature of the warmest quarter (BIO10), exert the strongest influence on habitat suitability. Currently, 35.43% is less suitable, 20.11% is more suitable, while 44.47% is most suitable of Nigeria land area. Under future projected timelines RCP 4.5 reveal, the most suitable category is 51.27%, more suitable is 21.37% and less suitable is 27.37%; while RCP 8.5 reveals, the most suitable area is 46.43, more suitable is 20.41% and less suitable is 33.16%. This demonstrates that while *Vitellaria paradoxa* may retain a substantial proportion of suitable habitat under both future scenarios, higher greenhouse gas emissions are projected to reduce optimal habitats and increase marginal areas. The expansion of less suitable zones under RCP 8.5 suggests potential challenges for natural regeneration, productivity, and long-term sustainability of the species. These findings underscore the importance of climate mitigation efforts and adaptive management strategies, such as assisted regeneration and conservation of climatically stable refugia, to safeguard the future distribution and ecological resilience of *Vitellaria paradoxa* in Nigeria.

Key words: Habitat Suitability Prediction, *Vitellaria paradoxa*, Maximum Entropy (Max Ent) modeling, Nigeria

ETHNOBOTANY AND PHYSICAL SEEDCOAT DORMANCY STUDIES ON AIDAN TREE *(Tetrapleura tetraptera*)

O.A. Obembe
Department of Plant Science and Biotechnology, Adekunle Ajasin University,Akungba Akoko, Ondo State, Nigeria
Corresponding Author's Email:olutayobembe@gmail.com

ABSTRACT

Aidan tree *Tetrapleura tetraptera* (Schum. and Thonn.) Taub is a Mimosoideae Fabaceae/Leguminosae tree plant widely exploited for its spicy, medicinal (bone setting, laxative, post-partum,mystical and other multifarious uses, but with seed coat dormancy challenge. An experiment to break dormancy associated with its seeds becomes expedient. Viable seeds determined by floatation method were subjected to pre sowing treatments of 98% concentrated Sulphuric acid, hot water (wet heat), physical abrasion using rough sand paper for varying time durations of 1,3 and 5minutes along with control experiment. A total of 1,000 randomly picked seeds were sown in 40 white, perforated plastic buckets filled with loose and well drained river sand from base to the brim at sowing depth of 3cm.The 40 buckets were arranged in a Complete Randomized Design (CRD). For each pre sowing treatment and control experiment. Four(4) replications were used with 25seeds sown per bucket. The study period was for 40days.Data obtained were subjected to statistical analysis. Results showed that 5minutes 98% concentrated Sulphuric acid with Seedling emergence of 42% and mean germination time/Seedling emergence rate of 6.33days was comparatively most effective, followed by both 1 and 3 minutes physical abrasion with Seedling emergence of 40% with mean germination time of 6 and 7.1days respectively.3minutes concentrated 98% concentrated Sulphuric acid gave a low result of 22% Seedling emergence and mean germination time of 11.2days.Control experiment had lowest Seedling emergence and with mean germination time of 20days.Though 5minutes concentrated Sulphuric acid with 42%Seedling emergence and with mean germination time of 6.33days was most effective but because of probable adversity of acid treatment,1 and 3minutes physical abrasion, both with 40%Seedling emergence respectively and mean germination time of 6 and 7.1days ,for eco friendly reasons are recommended for massive propagation of *T.tetraptera* tree for its multipurpose uses.

Keywords: *T.tetraptera* tree, pre- sowing treatments, control experiment, germination values.

HABITAT SUITABILITY PREDICTION FOR MAHOGANY TREE (*Khaya senegalensis* [DESR.] A. Juss) IN NIGERIA

Akwaji Patrick Ishoro*, Mayame Ernest Amap and Ibe Uno Eyong
Department of Plant and Ecological Studies, Faculty of Biological Sciences, University of Calabar, P.M.B. 1115, Calabar, Cross River State, Nigeria
Corresponding Author's Email: akwajiisnever@gmail.com

ABSTRACT

Khaya senegalensis (Desr.) A. Juss., commonly known as African Mahogany, is an ecologically and economically indispensable tree species in Nigeria, valued for its high-quality timber, medicinal properties, and role in dryland silvo-pasture is currently facing severe pressure from overexploitation and habitat fragmentation. Furthermore, the accelerating impacts of climate change threaten to alter its natural range, potentially leading to local extinctions in once-prime habitats. The study employed Maximum Entropy (MaxEnt) modeling, integrated with Geographic Information Systems (GIS). The model was calibrated using high-resolution occurrence records obtained from field surveys and the Global Biodiversity Information Facility (GBIF). Model performance was evaluated using the Area Under the Curve (AUC) of the Receiver Operating Characteristic and the True Skill Statistic (TSS). To assess the impact of climate change, the model was projected into future timelines (2070) using Representative Concentration Pathways (RCPs) 4.5 and 8.5. A total of 87 georeferenced occurrence records were analyzed alongside fifteen key bioclimatic variables representing temperature and precipitation patterns derived from the WorldClim and AfriClim databases. These variables capture critical climatic factors such as precipitation of the wettest month, mean temperature of the coldest quarter, and precipitation seasonality, which collectively influence the species' habitat suitability. The findings demonstrate that *Khaya senegalensis* thrives in regions with moderate rainfall and distinct seasonal temperature variations, which are characteristic of the Sudan and Guinea savanna zones. The model demonstrated high predictive accuracy (AUC > 0.70). The impact of climate change on the current and projected spatial distribution of *Khaya senegalensis* in Nigeria revealed complex but meaningful patterns of habitat suitability change. Under RCP 4.5, approximately 44.7% of Nigeria's land area is predicted to remain less suitable, while 28.2% and 16.2% are expected to retain more suitable and most suitable conditions, respectively. Under the more severe RCP 8.5 scenario, less suitable areas slightly contract to about 49.8%, while more suitable and most suitable zones show moderate expansions to 32.0% and 18.2%, respectively. The findings highlight a critical need for adaptive forest management. While some northern regions may become more climatically suitable, the loss of core habitats in the Guinea Savanna necessitates urgent in-situ conservation and the establishment of gene banks. This study provides a geospatial blueprint for policymakers and foresters to prioritize reforestation and conservation efforts in regions predicted to remain stable under future climates.

Key words: Habitat Suitability Prediction, *Khaya senegalensis*, Maximum Entropy (MaxEnt) modeling, Nigeria

EFFECTS OF SOIL PHYSICOCHEMICAL PROPERTIES ON THE DIVERSITY AND DISTRIBUTION OF TREE SPECIES ACROSS CONSERVATIVE REGIMES IN OBAN BIOSPHERE RESERVES OF CROSS RIVER NATIONAL PARK, NIGERIA

Akwaji Patrick Ishoro*, Etuk Inibehe Udomarcus and Akomaye, Ferdinand Akpo
Department of Plant and Ecological Studies, Faculty of Biological Sciences, University of Calabar, P.M.B. 1115, Calabar, Cross River State, Nigeria
*Corresponding Author's Email: akwajipatrick@unical.edu.ng

ABSTRACT

The Oban Biosphere Reserves within the Cross River National Park, are recognized as a biodiversity hotspot with high levels of species richness and endemism. Basic knowledge of the soil physicochemical properties driving tree species diversity and distribution is crucial for effective conservation planning in this priority area. This study examines the influence of soil physicochemical properties on the diversity and distribution of tree species across the Oban Biosphere Reserve, Cross River National Park, Nigeria using the modified systematic sampling design. In each zone (core, buffer and transition), three 205m lines spaced at 150m apart was delineated at each zone. Twenty $25 \times 25m^2$ plots spread out at 20m were mapped out in each zone, making a total of 60 plots with walking transects. Tree species with dbh>10 present in the plots were sampled, marked and identified. Tree species diameter was measured using a diameter tape while height was measured using a Nikon Pro Rangefinder. Also, soil samples were collected from each zone (plots) at a depth of 0 – 15cm, 15 – 30cm and 30 – 45cm, and analyzed for texture, pH, electrical conductivity, organic carbon, total nitrogen, available phosphorus, potassium, calcium, magnesium, and soil moisture. A total of 143 tree species belonging to 35 families, 121 species (37 families) and 102 species (36 families) were recorded in the core, buffer and transition zone, respectively. The core zone had the highest species richness index (4.03), and Shannon-Wiener diversity index (5.45). This was followed by the buffer zone with a species richness and Shannon Weiner index of 4.02 and 3.29 while the transition zone had the lowest (3.47 and 2.79), respectively. The family Fabaceae were the most dominant tree species across the three zones, followed by Malvaceae, Annonaceae, and Meliaceae while some families such as Annonaceae, Ochnaceae and Urticaceae had the lowest. Soil physicochemical analysis revealed varied proportion of physical and chemical properties across the zones. Principal component analysis (PCA) identified phosphorus, base saturation, electrical conductivity, calcium, and zinc as key soil variables influencing tree species growth, diversity and distribution across the zones. The results of the study have provided basic information for ecologists, conservationist and relevant stakeholders for effective conservation purpose in the Oban Biosphere Reserve, Cross River National Park, Nigeria.

Keywords: Tree Species Diversity, Soil Physicochemical Properties, Floristic Distribution, Oban Biosphere Reserves, Cross River National Park.

SPECIES-SPECIFIC PHYTOREMEDIATION INDICES FOR MULTI-METAL SOIL CONTAMINATION: RESTORATION EFFICACY AND THE PERSISTENCE OF LEAD

Kever, D.G[1], Aguoru C.U[2], Olasan, J.O[2] and Dibal, H.I. [3]
[1]Environmental Sustainability Department, Joseph Saawuan Tarka University Makurdi, Nigeria
[2]Botany Department, Joseph Saawuan Tarka University Makurdi, Nigeria.
Biology Department University of Maiduguri, Maiduguri, Borno State, Nigeria.
Correspondence E-mail: keversenator@gmail.com

ABSTRACT

Heavy metal contamination of soils by cadmium (Cd), lead (Pb), and mercury (Hg) threatens soil health and public safety, particularly where conventional remediation options are limited. This study evaluated the phytoremediation potential of Jatropha curcas, wild sugarcane (*Saccharum spontaneum*), and sunflower (*Helianthus annuus*) grown in metal-spiked soils, with and without cow-dung amendment, to determine their comparative effectiveness in restoring soil physicochemical quality. Control soil was characterized against WHO limits. Across contaminated treatments, root and stem metal concentrations, biomass, and uptake indices were quantified under augmented and non-augmented conditions, with treatment means compared using ANOVA and T-tests ($P < 0.05$). Cow-dung amendment significantly increased biomass and uptake indices in most treatments ($P < 0.05$). Metal concentrations were significantly higher in non-augmented than augmented treatments by week 10 for Cd, Pb, and Hg ($P < 0.05$), whereas week 5 differences were largely non-significant except for mercury, which diverged early, indicating that amendment effects accrue progressively rather than immediately. Only *J. curcas* restored key soil properties, including cation exchange capacity, moisture, nitrogen, phosphorus, and electrical conductivity, to values statistically comparable with the control ($P > 0.05$). Neither wild sugarcane nor sunflower achieved comparable restoration, and no species restored Pb-contaminated soil. These findings show phytoremediation efficacy is species-specific, metal-dependent, and time-sensitive. *J. curcas* emerges as the most promising candidate for organic-waste-assisted phytoremediation, while lead's persistence and delayed amendment onset indicate that longer exposure and integrated strategies are needed for multi-metal-impacted soils.

Keywords: *phytoremediation; heavy metal contamination; cadmium; lead; mercury; cow-dung amendment; Jatropha curcas; species-specific restoration*

THE IMPACT OF PALYNOMORPHS ON THE HEALTH AND WELL-BEING OF STUDENTS AT JOSEPH SARWUAN TARKA UNIVERSITY, MAKURDI, NIGERIA

Onyinyechi Priscilla Okpara*, Thomas Okoh, Ilebode-Sam Margret, Uma Suur Dorinda
Joseph Sarwuan Tarka University, Benue State, Makurdi, Nigeria
* Corresponding author's Details: okpara.onyinyechi@uam.edu.ng, ORCID: 0009-0002-2505-1499

ABSTRACT

Airborne pollen grains and fungal spores (palynomorphs) are important biological components of the atmosphere that influence air quality and are recognized as major triggers of allergic and respiratory diseases in humans. This study investigated the diversity of airborne palynomorphs and their potential impact on the health and well-being of students at Joseph Sarwuan Tarka University, Makurdi, Nigeria. A mixed-methods approach was employed involving 100 undergraduate students selected from five lecture venues. Airborne palynomorphs were sampled over four weeks using improvised pollen traps installed at the study sites, while dust samples collected from the same locations were analyzed for pollen content. Structured questionnaires were also administered to assess the prevalence of respiratory symptoms and their perceived effects on students' health and well-being. The results revealed that pollen grains belonging to the Asteraceae were the most abundant, exhibiting considerable variation in size, shape, ornamentation, and aperture characteristics. This was followed by members of the Poaceae and Malvaceae. In addition, a diverse assemblage of fungal and fern spores was identified and characterized based on their morphological features. The prevalence of respiratory ailments among respondents ranged from 50% to 65% across the lecture venues. The Student Lecture Theatre recorded the highest prevalence (65%), whereas Aper Aku Lecture Theatre and the Convocation Square recorded the lowest prevalence (50%). The findings suggest a positive association between the abundance of airborne palynomorphs and the occurrence of respiratory conditions among students. The study highlights the need for continuous aerobiological monitoring, the establishment of a palynomorph database, and interdisciplinary research to improve environmental health surveillance and allergen management. It also recommends improved ventilation, enhanced sanitation, reduced overcrowding, and targeted health awareness programmes to minimize exposure to airborne allergens and reduce the incidence of respiratory diseases within university learning environments.

Keywords: Aerobiology; Palynomorphs; Airborne pollen; Respiratory health; Environmental monitoring.

CAN SCATTER HOARDING RODENTS ASSUME THE ROLE OF EFFECTIVE LARGE FRUGIVOROUS SEED DISPERSERS IN A FRAGMENTED AFROMONTANE FOREST?

Babale Aliyu and Mohammed Ismaila
Department of Plant Sciences, Gombe State University, Tudan Wada Street, Gombe, Gombe State, Nigeria.

ABSTRACT

Anthropogenic pressure has led to fragmentation of tropical forests and defaunation of local animal communities (particularly large-bodied vertebrates). Loss of large frugivore species may be highly detrimental to fruiting species that produce large-sized seeds. This is because in their absence there might be a lack of frugivore species that can efficiently disperse their seed. Here, the dispersal of *Carapa oreophila* Kenfack (Meliaceae) is addressed in the context of a fragmented Afromontane forest (Ngel Nyaki) that suffers from human-driven degradation and has lost large-bodied frugivores. *Carapa oreophila* has seed and fruit traits (no odour and not attractive) that suggest mega-faunal dispersal presumably elephants but since these are no longer present at the study site (Ngel Nyaki Forest), In the highly degraded riparian fragments, where resources are scarce, rodents act more as seed predators than dispersers, consuming the majority of seed, whilst in forest, there was a greater propensity to hoard. Furthermore, it was deduced that rodents are more likely to disperse seed in the middle of *C. oreophila*'s fruiting season when the abundance of seed is greater. Results therefore suggest that the benefit *C. oreophila* receive from scatter hoarding rodents as substitute dispersers at Ngel Nyaki is dependent on the habitat and the variance in seed abundance throughout the fruiting season; these effects thus modulate the role of rodents as predators or dispersers.

Keywords: Anthropogenic Dissturbance, Seed Dispersal, Fragmented Forests, Rodents, Frugivores

COMPOSITION AND DIVERSITY OF BIRDS ALONG THE OLD GONGOLA RIVER FROM KUPTO TO DADIN-KOWA COMMUNITY IN GOMBE STATE, NIGERIA

Nsor Charles Ayuk[1*], Nya John Usim[2], Atukpa M. Elaigwu[3], Datheh Patrick[4]

[1] Department of Zoology and Wildlife Ecology, Gombe State University, Gombe, Nigeria.

[2] Department of Geography and Environmental Sciences, University of Calabar, Nigeria.

[3] Department of Biological Science, Gombe State University, Gombe, Nigeria.

[4] Department of Biological Science, Federal Polytechnic Kaltungo, Gombe State, Nigeria.

*Corresponding Author's Email: charlesnsor@yahoo.co.uk

ABSTRACT

The Gongola River is a significant tributary of the Benue River that meets the river Niger at Lokoja. It is a wetland that supports livelihood across six northern states and beyond. In this study, we sampled avifauna diversity from a section of the river (Kupto-Dadin-kowa reservoir) and surrounding landscapes to develop a checklist as a first step in measuring the ecological significance of the river. Point count census method was employed. We recorded a total of 3146 individuals from 212 species. One hundred and thirty eight genera, in 62 families and 20 orders were also recorded. Thirty eight AEWA listed species were recorded totaling 1188 individuals accounting for 37.8 % of the overall abundance of all species combined. The most abundant bird species was the white-faced whistling duck (*Dendrocygna viduata*) with a total of 622 individuals, followed by the laughing dove (*Spilopelia senegalensis*) with 170 individuals. The most species-rich family was Accipitridae with a total of 19 species, followed by Ardeidae, Columbidae and Estrildidae with 10 species each. Insectivores were the most diverse feeding guild with a total of 63 species and cumulative abundance of 721 individuals, followed by granivores and omnivores with a total of 39 and 36 individuals respectively. One hundred and fifty two species were resident within range of occurrence, accounting for 71.7 % of bird species recorded overall; while 60 bird species (28.3 %) were observed to be involved in one form of migration or the other. The preponderance of both migratory and resident bird species underscores the ecological significance of this wetland ecosystem for avian conservation. More detailed and systematic studies are required to assess the population dynamics and conservation status of the avifauna in the area. The river holds great potential as an avifaunal sanctuary if protective measures are taken to preserve and conserve its ecological integrity.

Keywords: Gongola River; Wetland Ecosystem; Avifauna; Biodiversity Conservation; Species Diversity.

UNORTHODOX FISHING PRACTICES AND THE BANE OF ICHTHYOFAUNAL DIVERSITY: THE ENIONG RIVER EXAMPLE

Isemin, Nsidibe Linus[1], Azua, Terese, and Ekanem, Idorenyen Emmanuel[2]
[1]Department of Zoology, Federal University of Agriculture, Makurdi, Benue State, Nigeria.
[2]Department of Fisheries and Aquatic Environmental Management, University of Uyo, Uyo, Akwa Ibom State, Nigeria.
Corresponding Author's Email: nsimin1@yahoo.com.

ABSTRACT

The Eniong River, Southeastern Nigeria is a freshwater ecosystem which serves as an important fishing ground for artisanal fishers, sand dredging, inland water transportation, as well as source of domestic water supply to the resident communities. Ichthyofaunal survey of the river was carried out between April, 2018 – March, 2020 at the upper and lower courses of the river; Ekweme and Ukpa Okon represented the upper river, while Ito and Itu represented the lower river. Traditional fishing practice included throw nets and traps, while unorthodox practices included the use of chemical and explosive, particularly at the upper course of the river. Species richness was calculated according to Margalef; Shannon's Index of general diversity (H') according to Shannon and Weaver; equitability according to Pielou, and Jaccard similarity index according to Jaccard. A total of 178 fish (14 families and 25 species) were sampled, with Cichlidae (5 species) as the dominant taxa. The ichthyofauna indicated superior spatial variations for in the lower river compared to the upper river. Two species, *Clarias macromystax* (Clariidae**)** and *Malapterurus electricus* (Malapteruridae) were only present in the upper Eniong river but not in the lower river; 9 species *Ctenopoma kingsleyae, Ctenopoma nebulosum*, *Pollimyrus adspersus, Hemichromis fasciatus, Coptodon zillii*, *Pelmatolapia mariae*, *Schilbe uranoscopus*, and *Protopterus annectens* were only present in the lower river but not in the upper river, while the remaining 14 species were found in both upper and lower streams. Diversity indices revealed that the upper stream has fish Shannon diversity of 2.088, while lower stream recorded fish Shannon diversity of 2.707; Margalef's richness showed 2.733 for upper stream and 4.788 for lower stream. The depauperate ichthyofaunal diversity in the upper Eniong river highlights the negative impacts of unorthodox fishing practice in the river. In addition to the unwholesome fishing practice, the size class of fish (8.30-33.80 cm) in this study which is considered juvenile implies that the stream serves as nursery ground, hence an indication of overfishing. The exploitation of fingerlings and juvenile fishes should be discouraged, while the use of unorthodox fishing method should be banned to ensure safety and integrity of Eniong River.

Keywords: Eniong River, Unorthodox Fishing, Ichthyofaunal Diversity, Freshwater Fauna, Species Composition

PREPONDERANCE OF OKRA (*Abelmoschus esculentus*) VIRUS DISEASES IN KWARA STATE, NIGERIA

Adelodun Maryam Ajoke

ABSTRACT

Viral diseases are among the major constraints to okra (*Abelmoschus esculentus* (L.) Moench) production worldwide, causing significant reductions in plant growth, fruit yield, and quality. This study assessed the incidence and severity of viral diseases affecting okra in the three senatorial districts of Kwara State, Nigeria, and evaluated the susceptibility of selected improved okra varieties to identified viral pathogens under screenhouse conditions. A comprehensive field survey was conducted in 2023 using a zigzag sampling technique, with thirty plants randomly assessed at each sampling location across Kwara North, Kwara Central, and Kwara South Senatorial Districts. Disease incidence and severity were recorded, while leaf samples were collected for laboratory identification of viral pathogens. In a complementary screenhouse experiment at the University of Ilorin, improved okra varieties obtained from the International Institute of Tropical Agriculture (IITA), Ibadan, were grown in sterilized sandy-loam soil using a Completely Randomized Design with four replications. Plant height, number of leaves, and number of infected leaves were monitored over seven weeks following artificial inoculation. The field survey revealed that Kwara South recorded the highest incidence of okra viral diseases, whereas Kwara North had the lowest, with disease incidence ranging from 31.2% to 63.4% and severity scores ranging from 1 to 6. Significant differences ($p<0.05$) were observed among the senatorial districts. Laboratory analyses identified three major viruses: Okra mosaic virus, Cucumber mosaic virus (CMV), and Black-eyed cowpea mosaic virus. Under screenhouse conditions, the uninoculated varieties 0463 and 0631 exhibited superior growth, producing the greatest plant height (43.4 and 42.2 cm, respectively), the highest number of leaves, and better yield attributes. However, plants inoculated with CMV (0463 × CMV and 0631 × CMV) exhibited the highest disease severity, with severity scores ranging from 2.6 to 2.7 and disease incidence of 17.4–20.1% throughout the assessment period. The findings highlight the widespread occurrence of viral diseases in okra-growing areas of Kwara State and underscore the importance of developing and deploying virus-resistant varieties as part of integrated disease management strategies to enhance sustainable okra production.

Keywords: Okra; Viral diseases; Disease incidence; *Cucumber mosaic virus*; Host resistance.

FULL PAPERS

COMPARATIVE PHYSICOCHEMICAL ANALYSIS OF SEED OILS FROM *Vitellaria paradoxa* AND *Ziziphus mauritiana* IN NORTHERN GUINEA SAVANNA ECOLOGICAL ZONE OF TARABA STATE, NIGERIA

[1*]Meer B. B., [2]Myina O. M. and [3]Mobuogwu-Osaji J. N.
[1]Department of Forestry and Wildlife Management, Faculty of Agriculture, Taraba State University, Jalingo, Nigeria
[2]Department of Chemical Sciences, Faculty of Science, Taraba State University, Jalingo, Nigeria
[3]Department of Family and Consumer Science (Home Economics), Faculty of Agriculture, Taraba State University, Jalingo, Nigeria
[*]Corresponding Author's Email: bbmeer@tsuniversity.edu.ng

ABSTRACT

The increasing demand for plant-derived oils has stimulated interest in underutilized indigenous tree species as alternative sources of high-quality oils with nutritional, pharmaceutical, and industrial potential. This study comparatively evaluated the physicochemical properties of seed oil extracts obtained from selected tree species in the Northern Ecological Zone of Taraba State, Nigeria. Specifically, the study assessed the oil yield and selected physicochemical characteristics of oils extracted from the seeds of *Vitellaria paradoxa* and *Ziziphus mauritiana*. A purposive sampling technique was employed to select the species based on their abundance, diversity, and seed yield potential. Three mature trees from each species were randomly selected, giving a total of six sampled trees. Mature, fresh, and undamaged seeds were harvested, sun-dried, and pulverized into powder prior to laboratory analysis. Standard analytical procedures were employed for oil extraction and the determination of physicochemical parameters, while data were analyzed using percentages, mean, variance, and Student's *t*-test. The results revealed that *Vitellaria paradoxa* produced a significantly higher oil yield (45.27 ± 0.65%) compared to *Ziziphus mauritiana*. The oil from *Vitellaria paradoxa* also exhibited higher moisture content (4.49 ± 0.30%), free fatty acid content (28.89 ± 0.59%), acid value (3.36 ± 0.04 mg KOH/g), and saponification value (187.37 mg KOH/g), indicating its suitability for industrial applications, particularly in soap and cosmetic production. In contrast, *Ziziphus mauritiana* seed oil demonstrated lower acidity (2.53 ± 0.18 mg KOH/g) and comparatively higher pH (5.6 ± 0.2), iodine value (66.80 g I_2/100 g), peroxide value (13.26 ± 0.20 meq/kg), refractive index (1.506 ± 0.015), and specific gravity (0.940 ± 0.006 g/mL), suggesting a more unsaturated and fluid oil profile. Overall, the findings indicate that *Vitellaria paradoxa* seed oil possesses superior oil yield and physicochemical characteristics favorable for specialized industrial utilization, although its relatively high free fatty acid and peroxide contents may require further refining before application. Conversely, the higher degree of unsaturation and relatively neutral pH of *Ziziphus mauritiana* seed oil suggest its potential suitability for domestic edible and related applications.

Keywords: Oil Seeds, Seed Oil, Underutilised Plants, *Vitellaria paradoxa*, *Ziziphus mauritiana,*

INTRODUCTION

The sustainable exploitation of indigenous oil-bearing tree species has attracted increasing global attention because of their potential contributions to food security, industrial development, and the circular bioeconomy. In many tropical regions, particularly in sub-Saharan Africa, numerous indigenous tree species produce seeds rich in edible and industrially valuable oils. However, many of these species remain

underutilized due to inadequate scientific characterization of their oil yield and physicochemical properties (Alhaji *et al.*, 2024; Mphande *et al.*, 2025).

The Northern Guinea Savanna ecological zone of Taraba State, Nigeria, harbours several indigenous tree species with considerable economic potential. Among these are *Vitellaria paradoxa* C.F. Gaertn. (family *Sapotaceae*) and *Ziziphus mauritiana* Lam. (family *Rhamnaceae*), both of which produce oil-rich seeds. *Vitellaria paradoxa*, commonly known as the shea tree, produces hard-shelled nuts containing kernels with approximately 40–60% oil, making it one of the most important indigenous oil crops in tropical Africa (Raimi *et al.*, 2014; Maurice *et al.*, 2022). Shea butter extracted from its kernels has long been utilized in food, cosmetics, pharmaceuticals, and traditional medicine owing to its excellent emollient and antioxidant properties (Maurice *et al.*, 2022). Similarly, *Ziziphus mauritiana*, commonly known as jujube or "Magarya" in northern Nigeria, is a drought-tolerant tropical fruit tree widely distributed across arid and semi-arid regions. Although primarily cultivated for its edible fruits, its seeds also contain appreciable quantities of oil with promising nutritional and industrial applications (Adenike *et al.*, 2020; Wang *et al.*, 2023).

Seed oils consist predominantly of triglycerides whose composition varies among plant species and determines their physicochemical characteristics and suitability for different applications (Praise *et al.*, 2017). Properties such as oil yield, density, refractive index, acid value, peroxide value, iodine value, and saponification value are widely employed to assess the quality, stability, nutritional value, and industrial potential of vegetable oils. These parameters provide essential information for determining the suitability of oils for edible purposes, cosmetics, soap production, pharmaceuticals, lubricants, biodiesel, and other industrial applications (Praise *et al.*, 2017; Popoola and Haruna, 2024).

Vegetable oils continue to play indispensable roles in human nutrition by supplying essential fatty acids, lipids, and energy while supporting tissue growth and cellular functions (Aremu *et al.*, 2015; Popoola and Haruna, 2024). Beyond their nutritional importance, naturally occurring seed oils are increasingly sought after as renewable raw materials for the manufacture of cosmetics, nutraceuticals, pharmaceuticals, bio-lubricants, and other value-added products. Consequently, the physicochemical characterization of oils obtained from indigenous tree species has become an important research area for identifying alternative and sustainable sources of industrial feedstocks (Oduor *et al.*, 2023; Timsina *et al.*, 2026).

Previous studies have reported the physicochemical properties of oils extracted from *Vitellaria paradoxa* and *Ziziphus mauritiana* collected from different ecological zones within Nigeria and other African countries (Akihisa *et al.*, 2010; Aremu *et al.*, 2018; Okolosi *et al.*, 2016; Adenike *et al.*, 2020; Kumar *et al.*, 2023). These investigations demonstrated that the oils possess desirable physicochemical characteristics that support their utilization in food, cosmetic, pharmaceutical, and industrial applications. However, variations in climate, soil composition, genotype, and environmental conditions are known to influence oil yield and composition, making regional evaluation necessary. Scientific information on the oil yield and physicochemical characteristics of *V. paradoxa* and *Z. mauritiana* seeds growing within the Northern Guinea Savanna ecological zone of Taraba State remains limited.

Despite their abundance in the study area, the seeds of these indigenous tree species are

frequently underutilized or discarded because of insufficient knowledge regarding their chemical composition, oil quality, and economic value (Adenike *et al.*, 2020). This knowledge gap limits their commercial exploitation and the development of value-added products that could enhance rural livelihoods and promote sustainable utilization of local biological resources. Therefore, this study evaluated the oil yield and physicochemical characteristics of oils extracted from the seeds of *Vitellaria paradoxa* and *Ziziphus mauritiana* collected from the Northern Guinea Savanna ecological zone of Taraba State, Nigeria. The findings are expected to provide baseline scientific data on the quality and potential applications of these indigenous seed oils, contribute to the existing body of knowledge, and support their sustainable utilization in food, cosmetic, pharmaceutical, and industrial sectors.

MATERIALS AND METHODS

The Study Area

The northern Guinea savanna ecological zone of Taraba State is located in the northeast part of the state. It lies between latitudes 8° 00' N and 9° 30' N and longitudes 10° 00' E and 12° 00' E. The zone covers Ardo Kola, Karim Lamido, Lau, Jalingo, Yorro, Zing, and parts of Bali and Gassol local government areas (LGAs) of Taraba State; and occupies a total land mass of approximately 22,504 km² (Figure 1). The ecological zone is bordered on the northwest by Plateau, Bauchi, and Gombe States, and by Adamawa State on the northeast. It also shares its southwest boundary with the Southern Guinea Savanna ecological zone made up of other LGAs in Southern Taraba (Meer and Tella, 2018).

The study area is characterized by two (2) seasons, wet and dry seasons, with annual average temperatures around 33°C and peak highs reaching 40 - 44°C in March and April. The wet season lasts, on average, from April to October, while November to March are the dry season months. Mean annual rainfall varies from 800 mm to 1,000 mm; the wettest months are August and September, while the driest months are December and January, with relative humidity dropping to about 15% (Adebayo and Orunoye, 2013, Weather and Climate, 2026).

The northern Guinea savanna ecological zone is made up of tall perennial-dominated open woodland with less dense and scattered trees. The open canopy is dominated by grass, shrubs (*Gardenia spp*. and *Protes elliottii*), and woody climbers (*Opilia celtidifolia* and *Uvaria chamae*) (Federal Republic of Nigeria [FRN], 2019). Trees common to the northern Guinea savanna include *Isoberlina species, Terminalia avicennoides, Afzelia africana, Daniellia oliveri, Vitex doniana, Afzelia africana, Prosopis africana, Khaya senegalensis, Vitellaria paradoxa, Ziziphus mauritiana*, etc. (Taraba State Ministry of Environment [TSME], 2024; Meer *et al.*, 2025a; Meer *et al.*, 2025b).

According to the National Population Commission (2006), the population of the northern Guinea savanna ecological zone in Taraba State was estimated to be 996,345. The study area is inhabited by different ethnic groups including Chamba, Mumuye, Fulani, Jukun Kona, Ichen, Tiv, Hausa, Ndoola, Dadiya, Dza, Jiba, Bandawa, Munga Pangseng, Wurkun, Yandang, Bambuka, Jenjo, Karimjo, Gomu, Panya, Nyong, Rang, etc (Eberhard *et al.*, 2026). The major agricultural activities in the region include crop farming, livestock production, and fishing. It is drained by many smaller rivers and streams that flow into the River Benue that cut across the ecological zone (Meer *et al.*, 2025a).

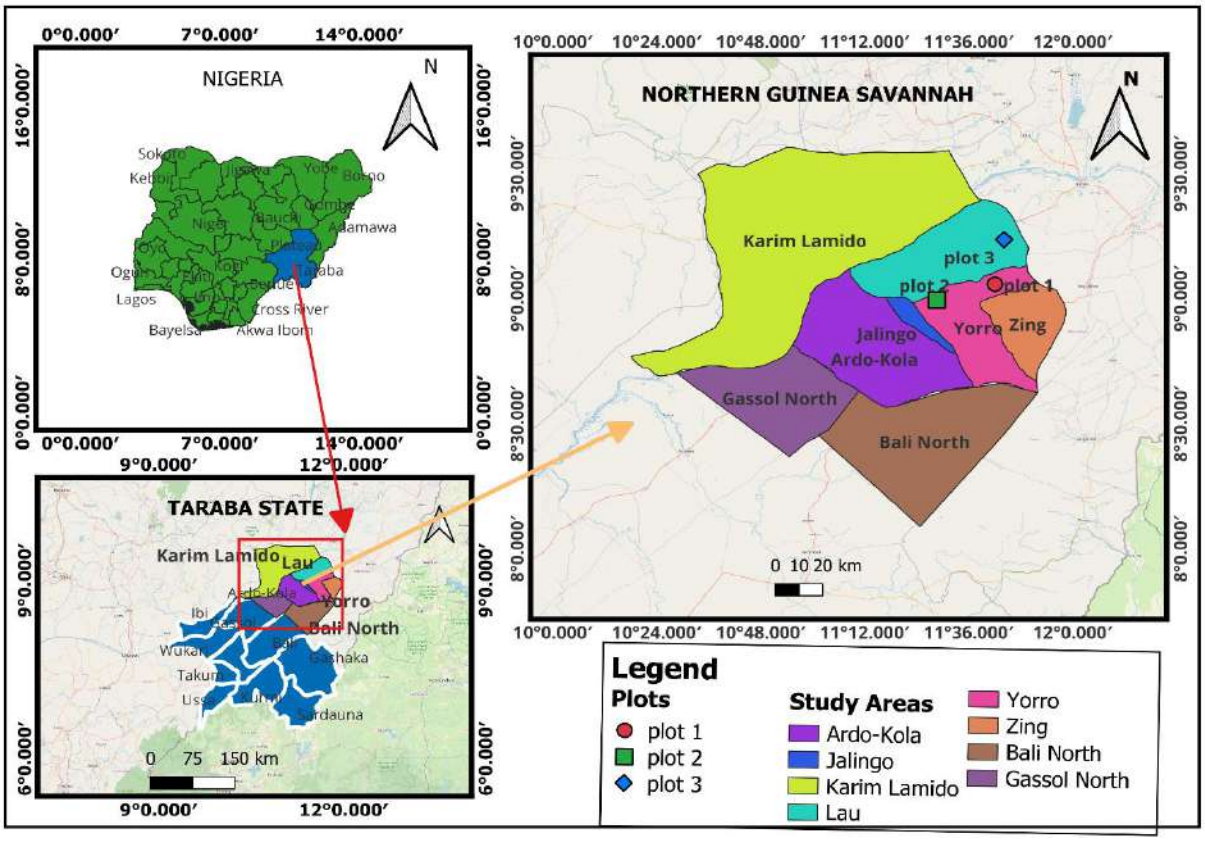


Figure 1: Map of Taraba State showing the Study Area. Source: Dan Research and Technology Consult (2026)

Sampling, Sample Collection and Preparation

Vitellaria paradoxa and *Ziziphus mauritiana* were purposely selected for this study based on their diversity, dominance, and high seed output in Northern Guinea Savanna ecological zone as reported by Meer *et al.* (2024). Three (3) individual standing trees of each species were randomly selected in 3 different radius plots laid at locations dominated by the sampled tree species. A total of six (6) standing trees were selected in the study area for sample collection. The matured, fresh, undamaged seeds (1.0 kg each) of *Vitellaria paradoxa* and *Ziziphus mauritiana* were harvested in the dry season (January 2025) from the sampled standing trees. The samples were identified and authenticated with authentication numbers 2025001A and 2025002B for *Vitellaria paradoxa* and *Ziziphus mauritiana*, respectively, at the Department of Forestry and Wildlife Management, Taraba State University, Jalingo, Nigeria.

Following the sample preparation protocols outlined by Adebayo *et al.* (2022), the seed samples were ground into a powder after being allowed to air dry for three weeks. The powdered samples were then sieved through a 0.425 mm mesh aperture (US Standard No. 40), bottled, and labeled for laboratory analysis at Biochemistry laboratory, Department of Biochemistry, Modibbo Adama University, Yola, Adamawa State, Nigeria.

Oil Extraction

The extraction of seed oil was done using maceration method as described in the

technique reported by Sunmonu *et al.* (2017), Warra *et al.* (2019), Datti *et al.* (2021) and Warra (2022). The seed powder sample (100g) was weighed into a 500-mLbeaker, 200 mL of petroleum ether were added and the beaker was securely sealed to prevent evaporation of the petroleum ether. The mixture was shaken and left to stand for 72 hours (3 days) with 4-hourly intermittent shaking. The mixture was filtered using filter paper, and the filtrate allowed to stand in the oven at 70°C for evaporation of the solvent. The oil yield was weighed, recorded and expressed as percentage oil yield (%) using equation (1):

$$\text{Oil Yield (\%)} = \frac{\text{Weight of oil extracted (g)}}{\text{Weight of seed sample (g)}} \times 100$$

Determination of Oil pH

This was carried out in accordance with the standard method described by Munir *et al.* (2014) and Kolawole *et al.* (2017). The oil sample (2.0 g) was weighed into a clean dry 25-mL beaker and 13.0 mL of hot distilled water was added to the sample and stirred slowly for a good dispersion. It was then cooled in a cold-water bath to 25 °C. The pH of the sample was then taken using a calibrated pH meter.

Determination Moisture and Volatile Content

The oil sample (2.0 g) was weighed into a porcelain crucible and dried in an oven at 105°C for 1 hour. The sample was removed from the oven and placed in the desiccator to cool. The cooled sample was weighed and returned to desiccator for further cooling and reweighing until change in weight between two successive observations did not exceed 1.0 mg. The percentage moisture and volatiles in the sample were calculated using equation (2):

$$\text{Moisture/Volatile Content (\%)} = \frac{W_1 - W_2}{W}$$

where W_1 is weight of oil sample before drying (g) and W_2 is weight of oil sample after drying (g).

Determination of Free Fatty Acids

Acid value titration method was used. Hot neutralized mentholated spirit (50.0 mL) was measured and added to 1.0 g of oil sample in a conical flask. The mixture was titrated with 0.1 N NaOH solution using 1.0 % phenolphthalein solution (0.2 mL) indicator, and shaking vigorously to the appearance of a persistent pink colour. The volume of alkali used was recorded and free fatty acid (3 A) calculated using equation (3) while acid value (AV) was calculated using equation (4):

$$FFA\ (\%) = \frac{V \times N \times M \times 100}{W \times 1000}$$

where V = volume of alkali used (mL), N = normality of alkali, M = molecular weight of dominant fatty acid (e.g., 282.47 g/mol for oleic acid), and W = weight of the oil (4 ple (g).

$$AV = \frac{56.1 \times V \times N}{W}$$

Iodine value

The oil sample (2.0 g) was weighed in a clean 500 mL iodine flask. Cyclohexane-acetic acid (15.0 mL) solvent mixture was added to the sample and swirled to ensure complete dissolution. Wijs solution (25.0 mL) was added to the flask, stoppered immediately and swirled to mix the contents intimately. The flask was allowed to stand in the dark for 1 hour followed by addition of 20 mL of 10% potassium iodide solution and 100 mL of distilled water. The liberated iodine was titrated immediately with 0.1 N sod (2 thiosulfate solution, shaking vigorously continuously until the blue color disappeared. Drops (2) of the starch indicator solution was added and titration with sodium thio (5 ate continued drop-wisely until the blue color disappeared after shaking. The volume of the

sodium thiosulfate solution used for the sample was recorded and the Iodine value (IV) was calculated using equation (5):

$$IV = \frac{12.69 \times C \times (V_1 - V_2)}{M}$$

where IV = iodine value (g iodine/100g of oil), C = concentration of the sodium thiosulphate solution (0.1 N), V_1 = volume of thiosulphate used for the blank titration (mL), V_2 = volume of sodium thiosulphate solution used for the sample titration (mL), M = mass of the oil sample (2.0 g).

Saponification Value

The oil sample (2.0 g) was refluxed with 25.0 mL of 0.5 M ethanolic KOH for 1 hour and ensured the oil was completely saponified. The mixture was cooled and excess KOH titrated with 0.5 M HCl using phenolphthalein (2 drops) as indicator. The same procedure was repeated but without the oil sample in the mixture (blank). The saponification value (mg KOH/g oil) was calculated from equation (6):

$$\text{Saponication Value (SV)} = \frac{(V_2 - V_1) \times M \times 56.1}{W}$$

where V_2 = volume of HCl used in the blank titration, V_1 = volume of HCl used in the test titration, M = molarity of HCl and W = weight of oil sample used (2.0 g).

Peroxide Value

The oil sample (2.0 g) was placed in a 250 mL glass-stoppered Erlenmeyer flask, 30.0 mL of the acetic acid-chloroform solvent mixture (20:10 mL) was added and swirled to dissolve the oil completely. Saturated KI solution (1.0 mL) was added, the flask stoppered immediately and shaken vigorously for a few seconds, and allowed to stand for 15 minutes in the dark. Starch solution (1.0 mL) was added immediately and the liberated iodine was titrated with 0.01 N sodium thiosulphate (NaS_2O_3) solution, shaking constantly until the blue color just disappeared. A blank determination was carried out without the oil sample. The peroxide value was calculated using equation (7):

$$\text{Peroxide Value} = \frac{(S - B) \times N \times 1000}{W}$$

where S = volume of the thiosulphate solution used for the sample (mL), B = volume of thiosulphate used for the blank titration (mL), N = exact normality of the sodium thiosulphate solution (meq/mL), W = mass of the oil sample (2.0 g)

Refractive Index

The refractive index was determined using a refractometer at 25°C.The instrument was calibrated using standard reference oil. Drops (2) of the oil sample were placed on the prism and the reading recorded after thermal equilibration.

Density

The density of the extracted seed oil was determined using standard physicochemical characterisation method. The weight of a 50-mL density bottle cultured at 25 ºC was recorded, the bottled filled with the oil sample and placed in a water bath at 25 ºC for 30 minutes. The oil volume was corrected and weight of bottle and its oil content was also recorded. The density (g/mL) of oil sample at 25 ºC was calculated using equation (8):

$$\text{Density} = \frac{\text{Weight of Oil Sample}}{\text{Volume of Oil Sample}} \quad (8$$

Statistical Analysis

Data collected from all determinations were analyzed using descriptive statistics like percentage, mean and variance and inferential statistical tool such as student's t-test.

RESULTS AND DISCUSSION

The physiochemical characteristics of oil extracted from the seeds of *Ziziphus mauritiana* and *Vitellaria paradoxa* are

presented in Table 1. The present study revealed substantial differences in the physicochemical characteristics of oils extracted from the seeds of *Vitellaria paradoxa* and *Ziziphus mauritiana*, highlighting their distinct potentials for food, cosmetic and industrial applications.

The significantly higher oil yield obtained from *V. paradoxa* (45.27%) confirms its status as one of the most important indigenous oil-bearing tree species in tropical Africa. The oil yield falls within the range previously reported for shea kernels (40–60%) (Raimi *et al.*, 2014; Maurice *et al.*, 2022) and is comparable with those reported for other economically important tropical oilseeds such as *Allanblackia floribunda*, *Hevea brasiliensis* and *Moringa oleifera* (Onyekwelu and Ayeni, 2021). The comparatively low oil yield recorded for *Z. mauritiana* (8.56%) suggests that, under the conditions of the present study, the species is a less efficient source of vegetable oil. Variations in oil yield among plant species may be attributed to genetic characteristics, ecological conditions, seed maturity, and extraction techniques rather than species differences alone. Nevertheless, the appreciable oil yield of *V. paradoxa* further supports its continued exploitation as an important raw material for food, cosmetic and industrial applications.

The lower pH observed in *V. paradoxa* oil indicates a more acidic nature than *Z. mauritiana* oil. Increased acidity may influence storage stability and necessitate refining before edible or cosmetic applications. This observation agrees with Maranz *et al.* (2004), who reported that the naturally acidic nature of shea butter often requires pH adjustment during cosmetic formulation. However, pH alone is not a universally accepted quality index for edible oils and should therefore be interpreted alongside acid value and free fatty acid content.

Moisture and volatile content were significantly higher in *V. paradoxa* oil than in *Z. mauritiana* oil, and both values exceeded the recommended limits reported by Okullo *et al.* (2004). Elevated moisture and volatile contents are undesirable because it promotes hydrolytic reactions, microbial growth and oxidative deterioration during storage (Alirezali *et al.*, 2011; Munir *et al.*, 2012). The relatively high moisture and volatile contents observed suggest that improved drying of seed materials and better post-extraction handling would be necessary to enhance the storage stability of both oils.

Free fatty acid (FFA) content is an important indicator of lipid hydrolysis and overall oil quality. The markedly higher FFA value recorded for *V. paradoxa* suggests greater hydrolysis of triglycerides, which may adversely affect flavour, storage stability and refining efficiency. In contrast, the low FFA content of *Z. mauritiana* indicates minimal hydrolytic deterioration and superior storage quality. These findings agree with Onyekwelu and Ayeni (2021), who observed that low FFA values are characteristic of high-quality vegetable oils with improved shelf stability. The FFA value obtained for *Z. mauritiana* also compares favourably with the value reported by Adenike *et al.* (2020), suggesting consistency in the quality of oil obtained from this species.

The iodine value demonstrated that *Z. mauritiana* oil possesses a higher degree of unsaturation than *V. paradoxa* oil. Oils with higher iodine values generally contain greater proportions of unsaturated fatty acids and are nutritionally desirable because of their favourable fatty acid profile, although they are relatively more susceptible to oxidative deterioration (Bello *et al.*, 2011; Pandey *et al.*, 2023). The iodine value obtained for *Z. mauritiana* closely agrees with previous reports by Adenike *et al.* (2020), confirming the predominance of unsaturated fatty acids in the oil. Conversely, the lower iodine value

of *V. paradoxa* reflects its higher proportion of saturated fatty acids, particularly stearic acid, which explains its characteristic semi-solid consistency at room temperature and enhanced oxidative stability.

The higher saponification value recorded for *V. paradoxa* indicates a greater abundance of relatively short-chain fatty acids that readily undergo saponification, making the oil particularly suitable for soap, shampoo, cosmetic creams and related industrial products. This observation corroborates previous findings by Okullo *et al.* (2010) and Maurice *et al.* (2022), who identified shea butter as an excellent raw material for soap manufacture. Although the saponification values of both oils were lower than those reported for highly saturated oils such as coconut and babassu oils (Praise *et al.*, 2017), they remain sufficiently high to support various industrial applications.

The acid values obtained for both oils fall within acceptable ranges reported for many edible and industrial vegetable oils, indicating relatively low levels of hydrolytic degradation. Nevertheless, the significantly higher acid value of *V. paradoxa* corroborates its elevated free fatty acid content and suggests that refining may be required before food applications. Acid value remains an important quality parameter because it reflects the extent of hydrolysis that has occurred during processing and storage (Maurice *et al.*, 2022; Adenike *et al.*, 2020).

Peroxide value is widely recognized as an indicator of the initial stages of lipid oxidation. The peroxide value recorded for *V. paradoxa* exceeded the commonly accepted limit of 10 meq O_2/kg for fresh edible oils, suggesting that the oil is more susceptible to oxidative deterioration if not adequately processed or stored. Similar observations have been reported by Bello *et al.* (2011) and Pandey *et al.* (2023). In contrast, the peroxide value of *Z. mauritiana* remained within acceptable limits, indicating better oxidative stability and greater suitability for food, cosmetic and pharmaceutical applications without extensive refining.

The refractive indices obtained for both oils fall within the typical range reported for vegetable oils and reflect differences in fatty acid composition. The slightly higher refractive index of *Z. mauritiana* is consistent with its higher iodine value, as refractive index generally increases with the degree of unsaturation. Similarly, the density values of both oils were comparable to those reported for common vegetable oils, indicating that both possess normal density characteristics suitable for commercial processing and formulation.

Table 1: Physiochemical Characteristics of Extracted *Vitellaria paradoxa* and *Ziziphus mauritiana* Seed Oil

Parameter	*Vitellaria paradoxa* Seed Oil	*Ziziphus mauritiana* Seed Oil
Oil yield (%)	45.267±0.648	8.557±0.611
pH	3.407±0.208	5.630±0.229
Moisture and volatile content (%)	4.493±0.295	3.383±0.178
Free fatty acid (%)	28.887±0.587	1.400±0.215
Iodine value (g I_2/100 g)	40.997±0.893	66.800±0.567
Saponification value (mg KOH/g)	187.37±6.270	139.430±26.505
Acid value (mg KOH/g)	3.360±0.036	2.527±0.175
Peroxide value (Meq/kg)	13.257±0.196	5.480±0.335
Refractive index	1.468±0.001	1.506±0.015
Density (g/mL)	0.920±0.032	0.940±0.006

The independent-samples *t*-test further confirmed significant differences between the two seed oils for most physicochemical parameters (Table 2). The highly significant difference in oil yield reinforces the superior oil-producing capacity of *V. paradoxa*, while the significantly higher iodine value and refractive index of *Z. mauritiana* confirm its greater degree of unsaturation. Conversely, the significantly higher free fatty acid, acid value and peroxide value observed in *V. paradoxa* indicate lower oxidative quality of the crude oil and emphasize the importance of refining before consumption or industrial utilization. Interestingly, no significant difference was observed in saponification value, suggesting that both oils possess comparable average molecular weights of their constituent triacylglycerols despite differences in fatty acid saturation. Collectively, these findings demonstrate that although *V. paradoxa* offers substantially higher oil yield and excellent suitability for soap and cosmetic production, *Z. mauritiana* produces oil of comparatively superior oxidative quality and nutritional characteristics, making it a promising alternative source of edible and industrial vegetable oil.

Table 2: t-test Results of the Physiochemical Characteristics of Seed Oil Extracts from Sampled Tree Species

Variable	Variance		t-test Value
	Vitellaria paradoxa	***Ziziphus mauritiana***	
Oil yield	1.261233333	1.121033333	-183.25
pH	0.130133	0.1579	95.29
Moisture and volatile content	0.261733	0.095233	-2.96
Free fatty acid	1.033233	0.1389	-34.90
Iodine value	2.394133	0.9652	62.07
Saponification value	117.9697	2107.471	-1.60
Acid value	0.0039	0.091433	-4.07
Peroxide value	0.115233	0.3367	-16.19
Refractive index	0.00000233	0.000709	2.41
Density	0.0031	0.0001	0.76

CONCLUSION

This study demonstrated that *Vitellaria paradoxa* and *Ziziphus mauritiana* seeds possess distinct physicochemical characteristics that influence their potential industrial and nutritional applications. *Vitellaria paradoxa* exhibited a significantly higher oil yield, confirming its suitability as a valuable source of vegetable oil for commercial exploitation. Its relatively high saponification value further supports its application in the manufacture of soaps, cosmetics, and other oleochemical products. However, the elevated free fatty acid, moisture and volatile contents, and peroxide values indicate that the crude oil is more susceptible to hydrolytic and oxidative deterioration and would, therefore, require appropriate refining and quality control before food or pharmaceutical use.

In contrast, *Ziziphus mauritiana* produced a lower oil yield but exhibited lower free fatty

acid, acid and peroxide values, together with a higher iodine value, indicating better oxidative quality and a greater degree of unsaturation. These characteristics suggest that the oil has promising potential for edible, cosmetic, and pharmaceutical applications where oxidative stability and nutritional quality are important. Although the two oils differed significantly in most physicochemical properties, their comparable saponification values indicate similarities in the average molecular characteristics of their constituent triacylglycerols.

Generally, the findings demonstrate that both indigenous tree species represent valuable but complementary sources of vegetable oils. Their utilization should therefore be guided by their specific physicochemical properties and intended industrial applications, thereby promoting the sustainable exploitation of indigenous plant resources and diversifying the raw materials available for food and non-food industries.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made: *Vitellaria paradoxa* seed oil should undergo appropriate refining processes to reduce moisture and volatile contents, free fatty acid, and peroxide levels before its utilization for edible and pharmaceutical purposes. The commercial exploitation of *Vitellaria paradoxa* and *Ziziphus mauritiana* seed oils should be encouraged to diversify the sources of vegetable oils available for food, cosmetic, pharmaceutical, and oleochemical industries, thereby reducing dependence on conventional oilseed crops.

Further studies should investigate the fatty acid composition, antioxidant profile, oxidative stability, and bioactive constituents of both seed oils using advanced analytical techniques such as gas chromatography–mass spectrometry (GC–MS) and Fourier-transform infrared spectroscopy (FTIR) to enhance their industrial characterization. Additional investigations should evaluate the influence of geographical location, environmental conditions, harvesting season, and extraction methods on the yield and physicochemical properties of these seed oils. Similar physicochemical and compositional studies should be extended to other indigenous oil-bearing tree species within the Northern Guinea Savanna ecological zone of Taraba State to identify alternative sources of high-value vegetable oils for sustainable industrial development.

REFERENCES

Abdul-Hammed, M., Jaji, A. O. and Adegboyega, S. A. (2020). Comparative studies of thermophysical and physicochemical properties of shea butter prepared from cold press and solvent extraction methods. *Journal of King Saud University - Science*, 32(4): 2343–2348. https://doi.org/10.1016/j.jksus.2020.03.012.

Aboki, E., Abubakar, K. H. and Ashindo, Z. E. (2023). Analysis of financial profitability of tomato growers in Taraba State, Nigeria. *AKSU Journal of Agriculture and Food Sciences*. **7** (3): 25–36. doi:10.61090/aksuja.2023.01.

Adebayo, O. L., Olanrewaju, A. M. and Ibrahim, K. O. (2022). Influence of processing methods on the physicochemical properties and lipid profile of select tropical oilseed flours. *Journal of Food Science and Technology*, 59(8): 3142–3151. https://doi.org/10.1007/s13197-021-05301-x.

Adebayo, A. A. and Orunoye, E. D. (2013). An assessment of climate change in Taraba State, Nigeria. *Nigerian Journal of Tropical Geography*, 4(2): 1-13.

Adenike, A. R., Odey, B. O. and Dauda, M. (2020). Physico-Chemical Properties, Functional Properties, and Chemical Compositions of *Ziziphus Mauritiana* (Jujube) Seed Oil. *World J Agri and Soil Sci*. 6(1): 1-5. WJASS.MS.ID.000626.

Adenike, A. R., Odey, B. O. and Dauda, M. (2020). Physico-Chemical Properties, Functional Properties, and chemical compositions of *Ziziphus mauritiana* (Jujube) seed oil. *World Journal of Agriculture and Soil Science*. 6(1): 1-5.

Agu, C. M., Menkiti, M. C., Ekwe, E. B. and Agulanna, A. C. (2020). Modeling and optimization of *Terminalia catappa* L. kernel oil extraction using response surface methodology and artificial neural network. *Artificial Intelligence in Agriculture*. 4: 1–11.

Akihisa, T., Kojima, N., Kikuchi, T., Yasukawa, K. and Kimura, Y. (2010). Constituents and potential anti-inflammatory effects of shea butter. *Journal of oleo science*. 59(6): 273-283.

Akinhanmi, T. F., Atasie, V. N. and Akintokun, P. O. (2008). Chemical composition and physicochemical properties of Cashew nut (Anacardium occidentale) oil and Cashew nut shell liquid. *Journal of Agricultural, Food, and Environmental Sciences*. 2(1): 1-10.

Alale, E. M., Tulashie, S. K., Miyittah, M., Baidoo, E. B., Adukpoh, K. E., Dadzie, E. O., Osei, C. A., Gah, B. K., Acquah, D. and Quasi, P. A. (2024). Oil produced from Ghana Shea Nut crop for prospective industrial applications. *Heliyon*, 10(11): e31171. https://doi.org/10.1016/j.heliyon.2024.e31171.

Al-dulaimi, L. S. and Al-yaqoobi, A. M. (2021). *Separation of oil/water emulsions bymicrobubble air flotation*. Top Conference Series Materials Science and Engineering. 1076, 012030: 1-12.

Alhaji, A. M., Almeida, E. S., Carneiro, C. R., da Silva, C. A. S., Monteiro, S. and Coimbra, J. S. d. R. (2024). Palm oil (Elaeis guineensis): A journey through sustainability, processing, and utilization. *Foods*, 13(17): 2814. https://doi.org/10.3390/foods13172814.

Alirezalu, A., Farhadi, N., Shirzad, H. and Hazarti, S. (2011). The effect of climatic factors on the production and quality of castor oil. *Nature and Science*. 9(4): 15-19.

Aremu, M. O., Hashim, I, Titilayo, O. B., Salau, R. B., Musa, B. Z. and Faleye, F. J. (2018). Nutrient and Anti–Nutrient Composition of Shea (Vitellaria paradoxa CF Gaertn) Kernel and Pulp in the North East Nigeria. International Journal of Sciences, 7(9), 56-66.

Aremu, M. O., Ibrahim, H. and Bamidele, T. O. (2015). Physicochemical characteristics of the oils extracted from some Nigerian plant foods – A Review. Chemical and Process Engineering Research. 32:36 – 52.

Bell, J. R. and Gillatt, P. N. (1994). Standards to ensure the authenticity of edible oils and fats. *Aliment. Nutr. Agric*. Food and Agricultural Organization. 11: 29-35.

Bello, M. O., Akindele, T. L., Adeoye, D. O., Oladimeji, A. O. (2011). Physicochemical properties and fatty acids profile of seed oil of *Telfairia occidentalis* Hook, F. *International Journal of Basic and Applied Sciences.* 11(6): 9–14.

Dan Research and Technology Consult (2026). Home of digital skills, Jalingo. Nigeria.

Datti, Y., Abdulhadi, M., Lado, U. A., Labaran, M., Abubakar, S. A. and Tijjani, Y. A. (2021). Study of the Physicochemical Properties of the Soap Prepared Using Oil Extracted from Neem Seed Collected from Kano Municipal, Kano State, Nigeria. *Nigerian Journal of Science and Research*, *2*(1), 13-23.

Eberhard, D. M., Gary, F. S. and Alison J. R. (2026). Ethnologue: Languages of the World. Twenty-ninth edition. Dallas, Texas: SIL Global. Online version: https://www.ethnologue.com/country/NG. Accessed on March 18, 2026.

Federal Republic of Nigeria (2015). *National Biodiversity Strategy and Action Plan 2016-2020*. Federal Ministry of Environment: 1-157.

Kolawole, O. P., Adetuyi, A. O., Abe, T. O. and Kolawole, B. O. (2017). Extraction, characterization and antibacterial screening of oil from the heartwood of *Pterocarpus erinaceus* (African rosewood powder). *J. Chem. Pharm. Res*. 9(10): 73-79.

Kumar, S. N., Das, U. and Immanuel, S. C. (2023). Indian jujube a potential fruit tree to improve the livelihood. *Saudi journal of biological sciences*, 30(9): 1-12. https://doi.org/10.1016/j.sjbs.2023.103769.

Maranz, S., Wiesman, Z., Bisgaard, J. and Bianchi, G. (2004). Germplasm resources of *Vitellaria paradoxa* based on variations in fat composition across the species distribution range. *Agroforestry Systems*. 60. 71-76.

Maurice J., Olaleye T. F. and Joseph P. S. (2022). Physicochemical Analysis and application of Shea Butter oil (*vitellaria paradoxa*): A case study of Funyallang Local production of Shea butter oil. *International Journal of Novel Research and Development*. 7(6): 470-481.

Meer, B. B. and Tella, I. (2018). Assessment of Woody Species Diversity in Different Ecological Zones of Taraba State, Nigeria: A Strategy for Conservation. *Asian Journal of Research in Agriculture and Forestry*. 1(4) 1-12.

Meer, B. B., Adedotun, A. and Shitu, N. (2025a). Effects of Tree Species Harvesting Practices on Taraba State Natural Ecosystems, Nigeria: A Case Study of Karim Lamido Local Government Area. *Indiana Journal of Agriculture and Life Sciences*, 5(4): 26-35. https://doi.org/10.5281/zenodo.16914285.

Meer, B. B**.**, Japhet, D. H., Coman, M. and Danjuma, D. G. (2025b). Evaluation of Wild Edible Tree Species Abundance and Diversity in Yorro Local Government Area of Taraba State, Nigeria. *Lapai Journal of Applied and Natural Sciences*. 10(1): 1-8. https://lajans.com.ng/article.php?id=223.

Mphande, W., Farrell, A. D. and Kettlewell, P. S. (2025). Research gaps in neglected indigenous vegetables in sub-Saharan Africa: A roadmap to mainstreaming. *Journal of Underutilized Crops Research*, 4(1): 33.

Munir, S. M., Umaru, M. Zinat, A., Mohammed, I. A., Aliyu, A. M. and Salihu, Y. (2012). Extraction and characterization of Nigeria shea butter oil. *Journal of Science, Technology, Mathematics and Education*. 8(2): 66-73.

Munir, S. M., Umaru, M., Zinat, A., Mohammed, I. A., Aliyu, A.M. and Salihu, Y. (2014). Extraction and

characterization of Nigerian Shea butter oil. *Journal of Science, Technology, Mathematics and Education*. 8(2): 66-73.

Murthy, H. N., Joseph, K. S., Madiwal, A., Gerald, D. R., Badiger, M., Kolkar, L., and Hiremath, R. (2017). Physicochemical characteristics of the seed and seed oil of the potentially medicinal plant *Ziziphus oenoplia*. *Journal of dietary supplements*. 14(6): 691–696.

National Population Commission (NPC). (2006). Nigeria National Census: Population Distribution by Sex, State, LGAs and Senatorial District: 2006 Census Priority Tables. Vol. 3. Available at http://www.population.gov.ng/index.php/publication/140-popn-distri-by-sex-state-jgas-and-senatorial-distr-2006. November 19, 2024.

Oduor, F. O., Kaindi, D. W. M., Abong, G. O., Thuita, F. and Termote, C. (2023). Diversity and utilization of indigenous wild edible plants and their contribution to food security in Turkana County, Kenya. *Front. Sustain. Food Syst*. 7: 1113771. doi: 10.3389/fsufs.2023.1113771.

Okolosi, B. N., Brorhie, F. O., Akpan S. W. and Ojugho C. B. (2016). Proximate and chemical composition of shea (Vitellaria paradoxa C.F. Gaertn) fruit pulp in the Guinea Savanna of Nigeria. *African Journal of Plant Breeding*. 3(4): 167-171.

Okullo, J. B. L. Omujal, F., Agea, J. G., Vuzi, P. C., Namutebi, A., Okello, J. B. A. and Nyanzi, S. A. (2010). Physico-chemical characteristics of shea butter (*Vitellaria paradoxa* c.f. gaertn.) oil from the shea districts of Uganda. African. *Journal of Food, Agriculture, Nutrition and Development*. 10(1): 2070-2084.

Okullo, J. B., Hall, J. B. and Obua, L. (2004). Leafing, flowering and fruiting of *Vitellaria paradoxa* subsp. Nilotica in Savanna parklands in Uganda. *Agroforestry Systems*. 60: 77 – 91.

Onyekwelu, J. C. and Ayeni, A. A. (2021). Proximate and antioxidant properties, oil yield and characterization of vegetable tallow tree (*Allanblackia floribunda* Oliv.). *Forests and Forest Products Journal*. 21: 16-27.

Pandey, J., Gaire, S., Sharma, K., Pun, D., Gyawali, A., Lamichhane, G., Budean, D. and Devkota, H. P. (2023). Exploring the potentials of *Ziziphus mauritiana* Lam. seed kernel oil as pharmaceutical oil base: Physicochemical characterization and ketoconazole soap formulation. *Heliyon.* 9(2023): e21034.

Pearson, D. (1976). The Chemical Analysis of Foods, 7th Edition, Longman Group Limited: 488-495.

Popoola, C. A. and Haruna, A. D. (2024). Comparative Analysis of Physicochemical Properties of Oils from Groundnut, Melon, Watermelon and Orange Seeds. International Journal of Research and Innovation in Applied Science. IX(VII): 117-129. https://doi.org/10.51584/IJRIAS.2024.907013.

Popstoyanova, D., Gerasimova, A., Gentscheva, G., Nikolova, S., Gavrilova, A. and Nikolova, K. (2024). Ziziphus jujuba: Applications in the pharmacy and food industry. *Plants*, 13(19): 2724. https://doi.org/10.3390/plants13192724.

Praise, O. A., Olatunji, O. A. and Owolabi, O. O. (2017). Refractive index and density of some Nigerian vegetable oils.

Journal of Applied Science and Technology. 22(1): 1-5.

Raimi, M. M., Adegoke, B. M. and Afolabi, O. (2014). Nutritional Composition of Seed and Physicochemical Properties of Seed Oil of *Vitellaria paradoxa*. *Scientific Research Journal*. II(IV): 35-39.

Sunmonu, M. O., Ajala, E. O., Odewole, M. M., Morrison, S. and Alabi, A. M. (2017). Comparative analysis of physico-chemical properties of oil extract from two varieties of Fluted pumpkin seeds using different extraction methods. *Journal of Science, Engeering and Technology*. 13(2): 48-60.

Taraba State Ministry of Environment (TSME) (2024). *Relevant Information on Taraba State Forest Estates*. Department of Forestry and Wildlife, Ministry of Environment. Taraba State:1-3.

Timsina, P., Timsina, D., Gautam, N., Subedi, A., Rai, K. and Dahal, S. (2026). The "Butter Tree" (*Diploknema butyracea*) for Sustainable Food Systems and Functional Applications. *Plant-environment interactions (Hoboken, N. J.)*, *7*(1): e70129. https://doi.org/10.1002/pei3.70129.

Ugwu-Dike, P. and Nambudiri, V. E. (2022). A review of ethnomedicinal uses of shea butter for dermatoses in Sub-Saharan Africa. *Dermatologic therapy*, *35*(3). https://doi.org/10.1111/dth.14786

Wang, Z. T., Liu, Y. P., Ma, Y. L., Pan, S. Y., Li, J. K., Shi, S. J., Wu, Z. F., Li, Z., Shang, Y. F. and Wei, Z. J. (2023). Insight into the phenolics and antioxidant activity of Indian jujube (Ziziphus mauritiana Lamk) peel and pulp subjected to the simulated digestion. *Heliyon*. 9(5): e16226.

Warra, A. A. (2022). Phytocosmetics and Phytopharmaceuticals from African Medicinal Plants. In *Natural Drugs from Plants*. IntechOpen. doi: 10.5772/intechopen.98603.

Warra, A. A., Babatola, L. J., Hassan, L. G., Prasad, M. N. V., Odutuga, A. A. and Omodolapo, A. A. (2019). Fourier Transform Infra-Red (FT-IR) Characterization of Plant Oils from Selected Cultivars Grown in Nigeria. *International Journal of Biochemistry Research and Review*, *98*, 34.

Warra, A. A., Umar, R. A., Atiku, F. A., Nasiru, A. and Gafar, M. K. (2012). Physical and phytochemical characteristics of seed oils from selected cultivars grown in Northern Nigeria. *Journal of Agriculture and Allied Sciences*. 1 (1): 4-8.

Weather and Climate (2026). The global historical weather and climate data: Taraba, NG climate zone, monthly weather averages and historical data. Available at https://weatherandclimate.com/nigeria/taraba. Accessed on March 18, 2026.

ECOTOXICOLOGICAL RISKS OF PESTICIDE RESISTANCE IN INSECTS AND ITS ECOSYSTEM IMPACTS

Auwalu Jalo*[1], Timothy Auta[2] and Zaharaddeen Hassan Yusuf[3]

[1] Biology Department, Faculty of Science, Federal University of Health Sciences Azare, Bauchi State, Nigeria

[2] Biology Department, Faculty of Life Sciences, Federal University Dutsin-ma, Katsina State, Nigeria

[3] Biology Department, School of Secondary Education Sciences, Federal College of Education Katsina, Katsina State, Nigeria

*Corresponding Author's Email: auwalu.jalo@fuhsa.edu.ng

ABSTRACT

Pesticide resistance in Insects documented in over 270 unique species worldwide has transformed from a farm-management headache into a pressing ecotoxicological concern. As resistance proliferates, weed control often shifts toward higher application rates, additional spray passes, Pesticide tank mixtures, and the reintroduction of older chemistries such as paraquat and atrazine. These shifts amplify exposure and toxicity risks for non-target plants and animals alter soil and aquatic microbial processes, perturb food webs, and accelerate landscape-level biodiversity loss. Mechanistically, resistance evolves via target-site resistance such as EPSPS gene amplification in *Amaranthus palmeri* conferring glyphosate resistance and increasingly through non-target-site resistance (NTSR) mechanisms that involve enhanced metabolism, sequestration, and reduced translocation. The NTSR frequently confers cross-resistance across modes of action, accelerating chemical substitution and cumulative environmental loads. This paper synthesizes current knowledge on how HR reshapes Pesticide-use patterns and ecological hazards, highlights sentinel case studies, and outlines integrated weed management and policy strategies that can mitigate both resistance evolution and downstream ecotoxicological risks.

Keywords: Ecotoxicology, Pesticide Resistance, Pesticide Risk Assessment, Insects, Weeds Management, Ecosystem Protection.

INTRODUCTION

Pesticides represent the backbone of modern crop protection, accounting for nearly 50% of total pesticide use worldwide and covering millions of hectares annually (FAO, 2022). Their adoption has played a pivotal role in reducing labor costs, supporting large-scale mechanization, and boosting agricultural productivity. The introduction of Pesticide-tolerant (HT) crop systems in the 1990s further accelerated Pesticide reliance, particularly on broad-spectrum active ingredients such as glyphosate. However, this chemical dependency has come at a cost: the rapid emergence and spread of Pesticide resistance in Insects**.**

At present, Pesticide resistance has been reported in more than 260 weed species across 72 countries**,** affecting all major cropping systems and climatic zones (Heap, 2025). Iconic cases such as glyphosate-resistant *Amaranthus palmeri* in the United States, *Lolium rigidum* in Australia, and *Conyza canadensis* across Europe highlight the global scale of the problem (Gaines *et al.*, 2010; Carrington, 2025). Insects evolve resistance through both target-site mutations which alter the Pesticide's binding site and

non-target-site mechanisms such as enhanced metabolism via cytochrome P450s, which confer cross-resistance to multiple Pesticide classes (Jugulam and Shyam, 2019; Chen *et al.*, 2025). These adaptive strategies make resistance not only inevitable but also increasingly difficult to manage.

The agronomic consequences of resistance are profound. Farmers often respond with higher application rates, increased spray frequency, Pesticide mixtures, and the reintroduction of older, more hazardous chemistries such as dicamba, 2,4-D, and paraquat (Duke, 2018; Gressel, 2020). While these measures may restore short-term weed control, they substantially increase the ecotoxicological footprint of agriculture. Pesticide drift, runoff, volatilization, and soil accumulation extend chemical exposure to non-target plants, pollinators, aquatic organisms, and soil microbial communities (Egan *et al.*, 2014; Battaglin *et al.*, 2014; Rose *et al.*, 2016). The resulting ecological disturbances can cascade through food webs, reducing biodiversity and compromising essential ecosystem services such as pollination, nutrient cycling, and water purification (Schütte *et al.*, 2017; Carvalho *et al.*, 2021).

Consequently, Pesticide resistance must be understood not merely as a weed management challenge, but as a driver of broader environmental change with implications for food security, sustainability, and ecological integrity. Modern ecotoxicology must adapt by moving beyond single-compound acute assessments toward holistic frameworks that incorporate chronic exposures, chemical mixtures, and landscape-level interactions. Only by integrating agronomy, ecology, and toxicology can we address the full spectrum of risks posed by Pesticide resistance.

The Biology of Resistance and Ecotoxicological Relevance

Target-Site Resistance (TSR).

TSR occurs when mutations or gene amplifications alter the Pesticide's target enzyme, reducing its binding affinity or overwhelming the inhibitory effect. These changes allow Insects to survive even at recommended field doses. A classic case is glyphosate resistance in *Amaranthus palmeri*, which arises through massive amplification of the 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) gene. In some populations, EPSPS copies exist on extrachromosomal circular DNA, enabling the plant to produce high levels of the enzyme and effectively "dilute" glyphosate's action (Gaines *et al.*, 2010; Koo *et al.*, 2018). TSR often results in high-level resistance that renders entire Pesticide classes ineffective. Ecologically, such strong resistance sustains high selection pressure, prompting farmers to adopt more aggressive chemical programs that elevate environmental loads and expand non-target exposures.

Non-Target-Site Resistance (NTSR)

NTSR encompasses a diverse set of mechanisms that reduce Pesticide effectiveness without altering the target site. These include changes in absorption, reduced translocation, vacuolar sequestration, and, most importantly, enhanced detoxification through metabolic pathways. Enzyme families such as cytochrome P450 monooxygenases, glutathione S-transferases (GSTs), and ATP-binding cassette (ABC) transporters are frequently implicated (Jugulam and Shyam, 2019; Rigon *et al.*, 2025). NTSR is ecologically significant because it can confer resistance to multiple Pesticide classes simultaneously**,** creating broad-spectrum cross-resistance. For example, metabolic resistance in *Lolium rigidum* and *A. palmeri* allows these species to survive applications of Pesticides with different modes of action, undermining

chemical rotation strategies (Chen *et al.*, 2025).

Unlike TSR, which is relatively specific, NTSR's broad adaptability accelerates the pace of Pesticide substitution and tank mixing, thereby compounding the ecotoxicological footprint of weed management. More chemicals enter the environment, often in combination, raising concerns about mixture toxicity, sublethal effects on non-target species, and long-term disruption of ecological processes.

How Resistance Reshapes Exposure and Risk

Increased Application Intensity and Mixtures

When Insects evolve resistance to a Pesticide (e.g., glyphosate), farmers often respond by increasing the dose or combining Pesticides with different modes of action in tank mixes. While this may temporarily control resistant populations, it introduces a larger number of active ingredients into the environment.

Ecotoxicological implications:

Each Pesticide has its own toxicological profile, but in mixtures, their effects can be additive, synergistic, or antagonistic. Synergistic toxicity is especially concerning because two chemicals at "safe" concentrations individually may become toxic when combined (Cedergreen, 2014). Non-target organisms—such as soil microbes, aquatic algae, or beneficial insects—are exposed to a chemical cocktail, making risk assessments more complex and less predictable. This escalation of chemical intensity is a direct feedback loop of resistance evolution: the more resistant Insects become, the more aggressive the chemical strategy, which in turn amplifies environmental loadings.

Chemical Substitution and Drift Concerns

As glyphosate and other commonly used Pesticides lose effectiveness, resistant crop systems (e.g., glyphosate/dicamba-tolerant soybeans) have led to the reintroduction of older Pesticides such as dicamba and 2,4-D. Dicamba and 2,4-D are highly volatile, meaning they can vaporize after application and move away from target fields. This cause Pesticide drift, which has been widely reported across the U.S. Midwest, damaging sensitive crops (like tomatoes, vineyards, and orchards) as well as non-target vegetation (Hager *et al.*, 2017). Drift extends the Pesticide's ecological footprint beyond farmland, affecting hedgerows, wildflowers, and natural habitats that serve as refuges for biodiversity. The substitution of newer, "safer" chemistries with older, more drift-prone Pesticides thus expands the risk to off-target plants and ecosystems, particularly in areas with mixed land use.

Cumulative and Chronic Contamination

Pesticide resistance often pushes farmers to spray more frequently within a season, and to continue this year after year. Over time, this leads to cumulative residues in soil, surface water, and groundwater.

- Chronic low-dose exposures can be more damaging than acute ones because they persistently stress organisms over long periods.
- Soil microbial communities, which are critical for nutrient cycling and organic matter decomposition, can be altered by continuous Pesticide inputs (Rose *et al.*, 2016).
- Aquatic ecosystems are also affected, as Pesticides and their metabolites leach into rivers and wetlands, where even low concentrations can impair algae, aquatic invertebrates, and amphibians.

Unlike acute toxicity events (e.g., fish kills after a spill), chronic contamination

represents a subtle but pervasive stressor, gradually eroding ecosystem health and resilience.

Landscape Biodiversity and Food-Web Effects

The ecological impacts of Pesticide resistance extend beyond fields into entire landscapes and food webs.

i. Non-target vegetation in and around fields (e.g., Insects in margins, flowering plants in hedgerows) are often collateral damage of intensified Pesticide use.

ii. This loss reduces the availability of floral resources (nectar and pollen) needed by pollinators such as bees and butterflies (Schütte *et al.*, 2017).

iii. Fewer flowering plants also mean fewer prey insects for higher trophic levels, affecting birds and small mammals.

iv. In this way, Pesticide resistance indirectly drives biodiversity decline and undermines key ecosystem services, such as pollination, pest control, and nutrient cycling.

Ultimately, what begins as an agronomic challenge (weed control failure) cascades into a landscape-scale ecological problem, reshaping interactions across trophic level.

Sentinel Case Studies

Glyphosate resistance in *Amaranthus palmeri* (EPSPS amplification)

Glyphosate resistance in *A. palmeri* is one of the most well-documented and economically damaging cases worldwide. This weed, native to the southern United States, has spread aggressively through maize, soybean, and cotton systems. Resistance arises through massive amplification of the EPSPS gene**,** enabling plants to survive Pesticide applications that would normally be lethal (Gaines *et al.*, 2010). Beyond yield losses, this resistance case has forced farmers to adopt complex tank mixtures and older Pesticides such as dicamba and atrazine, raising concerns over drift, groundwater contamination, and biodiversity impacts. Its spread into South America underscores the global biosecurity risk of highly adaptable weed species.

First UK glyphosate-resistant Italian ryegrass (*Lolium multiflorum*)

The discovery of glyphosate resistance in *L. multiflorum* in the United Kingdom in 2025 represents a critical turning point for European agriculture (Carrington, 2025). Ryegrass is already notorious for evolving resistance to multiple Pesticide classes, and glyphosate had long been considered a cornerstone of control programs. Its failure in temperate European systems signals the erosion of one of the few remaining reliable tools. Ecologically, this shift is significant because it is likely to drive greater reliance on volatile chemistries such as 2,4-D and dicamba**,** amplifying risks of non-target plant injury and undermining conservation efforts in hedgerows and field margins.

Metabolic resistance via P450 enzymes

Non-target-site resistance mediated by cytochrome P450 monooxygenases has emerged as a dominant resistance mechanism across diverse weed taxa, including *Lolium rigidum* and *Amaranthus palmeri* (Chen *et al.*, 2025; Rigon *et al.*, 2025). This metabolic resistance is especially problematic because it often confers cross-resistance to multiple Pesticide classes, including acetyl-CoA carboxylase (ACCase) and acetolactate synthase (ALS) inhibitors. Unlike target-site mutations, P450-mediated detoxification can evolve rapidly and spread widely, leaving few effective chemical options. From an ecotoxicological perspective, this mechanism fuels the use of broader-spectrum mixtures and higher doses, exacerbating risks of

mixture toxicity and chronic environmental exposure.

Ecotoxicological Endpoints of Concern

Non-target terrestrial plants

Pesticide drift, volatilization, and root uptake can damage vegetation beyond treated fields. Sensitive flora in field margins, hedgerows, conservation strips, and natural habitats are particularly vulnerable. Injury to these non-target plants reduces overall plant biodiversity, diminishes seed banks, and compromises the structural integrity of ecosystems. Since many wild plants provide food and habitat for insects, birds, and small mammals, drift-driven vegetation loss can cascade through food webs, undermining resilience and ecological balance (Egan *et al.*, 2014; Schütte *et al.*, 2017).

Aquatic organisms

Runoff and leaching transport Pesticides and their metabolites into rivers, lakes, and wetlands. These chemicals affect primary producers such as algae and macrophytes, altering photosynthesis and nutrient cycling. Aquatic invertebrates (e.g., daphnia, insects) are highly sensitive to sublethal Pesticide exposures, which may impair reproduction and survival. Amphibians and fish experience both direct toxicity (e.g., gill damage, endocrine disruption) and indirect effects through food-web alterations and loss of aquatic vegetation. Long-term contamination threatens aquatic biodiversity and water quality, with implications for drinking water safety and fisheries (Battaglin *et al.*, 2014).

Soil biota and processes

Repeated Pesticide inputs can significantly reshape soil ecosystems. Studies show disruptions in the abundance and diversity of bacteria, fungi, and actinomycetes, including suppression of beneficial mycorrhizal fungi critical for nutrient uptake. Key soil functions such as nitrogen fixation, organic matter decomposition, and carbon cycling may be compromised (Rose *et al.*, 2016). These changes reduce soil fertility and resilience, ultimately affecting crop productivity. Because soils act as both a sink and a source of Pesticide residues, their contamination has long-term ecological and agronomic implications.

Pollinators and beneficial insects

The loss of non-target flowering plants due to intensified Pesticide use reduces nectar and pollen availability, directly affecting pollinators such as bees, butterflies, and hoverflies. This reduction can lower colony health, reproduction rates, and pollination services essential for both wild plants and crops. Additionally, the simplification of agroecosystems reduces habitat for predatory and parasitic insects, weakening natural pest control services (Schütte *et al.*, 2017). Such indirect effects on beneficial insects amplify dependence on chemical pest control, perpetuating a cycle of ecological imbalance.

Methods to Detect and Evaluate Impacts

Environmental monitoring

Systematic monitoring of Pesticide residues in water, soil, sediments, crops, and field margins is essential for establishing baseline exposure levels and detecting contamination trends over time. Advanced analytical techniques such as liquid chromatography–mass spectrometry (LC-MS/MS) and gas chromatography–mass spectrometry (GC-MS) allow detection of Pesticides and their metabolites at trace concentrations. Long-term monitoring programs also help identify seasonal peaks, cumulative loading, and emerging contaminants, providing critical data for risk assessments and regulatory action (EFSA, 2020).

Bioassays and biomarkers

Laboratory and in situ bioassays using indicator species (e.g., algae, *Daphnia magna*, earthworms, honeybees) are invaluable for detecting sublethal effects that may not be evident from residue analysis alone. Biomarkers such as oxidative stress indicators, enzyme inhibition (AChE, GST), DNA damage (comet assay), and reproductive impairment provide sensitive early-warning signals of ecological stress. These tools help bridge the gap between chemical presence and actual biological impact, revealing effects that accumulate over chronic, low-dose exposures (Cedergreen, 2014).

Mesocosm and field experiments

Controlled outdoor mesocosms and large-scale field trials replicate realistic environmental conditions while allowing for the assessment of Pesticide effects across multiple trophic levels. Such experiments capture indirect and cascading impacts—such as reduced floral resources for pollinators, altered predator-prey interactions, or shifts in microbial communities—that may not emerge in laboratory bioassays. These approaches are especially valuable for evaluating mixture toxicity and ecosystem-level feedbacks under conditions that approximate agricultural landscapes (Rico *et al.*, 2018).

Modeling

Computational models integrate Pesticide use data, application practices, drift dynamics, degradation rates, and hydrological transport to predict exposure patterns at landscape and regional scales**.** Coupled fate-and-transport models and ecological risk assessment frameworks help identify vulnerable ecosystems, simulate cumulative exposures, and forecast long-term ecological consequences. Incorporating spatial data (e.g., GIS-based modeling) enables policymakers to evaluate scenarios of Pesticide use, resistance management strategies, and regulatory interventions before they are implemented (EFSA, 2020).

Management to Reduce Both Resistance and Ecotoxicological Risk

Integrated Weed Management (IWM).

IWM provides a holistic framework that combines agronomic, ecological, and technological approaches to manage Insects while minimizing reliance on Pesticides. By integrating multiple strategies, IWM reduces the selection pressure for resistance and lowers the chemical burden on ecosystems (Mortensen *et al.*, 2012). Key components include:

Cultural practices: Crop rotation, intercropping, delayed sowing, and the use of cover crops enhance crop competitiveness and suppress weed seed banks. Adoption of competitive cultivars and diversified rotations can break weed life cycles and reduce Pesticide dependence.

Mechanical strategies: Strategic tillage, hand weeding, hoeing, mowing, and the use of precision or robotic weeding technologies provide effective physical weed suppression. These methods reduce the need for repeat Pesticide applications and prevent seed set in resistant populations.

Biological controls: Habitat management to support weed seed predators (e.g., ground beetles, birds), the use of allelopathic cover crops (e.g., rye, sorghum), and microbial bioPesticides represent promising ecological tools that complement other practices.

Chemical stewardship: When Pesticides are necessary, responsible use is essential. This includes rotating Pesticide modes of action, applying only when thresholds are met (rather than by calendar), optimizing dosage to minimize overuse, and employing drift-reduction technologies to protect adjacent habitats.

Policy and Institutional Support.

Technical solutions must be paired with supportive policies to achieve large-scale impact. Governments and regulatory agencies can play a transformative role by:

- Establishing and maintaining resistance monitoring and reporting networks, allowing for early detection and coordinated responses.
- Enforcing drift-reduction standards through buffer zones, application restrictions, and improved spraying technologies.
- Providing financial incentives and extension support for farmers adopting IWM practices, including subsidies for cover crops, mechanical weeding tools, and precision technologies.
- Funding long-term ecological and toxicological monitoring programs to assess Pesticide impacts on biodiversity, soil health, and water quality.
- Encouraging the transition toward agroecological systems that balance productivity with ecological integrity, aligning with global sustainability goals (Carvalho *et al.*, 2021).

Discussion on Previous Researches

The evolution of Pesticide resistance (PR) has been extensively documented across continents, with early studies emphasizing its agronomic and evolutionary dimensions. Gaines *et al.* (2010) and Koo *et al.* (2018) provided groundbreaking evidence of EPSPS gene amplification in *Amaranthus palmeri*, which established glyphosate resistance as one of the most critical weed management challenges in North and South America. Similarly, research on *Lolium rigidum* in Australia revealed the diversity of resistance mechanisms, including both target-site mutations and enhanced metabolism, underscoring the adaptive capacity of Insects in response to intensive Pesticide use (Powles and Yu, 2010). These findings firmly positioned resistance as an inevitable outcome of chemical dependency in weed management systems.

As research progressed, greater attention turned to non-target-site resistance (NTSR), which is often metabolism-based and mediated by detoxifying enzymes such as cytochrome P450 monooxygenases and glutathione S-transferases. Jugulam and Shyam (2019) highlighted how NTSR can undermine chemical rotations, while recent studies (Chen *et al.*, 2025; Rigon *et al.*, 2025) demonstrated that P450-mediated resistance is now a dominant mechanism in globally problematic species like *Lolium multiflorum* and *Amaranthus palmeri*. These works point to an urgent need to better understand the molecular and biochemical underpinnings of NTSR, given its role in conferring cross-resistance to multiple Pesticide classes**.**

From an ecotoxicological standpoint**,** previous studies have drawn attention to the unintended consequences of intensified Pesticide programs in resistant systems. Duke (2018) and Gressel (2020) described how the loss of glyphosate efficacy has led to escalating Pesticide use, mixtures, and reliance on older chemistries such as dicamba, 2,4-D, and paraquat. Field studies in the U.S. Midwest reported extensive off-target damage from dicamba drift**,** with significant injury to non-target crops and wild vegetation (Egan *et al.*, 2014; Hager *et al.*, 2017). These findings illustrate how resistance not only undermines weed control but also reshapes the risk landscape for biodiversity conservation**.**

Environmental monitoring studies have consistently detected Pesticide residues across ecosystems. Battaglin *et al.* (2014) found glyphosate and its metabolite AMPA in surface waters, groundwater, and precipitation across the United States, while

Rose *et al.* (2016) reported that chronic Pesticide exposure alters soil microbial diversity and nutrient cycling. Such findings support the argument that HR-driven chemical intensification magnifies the risk of chronic, low-dose contamination**,** with subtle but widespread impacts on ecological processes.

A growing body of research also emphasizes the indirect impacts of Pesticide resistance on ecosystem services. Schütte *et al.* (2017) documented declines in floral resources and pollinator forage linked to intensified Pesticide use, while studies on farmland birds and beneficial insects have noted reduced prey availability in simplified landscapes. These works collectively suggest that resistance-driven Pesticide intensification contributes to food-web disruptions and erosion of ecosystem services such as pollination, pest control, and soil fertility.

Policy and management research has consistently advocated for Integrated Weed Management (IWM) as the most sustainable solution. Mortensen *et al.* (2012) argued that IWM, which combines cultural, mechanical, biological, and chemical practices, is the only long-term pathway to slow resistance while safeguarding ecosystem health. More recent contributions (Carvalho *et al.*, 2021) stress that successful implementation requires policy support, farmer incentives, and stronger monitoring systems. Yet, adoption remains limited due to economic pressures, cultural practices, and lack of institutional support, highlighting a gap between scientific recommendations and practical realities.

Overall, previous research provides strong evidence that Pesticide resistance is both an inevitable evolutionary process and a driver of expanded ecological risk**.** However, most studies have approached these issues separately—focusing either on resistance biology or on ecotoxicological effects—without fully integrating the two perspectives. This paper contributes by synthesizing these strands of evidence, framing HR not only as a weed management problem but as a multidimensional challenge that links agriculture, ecology, and public policy.

Recommendations

Based on the evidence reviewed, several key recommendations emerge for research, policy, and practice to mitigate both Pesticide resistance (PR) evolution and its broader ecotoxicological consequences:

Strengthen Integrated Weed Management (IWM) adoption.

Farmers should be encouraged to diversify weed control strategies by integrating cultural (crop rotations, cover crops), mechanical (tillage, robotic weeding), and biological (allelopathic crops, habitat management for weed predators) practices alongside judicious chemical use. Governments and extension services should promote IWM through training, subsidies, and farmer-to-farmer knowledge exchange (Mortensen *et al.*, 2012; Carvalho *et al.*, 2021).

Enhance Pesticide stewardship and chemical use practices

Responsible Pesticide use—including rotating modes of action, avoiding unnecessary prophylactic applications, and adopting drift-reduction technologies—can slow resistance development while reducing off-target impacts. Precision agriculture tools (e.g., sensor-based spraying, site-specific applications) should be expanded to minimize chemical loads and environmental exposure (Gressel, 2020).

Expand monitoring and surveillance systems

Establishing regional and global networks for resistance reporting and Pesticide residue monitoring is crucial. Long-term

environmental monitoring should track residues in soils, waterways, and field margins to detect chronic contamination trends and ecological risks early (EFSA, 2020).

Prioritize research on mixture toxicity and chronic exposures

Future ecotoxicological studies must go beyond single-compound acute assays to include realistic mixture scenarios and low-dose chronic exposures, which better reflect conditions in resistance-driven farming systems. This will help capture sublethal and ecosystem-level effects (Cedergreen, 2014; Rico *et al.*, 2018).

Advance understanding of non-target-site resistance (NTSR)

Molecular and biochemical research should focus on characterizing P450-mediated and other metabolic resistance pathways. Improved understanding of NTSR will inform predictive models and guide the design of new chemistries or non-chemical control strategies (Jugulam and Shyam, 2019; Chen *et al.*, 2025).

Ecotoxicological evaluations should explicitly consider indirect impacts on biodiversity and ecosystem services such as pollination, natural pest control, and nutrient cycling. This requires shifting from narrow, organism-level endpoints to landscape-scale ecological assessments (Egan *et al.*, 2014; Schütte *et al.,* 2017).

Policymakers should enforce stricter drift-reduction standards, regulate the reintroduction of highly ecotoxic Pesticides, and incentivize the transition toward agroecological systems. Funding should also support farmer-led innovation, ecological monitoring, and education campaigns to raise awareness about the ecological risks of resistance-driven Pesticide use (Carvalho *et al.*, 2021).

Promote interdisciplinary, One Health approaches

Tackling Pesticide resistance requires collaboration among agronomists, ecotoxicologists, economists, and policymakers. A One Health perspective, linking agricultural practices, environmental impacts, and human health, is essential to ensure both food security and ecological sustainability.

CONCLUSION

Pesticide resistance has escalated from a localized agronomic issue into a global ecotoxicological challenge. As resistant Insects spread, they drive shifts in management practices that increase Pesticide intensity, promote the use of chemical mixtures, and revive older, more hazardous active ingredients. These changes amplify risks of mixture toxicity, chronic contamination, drift injury, and biodiversity loss**,** with cascading effects on soil health, aquatic ecosystems, pollinators, and ecosystem services.

Understanding the biological foundations of resistance particularly the rise of non-target-site metabolic pathways reveals why resistance accelerates across Pesticide classes and intensifies environmental pressures. Sentinel case studies, from glyphosate-resistant *Amaranthus palmeri* in the Americas to glyphosate-resistant ryegrass in Europe, highlight how resistance both undermines weed control and reshapes exposure pathways at landscape scales.

Mitigating these risks requires a transition from chemically dependent systems toward Integrated Weed Management (IWM)**,** underpinned by cultural, mechanical, biological, and judicious chemical strategies. Coupled with strengthened monitoring, mixture-focused ecotoxicological assessments, and supportive policy frameworks, such approaches can slow

resistance evolution while protecting ecological integrity.

Addressing Pesticide resistance demands a One Health perspective that links agricultural productivity, environmental sustainability, and human well-being. Only through proactive, interdisciplinary action can society secure food systems while safeguarding biodiversity and ecosystem resilience in the face of accelerating Pesticide resistance.

REFERENCES

Battaglin, W.A., Meyer, M.T., Kuivila, K.M., and Dietze, J.E. (2014). Glyphosate and its degradation product AMPA occur frequently and widely in U.S. soils, surface water, groundwater, and precipitation. *Journal of the American Water Resources Association*, 50(2), 275–290.

Carrington, D. (2025). UK's first glyphosate-resistant weed found (Italian ryegrass). *The Guardian*.

Carvalho, F.P., *et al.* (2021). Pesticides, environment, and food safety. *Food and Energy Security*, 10(1), e261.

Cedergreen, N. (2014). Quantifying synergy: A systematic review of mixture toxicity studies within environmental toxicology. *PLOS ONE*, 9(5), e96580.

Chen, W., *et al.* (2025). P450-mediated resistance to dinitroanilines in Insects. *Weed Research*, 65(3), 233–245.

Duke, S.O. (2018). The history and current status of glyphosate. *Pest Management Science*, 74(5), 1027–1034.

Egan, J.F., Barlow, K.M., and Mortensen, D.A. (2014). A meta-analysis on the effects of 2,4-D and dicamba drift on soybean and cotton. *Environmental Toxicology and Chemistry*, 33(8), 1937–1946.

European Food Safety Authority (EFSA). (2020). Guidance on risk assessment of plant protection products. EFSA Journal, 18(4), e06034.

FAO. (2022). Pesticides Use Database. Food and Agriculture Organization of the United Nations.

Gaines, T.A., *et al.* (2010). Gene amplification confers glyphosate resistance in *Amaranthus palmeri*. *PNAS*, 107(3), 1029–1034.

Gressel, J. (2020). Pesticide resistance in Insects: The inevitable, the preventable, and what to do now. *Pest Management Science*, 76(1), 7–14.

Heap, I. (2025). The International Pesticide-Resistant Weed Database. Available at: www.Insectscience.org

Hager, A.G., *et al.* (2017). Off-target movement of dicamba in soybean production systems. *Weed Technology*, 31(1), 147–155.

Jugulam, M., and Shyam, C. (2019). Non-target-site resistance to Pesticides: Recent developments. *Plants*, 8(10), 417.

Koo, D.H., *et al.* (2018). Extrachromosomal circular DNA-based amplification of Pesticide resistance in *A. palmeri*. *PNAS*, 115(12), 3332–3337.

Mortensen, D.A., *et al.* (2012). Navigating a critical juncture for sustainable weed management. *BioScience*, 62(1), 75–84.

Rigon, C.A.G., *et al.* (2025). Cytochrome P450 CYP72A1182 in metabolic resistance in *A. palmeri*. *Journal of Experimental Botany*, 76(4), 1054–1067.

Rico, A., *et al.* (2018). Use of mesocosms in aquatic ecotoxicology: A review.

Environmental Pollution, 243, 977–993.

Rose, M.T., *et al.* (2016). Impact of Pesticides on soil microbial communities and processes. *Soil Biology and Biochemistry*, 95, 30–38.

Schütte, G., *et al.* (2017). Pesticide resistance and biodiversity: Threats to food security and ecosystem services. *Environmental Sciences Europe*, 29(1), 5.

REFORESTATION VERSUS AFFORESTATION: A REVIEW OF ECOLOGICAL IMPLICATIONS FOR PROJECT DEVELOPERS IN THE TROPICAL REGION

Olatidoye, O. R.
Forestry Research Institute of Nigeria, Jericho Hills, Ibadan. Nigeria
Corresponding Author's Email: olaremiolatidoye@gmail.com

ABSTRACT

Afforestation and restoration are widely recognized as effective nature-based solutions for enhancing biodiversity, restoring degraded ecosystems, and mitigating climate change through carbon sequestration. Although the terms *afforestation* and *reforestation* are often used interchangeably, they represent distinct ecological interventions with different implications for biodiversity conservation and ecosystem functioning. Selecting the appropriate approach is essential for avoiding costly implementation errors, preserving ecological integrity, and maximizing long-term environmental benefits. However, poorly planned afforestation or restoration initiatives can pose significant ecological risks, particularly when implemented in habitats where trees are not the natural or most suitable vegetation. This paper examines the ecological distinction between afforestation and reforestation and highlights the importance of adopting evidence-based, site-specific strategies to guide restoration efforts. It emphasizes the need to avoid tree establishment in high-biodiversity, non-forested ecosystems, including natural grasslands, savannas, and wetlands, where afforestation may lead to habitat degradation and biodiversity loss. An integrated framework that simultaneously considers carbon sequestration potential, habitat suitability, and ecosystem resilience is advocated to ensure that afforestation and reforestation initiatives achieve climate mitigation objectives while safeguarding biodiversity. The study underscores the importance of ecological planning, appropriate species selection, and landscape-specific implementation in promoting sustainable restoration and enhancing the success of nature-based climate solutions.

Keywords: Afforestation; Reforestation; Biodiversity conservation; Ecosystem restoration; Carbon sequestration.

INTRODUCTION

Benefits of trees are not only limited to human health, trees are also responsible for several ecosystem services ranging from decreasing pollution and use of energy to increasing tourism, property value and local economy (Nowak and Greenfield, 2018). Trees are important regarding human health as forests reduce air pollution (Nowak *et al.,* 2018). Polluted air contains nitrogen oxide, carbon monoxide, ozone and Sulphur dioxide that are linked with bronchitis symptoms, blood pressure, heart failure, myocardial infarction, problems of cognitive development in children and increased mortality in human (Nwanaji-Enwerem *et al.,* 2019). Forests eliminate substantial number of pollutants from air. Literature studies have documented that forests remove air pollution of approximately 711,000 metric tons annually in United State (Nowak *et al.,* 2018).

Out of many consequences of forest cutting, global warming is also associated with increased deforestation. Forests of tropical areas are reducing at the rate of 5% per decade basically to provide biofuel, agricultural turnout, clear land and wood products to national and global marketers and locals (Anon., 2010). Annually about 2 billion tons of CO_2 (Carbon dioxide) discharged in atmosphere is due to tropical deforestation. This carbon accumulated in the atmosphere as greenhouse gases (GHG)

results in rise in global mean temperature that adds global warming. (Health Effects of Global Warming, 2009).

The need for mitigating strategies such as Afforestation and Reforestation to rescue the ecological integrity and stability is therefore very eminent. Large-scale planting of trees can have significant beneficial environmental effects if done right, otherwise, it can be highly detrimental for local ecosystems and biodiversity (IPCC AR6 Wg3, 2022). Although interest in emerging technologies such as direct air capture, bioenergy with carbon capture and storage is growing, afforestation and reforestation are conventional carbon dioxide removal approaches that remain central to near-term mitigation (Smith *et al.,*2024)

Afforestation includes the conversion of degraded and abandoned agricultural land into forest. It includes the growth of forest on the land where there was no forest previously (UNFCCC, 2000) while Reforestation is the conversion of deforested land (where forest has been removed) into forest. Reforestation takes place in the area that was originally forested, but due to deforestation trees have been cut down (Santos *et al.,* 2019). Afforestation can lead to displacement or extinction of species that were uniquely adapted to the original habitat (Barnes *et al.,* 2018). Numerous studies have documented negative impacts of afforestation in diverse ecosystems, including grasslands (Buscardo *et al.,* 2008) and savannas (Pellegrini *et al.*, 2016). On the other hand, reforestation is a deliberate effort to restore a historically forested biome (UNFCCC, 2000). This contributes to habitat restoration and biodiversity recovery, particularly in fragmented or degraded landscapes (Kemppinen *et al.,* 2020). Globally, 130.9 ×106 ha of tree cover was established or restored by 2020 on land that was non-forested in 2000 (Potapov *et al.,* 2022, Global Forest Review 2024). The growing interest in Afforestation or Restoration is evident in global and regional initiatives such as the Bonn Challenge, which aims to restore 350 × 106 ha of forest by 2030 (IUCN, 2015). Although global studies often highlight the possibility that Afforestation or Restoration will increase plant species richness, they frequently over look associated biodiversity losses (Pérez-Silos *et al.,* 2021).

Evidence suggests that efforts to promote forestation in open habitat ecosystems sequester significant carbon belowground, and are less prone to catastrophic fires, and reflect more solar radiation due to their higher albedo (Tölgyesi *et al.*, 2022). Thus, Afforestation or Restoration in open habitats may not maximize climate benefits but may instead disrupt existing carbon dynamics while diminishing biodiversity (Prangel *et al.,* 2023); it also alters ecosystem services (Huang *et al.,* 2023) and compromises landscape multifunctionality while providing limited net benefits (Pellegrini *et al.,* 2016). Furthermore, open habitat forestation reduces native savanna plant diversity, even if it increases the abundance of the encroaching forest species (Veldman *et al.,* 2015).

Tropical Savannas and Grasslands (the largest terrestrial biome globally) have been severely impacted by anthropogenic activities such as overgrazing or conversion to crop production. Forestation in tropical regions comes with significant biophysical climate benefits suited for restoration, although, Windisch *et al.*, (2022) note that such projects would likely clash with food production. Forestation impact in these regions has often been exacerbated by relying on the establishment of exotic eucalypt (*Eucalyptus* spp.) and pine (*Pinus* spp.) monocultures particularly in developing countries where lower land prices and minimal competition with agriculture make such projects economically attractive (Veldman *et al.,* 2015) and availability of extensive information about the management

and propagation of these species (Lamb *et al.,* 2005). This underscores the need for careful considerations before implementing forestation projects in ecologically unique and vulnerable biomes. Proper project classification indicates that the developer has adequately considered the implications of site selection and aligned the project with broader carbon integrity standards. The distinction between afforestation and reforestation is important for several reasons, with significant implications for project quality and ecological integrity.

Afforestation

Afforestation is generally a popular and acceptable Carbon dioxide removal method and often framed as a "natural" measure (Waller *et al.,* 2023) Afforestation can entail significant climatic, ecological, or social tradeoffs and is therefore not often appropriate. However, afforestation may be desirable on severely degraded lands, areas that have experienced long-term declines in productivity, ecological integrity, or human-valued services. It importantly provides additional sources of income and restores soils and biodiversity. Although it is generally noted that afforestation could also compete for land and drive-up food prices (Kreidenweis *et al.,* 2016)

Site Selection and Site Preparation

Site preparation is a conventional site treatment in favor of survival and growing planted trees before afforestation by limiting the competition from undestroyed vegetation. It can be done by using several mechanisms such as ripping, plowing, and disking. During soil preparation when the surface organic layer is mixed with soil minerals, new conditions for organisms are created and it reinforces the enhancement of the decomposition rate of organic matter. It can disrupt aggregates of soil and can transfer organic matter to microorganisms. It results in a reduced amount of intra-aggregate organic carbon in soil (Wang *et al.,* 2016).

Reforestation

Restoration can take diverse forms, from single-species plantations aimed at production to multi-species native tree stands aimed at restoring forest function and its self-sustaining dynamics. Forest restoration method that involves natural regeneration is considered to be less costly as compared to planting new trees (Chazdon and Uriarte, 2016). It is a gradual and natural way of repossession of composition, function and structure of pre-disturbed ecosystem. All over the world, there is movement to recover the forest land in such a way to ameliorate ecosystem services and to lessen the effects of human induced global warming and climate changes (Griscom *et al.,* 2017). To meet goals of sustainable development, especially goal number 17 "life on land" informing the choice for reforestation of forest land cover (Zhang *et al.,* 2020).

Natural Regeneration

Direct seeding: This method includes immediately sowing the seed in the soil and eliminating the needs for transplanting of seedling. This is a cost effective and practical approach to increase the number of plants and reducing the time and resources. Direct seeding is considered as an appropriate approach for ecological rewilding having diverse species as it is simple to give rise to a variety of species in contrast to planting, (Pandey and Prakash, 2014), which have wide variety at higher plant densities and are economical to carry out as compared to classical seedling planting methods. Seed burial method was found effective to enhance the rates of development as compared to broadcast seeding (Sovu *et al.,* 2010). Broadcast seeding method has a benefit as it covers a vast land area effectively and helps to plant in distant as well as tough land areas therefore it is useful in rehabilitation

programs (Florentine *et al.,* 2013). Site preparation procedures that enhance the seedbed can cause an increase in the germination and development of seedlings (Birkedal *et al.,* 2010). Spot seeding has long been regarded as a preferred method of direct seeding. Spots are made for sowing seeds by using tools i.e. hoe and rake to dig and move soil and remove foliage and debris (Barnett, 2014).

Agroforestry system: This approach involves combining agricultural practices with trees and bring several benefits. This system reduces soil erosion, increases biodiversity and revamp soil fertility (Mankur *et al.,* 2023).

Assisted Natural Regeneration (ANR): It is an effective, inexpensive and simple technique to convert degraded vegetation into productive forests. It created a balance between high-cost plantation to recover biodiversity and venture high plantation on vast area. In Philippines this approach has been used for more than thirty years for reforestation. In some other countries such as Nepal, Nigeria, China, Sri Lanka, Ethiopia, Indonesia and Malaysia, ANR under different names has been practiced for many years in combination with some other reforestation methods.

Ecological Benefits of Trees

Economic value of trees: It is reported that trees bring almost 18.3 billion dollars each year by reducing energy use, air pollution and increasing carbon sequestration. Many species of trees are being used to bring food sustainability and low-cost nutritional security (Dawson *et al.,* 2013). Climate change: A study of 94 city areas throughout the world have specified that trees have positive impact on the temperature and cause cooling effect of an average of 1.9˚Cin the city. Trees planted near urban areas reduce the temperature by 9˚C in the cities. The lowering of temperature in cities will ultimately ameliorate the effect of climate change on the environment and human health (McDonald *et al.,* 2016).

Phytoremediation: Trees also reduce water runoff that is a major issue in urban areas where it causes property damage and exposes many pollutants (Berland *et al.,* 2017). Other environmental impacts of trees include phytoremediation in which trees remove heavy metals from water and soil (French *et al.,* 2006).

Sustainable Development Goals: Planting trees and promoting forestation will help a country to meet the various sustainable development goals viz ensuring health lives and promoting wellbeing for all stages (Goal 3), taking actions against climate change (Goal 13) and promote, protect and restore sustainable usage of terrestrial ecosystem, preserve forests, combat desertification, halt the degradation of land and biodiversity loss (Turner-Skoff and Cavender; 2019). If countries realize their pledges regarding forests to the Paris Agreement, forests could become a net carbon sink by 2030 (Grassi *et al.,* 2017).

Carbon Sequestration and Climate Change Mitigation: The amount of carbon in the atmosphere can be reduced by capturing it from the atmosphere by a process called carbon sequestration which is vital approach in alleviating the impacts of greenhouse gases and climate change (Roy *et al.,* 2023). Carbon sequestration is a strategy that combines both technological and natural methods to capture (remove) carbon dioxide from the air and to store it in different reservoirs like soil, geological formations, forests and oceans (McLaughlin *et al.,* 2023). Expanding and maintaining the forest cover increases carbon sequestration and lead towards long term environment preservation (Prajapati *et al.,* 2023). Although Afforestation or Restoration can contribute to carbon sequestration, its ecological

consequences must be critically evaluated (Hirata *et al.,* 2024). In particular, the popular carbon finance projects in some biomes can succeed only if supported by robust governance, local participation, and safeguards that prevent biodiversity goals from being undermined by a narrow focus on carbon outcomes (Seddon *et al.,* 2020). Thus, well-designed carbon finance mechanisms present an opportunity to align climate and biodiversity goals, especially in ecologically rich but economically vulnerable tropical regions (IPBES, 2024).

Ecological considerations

Not all landscapes are suitable for forest growth. Even if trees can survive in areas where they do not naturally occur, establishing forests in these locations can create unintended negative consequences. Natural grasslands and savanna are complex, often ancient ecosystems hosting unique biodiversity assemblage and provide critical ecological functions. Nevertheless, they are often targeted for afforestation of reforestation. Attempting to convert these ecosystems by planting trees can cause significant ecological harm with far-reaching impacts. Although trees could capture large amounts of carbon effectively, ineffective strategies, forest fires, droughts, and other causes could lead to massive re-release of CO_2 (Chiquier *et al.,* 2022).

Climate change considerations

From the carbon cycling perspective, planting trees in previously unforested areas can actually lead to carbon loss. Native grasslands store significant amounts of carbon below ground in extensive root systems and soil organic matter, especially in high rainfall regions. Consequently, converting these grasslands to forest can lead to long-term reductions in carbon storage. In addition, planting forests on previously unforested areas can reduce albedo, that is, the fraction of sunlight that a surface reflects back into the atmosphere. Light-colored surfaces, such as grasslands, reflect more sunlight back to space and absorb less heat. Dark forest canopies, by contrast, absorb more sunlight and trap heat. When afforestation replaces light grasslands with dark forests, the additional heat absorbed can counteract the climate benefit of the carbon stored in the trees. This is especially true in high latitude regions (e.g., boreal and some temperate), and to a lesser extent, in some tropical grasslands and savannas. Therefore, while sometimes appropriate, developers should only pursue afforestation or reforestation projects when the benefits (e.g., climate mitigation and/or adaptation) clearly outweigh the potential harms.

Lessons Learned from Failed Initiatives

Not all the projects of reforestation and afforestation become successful as failed projects are more common than successful ones. These failures bring negative impacts on forest restoration efforts (Hohl *et al.,* 2020). The reasons behind the failed projects range from environmental to socioeconomics. Management decisions regarding reforestation also become a cause of failure. These decisions include site preparation, planting time, mishandling of pre-plantation stock, and unsuitable plant selection (Smanis *et al.,* 2021). Some additional factors include improper ecological zoning (Ceacero *et al.,* 2020), inadequate Eco physiological criteria, and poor quality of planting stock (Grossnickle and MacDonald, 2018). Failed projects communicate many lessons for new projects to be successful. These lessons include:

1. Long-term success can be accomplished by recognizing and actively compelling key national, regional, local, or international partners and stakeholders. These stakeholders and partners include owners and users of forest (deforested or degraded) land,

beneficiaries, private investors, NGOs, and government bodies (Wortley *et al.* 2013).

2. It is important to address the socio-economic needs because it has crucial impact on the quality of life and well-being of people. Without the support of the local community, large-scale reforestation programs cannot be sustained and it's only possible if the needs of the local community are considered and well understood (Grabowski and Chazdon, 2012).

3. Identifying mutual interests among stakeholders is also a fundamental step toward sustainable restoration programs.

4. Knowledge about indigenous plant species is needed for successful plantation projects.

5. Securing the land rights is also important to ensure the sustainability and success of restoration projects. Literature studies revealed that there was a reduction in incentives for investments due to unclear land rights including the use and access of land.

6. Donors, stakeholders, landowners, and politicians must understand that an extensive time duration of almost 10 years is essential to implement, sustain, fund, and monitor restoration programs.

7. Designing and executing a strong monitoring structure for forest restoration is complex but it is necessary and should be built at the initial stage of the project.

Challenges in Reforestation and Afforestation

Unsuitable climatic conditions and topography: Unstable weather conditions and the climate of the area largely affect plant growth and cause a high mortality rate in early plant growth (del Campo *et al.,* 2020). Successful forestation projects revealed that the topography and microclimate of the area were homogeneous and favorable for plant growth.

Competition: The vegetation like weeds and herbs that are present in the surrounding may also compete for shelter and resources with planted seedlings thereby reducing the growth of plants. Sometimes seed germination and total emergence are not affected by competitors but the plants at the 2-month growth stage are affected by negative vegetation (Loranger *et al.* 2017).

Economic and Funding Barriers: Economic barriers include high investment and uncertainty about the revenue from forestry as compared to the outputs that are gained from agriculture. Long production time and irreversibility of land use are also hurdles in forestry management (Gosling *et al.*, 2020).

Future Perspectives

Drones: The latest technological innovation in pilotless aircraft (drones) and imaging systems increases the probability of carrying out various projects of rehabilitation by automating (Elliott, 2016). These newly developed devices have the power to operate the observation of site (i.e. assess site regeneration potential, plan interventions and assess progress), management of vegetation and aerial seeding. The remote-sensing technique has become a crucial technology for obtaining knowledge and information about the ecological and temporal conditions of a specific region. This technology has enabled the efficient monitoring on conditions that lead to the deforestation and ecosystem repossession process in larger regions by long-term spatial information (Sun *et al.,* 2023).

Machine Learning: The Incorporation of machine learning in remote-sensing technique has proved to be more beneficial for ecosystem monitoring and recovery process. Many researchers have used this combined technique to study various aspects of forestry such as the classification of areas for restoration (Ball *et al.,* 2023), forest canopy cover development (Zurqani, 2024)

and determining the changes of forest cover (Xiong *et al.,* 2024).

CONCLUSION

Although global studies often highlight the possibility that Afforestation or Reforestation will increase plant species richness, they frequently overlook associated biodiversity losses (Pérez-Silos *et al* 2021). Highly sensitive biomes could risk biodiversity loss as a result of Afforestation or Reforestation if carbon sequestration is prioritized over the habitat suitability, therefore ecological consequences must be critically evaluated before forestation processes commence. Implementing Afforestation or Reforestation in biodiversity-rich yet sensitive regions, risks irreversible habitat loss whose ecological costs may outweigh the carbon storage benefits. By combining suitable methods of reforestation, innovative technologies and formulating strong policies in the tropics through policymakers, stakeholders, NGOs, and local communities, degraded land can be turned into green land sustainably.

REFERENCES

Ball, J., Gimona, A., Cowie, N., Hancock, M., Klein, D., Donaldson-Selby, G., and Artz, R. R. (2023). Assessing the Potential of using Sentinel-1 and 2 or high-resolution aerial imagery data with Machine Learning and Data Science Techniques to Model Peatland Restoration Progress–a Northern Scotland case study. International Journal of Remote Sensing, 44(9), 2885-2911.

Barnes, A. D,, Jochum, M., Mumme, S., Haneda, N. F., Farajallah, A., Widarto, T. H. and Brose, U. (2018). Consequences of tropical land use for multitrophic biodiversity and ecosystem functioning Nat. Commun. 9 1–9

Barnett, J.P. (2014). Direct Seeding Southern Pines: Development of Techniques, Use, and Current Status. Tree Planters' Notes 57: 35-58.

Barton, C., Miller, J., Sena, K., Angel, P., and French, M. (2015) "Evaluating the Use of Tree Shelters for Direct Seeding of Castanea on a Surface Mine in Appalachia." Forests 6, no. 10: 3514-3527. https://doi.org/10.3390/f6103514

Berland, A., Shiflett, S. A., Shuster, W. D., Garmestani, A. S., Goddard, H. C., Herrmann, D. L., and Hopton, M. E. (2017). The role of trees in urban stormwater management. Landscape and Urban Planning, 162, 167-177.

Birkedal, M., Löf, M., Olsson, G.E. and Bergsten, U. (2010). Effects of granivorous rodents on direct seeding of oak and beech in relation to site preparation and sowing date. For Ecol Management 259: 2382–2389. https://doi.org/10.1016/j.foreco.2010.03.014

Bratman, G. N., Hamilton, J. P., Hahn, K. S., Daily, G. C., and Gross, J. J. (2015). Nature experience reduces rumination and subgenual prefrontal cortex activation. Proceedings of the National Academy of Sciences, 112(28), 8567–8572. https ://doi.org/10.1073/pnas.15104 59112

Buscardo, E., Smith, G. F., Kelly, D. L., Freitas, H., Iremonger, S., Mitchell, F. J. G., McKee, A.M. and McEvoy, P. M. (2008). The early effects of afforestation on biodiversity of grasslands in Ireland Biodivers. Conserv. 17 1057–72

Ceacero, C. J., Díaz-Hernández, J. L., del Campo, A. D., and Navarro-Cerrillo, R. M. (2020). Soil rock fragment is stronger driver of spatio-temporal soil water dynamics and efficiency of water use than cultural management in holm oak plantations. Soil Till Res, 197, 104495.

Chazdon, R. L., and Uriarte, M. (2016). Natural regeneration in the context of large-scale forest and landscape restoration in the tropics. Biotropica, 48(6), 709-715.

Chiquier, S., Patrizio, P., Bui, M., Sunny, N., and Mac Dowell, N. (2022). A comparative analysis of the efficiency, timing, and permanence of CO 2 removal pathways. Energy and Environmental Science, 15(10), 4389-4403. https://doi.org/10.1039/D2EE01021F

Dawson, I. K., Place, F., Torquebiau, E., Malézieux, E., Iiyama, M., Sileshi, G. W., and Jamnadass, R. (2013). Agroforestry, food and nutritional security. In: United Nations Food and Agriculture Organization.

Del Campo, A. D., Segura-Orenga, G., Ceacero, C. J., González-Sanchis, M., Molina, A. J., Reyna, S., and Hermoso, J. (2020). Reforesting drylands under novel climates with extreme drought filters: The importance of trait-based species selection. For. Ecology Management, 467, 118156.

Donovan, G. H. (2017). Including public-health benefits of trees in urbanforestry decision making. Urban Forestry and Urban Greening, 22,120123. https://doi.org/10.1016/j.ufug.2017.02.010

Elliott, S. (2016). The potential for automating assisted natural regeneration of tropical forest Ecosystems. Biotropica, 48(6): 825–833. https://doi.org/10.1111/btp.12387

FAO [Food and Agriculture Organization] (2014). The state of the world's forest genetic resources: thematic study. Genetic considerations in ecosystem restoration using native tree species. Food and Agriculture Organization of the United Nations, Rome, Italy.

Florentine, S.K., Graz, F.P., Ambrose, G. and O'brien, L. (2013). The current status of different age, direct-seeded revegetation sites in an agricultural landscape in the burrumbeet Region, Victoria, Australia. Land Degradation and Development, 24(1): 81-89. https://doi.org/10.1002/ldr.1110

French, C. J., Dickinson, N. M., and Putwain, P. D. (2006). Woody biomass phytoremediation of contaminated brownfield land. Environmental Pollution, 141(3), 387–395. https://doi.org/10.1016/j.envpol.2005.08.065

Global Forest Review. (2024). Forest gain indicator, world resource institute (available at: https://research.wri.org/gfr/forestextent-indicators/forest-gain) (Accessed 4 May 2025)

Gosling, E., Reith, E., Knoke, T., and Paul, C. (2020). A goal programming approach to evaluate agroforestry systems in Eastern Panama. Journal of Environmental Management, 261, 110248.

Grabowski, Z. J., and Chazdon, R. L. (2012). Beyond carbon: redefining forests and people in the global ecosystem services market. SAPI EN. S. Surveys

and Perspectives Integrating Environment and Society, (5.1).

Grassi, G., House, J., and Dentener, F. (2017). The key role of forests in meeting climate targets requires science for credible mitigation. Nature Clim Change 7, 220–226 https://doi.org/10.1038/nclimate3227

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., and Fargione, J. (2017). Natural climate solutions. Proceedings of the National Academy of Sciences, 114(44), 11645-11650.

Grossnickle, S. C., and MacDonald, J. E. (2018). Why seedlings grow: influence of plant attributes. New for 49: 1–34.

Hirata, A., Ohashi, H., Hasegawa, T., Fujimori, S., Takahashi, K., Tsuchiya, K. and Matsui, T. (2024). The choice of land-based climate change mitigation measures influences future global biodiversity loss Commun. Earth Environ. 5(259)

Hohl, M., Ahimbisibwe, V., Stanturf, J. A., Elsasser, P., Kleine, M., and Bolte, A. (2020). Forest landscape restoration what generates failure and success?. Forests, 11(9), 938.

Huang, B., Lu, F., Wang, X., Wu, X., Zheng, H., Su, Y., Yuan ,Y. and Ouyang, Z. (2023). The impact of ecological restoration on ecosystem services change modulated by drought and rising CO2 Glob. Change Biol. 29 5304–20

IPBES. (2024). Summary for Policymakers of the Thematic Assessment Report on the Interlinkages among Biodiversity, Water, Food and Health of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES secretariat) (https://doi.org/10.5281/zenodo.13850289)

IUCN. (2015). Forest landscape restoration (available at: www.iucn.org/about/work/programmes/forest/fp_our_work/fp_our_work_thematic/fp_our_work_flr/) (Accessed 4 May 2025)

Kreidenweis, U., Humpenöder, F., Stevanović, M., Bodirsky, B. L., Kriegler, E., Lotze-Campen, H., and Popp, A. (2016). Afforestation to mitigate climate change: impacts on food prices under consideration of albedo effects. Environmental Research Letters, 11(8), 085001. https://doi.org/10.1088/1748-9326/11/8/085001

Lewis, T., Verstraten, L., Hogg, B., Wehr, B. J., Swift, S., Tindale, N., and Smith, T. E. (2019). Reforestation of agricultural land in the tropics: The relative contribution of soil, living biomass and debris pools to carbon sequestration. Science of the Total Environment, 649, 1502-1513. https://doi.org/10.1016/j.scitotenv.2018.08.351

Li, D., Deal, B., Zhou, X., Slavenas, M., and Sullivan, W. C. (2018). Moving beyond the neighborhood: Daily exposure to nature and adolescents' mood. Landscape and Urban Planning, 173, 33–43. https://doi.org/10.1016/j.landurbplan.2018.01.009

Loranger, H., Zotz, G. and Bader, M.Y. (2017). Competitor or facilitator? The ambiguous role of alpine grassland for the early establishment of tree seedlings at treeline. Oikos

126:1625–1636. https://doi.org/ 10.1111/ oik. 04377

Mankur, M. K., Shil, S., and Pratap Toppo, P. (2023). Forest restoration and reforestation: best practices and challenges. Advances in Forestry and Agro-forestry, 147.

McLaughlin, H., Littlefield, A. A., Menefee, M., Kinzer, A., Hull, T., Sovacool, B. K., and Griffiths, S. (2023). Carbon capture utilization and storage in review: Sociotechnical implications for a carbon reliant world. Renewable and Sustainable Energy Reviews, 177, 113215.

Nowak, D. J., and Greenfield, E. J. (2018). US urban forest statistics, values, and projections. Journal of Forestry, 116(2), 164–177.

Nowak, D. J., Hirabayashi, S., Doyle, M., McGovern, M., and Pasher, J. (2018). Air pollution removal by urban forests in Canada and its effect on air quality and human health. Urban Forestry and Urban Greening, 29, 40–48. https ://doi.org/10.1016/j.ufug.2017.10.01 9

Nwanaji-Enwerem, J. C., Wang, W., Nwanaji-Enwerem, O., Vokonas, P., Baccarelli, A., Weisskopf, M., and Schwartz, J. (2019). Association of long term ambient black carbon exposure and oxidative stress allelic variants with intraocular pressure in older men. JAMA Ophthalmology, org/10.1093/jofor e/fvx004 137(2), 129–137. https://doi.org/10.1001/jamao phtha lmol.2018.5313

Pandey, D.N. and Prakash. N.P. (2014). "Tropical Dry Forest Restoration: Science and Practice of Direct Seeding in a Nutshell". RSPCB Occasional Paper 7.

Pellegrini, A. F., Socolar, J. B., Elsen, P. R. and Giam, X. (2016). Trade-offs between savanna woody plant diversity and carbon storage in the Brazilian Cerrado Glob. Chang Biol. 22 3373–82

Pérez-Silos, I., Alvarez-Martínez, J. M. and Barquín, J. (2021). Large-scale afforestation for ecosystem service provisioning: learning from the past to improve the future Landsc. Ecol. 36 3329–47

Potapov, P. *et al* (2022). The global 2000–2020 land cover and land use change dataset derived from the Landsat archive: first results Front. Remote Sens. 3 856903

Prajapati, S. K., Choudhary, S., Kumar, V., Dayal, P., Srivastava, R., Gairola, A., and Borate, R. B. (2023). Carbon Sequestration: A Key Strategy for Climate Change Mitigation towards a Sustainable Future, Emrg. Trnd. Clim. Chng. 2(2), 1-14. doi: http://dx.doi.org/10.18782/2583 4770.128

Prangel, E. *et al* (2023). Afforestation and abandonment of semi-natural grasslands lead to biodiversity loss and a decline in ecosystem services and functions J. Appl. Ecol. 60 825–36

Reque, J.A. and Martin, E. (2015). Designing acorn protection for direct seeding of Quercus species in high predation areas. Forest Systems, 24 (1): e-018, 5 p.

Roy, P., Mohanty, A. K., and Misra, M. (2023). Prospects of carbon capture, utilization and storage for mitigating

climate change. Environmental Science: Advances, 2(3), 409-423.

Santos, F. M., Gonçalves, A. L., and Pires, J. C. (2019). Negative emission technologies. In Bioenergy with Carbon Capture and Storage (pp. 1-13). Academic Press.

Smanis, A., Fuentes, D., Fuente, P., and Valdecantos, A. (2021). How far surface water fluxes determine restoration success in Mediterranean degraded areas? Implications for dryland precision restoration. Journal Arid Environment, 187, 104445.

Smith, S. M. *et al* (2024). The state of carbon dioxide removal 2024. 2nd Edition (https://doi.org/10.17605/OSF.IO/F85QJ)

Sovu, Savadogo, P., Tigabu, M., Odén, P. C. (2010). Restoration of former grazing lands in the highlands of Laos using direct seeding of four native tree species: seedling establishment and growth performance. Mt Research Dev, 30: 232–243. https://doi.org/10.1659/MRD-JOURNAL-D 10-00031.1

Sun, W., Liu, S., Wang, M., Zhang, X., Shang, K., and Liu, Q. (2023). Soil copper concentration map in mining area generated from AHSI remote sensing imagery. Science of the Total Environment, 860, 160511.

Tölgyesi, C., Buisson, E., Helm, A., Temperton, V. M. and Török, P. (2022). Urgent need for updating the slogan of global climate actions from “tree planting” to “restore native vegetation” Restor. Ecol. 30 e13594

Turner-Skoff, J. B., and Cavender, N. (2019). The benefits of trees for livable and sustainable communities. Plants, People, Planet, 1(4), 323-335. https://doi.org/10.1002/ppp3.39

UNFCCC. (2000). Methodological issues: land-use, land-use change and forestry. Submissions from parties. Note by the secretariat (available at: https://unfccc.int/resource/docs/2000/sbsta/misc06.htm) (Accessed 2 May 2025)

Veldman, J. W., Overbeck, G. E., Negreiros, D., Mahy, G., Le Stradic, S., Fernandes, G. W., Durigan, G. and Buisson, E. (2015). Where tree planting and forest expansion are bad for biodiversity and ecosystem services Bioscience 65 1011–8

Waller, L., Rayner, T., and Chilvers, J. (2023). Searching for a public in controversies over carbon dioxide removal: An Issue Mapping Study on BECCS and afforestation. Science, Technology, and Human Values, 48(1), 34-67. https://doi.org/10.1177/01622439211043568

Windisch, M. G., Humpenöder, F., Lejeune, Q., Schleussner, C. F., Lotze-Campen, H., and Popp, A. (2022). Accounting for local temperature effect substantially alters afforestation patterns. Environmental Research Letters, 17(2), 024030. https://doi.org/10.1088/1748-9326/ac4f0e

Wortley, L., Hero, J. M., and Howes, M. (2013). Evaluating ecological restoration success: a review of the literature. Restoration ecology, 21(5), 537-543.

Xiong, Y., Dai, Z., Long, C., Liang, X., Lou, Y., Mei, X., Nguyen, B.A. and Cheng, J., 2024. Machine Learning-Based examination of recent mangrove forest changes in the western

Irrawaddy River Delta, Southeast Asia. Catena, 234, p.107601.

Zhang, J., Fu, B., Stafford-Smith, M., Wang, S., and Zhao, W. (2020). Improve forest restoration initiatives to meet Sustainable Development Goal 15. Nature Ecology and Evolution, 5(1), 10–13.

Zurqani, H. A. (2024). High-resolution forest canopy cover estimation in ecodiverse landscape using machine learning and Google Earth Engine: Validity and reliability assessment. Remote Sensing Applications: Society and Environment, 33, 101095.

EFFICACY OF DUCKWEED (*Lemna minor*) AND WATER LETTUCE (*Pistia stratoites*) IN THE TREATMENT OF HERBICIDE POLLUTED WATER

***Okoh, T., Azua, E.T. and Uke, M.M.**
Environmental Science Unit, College of Biological Sciences, Joseph Sarwuan Tarka University Makurdi.
*Corresponding Author's Email: Thomasokoh@gmail.com

ABSTRACT

Agrochemicals including synthetic herbicides are being applied intensively by farmers in Benue State. The aim of this study was to investigate the biosorption potentials of duckweed (*Lemma minor*) and water lettuce (*Pistia stratoites*) in the treatment of water contaminated with herbicide. The complete randomized design (CRD) was used. Experimental water samples containing test plants were analysed for heavy metals (Pb, Cr, Mn), nutrient enrichment (N, P, K) and physicochemical parameters while test plants were evaluated for growth features. Indices of aquatic phytoremediation were computed including HPI (heavy metal pollution indices), PRI (phytoremediation index) and PE (phytoremediation efficiency). Data analysis was done using multivariate analysis tool while mean separation of ANOVA was done using Fisher LSD at P≤005. Plant-herbicide interaction showed that only duckweed had a reducing effect where Cr (0.01 ppm) and Pb (0.009 ppm) concentrations were very low in water. Hence, duckweed treated water had HPI <1, with higher PE in Pb (90%) and Cr (85.7%) than water lettuce, but the two test plants had high PE (99%) for Mn. Levels of nutrients (N, P, K) were reduced in duckweed treatment. Test plants demonstrated potentials in improving physicochemical parameters of herbicide contaminated water except the pH. Only water lettuce showed an increase in stem diameter and leaf sizes while duckweed recorded a decrease in all growth parameters. Duckweed is recommended for herbicide polluted water. The two adaptable test plants demonstrated capacity to improve physicochemical properties of water contaminated with herbicide.

Keywords: Aquatic plants, phytoremediation, heavy metals, herbicide

INTRODUCTION

Overuse and misuse of agrochemicals can result in harmful effects on humans and the environment and toxicity to non- target organisms, thus impacting negatively on biodiversity, in addition to depletion of ozone layer (Weldeslassie *et al.*, 2018). As a consequence of rapid urbanization, industrialization and the excessive use of herbicides, the levels of nitrate in ground and surface water has increased several-fold in both developing and rapidly developing countries (Weldeslassie *et al.*, 2018). Herbicide is a composite term that includes all chemicals that are used to kill or control pests. Herbicides are used to protect crops against insects, weeds, fungi, and other pests. They also play a significant role in food production. They protect or increase yields, and the number of times per year a crop can be grown on the same land (Vymazal and Brezinova, 2015; Shattar *et al.,* 2019). In agriculture, this includes herbicides (weeds), insecticides (insects), fungicides (fungi), nematocides (nematodes), and rodenticides (vertebrate poisons). Herbicides are potentially toxic to humans and can have both acute and chronic health effects, depending on the quantity and the ways in which the individual is exposed.

Water contaminations, along with limited availability of potable water, have put a severe burden on the environment (Gall *et al.,* 2015; Chandra *et al.,* 2018). Removal of heavy metals from the wastewater is difficult because they exist in different chemical forms. Most metals are not biodegradable, and they can easily pass through different trophic levels to persistently accumulate in the biota (Gall *et al.,* 2015). Removal of toxic pollutants is extremely important to minimize the threat to human health and the surrounding environment. Removal of heavy metals achieved through various techniques such as reverse osmosis, ion exchange, chemical precipitation, adsorption and solvent extraction include enormous operational and maintenance costs and are usually not environmentally friendly (Gall *et al.,* 2015; Huang *et al.,* 2017). These conventional techniques for the remediation of heavy metals are generally costly and time-consuming. These treatment technologies require high capital investment and generate the problem of sludge disposal. For the remediation of wastewater polluted with heavy metals contaminants, an environmentally friendly and economical treatment technology is needed (Gall *et al.,* 2015; Huang *et al.,* 2017).

Studies showed the potential of aquatic plants to have biosorption capacity to remove heavy metals and stabilize water quality parameters (Kim *et al.,* 2020). Some of the free-floating aquatic plants that are well recognized for their capability to eliminate the heavy metals from the contaminated environment include: duckweeds (*Lemna minor*), water lettuce (*Pistia stratoites*), water cress (*Nasturtium offcinale*), water hyacinth (*Eichhornia crassipes*) and water ferns (*Salvinia minima*) (Daud *et al.,*2018; Abbas *et al.,*2018; Shi *et al.,* 2020). These plants are evasive, apart from their economic uses and good recovery from the aquatic environment (Abbas *et al.,*2019; Shi *et al.,* 2020). In Benue State, farmers rely solely on intensive application of herbicides to protect crops. The negative impacts of herbicides on the environment cannot be over emphasized. The aim of this research was to investigate the biosorption potentials of duckweeds (*Lemna minor*) and water lettuce (*Pistia stratoites*) in the treatment of herbicide contaminated water.

MATERIALS AND METHODS

Collection of water sample

Clean water was collected from the Water Works Unit of the Joseph Sarwuan Tarka University Makurdi using sterile 50L capacity can. Water was poured into plastic containers to 2.5 liters level each and arranged in a working bench in accordance with the experimental design.

Procurement of herbicide

Phosphate liquid herbicide (2L) was procured from agrochemical shop along Otukpo road, within Makurdi metropolis

Preliminary collection and identification of two aquatic plants

Samples of two common aquatic plants namely: duckweed (*Lemma minor*) and water lettuce (*Pistia stratoites*) were collected from the River Benue and transported to the Botany Department of the Joseph Sarwuan Tarka University Makurdi, Benue State, for identification by taxonomic experts. Floral album of West Africa was also used in identification.

Collection of identified plants for experimentation

Twenty (20) stands each of duckweed and water lettuce of equal weight (using handy digital weighing instrument) and sizes (using meter rule) were collected from River Benue, and transported to the laboratory for experimentation. They were thoroughly

rinsed in distilled water before introduction into plastic pots (Hegazy *et al.,* 2011).

Experimental Design and Layout

Thirty-four (34) pots (P1-P34) were set up in the Biochemistry Laboratory of the College of Biological Sciences, Joseph Sarwuan Tarka University Makurdi. The Completely Randomized Design (CRD) (Hegazy *et al.,* 2011). The plant factor consisted of two treatments: duckweed and water lettuce. The experiments were grouped into 5 sections that ran concurrently and independently: week 1 (reference = 2 pots), week 2 (8 pots), week 3 (8 pots), week 4 (8 pots) and week 5 (8 pots). Each section terminated at the specified period of time (Ochekwu and Ezekwe, 2020) as shown below:

Week 1 (reference samples)
Plant 1 x herbicide (no replication)
Plant 2 x herbicide (no replication)
Total = 2 samples

Week 2 experiment
Plant 1 x herbicide x 4 reps
Plant 2 x herbicide x 4 reps
Total = 8 samples

Week 3 experiment
Plant 1 x herbicide x 4 reps
Plant 2 x herbicide x 4 reps
Total = 8 samples

Week 4 experiment
Plant 1 x herbicide x 4 reps
Plant 2 x herbicide x 4 reps
Total = 8 samples

Week 5 experiment
Plant 1 x herbicide x 4 reps
Plant 2 x herbicide x 4 reps
Total = 8 samples

Determination of reference values

The week 1 experiment was used for the determination of all reference values (when phytoremediation had not taken place). After introduction of agrochemicals into buckets, it was allowed to stand for 3 hours before reference values were taken for each of the parameters evaluated at day (week 1) of the experiment including plant growth features (Hegazy *et al.,* 2011).

Evaluation of Water Quality and Plant Growth Parameters

Evaluation of phytoremediation was done at week 2-5 in the laboratory.

Heavy metal and mineral analysis

Heavy metals and minerals commonly present in herbicides and herbicides were analyzed in the experimental water treated with aquatic plants. These were: Lead (Pb), Chromium (Cr) and Manganese (Mn). The amount of each heavy metal was determined using the Atomic Absorption Spectrophotometer (AAS). Potassium (K) content was measured using flame photometer (Bokhari *et al.,* 2016).

Physicochemical analysis of experimental water

Physicochemical parameters of contaminated water samples were determined following standard methods (AOAC, 2016). Temperature (^{o}C), pH and conductivity were determined with the aid of a combined portable digital HANNA instrument (APHA 46). Total dissolved solid (TDS) (in mg/L) was measured using Palintest conductivity meter. Dissolved oxygen was measured by dissolved oxygen meter. Amount of nitrate and phosphate were quantified using Hanna instruments HI 83200 benchtop multiparameter photometer. Result were expressed in mg/L. All readings were taken in triplicates.

Morphometric characterization of plant

This was done from plant samples at week 1 (reference) to week 5 experiments. The following features were evaluated suing metre rule and digital weighing balance: plant height, stem diameter, plant biomass, leaf length (cm), leaf width (cm) and root length (cm) following the procedures of Zhang *et al.* (2014).

Computation of Biosorption Parameters

Indices of aquatic phytoremediation and biosoption potentials of aquatic plants were computed including HPI (heavy metal pollution indices), PRI (phytoremediation index) and PE (phytoremediation efficiency) values using standard formula (Akinbile *et al.,* 2012; Bokhari *et al.,* 2016). Heavy metal pollution index (HP) was computed as: $\sum Ci/Si * Wi$

Where Ci = concentration of heavy metals in experimental water
Si = regulatory permissible limit of exposure of the heavy metal
Wi= regulatory weighted value for the heavy metal under consideration
PRI was computed as initial heavy metal concentration (IHC) – final heavy metal concentration (FHC).
PE = PRI/IHC x 100% (Bokhari *et al.,* 2016).

Data Analysis

Data analysis was done on the Genstat application package (v17) for descriptive statistics and inferential statistics. The multivariate statistical tool will be applied. Mean separation of ANOVA waas done using the LSD method at $P \leq 0.05$

RESULTS

Table 1 presents the effects of herbicide and plant interaction on heavy metal concentrations in experimental water from week 2 to 5. The reference Lead (Pb) concentration was obtained as 0.033 ppm. It reduced across the duration of the experiment from week 2 (0.013ppm) to week 5 (0.010 ppm). The observed differences in level of Pb from week 2-5 were significant ($P<0.05$). The two aquatic plants reduced the Pb level in experimental using the reference value as the baseline value. However, duckweed caused a significantly lower reduction ($P< 0.05$) in lead level to 0.009 ppm than water lettuce (0.019 ppm). The reference Chromium (Cr) concentration in herbicide contaminated water was 0.029 ppm. There was a sharp reduction in the Cr level throughout the experiment from 0.0017 ppm at week 2 to 0.012 ppm at week 5. The observed differences in level of Cr from week 2-5 were insignificant ($P>0.05$). The two test plants reduced Cr level in contaminated water as against the reference value. However, duckweed caused a significantly higher reduction in Cr level (0.01 ppm) than water lettuce (0.022) ($P<0.05$). The reference Manganese (Mn) concentration in herbicide contaminated water was 0.015 ppm. The value reduced to a range of 0.002 ppm at week 2 to 0.006 ppm at week 5. However, the observed differences were insignificant ($P>0.05$). The two test plants caused a high reduction in Mn level with the same effects ($P>0.05$) where Mn in duckweed and water lettuce was 0.006 and 0.005ppm respectively.

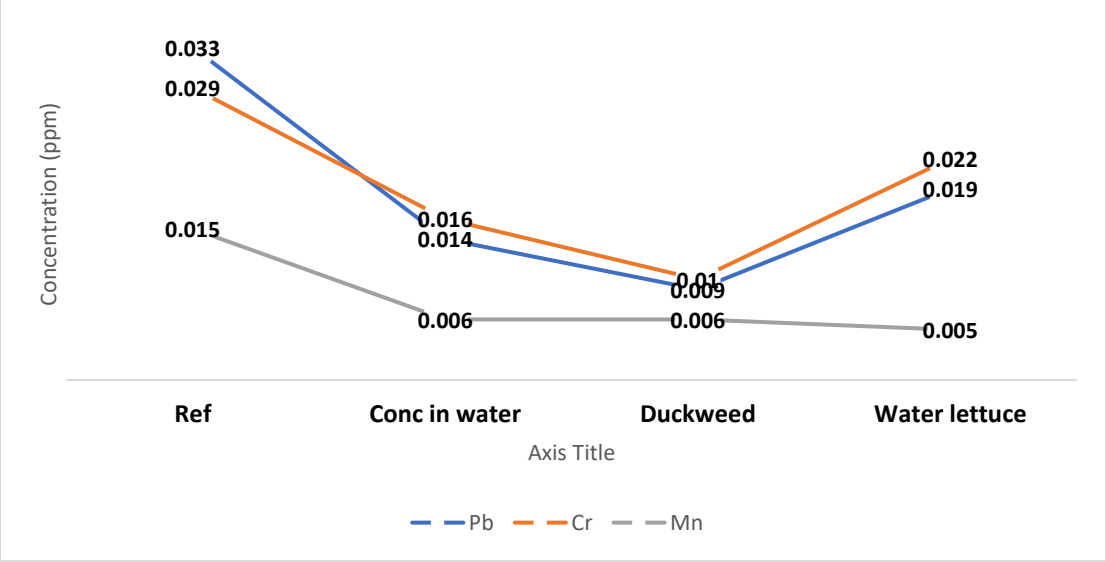
As shown in figure 1, the reference concentration of Lead (Pb), Chromium (Cr) and Manganese (Mn) levels in water were 0.033, 0.029 and 0.015ppm respectively. Treatment with aquatic plants reduced these heavy metals to 0016, 0.014 and 0.006ppm respectively. Only duckweed produced an effect where Cr (0.01 ppm) and Pb (0.009 ppm) concentrations were very low in water. Table 2 gives the pollution indices of heavy metal in herbicide contaminated water and plants. The reference value for HPI (Heavy metal pollution index) was calculated as 16.0. Plant based treatment reduced the HPI of

water to 1.47. Water lettuce-based medium had an HPI of approximately 2.0 while the value was <1 in duckweed based medium. Table 3 gives the phytoremediation index (PRI) and efficiency (PE) of aquatic plants in herbicide contaminated water. The two test plants recorded >70% in PE value for the three heavy metals except in Cr where PE was 68.6% in water lettuce. Results showed that duckweed recorded higher PRI values in Pb (0.081) and Cr (0.06) than water lettuce. This translated to high PE values of 90 and 85.7% respectively. The two test plants had the same PRI (0.5) and PE (99%) for manganese.

Table 1: Herbicide and Plant Interaction Effect on Heavy Metal Concentrations in Contaminated Water

Heavy metals (ppm)	W2	W3	W4	W5	P-value	LSD	Duckweed	Water lettuce	P-value
							Plant		
Pb	0.013 ±0.002^{ab}	0.018 ±0.003^{a}	0.015 ±0.008^{ab}	0.010 ±0.009^{b}	0.183 P>0.05	NA	0.009 ±0.00^{b}	0.019 ±0.00^{a}	P= 0.000 P<0.05
Cr	0.017 ±0.006^{a}	0.020 ±0.014^{a}	0.015 ±0.007^{a}	0.012 ±0.00^{a}	0.424 P>0.05	NA	0.010 ±0.00^{b}	0.022 ±0.01^{a}	P=0.000 P<0.05
Mn	0.002 ±0.001^{b}	0.009 ±0.006^{a}	0.005 ±0.003^{ab}	0.006 ±0.003^{ab}	0.111 P>0.05	NA	0.006 ±0.005^{a}	0.005 ±0.003^{a}	P= 0.498 P>0.05

Ref: Pb= 0.033; Cr= 0.029; Mn= 0.015 (W = weeks; Pb = Lead; Cr = Chromium; Mn= Manganese)



Ref = reference; Conc.= concentration

Figure 1: Average Concentration of Herbicide Induced Heavy Metals in Experimental Water and Aquatic Plants

Table 2: Heavy Metal Pollution Indices in Herbicide Contaminated Water and Plants

Heavy metal (ppm)	Si	Weighted	Reference	HPI Reference	Concentration in water	HPI water	Duckweed	Duckweed HPI	Water lettuce	Water lettuce HPI
Pb	0.01	0.8	0.09	7.2	0.014	1.12	0.009	0.72	0.019	1.52
Cr	0.05	0.8	0.07	1.12	0.016	0.256	0.01	0.16	0.022	0.352
Mn	0.05	0.8	0.48	7.68	0.006	0.096	0.006	0.096	0.005	0.08
∑				16		1.472		0.976		1.952

Si = WHO Permissible limit
HPI = Heavy metal pollution index (Ci/Si * Wi)

Table 3: Phytoremediation Index (PRI) and Efficiency (PE) of Aquatic Plants in Herbicide Contaminated Water

	Heavy metal (HM)	Phytoremediation Index (PRI)	Phytoremediation Efficiency (PE) %
Duckweed	Pb	0.081	90.0
Water lettuce		0.071	78.9
Duckweed	Cr	0.06	85.7
Water lettuce		0.048	68.6
Duckweed	Mn	0.474	98.8
Water lettuce		0.475	99.0

PRI = Initial HM conc (IHC) – Final HM conc (FHC)
PE= PRI/IHC *100%

Table 4 presents the effects of herbicide and plant interaction on nutrient enrichment of experimental water from week 2 to 5. The reference Potassium (K) concentration was 0.19 ppm. It reduced slightly to 0.15 ppm at week 2- 5, with maximum concentration at 0.18 ppm at week 4. The observed differences in level of K from week 2-5 were insignificant ($P<0.05$). Only duckweed caused a reduction in K level (0.13 ppm) below the reference value and the differences in K level performances between the two test plants were significant ($P<0.05$). The reference Phosphorus (P) concentration in herbicide contaminated water was 1.40 ppm. There was a slight increase at week 3 (1.42 ppm) and week 4 (1.53 ppm) with reduction observed at week 2 (1.32 ppm). The observed differences in level of P level from week 2-5 were significant ($P<0.05$). The effect produced by the two test plants were also significantly different ($P<0.05$). While P level reduced to 1.34 ppm in duckweed as against the reference value, it increased to 1.49 in water lettuce. The reference Nitrogen (N) concentration in herbicide contaminated water was 12.3 ppm. The value reduced slightly to a range of 11.65 at week 2 ppm at week 2 to 12,27 ppm at week 4. However, the observed differences were insignificant

(P>0.05). Water lettuce caused a significantly higher level of N level (22.96 ppm) than duck weed (1.22 ppm) (P<0.05).

Figure 2 shows that concentration of herbicide-based elements in experimental water had a direct and significant relationship (P<0.05) with water lettuce as deduced through a fitted regression line (figure 6) where R^2 (coefficient of determination) was 99.7%. The linear regression equation is given as: Water lettuce = - 0.2484 + 1.911 Water. Figure 2 shows that concentration of herbicide-based elements in experimental water had no significant relationship (P>0.05) with concentration in duckweed as regression line was not fit where R^2 was 31.5%.

Table 4: Herbicide and Plant Interaction Effect on Nutrient Enrichment of Experimental Water

Nutrients (ppm)	W2	W3	W4	W5	P-value	LSD	Duckweed	Water lettuce	P-value
	Herbicide						Plant		
K	0.15	0.16	0.18	0.15	0.744	NA	0.13	0.19	P= 0.002
	±0.06[a]	±0.06[a]	±0.06[a]	±0.04[a]	P>0.05		±0.04[b]	±0.05[a]	P<0.05
P	1.32±	1.42±	1.53±	1.39±	0.025	0.13	1.34	1.49	P =0.003
	0.034[b]	0.148[ab]	0.140[a]	0.058[b]	P<0.05		±0.05[b]	±0.14[a]	P<0.05
N	11.65±	12.19±	12.27±	12.24±	1.000	NA	1.22	22.96	P= 0.000
	11.33[a]	12.08[a]	12.07[a]	12.16[a]	P>0.05		±0.07[b]	±0.59[a]	P<0.05

Ref: K= 0.19; P= 1.40; N=12.25 (W = Weeks; K= Potassium; P= Phosphorus; N= nitrogen)

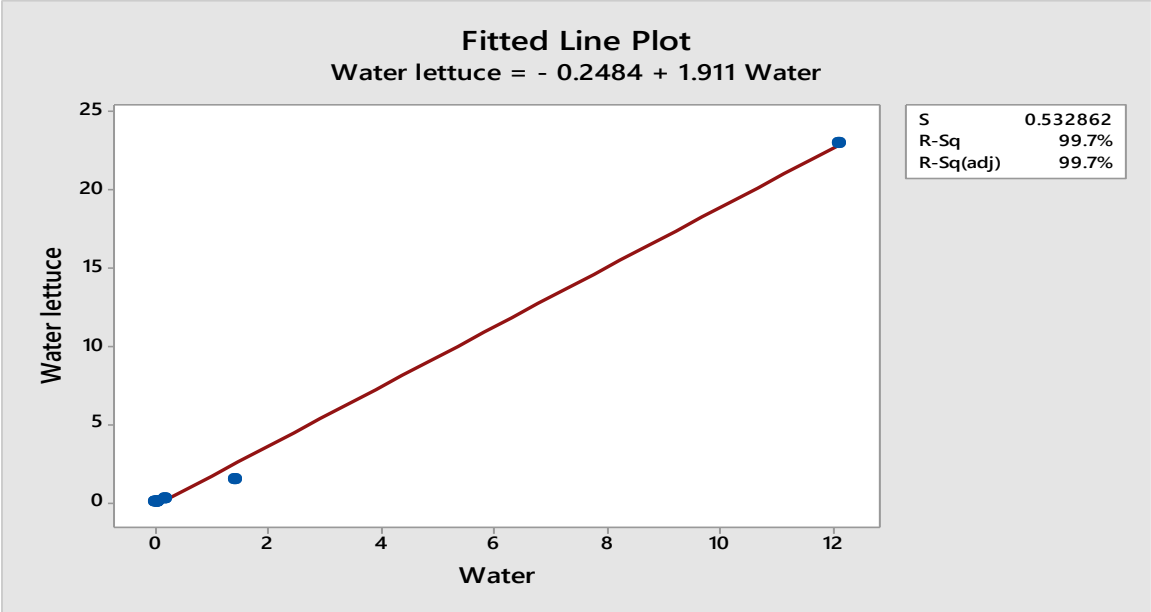


Figure 2: Regression Model Fitted Line of Elements (Heavy Metal and Nutrients) in Herbicide Contaminated Water and Water Lettuce Plants
Water lettuce = - 0.2484 + 1.911 Water (F = 1501.83, P<0.05)

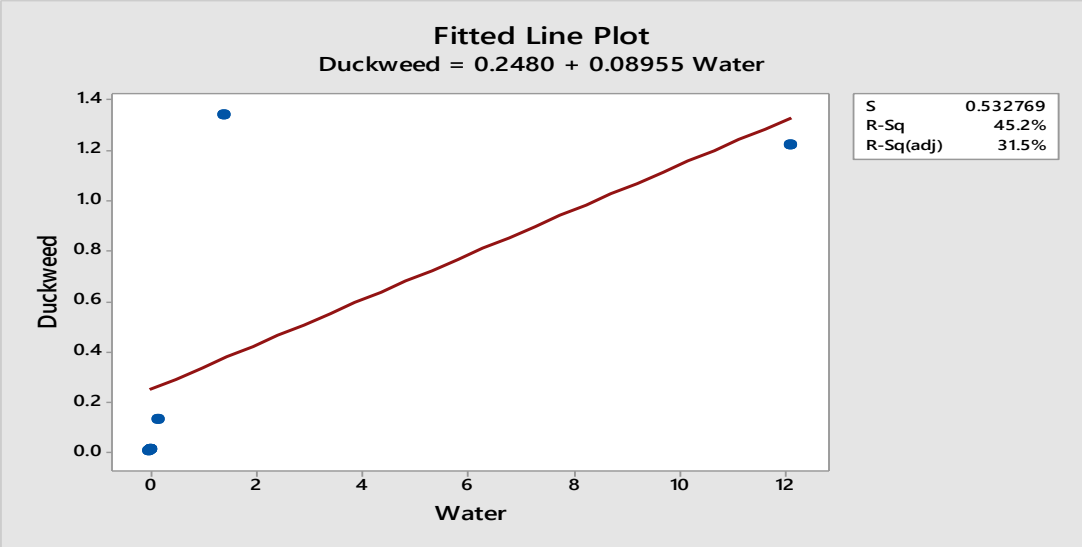


Figure 3: Regression Model Fitted Line of Elements (Heavy Metal and Nutrients) in Herbicide Contaminated Water and Water Duckweed Plants
Duckweed = 0.2480 + 0.08955 Water (F = 3.30, P>0.05)

Table 5 presents the effects of herbicide and plant interaction on physicochemical properties of experimental water. Results on pH gave 5.6 as the reference value. It reduced to 5.47, 5.4, 5.52 and 5.33 at week 2-5 respectively. However, the observed differences in pH readings in the course of the experiment from week 2-5 were insignificant (P>0.05). The two plants had impacts on the pH values where it was 5.36 in duckweed medium and 5.5 in water lettuce medium with significant differences (P<0.05). Results on TDS (total dissolved solid) gave 135.9 mg/L as the reference value. It increased to 147.2 mg/L at week 2 but reduced to 111.0 mg/L at week 5. The observed differences in TDS readings in the course of the experiment from week 2-5 were significant (P<0.05). Results further showed that TDS was reduced under the influence of the two aquatic plants (115.7 mg/L in duckweed medium; 119.9 mg/L in water lettuce medium). The test plants had the same effects (P>0.05). Results of EC (electrical conductivity) gave 182.5 µS/cm as the reference value. It increased to 192.3 µS/cm at week 2 and finally at 242.0 µS/cm at week 5. The observed differences in EC readings in the course of the experiment from week 2-5 were significant (P<0.05). Results further showed that EC was improved under the influence of the two aquatic plants (213.3 µS/cm in duckweed medium; 209.8 µS/cm in water lettuce medium). The test plants had the same effects (P>0.05).

Results of temperature gave 26.5ºC as the reference value. The values fluctuated slightly (26.8, 26.5, 26.4, and 26.3) with no significant differences from week 2-5 respectively (P>0.05). The two plants had impacts on the temperature values of the experimental water where it was 26.3ºC in duckweed medium and 26.7ºC in water lettuce medium with significant differences (P<0.05).

Results of DO (dissolved oxygen) gave 2.22 mg/L as the reference value. The values fluctuated slightly from 2.42 to 2.62 mg/L with no significant differences during the experiment (P>0.05). The two plants had impacts on the DO values of the experimental water where it was 2.69 mg/L in duckweed medium and 2.38 mg/L in water lettuce

medium with significant differences (P<0.05).

Table 5: Herbicide and Plant Interaction Effect on Physico-chemical properties of Experimental Water

Physico-chemical parameter	W2	W3	W4	W5	P-value	LSD	Duckweed	Water lettuce	P-value
	Herbicide						Plant		
pH	5.47 ±0.12^{ab}	5.40 ±0.21^{ab}	5.52 ±0.13^{a}	5.33 ±0.12^{b}	0.204 P>0.05	NA	5.36 ±0.15^{b}	5.50 ±0.13^{a}	P= 0.024 P<0.05
TDS (mg/L)	147.17 ±20.13^{a}	104.17 ±4.96^{b}	108.83 ±23.51^{b}	111.00 ±2.76^{b}	0.000 P<0.05	18.94	115.67 ±31.16^{a}	119.92 ±10.48^{a}	P=0.659 P>0.05
EC (µS/cm)	192.3 ±26.5^{b}	224.50 ±31.80^{a}	187.50 ±11.04^{b}	242.00 ±24.80^{a}	0.003 P<0.05	29.73	213.33 ±33.93^{a}	209.83 ±32.72^{a}	P=0.799 P>0.05
Temp (˚C)	26.75 ±0.53^{a}	26.52 ±0.52^{a}	26.43 ±0.23^{a}	26.33 ±0.08^{a}	0.307 P>0.05	NA	26.31 ±0.22^{b}	26.71 ±0.43^{a}	P=0.009 P<0.05
DO (mg/L)	2.62 ±0.35^{a}	2.57 ±0.12^{a}	2.55 ±0.08^{a}	2.42 ±0.29^{a}	0.527 P>0.05	NA	2.69 ±0.18^{a}	2.38 ±0.18^{b}	P=0.000 P<0.05

Ref: pH=5.63; TDS 135.9; EC= 182.5; Temp = 26.52; DO= 2.22

W= weeks, TDS =total dissolved solid; EC =electrical conductivity; Temp= temperature; DO = dissolved oxygen

Table 6 presents the effects of herbicide and plant interaction on growth parameters of experimental plants. The reference plant height was 16.3 cm for duckweed and 7.3 cm for water lettuce. Growth parameters decreased in herbicide solutions. Percentage decrease in height was lower in duckweed (16.2%) than water lettuce (19.9%).

The reference stem diameter was 0.53cm for duckweed and 0.11cm for water lettuce. Stem diameter was found to increase by 66.7% in water lettuce but decreased by 7.5% in duckweed. Other parameters with decrease in sizes were: plant biomass (5.9% in duckweed; 7.8% in water lettuce), leaf length (14% in duckweed only), leaf width (18.0% in duckweed only) and root sizes (51.0 % in duckweed; 54.4 % in water lettuce). Only water lettuce plant had an increase in some growth features including stem diameter and leaf sizes while duckweed recorded a decrease in all growth features.

Table 6: Herbicide and Plant Interaction Effect on Growth Characteristics of Plants in Experimental Water

Growth Parameter	Duckweed	% Decrease	Water lettuce	% decrease
Plant height (cm)	13.58±0.60^{a}	16.4%	5.81±0.19^{b}	19.9%
Stem diameter (cm)	0.49±0.07^{a}	7.5%	0.33±0.05^{b}	+66.7%
Biomass (g)	1.59±0.18^{a}	5.9%	1.06±0.15^{b}	7.8%
Leaf length (cm)	4.99±0.26^{a}	14.0%	4.91±0.48^{a}	+54.2%
Leaf width (cm)	2.64±0.10^{b}	18.0%	3.21±0.09^{a}	+38.3%
Root length (cm)	4.02±0.59^{a}	51.0%	1.60±0.37^{b}	54.4%

Duck weed Ref: Height=16.25; Diameter = 0.53; Biomass = 1.69; Leaf length = 5.80; Leaf width = 3.22; Root length = 8.21 Water lettuce Ref: Height=7.25; Diameter = 0.11; Biomass = 1.15; Leaf length = 2.25; Leaf width = 1.98; Root length = 3.51

DISCUSSION

The present investigation on plant-herbicide interaction showed that only duckweed had a reducing effect where Cr (0.01 ppm) and Pb (0.009 ppm) concentrations were very low in water. Duckweed treated water had heavy metal pollution index (HPI) <1 in herbicide based medium, with higher phytoremediation efficiency in Pb (90%) and Cr (85.7%) than water lettuce. The two test plants had high phytoremediation efficiency (99%) for Mn in herbicide based medium. The outcome aligned with previous findings that explored the live biomass of aquatic plants to remove heavy metals (Iha and Bianchini, 2015; Kim *et al.,* 2020). In general, media with pollution indices that are <1 are considered decontaminated while plants with phytoremediation efficiency of >70% are hyper accumulators and excellent phytoremediants (Bonanno *et al.,* 2017). The ability of the two test plants to decontaminate heavy metal polluted might possibly be to their abilities to accumulate contaminants through their roots and then translocate these contaminants in part of their body as shown in other reports (Sharma *et al.,* 2015; Ashraf *et al.,* 2018).

Aquatic plants remove heavy metals via absorption or through surface adsorption and integrate them into their system, and then accumulation them in certain bounded forms (Bonanno *et al.,* 2017). Reduction in heavy metals were noticeable from week 2 of the experiment. The timing of removal of heavy metals and the phytoremediation efficiencies of duckweed add water lettuce (>70%) in herbicide media were in tandem with other studies. For instance, root and shoot tissues of *Typha domingensis* showed maximum accumulation of Zn, Cd, Ni, Fe and Mn during the first 48 h of study, planted in pots filled with municipal wastewater (Mojiri, 2012).

Herbicide applications caused more harms to terrestrial and aquatic life forms due to their high toxicity and persistence in the environment. There are different types in the markets manufactured to kill pests, weeds and other biotic constraints of crops. Only duckweed demonstrated strong potentials to decontaminate herbicide polluted water. This outcome was in agreement with other reports on duckweed. It was reported that duckweed can eliminate a vast variety of different heavy metals, inorganic and organic contaminants, herbicides, nutrients arise from agricultural runoff, sewage, industrial and domestic wastewater (Chen *et al.,* 2018). The plant was found to be an excellent contender for the remediation of arsenic (Alvarado *et al.,* 2008). In comparison with other macrophytes, duckweed was reported as the most suitable plant for phytoremediation. Use of duckweed for the remediation of nutrient pollutants and HMs from industrial and agricultural wastewater was reported in previous reports (Zhang *et al.,* 2014).

Duckweed showed an increase in chromium uptake percentage of 26.5% at a different exposure concentration of chromium stress (Sallah-Ud-Din, 2017). In this work, the plant showed phytoremediation efficiency of 85.5% for chromium, 90% for Lead and 99% for Manganese in herbicide solutions. In the work of Daud *et al.* (2018) application of duckweed also showed a significant reduction in copper, zinc, lead, nickel, and iron from landfill leachate. The present outcome showed that Levels of nutrient enrichment (N, P, K) were also reduced in duckweed treatment for herbicide pollutant while demonstrating potentials in improving physicochemical parameters of herbicide contaminated water.

In herbicide solution, only water lettuce showed an increase in stem diameter and leaf sizes while duckweed recorded a decrease in all growth parameters but in stable condition. Confinement in plastic containers might have affected the growth performance of duckweed in herbicide solution, not necessarily due to the toxic effects of pollutants because of its high PE values and low pollution indices of the media. The plant is well known as an invasive aquatic plant due to its exceptionally rapid proliferation, rapid growth and quest for nutrient absorption (Kim *et al.,* 2020). factors like pH and nutrient availability greatly influence the phytoremediation potential and growth of the plant (Burges *et al.,* 2018). In this report, the pH of the herbicide solution remained in acidic condition in all treatments despite the low pollution indices recorded in duckweed treatment (with low growth rate) and water. Plants should have the following characteristics in order to make the phytoremediation an eco-sustainable technology: native and quick growth rate, high biomass yield, the uptake of a large amount of heavy metals, the ability to transport metals in above ground parts of plant, and a mechanism to tolerate metal toxicity (Ali *et al.,* 2013; Arslan *et al.,* 2017; Burges *et al.,* 2018). Both duckweed and water lettuce plants tested in this work have met the above conditions and therefore could be considered for phytoremediation of Pb, Cr and Mn contaminated water.

CONCLUSION

Duckweed showcased high potentials in the remediation of HMs and excessive nutrients in herbicide polluted water. The two test plants demonstrated capacity to improve physicochemical properties of water contaminated with herbicide. They also showcased high stability and adaptability in their growth features in polluted water.

REFERENCES

Abbas, Z., Arooj, F., Ali, S., Zaheer, I.E., Rizwan, M. and Riaz, M.A. (2018). Phytoremediation of landfill leachate waste contaminants through floating bed technique using water hyacinth and water Lettuce. *International Journal of Phytoremediation*, 21: 1356–1367.

Akinbile, C.O., Yuso, M.S. and Shian, L.M. (2012). Leachate Characterization and Phytoremediation Using Water Hyacinth (*Eichorrnia crassipes*) in Pulau Burung, Malaysia. *Journal of Bioremediation*, 16: 9–18.

Ali, H., Khan, E. and Sajad, M.A. (2013). Phytoremediation of heavy metals-Concepts and Applications. *Chemosphere*, 91:869–881.

Arslan, M., Imran, A., Khan, Q.M., Afzal, M. (2017). Plant–bacteria partnerships for the remediation of persistent organic pollutants. *Environmental Science Pollution Research*, 24: 4322–4336.

Ashraf, S., Afzal, M., Naveed, M., Shahid, M. and Zahir, Z.A. (2018). Endophytic bacteria enhance remediation of tannery effluent in constructed wetlands vegetated with Leptochloa fusca. *International Journal of Phytoremediation*, 20:121–128.

Bokhari, S.H., Ahmad, I., Mahmood-Ul-Hassan, M. and Mohammad, A. (2016). Phytoremediation potential of *Lemna minor* L. for heavy metals. *International Journal of Phytoremediation*, 18: 25–32.

Bonanno, G., Borg, J.A. and Di Martino, V. (2017). Levels of heavy metals in wetland and marine vascular plants

and their biomonitoring potential: A comparative assessment. *Science of the Total Environment*, 576: 796–806.

Burges, A., Alkorta, I., Epelde, L., Garbisu, C. (2018). From Phytoremediation of soil contaminants to phyto-management of ecosystem services in metal contaminated sites. *International Journal of Phytoremediation*, 20: 384–397.

Chandra, R., Kumar, V., Tripathi, S. and Sharma, P. (2018). Heavy metal phytoextraction potential of native weeds and grasses from endocrine-disrupting Chemicals rich complex distillery sludge and their histological observations during in-situ Phytoremediation. *Ecology and Engineering*, 111:143–156.

Chen, G., Huang, J., Fang, Y., Zhao, Y., Tian, X., Jin, Y. and Zhao, H. (2018). Microbial community succession and pollutants removal of a novel carriers enhanced duckweed treatment system for rural wastewater in Dianchi lake basin. *Bioresearch Technology*, 276: 8–17.

Daud, M., Ali, S., Abbas, Z., Zaheer, I.E., Riaz, M.A., Malik, A. and Zhu, S.J. (2018). Potential of Duckweed (*Lemna minor*) for the Phytoremediation of Landfill Leachate. *Journal of Chemistry*, 1–9.

Gall, J.E., Boyd, R.S. and Rajakaruna, N. (2015). Transfer of heavy metals through terrestrial food webs: A Review. *Environmental Monitoring and Assessment*, 187: 201.

Hegazy, A., Abdel-Ghani, N. and El-Chaghaby, G. (2011). Phytoremediation of industrial wastewater potentiality by *Typha domingensis*. *International Journal of Environmental Science and Technology*, 8: 639–648.

Huang, H., Liu, J., Zhang, P., Zhang, D., Gao, F. (2017). Investigation on the simultaneous removal of fluoride, ammonia nitrogen and phosphate from semiconductor wastewater using Chemical precipitation. *Journal of Chemical Engineering*, 307: 696–706.

Iha, D.S. and Bianchini, I. (2015). Phytoremediation of Cd, Ni, Pb and Zn by *Salvinia minima*. *International Journal of Phytoremediation*, 17: 929–935.

Kim, Z. V., Frankie, G. M. and Jacklyn, C. A. (2020). Biosorption Capacity of Selected Aquatic Plants. *Chemical Engineering Transaction*, 78: 553-559

Mojiri, A. (2012). Phytoremediationion of heavy metals from municipal wastewater by *Typha domingensis*. *African Journal of Microbiological Research*, 6: 643–647.

Ochekwe, E.B. and Ezekwe, T.C. (2020). Phytoremidation of crude oil polluted water by *Pistia stratiotes.* *Journal of Plant Science,* 15: 17-21

Sallah-Ud-Din, R., Farid, M., Saeed, R., Ali, S., Rizwan, M., Tauqeer, H.M. and Bukhari, S.A.H. (2017). Citric acid enhanced the antioxidant defense system and chromium uptake by *Lemna mino*r L. grown in hydroponics under Cr stress. *Environmental Science and Pollution Research*, 24: 17669–17678.

Sharma, S., Singh, B. and Manchanda, V. (2015). Phytoremediation: Role of terrestrial plants and aquatic macrophytes in the remediation of radionuclides and heavy metal contaminated soil and water. *Environmental Science and Pollution Research*, 22: 946– 962.

Shattar, S.F.A., Zakaria, N.A. and Foo, K.Y (2019). Preparation of a montmorillonite-derived adsorbent for the practical treatment of ionic and nonionic pesticides. *Journal of Material and Research Technology*, 8(5):4713–4724

Shi, J., Xiang, Z., PEngineering, T., Li, H., Huang, K., Liu, D. and Huang, T. (2020). Effects of melatonin-treated *Nasturtium offcinale* on the growth and cadmium accumulation of subsequently grown rice seedlings. *International Journal of Environmental and Analytical Chemistry*.

Vymazal, J. and Brezinova, T. (2015). The use of constructed wetlands for removal of pesticides from Agricultural runoff and drainage: A Review. *International Journal of Environment*, 75: 11–20.

Weldeslassie, T., Naz, H., Singh, B. and Oves, M. (2018). Chemical contaminants for soil, air and aquatic ecosystem. In: Modern Age Environmental Problems and Their Remediation (M. Oves, M. Z. Khan and I. M. Ismail, eds). Springer, Cham, pp. 1–22.

Zhang, K., Chen, Y.P., Zhang, T.T., Zhao, Y., Shen, Y., Huang, L., Guo, J.S. (2014). The logistic growth of duckweed (*Lemna minor*) and kinetics of ammonium uptake. *Environmental Technology*, 35: 562–567.

POTENTIALS OF GREEN SYNTHESIZED TITANIUM OXIDE (TIO_2) NANOPARTICLES AND POWDERED BANANA PEEL AS ALTERNATIVE ECOFRIENDLY FERTILIZERS IN COWPEA PRODUCTION

Okoh Thomas and Ajene Ewaoche
Department of Plant Science and Biotechnology, Joseph Sarwuan Tarka University Makurdi, 970101, Nigeria
*Corresponding Author's Email: Thomasokoh@gmail.com

ABSTRACT

This study investigated the potentials of green synthesized titanium oxide (TiO_2) nanoparticles and powdered banana peel as alternative ecofriendly fertilizers in cowpea production. The randomized experimental design was used where 4 levels of each treatment applied to the plant were replicated 5 times in a potted experiment. Data were collected on growth and yield parameters (pods, seeds, biomass, fiber and chlorophyll) as a measure of plant productivity. Pre-treatment investigation revealed significant differences in number of leaves only ($P<0.05$) at 20DAP. Titanium oxide applied at 400ppm gave the highest number of leaves in cowpea (24 leaves in pot) at 40DAP with significant effect. Treatments produced significant effects only on number of branches produced where banana peel applied at 5g and 7.5 produced the highest branches (13 branches per plant). Treatments had significant effects ($P<0.05$) on number of pods, pod length and total pod weight. Plants treated with titanium oxide nanoparticles at 800ppm produced the highest number of pods (4.4 pods), pod size (16.9cm) and pod weight (1.95g). Treatments produced significant effects on three of the four physiological yield parameters investigated. Banana peel applied at 5g and 10g significantly influenced wet biomass. Application of TIO_2 nanoparticle at 400 and 800ppm significantly improved the seed fiber content (0.8-0.9%). Both TIO_2 and banana peel had no effect on leaf chlorophyll content. Therefore, results showed that both titanium oxide nanoparticle and banana peel at varying concentrations positively impacted on some growth and yield components of cowpea. Titanium oxide nanoparticle (400-800ppm) increased number of leaves, number of pods, pod sizes, pod weight and seed fiber. Banana peel (5-7.5g) increased plant's branches and wet biomass. The two approaches are recommended to stakeholders to boost cowpea production.

Keywords: Titanium oxide nanoparticle, banana peel, ecofriendly fertilizers, cowpea

INTRODUCTION

Cowpea (*Vigna unguiculata* L. Walp) is an essential legume crop cultivated extensively in tropical and subtropical regions. Renowned for its high protein content and nutritional value, cowpea serves as a staple food and a significant source of income for millions of smallholder farmers. Additionally, cowpea's ability to fix atmospheric nitrogen enriches the soil, reducing the need for chemical fertilizers and promoting sustainable agricultural practices (Boukar *et al.,* 2016). The plant's adaptability to various soil types and resistance to drought conditions make it particularly valuable in arid and semi-arid regions where food security is a major concern (Timko *et al.,* 2007). Despite its importance, cowpea cultivation faces numerous challenges that limit its productivity. Nutrient deficiencies, poor soil fertility, and pest infestations are some of the primary factors that affect cowpea yields (Singh *et al.,* 2002; Timko *et al.,* 2007; Boukar *et al.,* 2016). Traditional methods of addressing these issues, such as the use of chemical fertilizers and pesticides,

often lead to environmental degradation and increased production costs. Therefore, there is a growing interest in exploring sustainable and innovative approaches to enhance cowpea productivity and ensure food security. One such innovative approach is the application of green synthesized nanoparticles as an ecofriendly approach. Nanotechnology has emerged as a promising field in agriculture, offering new solutions to age-old problems (Rastogi *et al.,* 2019).

Titanium oxide nanoparticles, in particular, have garnered attention due to their unique physicochemical properties. These nanoparticles can enhance photosynthetic efficiency, promote growth, and increase the overall resilience of plants (Nair *et al.*, 2010; Okwu *et al.,* 2021). The use of organic amendments presents an eco-friendly and sustainable method to improve soil fertility and plant productivity (Riaz *et al.,* 2018). Banana peels, a common agricultural waste, are rich in essential nutrients, including potassium, phosphorus, calcium, and magnesium (Oliveira *et al.*, 2013). These nutrients are crucial for plant growth and development. When decomposed, banana peels release these nutrients into the soil, enhancing its fertility and structure. The use of banana peels as a soil amendment not only reduces waste but also provides an inexpensive source of nutrients for plants, promoting sustainable agricultural practices.

The combined use of TiO_2 nanoparticles and banana peel amendments offers a novel approach to enhance cowpea productivity. While TiO_2 nanoparticles can improve the physiological processes of cowpea plants, banana peels can enrich the soil with essential nutrients, creating a synergistic effect that can potentially lead to higher yields. However, the combined effects of these treatments on cowpea productivity have not been extensively studied, presenting a significant research gap. Despite the potential benefits of TiO_2 nanoparticles and organic amendments, comprehensive work investigating their combined effects on the productivity of cowpea is lacking. Most existing research has focused on the individual effects of nanoparticles or organic amendments on various crops (Nair *et al.*, 2010; Rastogi *et al.*, 2019). Therefore, the present study was designed to determine the potentials of green synthesized titanium oxide (TiO_2) nanoparticles and powdered banana peel as alternative ecofriendly fertilizers in cowpea production.

Materials and methods

Study area

This study was carried out in the Makurdi metropolis of Benue State, which is located between Longitude 8°30'E and 8°30'E and Latitude 7°30'N and 7°43'N. The area encompasses a circular radius of approximately 16 km, covering a total land area of around 804 km². As of 2003, the estimated population of Makurdi was approximately 500,000 (The World Gazetteer, 2003). Positioned in the Lower Benue Valley, the terrain of the Local Government Area (L.G.A) is predominantly flat, with elevations ranging from 70 to 170 meters above sea level. The soils in Makurdi are generally classified as highly ferruginous tropical soils. The climate is characterized as tropical, sub-humid, with distinct wet and dry seasons. Farmers in the region engage in cowpea production in both small and large scale. It is among the most commonly cultivated crop that provides means of livelihood to people living in the study area.

Sample collection and preparation

Viable cowpea seeds (FUAMPEA-1 variety) were collected from the Seed Store of the Department of Plant Breeding and Science, Joseph Sarwuan Tarka University, Makurdi.

Ripe bananas purchased from Railway market, Makurdi. Peels were collected as wastes after eating the pod. The collected peels were thoroughly washed with distilled water, allowed to air-dry at room temperature for 48 hours and crushed into fine powder using a mechanical grinder. The powdered banana peels were then sieved through a 2 mm mesh to ensure uniform particle size for effective application as an organic manure (Dias *et a.,* 2019). Titanium oxide (TIO_2) powder was purchased from Emule Chemical Company Makurdi, Benue State. Arable soil, with pre-existing physicochemical properties, was collected from the Botanical Garden of the Joseph sarwuan Tarka University. Soil was collected, sieved and filled into Forty- Five pots (45), each with 25kg of the sieved soil, based on the experimental design, in preparation for seed sowing.

Green synthesis of titanium oxide (TIO_2) nanoparticle

The procedures outlined in Sathishkumar *et al.* (2010) and Fayomi *et al.* (2024) were followed. Fresh leaves of *Jatropha tanjorensis* were harvested, prepared, air dried and grinded using electric blender. Exactly 6g of the product was mixed with 100mL of double distilled water in a beaker, and heated at 80ºC for 1 hour. Exactly 1 mM of Titanium oxide (TIO_2) was added to the extract and allowed to stand for 1hr. The resulting paste was calcined in a furnace at 400 °C for about 2hr then the residual was washed by ethanol and distilled water several times. The powder was then heated at 100 °C to dry

Experimental design

The experiment was designed using a complete randomized method with powdered banana peel and titanium oxide nanoparticles as treatments, each with five levels replicated five times. The titanium oxide nanoparticle treatment was applied at 200,400,600 and 800ppm while banana peel had the following levels: 2.5, 10, 15 and 20g. There were 45 experimental units in total (40 treated pots and 5 control pots) (Olasan *et al.,* 2021).

Seed sowing

Three seeds were sown in each pot at 3cm depth and watered twice daily. Pots were protected from external influences using locally constructed nets.

Pre-treatment characterization of seedlings at 20 DAP (day after planting)

Seedlings were characterized at 20 DAP prior to treatment application. Standard description guide was used in determination of plant height, leaf length, leaf width and number of leaves (Ehlers and Hall, 1997; Boukar *et al.,* 2016).

Treatment applications

Treatments were applied at the base of the plant stem following the procedures employed by Olasan *et al.* (2021). Treatment levels specified in the experimental design were followed. Titanium oxide nanoparticle was dispensed using the micro pipette while powdered banana peel of known quantity was applied using the spatula.

Assessment of growth parameters at 40, 60 and 80 DAP

The procedures outlined in Ehlers and Hall (1997) and Boukar *et al.* (2016) were adopted. Plant height was determined using the meter rule in centimeter (cm). All the leaves and branches in the plant stands present in the pot were counted. Leaf length and breadth were measured in centimeter (cm). Stem diameter was determined by measuring the distance between the widest parts of the stem with a meter rule in centimeter (cm).

Flowering and biological yield

The procedures outlined in Boukar *et al.* (2016) was used. Day to flowering was determined by recording the day the plant first produced flower after seed sowing. The number of pods produced by the plant was counted. The pod length was determined using a meter rule the stalk or peduncle in centimeter (cm). After maturity and harvesting, number of seeds present in each pod was counted per pot. Pod weight and seed weight were determined using the digital weighing balance and recorded in gram (g).

Determination of physiological yield

Wet and dry plant biomass

One fresh mature plant collected from each pot was weighed using the weighing balance after soil had been removed from the root. This was taken as the wet plant biomass (g). The plant was oven dried in the oven at 200°C for 12 hours to remove the moisture content. This was recorded as the dry plant biomass (g) (AOAC, 2000).

Determination of fiber

The fiber content was determined using the neutral detergent fiber (NDF) method (AOAC, 2000). Approximately 1 gram of dried and ground plant sample was weighed and placed in a filter bag, which was then submerged in a neutral detergent solution. The sample was heated for one hour at 100°C to dissolve soluble components, leaving the fibrous material. After cooling, the filter bag was rinsed with hot water and dried in an oven at 105°C for 24 hours. The dried sample was then weighed, and the fiber content was calculated as the percentage of the initial sample weight that remained after the treatment. The fiber content was determined using the formula:

Fiber Content (%) = Weight of dried residue (g) / Initial sample weight (g) × 100

Determination of chlorophyll

This was determined according using standard method of AOAC (2000). A quantity of 0.1 g of fresh leaves of Cowpea seed was collected and placed into a test tube filled with 10 ml of acetone. The test tube was then incubated in a dark environment at 4°C for 24 hours to generate a green extract. Subsequently, the green extract was transferred to a cuvette for spectrophotometric measurement, where the absorbance was recorded at 663 nm for chlorophyll a and at 645 nm for chlorophyll b. The Chlorophyll content was determined using the formula:

Total Chlorophyll Content: Total Chl (mg/g) = (8.2 × A663) + (20.2 × A645)

Statistical analysis

Minitab 17 software was used for data analysis. One-way analysis variance was used to determine the variation in performances among the treatments. Mean separation was done using the Fisher LSD method for significant differences at $p \leq 0.05$.

Results

Preliminary characterization of growth parameters of cowpea 20 DAP before treatment

Table 1 gives the preliminary characterization of growth parameters of cowpea plants before treatment at 20 DAP (day after planting). There were no significant differences ($P>0.05$) in plant heights, number of plants in pots and leaf sizes among the growth parameters. Number of leaves differed in potted plants ($P<0.05$) at 20 DAP prior to treatment application

Effects of titanium oxide nanoparticles and banana peel manure on the growth parameters of cowpea plant 40 DAP

Table 2 gives the effect of titanium oxide nanoparticles and powdered banana peels as organic manure at different concentration on

the growth parameters of cowpea at 40 DAP. Treatments had significant effects (P<0.05) on number of plants in pots, number of leaves and leaf length only. Titanium oxide applied at 400ppm gave the highest number of leaves in cowpea (24 leaves in pot). The control pot contained plants with the longest leaves (9.6cm) whereas leaf length tends to reduce in all treated plants.

Effects of titanium oxide and banana peel manure on growth parameters of cowpea 60 DAP

Table 3 gives the effect of titanium oxide nanoparticles and powdered banana peels as organic manure (OG) at different concentration on the growth parameters of cowpea 60 DAP. Treatments produced significant effects only on number of branches produced where banana peel applied at 5g and 7.5 produced the highest branches (13 branches per plant).

Table 1. Effects of nano and organic manure on growth parameters at 20 DAP

Treatments	Plant height at day 20(cm)	Number of plants at day 20	Number of leaves at day 20	Leaf Length at day 20 (cm)	Leaf width at day 20 (cm)
Pot 1	23.50 ±8.59	2.80 ±0.44	14.00 ±1.58^{a}	9.48 ±1.47^{ab}	5.02 ±3.00
Pot 2	23.90 ±11.30	2.80 ±0.44	11.40 ±1.94^{cd}	10.00 ±0.83^{a}	4.42 ±1.65
Pot 3	24.40 ±5.81	2.80 ±0.44	6.20 ±1.92^{d}	7.96 ±2.21^{bc}	3.28 ±0.44
Pot 4	22.30 ±4.26	3.00 ±0.00	9.00 ±3.74^{ab}	6.94 ±1.57^{c}	4.76 ±0.80
Pot 5	22.16 ±2.27	3.00 ±0.00	7.60 ±3.65^{bcd}	9.50 ±1.13^{ab}	4.72 ±1.03
Pot 6	27.90 ±4.70	2.80 ±0.44	7.20 ±2.04^{d}	9.94 ±1.48^{ab}	3.68 ±1.52
Pot 7	26.10 ±4.13	3.00 ±0.00	7.40 ±0.89^{cd}	9.52 ±1.58^{a}	5.36 ±1.30
Pot 8	22.00 ±4.82	2.80 ±0.44	8.60 ±1.09^{bcd}	8.20 ±1.02^{abc}	5.06 ±1.01
Pot 9	21.80 ±2.74	2.80 ±0.44	10.20 ±1.34^{bc}	7.94 ±1.98^{bc}	5.96 ±0.79
P -VALUE	0.77 (P>0.05)	0.92 (P>0.05)	0.00 (P<0.05)	0.02 (P<0.05)	0.16 (P>0.05)
LSD	NS	NS	1.23	NS	NS

LSD indicates Least Significant Difference (p≤0.05); OG: Organic Manure treatment, NA: Nano treatment; NS = Not significant

Table 2. Effects of nano and organic manure on growth parameters at 40 DAP

Treatments	Plant height at day 40 (cm)	Number of plant at day 40	Number of leaves at day 40	Leaf Length at day 40 (cm)	Number of branches at day 40	Leaf width at day 40 (cm)	Stem diameter at day 40 (cm)
C	27.30 ±6.72	3.00 ±0.00^{a}	17.30 ±3.90^{bcd}	9.60 ±1.93^{a}	8.00 ±1.58	5.80 ±0.53	2.50 ±0.20
NA200ppm	36.38 ±11.36	3.00 ±0.54^{b}	20.40 ±2.86^{bcd}	8.54 ±1.37^{ab}	7.60 ±1.51	5.66 ±0.58	2.06 ±0.23
NA400ppm	35.18 ±3.53	3.00 ±0.00^{a}	24.40 ±9.40^{a}	8.58 ±0.73^{ab}	6.60 ±2.07	6.78 ±1.04	2.12 ±2.54
NA600ppm	33.66 ±3.43	2.60 ±0.54^{b}	18.50 ±3.39^{bc}	8.50 ±1.45^{ab}	7.40 ±1.81	4.98 ±1.06	2.18 ±0.19
NA800ppm	30.20 ±5.32	2.60 ±0.00^{a}	15.80 ±4.12^{bcd}	7.80 ±0.80^{abc}	7.40 ±0.89	6.04 ±0.77	2.14 ±0.24
OG2.5g	34.42 ±5.30	3.00 ±0.00^{a}	19.00 ±5.22^{bcd}	7.80 ±2.03^{bc}	7.60 ±1.81	6.12 ±0.68	2.08 ±0.34
OG5.0g	33.74 ±7.48	3.00 ±0.00^{a}	17.20 ±1.51^{bcd}	7.86 ±0.98^{abc}	7.20 ±1.64	6.30 ±1.19	3.48 ±0.31
OG7.5g	30.96 ±1.84	3.00 ±0.00^{a}	13.60 ±0.54^{cd}	6.26 ±1.04^{c}	6.20 ±1.09	6.80 ±0.92	3.20 ±2.80
OG10.0g	33.30 ±4.12	3.00 ±0.00^{a}	12.40 ±0.54^{ab}	6.18 ±1.81^{c}	6.20 ±1.30	7.14 ±1.19	2.34 ±0.45
P -VALUE	0.40 (P>0.05)	0.03 (P<0.05)	0.00 (P<0.05)	0.00 (P<0.05)	0.56 (P>0.05)	0.23 (P>0.05)	0.57 (P>0.05)
LSD	NS	2.22	3.66	2.78	NS	NS	NS

LSD indicates Least Significant Difference ($p \leq 0.05$); OG: Organic Manure treatment, NA: Nano treatment; NS = Not significant

Effects of titanium oxide and banana peel manure on biological yield parameters of cowpea

Table 4 gives the effects of titanium oxide nanoparticles and powdered banana peels on flowering, pod and seed yield of cowpea. Flowering time (32-34 days) was not influenced by treatment application. Treatments had significant effects (P<0.05) on number of pods, pod length, total pod weight and total seed weight. Plants treated with titanium oxide nanoparticles at 800ppm produced the highest number of pods (4.4 pods), pod size (16.9cm) and pod weight (1.95g). Banana peel applied at 10g produced the same effect on pod weight (1.9) as TIO^{2} applied at 800ppm. The highest seed weight (1.2g) was recorded in the control treatment.

Table 3. Effects of nano and organic manure on growth parameters at 60 DAP

Treatments	Plant height at day 60 (cm)	Number of plant at day 60	Number of leaves at day 60	Leaf Length at day 60 (cm)	Number of branches at day 60	Leaf width at day 60 (cm)	Stem diameter at day 60 (cm)
C	30.58 ±7.52	3.00 ±0.00	18.80 ±4.15	9.94 ±1.77	11.00 ±2.12^{bc}	5.96 ±0.58	2.62 ±0.16
NA200ppm	34.12 ±5.24	3.00 ±0.54	18.00 ±3.16	8.66 ±1.38	9.60 ±1.34^{c}	6.48 ±0.79	2.20 ±0.22
NA400ppm	33.84 ±5.86	2.60 ±0.00	19.60 ±3.70	8.02 ±0.73	11.40 ±1.81^{abc}	7.02 ±1.06	2.34 ±0.32
NA600ppm	33.50 ±3.65	2.60 ±0.54	23.20 ±9.01	9.60 ±1.36	11.60 ±1.94^{abc}	6.38 ±0.61	2.32 ±0.14
NA800ppm	36.00 ±6.33	2.80 ±0.44	19.80 ±4.38	7.82 ±0.89	10.80 ±1.30^{bc}	5.68 ±0.79	2.24 ±0.24
OG2.5g	33.12 ±4.93	3.00 ±0.00	26.20 ±3.61	8.02 ±1.32	12.40 ±1.51^{ab}	5.90 ±0.77	2.16 ±0.34
OG5.0g	35.98 ±7.92	3.00 ±0.00	21.00 ±4.98	9.02 ±1.13	13.40 ±1.51^{a}	6.88 ±1.23	2.12 ±0.32
OG7.5g	31.56 ±1.91	2.80 ±0.44	27.00 ±9.70	8.48 ±0.99	13.40 ±1.81^{a}	7.02 ±0.88	2.24 ±0.16
OG10.0g	37.48 ±3.14	2.80 ±0.44	24.80 ±4.76	8.24 ±1.22	12.80 ±1.92^{ab}	7.38 ±1.46	2.44 ±0.45
P -VALUE	0.60 (P>0.05)	0.42 (P>0.05)	0.13 (P>0.05)	0.11 (P>0.05)	0.01 (P<0.05)	0.08 (P>0.05)	0.18 (P>0.05)
LSD	NS	NS	NS	NS	1.11	NS	NS

LSD indicates Least Significant Difference (p≤0.05); OG: Organic Manure treatment, NA: Nano treatment; NS = Not significant

Effects of titanium oxide nanoparticle and banana peel on physiological yield of cowpea

Treatments produced significant effects on three of the four physiological yield parameters investigated. Banana peel applied at 5g and 10g significantly yielded the highest wet biomass (>40g) while the lowest biomass was recorded in control plants (without any treatment). Application of TIO_2 nanoparticle did not improve plant wet biomass (Figure 1). Banana peel applied at 5g significantly yielded the highest dry biomass (<10g) (Figure 2). Application of TIO_2 nanoparticle at 400ppm significantly improved the seed fiber content (0.9%) followed by 800ppm level of treatment (0.8%) as shown in figure 3. Treatment application did not enhance leaf chlorophyll content except TIO_2 at 200ppm that produced almost the same result as the control treatment (Figure 4).

Table 4. Effects of nano and organic manure on flowering and yield parameters

Treatments	Day to flowering	Number of pods	Pod length (cm)	Number of seeds per pod	Total Pod weight (g)	Total seed weight
C	34.80 ±4.66	3.40 ±0.54^{cde}	15.10 ±1.74^{ab}	11.40 ±1.14	1.45 ±0.11^{de}	1.20 ±0.00^{a}
NA200ppm	32.20 ±1.92	4.00 ±0.00^{abc}	14.10 ±2.71^{abc}	11.40 ±4.83	1.24 ±0.00^{f}	1.16 ±0.15^{ab}
NA400ppm	32.40 ±3.65	3.20 ±0.44^{de}	12.80 ±3.44^{bc}	12.20 ±1.64	1.33 ±0.24^{ef}	1.06 ±0.05^{cde}
NA600ppm	32.60 ±2.30	4.20 ±1.09^{ab}	11.96 ±2.62^{c}	14.00 ±1.58	1.80 ±0.11^{ab}	1.10 ±0.00^{bcd}
NA800ppm	34.00 ±3.39	4.40 ±0.89^{a}	16.90 ±1.43^{a}	11.80 ±1.92	1.95 ±0.11^{a}	1.14 ±0.08^{abc}
OG2.5g	33.20 ±4.21	4.00 ±0.00^{abc}	13.20 ±1.92^{bc}	13.40 ±2.07	1.71 ±0.08^{bc}	1.02 ±0.04^{e}
OG5.0g	34.20 ±1.30	3.80 ±0.44^{abc}	15.60 ±2.07^{ab}	14.00 ±1.58	1.59 ±0.08^{cd}	1.04 ±0.05^{de}
OG7.5g	30.80 ±2.39	3.60 ±0.00^{cde}	14.20 ±2.39^{abc}	11.80 ±1.92	1.80 ± 0.11^{ab}	1.10 ±0.00^{bcd}
OG10.0g	32.80 ±2.28	3.00 ±0.54^{e}	13.20 ±1.78^{bc}	12.20 ±1.92	1.90 ±0.17^{a}	1.12 ±0.04^{ab}
P -VALUE	0.63 (P>0.05)	0.00 (P<0.05)	0.00 (P<0.05)	0.42 P>0.05)	0.00 (P<0.05)	0.00 (P<0.05)
LSD	NS	4.78	6.35	NS	1.64	5.5

LSD indicates Least Significant Difference ($p \leq 0.05$); OG: Organic Manure treatment, NA: Nano treatment; NS = Not significant

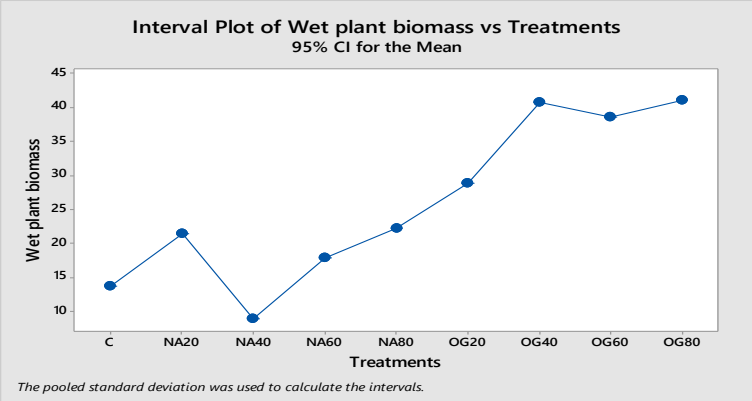


Fig. 1. Interval plot of wet plant biomass vs treatments (95% Cl for the mean)

Keys:NA20 = 200ppm nanoparticle; NA40 = 400ppm nanoparticle, NA60 = 600ppm nanoparticle, NA80 = 800ppm nanoparticle; OG20 = 2.5g organic banana peel; OG40 = 5.0g organic banana peel; OG60 = 7.5g organic banana peel, OG80 = 10g organic banana peel

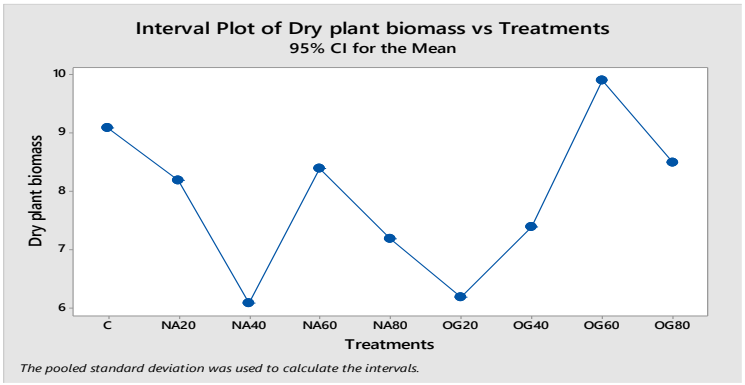


Fig. 2. Interval plot of dry plant biomass vs treatments (95% Cl for the mean)

Keys:NA20 = 200ppm nanoparticle; NA40 = 400ppm nanoparticle, NA60 = 600ppm nanoparticle, NA80 = 800ppm nanoparticle; OG20 = 2.5g organic banana peel; OG40 = 5.0g organic banana peel; OG60 = 7.5g organic banana peel, OG80 = 10g organic banana peel

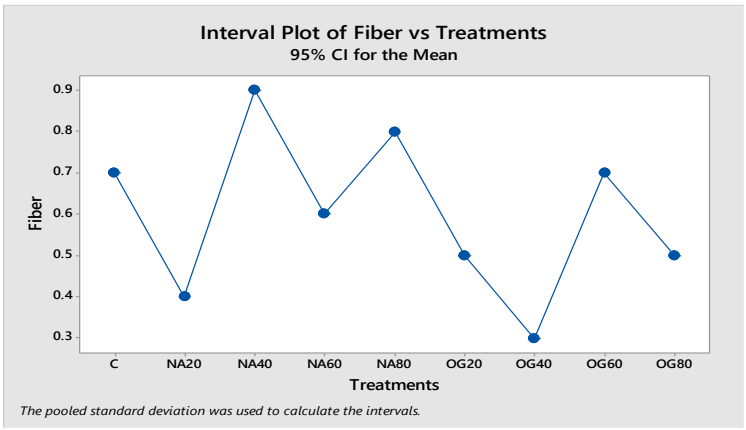


Fig. 3. Interval plot of fiber vs treatments (95% Cl for the mean)

Keys:NA20 = 200ppm nanoparticle; NA40 = 400ppm nanoparticle, NA60 = 600ppm nanoparticle, NA80 = 800ppm nanoparticle; OG20 = 2.5g organic banana peel; OG40 = 5.0g organic banana peel; OG60 = 7.5g organic banana peel, OG80 = 10g organic banana peel

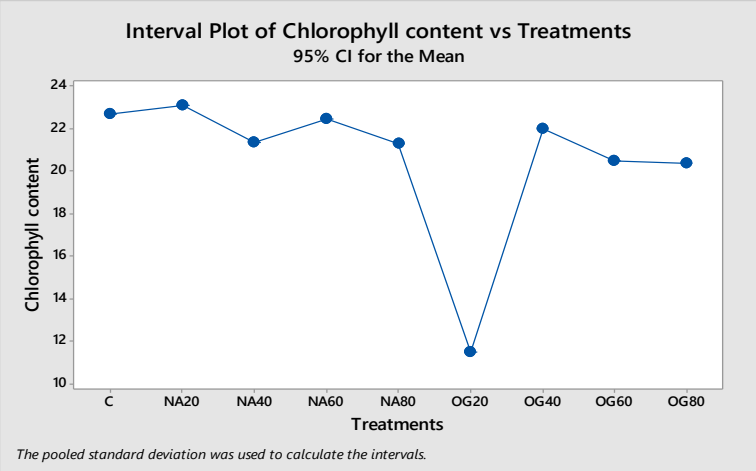


Fig. 4. Interval plot of chlorophyll content vs treatments (95% Cl for the mean)
Keys:NA20 = 200ppm nanoparticle; NA40 = 400ppm nanoparticle, NA60 = 600ppm nanoparticle, NA80 = 800ppm nanoparticle; OG20 = 2.5g organic banana peel; OG40 = 5.0g organic banana peel; OG60 = 7.5g organic banana peel, OG80 = 10g organic banana peel

DISCUSSION

Pre-treatment investigation revealed significant differences in number of leaves only at 20DAP. The observed differences may be attributed to environmental influences such as responses to light direction and water uptake but not inherent variability in the genetic make up since only one variety of cowpea (FUAMPEA-1) was used. Therefore, significant effects observed in other vegetative features, other than number of leaves, due to treatments increase the validity of conclusion in this work. At 40DAP, titanium oxide applied at 400ppm gave the highest number of leaves. Due to the results obtained in preliminary assessment where natural variability was observed in number of leaves, the effect produced by titanium oxide on this parameter at 40DAP cannot be attributed to the applied treatment alone.

Results showed efficacy of banana peel treatment in increasing the number of branches produced by cowpea. This is an important vegetative trait in cowpea productivity as branching is closely linked to folder production, which may be a top priority in livestock management. Although treatment had no effects on plant height, the outcome seems not important in cowpea because the plant habit of many varieties of cowpea is more of decumbent and prostrate than erect. Therefore, branching is a more valuable attribute than height. In this study, organic application of banana peels a 5g and 7g has helped to increase branching. This aligns with findings by Adeyemi *et al.* (2020), who reported improved vegetative growth performances with the application of organic amendments, emphasizing the potential of utilizing organic materials in crop production. Result deviated from the findings of Kumar *et al.* (2023) found that varying concentrations of titanium dioxide nanoparticles significantly affected plant height and leaf area in some leguminous plants.

Also, Okwu *et al.* (2021) found that the application of titanium dioxide nanoparticles significantly increased plant height and biomass in legumes. The divergence in results may be attributed to differences in experimental conditions, including soil type, plant variety, application methods or residual factors.

Titanium oxide nanoparticle has shown to be effective as biological yield enhances at 800ppm where it influenced pod quantity, pod sizes and weight. This is consistent with the findings of Kumar *et al.* (2023) who demonstrated the significance of nanoparticle as yield enhancers in legumes. However, the present investigation did not establish any improvement on flowering time attributed to titanium dioxide nanoparticles.

Among the physiological yield parameters, banana peel applied at 5g and 10g significantly influenced wet biomass while TIO_2 nanoparticle at 400 and 800ppm significantly improved the seed fiber content. Here, the two treatments (nanoparticle and organic manure) are valuable in improving the physiological and biochemical attributes of cowpea. Biomass describes the weight of the crop as a function of the quantity of water and protoplasmic component of the plant system. High biomass may translate into plant wellness, high vigour, improved nutrient uptake and productivity. This aligns with some reports on the efficacy of organic amendments in boosting plant performances (Adeyemi *et al.,* 2020; Mofeed *et al.*, 2022). This is consistent with the findings of Oliveira *et al.* (2013) who reported high nutrient uptake by maize plants fertilized with decomposed and non-decomposed residues of banana plant stems. Banana peels, a common agricultural waste, are rich in essential nutrients, including potassium, phosphorus, calcium, and magnesium (Oliveira *et al.*, 2013). These nutrients are crucial for plant growth and development. The effects of TIO2 nanoparticle in fiber contents of the seed suggests the potentials of this treatment in enhancing the nutritional values of the seeds. This finding aligns with some reports on the application of nanoparticle in improving the nutritional quality of cereals (Mousavi *et al.,* 2020).

Conclusion

Therefore, results showed that both titanium oxide nanoparticle and babana peel at varying concentrations positively impacted on some growth and yield components of cowpea. Titanium oxide nanoparticle (400-800ppm) increased number of leaves, number of pods, pod sizes, pod weight and seed fiber. Banana peel (5-7.5g) increased plant's branches and wet biomass. The specified levels of treatments are recommended to boost cowpea production.

REFERENCES

Adeyemi, A., Olawale, F. and Adebayo, M. (2020). Effects of organic amendments on growth and yield of cowpea (*Vigna unguiculata*). *Journal of Agricultural Science* 12(3): 150-158.

AOAC (2000). Official Method of Analysis. Association of Official Analytical Chemists, Washington, DC, USA. 17th edition.

Boukar, O., Belko, N., Chamarthi, S., Togola, A., Batieno, J., Owusu, E. Y., Haruna, M., Diallo, S., Umar, M. L., Olufajo, O. and Fatokun, C. (2016). Cowpea (*Vigna unguiculata*): Genetics, genomics and breeding. *Plant Breeding* 135(2): 1-12.

Dias, B. O., Silva, C. A., Higashikawa, F. S., Roig, A., Sánchez-Monedero, M. A. and De La Rosa, J. M. (2019). Use of biochar as bulking agent for the composting of poultry manure: Effect on organic matter degradation, humification and compost quality. *Journal of Environmental Management* 231: 1059-1067.

Ehlers, J. D. and Hall, A. E. (1997). Cowpea (*Vigna unguiculata* L. Walp.). *Field Crops Research* 53(1-3): 187-204.

Fayomi, O.M., Olasan, J.O., Aguoru, C.U., Anjorin, T.S. and Sule, A.M. (2024). Effect of Biosynthesized ZnO Nanoparticles Derived from *Jatropha*

tajonensis on the yield of Bambara groundnut (*Vigna subterranean* L.). *African Journal of Agriculture and Allied Sciences* 4(1): 192-212

Kumar, R., Verma, A. and Gupta, N. (2023). Impact of titanium dioxide nanoparticles on the growth of leguminous crops. *Plant Growth Regulation* 99(2): 207-218.

Mofeed, J. M., Al-Mutairi, K. A. and Saleh, M. M. (2022). Influence of organic amendments on biomass and chlorophyll content in legumes. *Journal of Plant Nutrition* 45(4): 552-564.

Mousavi Kouhi, S. M., Lahouti, M., Ganjeali, A. and Entezari, M. H. (2020). Investigating the effect of titanium dioxide nanoparticles (TiO2 NPs) on growth and biochemical characteristics of barley under salinity stress. *Journal of Plant Nutrition* 43(11): 1643-1655.

Nair, R., Varghese, S. H., Nair, B. G., Maekawa, T., Yoshida, Y. and Kumar, D. S. (2010). Nanoparticulate material delivery to plants. *Plant Science* 179(3): 154-163.

Okwu, D. E., Ogbonna, J. C. and Ndukwu, B. I. (2021). The role of titanium dioxide nanoparticles in enhancing growth parameters of legumes. *International Journal of Agronomy and Agricultural Research,* 16(1): 25-34.

Olasan J.O., Aguoru, C.U., Omoigui L.O. and Awoji, P. (2021). Effects of Animal Based Manures (Bone Meal, Earthworm Cast and Crab Shell) on the Growth of Groundnut (*Arachis hypogaea* L.). *Journal of Agricultural Science and Engineering* 7(3): 43-4

Oliveira, L. M., Santos, V. D. and Fernandes, S. A. (2013). Nutrient uptake by maize plants fertilized with decomposed and non-decomposed residues of banana plant stems. *Revista Brasileira de Ciência do Solo* 37(1): 245-254.

Rastogi, A., Zivcak, M., Sytar, O., Kalaji, H. M., He, X., Mbarki, S. and Brestic, M. (2019). Impact of metal and metal oxide nanoparticles on plant: A critical review. *Frontiers in Chemistry*, 7: 767.

Riaz, M., Ahmed, M., Zhang, M., Wu, Y. and Wu, H. (2018). Effect of organic amendments on soil suppressiveness to Fusarium wilt of cucumber in soils with different cropping histories. *European Journal of Plant Pathology* 150(2): 501-513.

Sathishkumar, T., Karthikeyan, S. and Ramesh, S. (2010). Synthesis of Silver Nanoparticles from Plant Extracts: An Eco-Friendly Approach. *Journal of Nanotechnology*, 2010, Article ID 762473.

Singh, B. B., Chambliss, O. L. and Sharma, B. (2002). Recent advances in cowpea breeding. In Challenges and Opportunities for Enhancing Sustainable Cowpea Production (pp. 22-40). *International Institute of Tropical Agriculture* (IITA).

Timko, M. P., Ehlers, J. D. and Roberts, P. A. (2007). Cowpea. In C. Kole (Ed.), Genome Mapping and Molecular Breeding in Plants, *Springer* 3:49-67).

World Gazetteer. (2003). *World Gazetteer: A comprehensive resource for world demographics and geography*. Retrieved from www.world-gazetteer.com

ENVIRONMENTAL CONCERNS ARISING FROM EXHAUST EMISSIONS OF ENGINES OPERATING ON PETROL, DIESEL AND BIODIESEL BLENDS PRODUCED FROM WASTE COOKING OIL IN SOUTH EAST, NIGERIA

ONWUGBUTA NNEKA
Department of Biology, Ignatius Ajuru University of Education, Port Harcourt
Correspondence: nneka.onwugbuta@iaue.edu.ng

ABSTRACT

Analysis of exhaust emissions from engines fueled with petrol, diesel, and biodiesel blends was conducted. Biodiesel was produced from waste cooking oil via transesterification, and its physicochemical properties were determined using ASTM methods. Exhaust emissions (CO, CO_2, O_2, and NO_x) from petrol and diesel vehicles, as well as small and large generators, were measured using a Bacharach Portable Combustion Analyzer. Petrol and diesel were blended with biodiesel (B5–B40) and tested in three generators and one motorcycle. Biodiesel showed acceptable fuel properties, including 0.05% moisture, 0.90 specific gravity, 0.22 mgKOH/g acid value, 155°C flash point, 1.90 mm^2/s viscosity, and 34,400 kJ/kg calorific value. Among petrol vehicles, mini-buses emitted the highest CO and CO_2, while small cars emitted the highest NO_x. Diesel vehicles produced lower CO and CO_2 but significantly higher NO_x than petrol vehicles. CO emissions from all vehicles exceeded Nigeria's adopted European emission standards. Small generators emitted more CO, whereas large generators emitted more CO_2 and NO_x. Biodiesel blends consistently reduced CO and CO_2 emissions but generally increased NO_x emissions, particularly in motorcycles and diesel generators. The findings indicate that current vehicular and generator emissions in Nigeria remain above acceptable limits, posing significant environmental and public health risks and highlighting the need for stricter emission control measures and cleaner fuel alternatives. Waste cooking oil, which is abundantly available, serves as an excellent feedstock for biodiesel production. Blending petrol or diesel with biodiesel derived from this feedstock has been shown to reduce exhaust emissions. The biodiesel-diesel blend decreased CO2 and CO emissions in diesel generators which is friendly to the ecosystem.

Keywords: Environment, Exhaust Emissions, Petrol, Diesel, Biodiesel, Waste, Cooking Oil

INTRODUCTION

The rapid growth in global energy demand, industrialization, and urbanization has significantly increased the consumption of fossil fuels, particularly petroleum-derived fuels such as petrol and diesel (Ikechukwu *et al.*, 2026). These fuels remain the dominant energy sources for transportation, power generation, and industrial operations due to their high energy density, established infrastructure, and widespread availability. However, the extensive reliance on fossil fuels has contributed substantially to environmental degradation through the emission of greenhouse gases (GHGs) and other harmful pollutants. The combustion of conventional petrol and diesel engines releases carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur dioxide (SO_2), hydrocarbons (HC), particulate matter (PM), and other toxic compounds that adversely affect air quality, ecosystem health, and human well-being (Itodo *et al.*, 2021). These emissions have been identified as major contributors to climate change, acid rain, photochemical smog, respiratory diseases, cardiovascular disorders, and premature mortality (Kean *et al.*, 2003). The transportation sector accounts

for a significant proportion of global atmospheric pollution, with internal combustion engines being one of the largest sources of urban air contaminants. In many developing countries, including Nigeria, the problem is exacerbated by the increasing number of aging vehicles, poor engine maintenance practices, inadequate emission control technologies, and the continued use of low-quality petroleum products (Ekpo *et al.*, 2025). Consequently, vehicular emissions have become one of the leading environmental challenges facing rapidly expanding urban centers. Addressing these emissions has become an international priority, prompting researchers and policymakers to explore cleaner and renewable alternatives capable of reducing dependence on fossil fuels while maintaining engine performance. Among the various renewable fuel alternatives, biodiesel has emerged as one of the most promising substitutes for conventional diesel fuel. Biodiesel is a renewable, biodegradable, non-toxic fuel produced through the transesterification of vegetable oils, animal fats, or waste oils into fatty acid methyl esters (FAME). Unlike fossil diesel, biodiesel contains virtually no sulfur, possesses a higher oxygen content, exhibits better lubricating properties, and generally produces lower emissions of particulate matter, carbon monoxide, and unburned hydrocarbons during combustion. Furthermore, biodiesel is compatible with most compression ignition engines with little or no engine modification, making it an attractive option for reducing environmental pollution (Fazal *et al.*, 2011). In recent years, waste cooking oil (WCO) has attracted considerable attention as a sustainable feedstock for biodiesel production. The utilization of WCO addresses two important environmental concerns simultaneously: the management of waste cooking oil and the production of renewable energy. Disposal of waste cooking oil into drainage systems and water bodies causes blockage of sewage systems, contamination of aquatic ecosystems, and increased wastewater treatment costs (Dorado *et al.*, 2003). Converting this waste into biodiesel not only minimizes environmental pollution but also reduces the cost of biodiesel production, since feedstock accounts for a substantial proportion of total production expenses. Moreover, the use of waste-derived biodiesel supports the principles of the circular economy by transforming waste materials into valuable energy resources. Several studies have evaluated the combustion characteristics, engine performance, fuel consumption, and emission profiles of biodiesel produced from various feedstocks. Most investigations have reported reductions in carbon monoxide, hydrocarbons, smoke opacity, and particulate emissions when biodiesel or biodiesel blends are used in diesel engines (Umudi *et al.*, 2025). However, some studies have also observed slight increases in nitrogen oxide emissions depending on engine operating conditions, biodiesel composition, and blending ratios. Similarly, research has shown that blending biodiesel with conventional diesel at different proportions (such as B5, B10, B20, and B50) can optimize engine efficiency while minimizing undesirable emissions. Comparatively fewer studies have investigated blended fuels involving petrol engines, despite the growing interest in renewable fuel integration across different engine types (Obruche *et al.*, 2019). In Nigeria, increasing urbanization, population growth, and the continuous importation of used vehicles have intensified concerns regarding vehicular air pollution. The South-East geopolitical zone, comprising major commercial and industrial cities such as Enugu, Onitsha, Aba, Owerri, Abakaliki, and Nnewi, experiences high traffic density and substantial fuel consumption due to extensive

commercial transportation and manufacturing activities. These urban centers are increasingly exposed to deteriorating air quality associated with exhaust emissions from petrol- and diesel-powered engines (USEPA, 2000). Despite this growing environmental challenge, there is limited locally generated data on the comparative exhaust emission characteristics of engines fueled with conventional petrol, diesel, and biodiesel blends produced specifically from waste cooking oil under operating conditions representative of South-East Nigeria. This study addresses this gap by systematically analyzing and comparing the exhaust emissions of engines fueled with petrol, diesel, and their biodiesel blends produced from waste cooking oil. The findings will provide region-specific scientific evidence to support cleaner fuel policies, promote sustainable waste management, improve air quality, and encourage the adoption of renewable fuels for environmentally friendly transportation in Nigeria.

MATERIALS AND METHOD

Sample Collection

The used cooking oil was sourced from Chitis restaurant located at the University of Nigeria, Nsukka. Subsequently, the waste cooking oil was poured into a clean plastic bottle. It was then filtered to eliminate any food particles. The filtered waste cooking oil was collected in a clean conical flask for use in the study.

Characterization of Waste Cooking Oil

Specific Gravity

To ascertain the specific gravity of the oil, a specific gravity bottle was utilized. A clean and dry specific gravity bottle with a capacity of 25 mL was first weighed (W0), then filled with water, stopper inserted, and reweighed to obtain (W1). After washing and drying the bottle, the water was replaced with oil, and the weight was recorded as (W2) (Obruche *et al.*, 2025). The formula for specific

$$p.gr = \frac{Mass\ of\ the\ oil}{Mass\ of\ an\ equal\ volume\ of\ water}$$

Moisture Content

A total of 40g of the purified oil was weighed and subsequently dried in an oven at 80°C for a duration of 7 hours, with weight measurements taken every 2 hours. This process was repeated until a stable weight was achieved. After each 2-hour interval, the oil was removed from the oven and placed in a desiccator for 30 minutes to cool before being re-weighed. The percentage of moisture in the oil was calculated using the following formula:

$$Moisture = 100 \times \frac{W1 - W2}{W1}$$

Where;

W1 = Initial weight of the oil prior to drying

W2 = Weight of the oil post-drying.

Determination of Viscosity

A clean, dried viscometer with a flow time exceeding 200 seconds for the fluid under examination was selected. The oil was filtered through a sintered glass (fine mesh screen) to remove dust and other solid particles present in the oil. The viscometer was filled with the oil by inverting the thinner arm into the oil and applying suction until the liquid reached the upper timing mark of the viscometer. The instrument was then returned to its upright position. The viscometer was placed in a holder and immersed in a constant temperature bath set at 29°C, allowing approximately 10 minutes for the oil to equilibrate to this temperature. Suction was then applied to the thinner arm to draw the sample slightly above the upper timing mark. The efflux time was recorded by timing the flow of the sample as it moved freely from the upper timing mark to the lower timing mark.

Acid Value/Free Fatty Acid (FFA)

Precisely 2g of the oil was placed into a beaker. A neutral binary solvent, consisting of a mixture of petroleum ether and ethanol, was prepared, and 50 ml of this solvent was added to the oil sample. The mixture was stirred vigorously for 30 minutes. In a separate beaker, 0.56g of potassium hydroxide (KOH) pellets was measured, and a 0.1M KOH solution was prepared. Three drops of phenolphthalein indicator were added to the sample, which was then titrated against the 0.1M KOH until a pink color was observed and remained for 15 minutes (Umudi *et al.*, 2025).

AV = Woil × A × N × 1.0056

Where;

V= volume of standard alkali used

N= normality of standard alkali used

Woil = weight of oil used

FFA = AV × 0.503

Peroxide Value

One gram (1g) of an oil sample was combined with 1g of potassium iodide and 20ml of glacial acetic acid chloroform in a 2:1 ratio. The mixture was then boiled for one minute. The heated solution was subsequently transferred into a flask containing 20ml of a 5% potassium iodide solution. A few drops of starch solution were added, and the mixture was titrated with 0.025 N Na2S2O3 until a faint yellow color was observed. Following this, one milliliter (1ml) of starch indicator was introduced, and the titration continued until the blue color vanished (Abeokuta *et al.*, 2025).

$$Peroxide\ Value = \frac{Molar\ equivalent}{Weight\ of\ oil\ sample}$$

Iodine Value

Approximately 0.5g of the sample was dissolved in 10ml of chloroform within a conical flask. To this, 25ml of the Hanus solution was added, and the flask was corked. The mixture was then placed in a desiccator for 30 minutes in the dark. A blank (b) was also prepared under identical conditions. Upon completion of the reaction in the flask, 15ml of 10% potassium iodide (KI) solution and 10ml of distilled water were added to each flask and mixed gently. The contents of both flasks were titrated with 0.1M Na2S2O3 until a pale yellow color was achieved, followed by the addition of 2ml of starch solution indicator. The titration continued until the blue-black color was entirely eliminated (Erienu *et al.*, 2022).

$$IV = \frac{0.1269\ x\ (B\ -\ A)\ x\ N\ x\ 100}{Woil}$$

B = volume of sodium thiosulphate utilized in the blank titration.

A = volume of sodium thiosulphate used in the titration with oil.

N = normality of sodium thiosulphate.

Woil = weight of oil employed.

Saponification Value

The alcoholic KOH was freshly prepared by dissolving KOH pellets in ethanol. Two grams of oil were measured and placed into a conical flask. To this, 25ml of the alcoholic KOH was added, and a blank was also prepared. The sample was securely covered and placed in a steam water bath for 30 minutes, with periodic shaking. One milliliter of phenolphthalein was added to the mixture and titrated against 0.5M HCl to determine the endpoint (Ekpo *et al.*, 2023).

$$IV = \frac{5.61\ x\ (B\ -\ A)\ x\ N}{Woil}$$

Where;

B= volume of standard ethanolic potassium hydroxide used in blank titration

A= volume of standard ethanolic potassium hydroxide used in titration with the oil

N= normality of standard acid

Woil= weight of oil used.

Refractive Index

Abbe's refractometer was utilized to ascertain the refractive index of the oil sample. The apparatus was thoroughly cleaned with cotton wool and positioned in a well-lit room. The refractometer was calibrated using distilled water, after which a small quantity of the oil was applied, and the observed refractive index was recorded (Obruche *et al.*, 2019; Umudi *et al.*, 2025).

Biodiesel Production

A precise volume of 1000 ml of the filtered waste cooking oil was measured and transferred into a clean conical flask. The oil was subsequently heated to 55°C. An excess amount of methanol (220 ml per liter of oil) was introduced to facilitate transesterification. A 1% NaOH catalyst was added to enhance the transesterification process. The reaction was considered to commence at this point, as the heated oil promotes the reaction. The mixture was then agitated for 60 minutes (Samuel *et al.*, 2013).

Separation of biodiesel from by-products

The resultant product was allowed to settle overnight, resulting in two distinct liquid layers: the crude ester phase on top and the glycerol phase at the bottom, indicative of a successful transesterification reaction.

Purification of biodiesel by washing

The upper ester phase (biodiesel) was separated from the lower glycerol phase by transferring it to a clean 1000 ml conical flask. The biodiesel was then purified by washing with warm distilled water to eliminate residual by-products, including excess alcohol, catalysts, soap, and glycerin. Approximately 15% of the biodiesel volume was added as distilled water. The flask was gently shaken for one minute and then allowed to rest on the table to facilitate the separation of the biodiesel and water layers. Following separation, the biodiesel was transferred to a clean conical flask (Ugochukwu *et al.*, 2025).

Characterization of Biodiesel

The characterization of the biodiesel involved determining its Specific Gravity, viscosity, Moisture Content, and Iodine Value using the same methods and formulas applied to Waste Cooking Oil.

Flash Point:

A sample of the biodiesel was heated in a closed vessel and ignited. Upon ignition, the sample burned, and the temperature was recorded. The biodiesel was poured into a cup to the designated mark on its interior. Subsequently, a cover was secured onto the cup, and a Bunsen burner was employed to heat the apparatus at a rate of approximately 5°C per minute. Throughout the heating process, the oil was continuously stirred. As the oil neared its flash point, the injector burner was ignited and injected into the oil container at intervals of 12 seconds until a noticeable flash was detected within the container. The temperature at which the flash occurred was recorded. This procedure was repeated three times, and the average was calculated (ASTM D 93, 2002).

Pour Point

Following initial heating, the biodiesel was cooled at a specified rate and assessed at intervals of 3°C for its flow characteristics. The lowest temperature at which movement of the biodiesel was noted was documented as the pour point (ASTM D 97, 2002).

Acid Number

A sample of biodiesel was measured and transferred into a beaker. A neutral solvent, consisting of a mixture of petroleum ether and ethanol, was prepared, and 50 ml of this

mixture was added to the beaker containing the biodiesel. The mixture was stirred vigorously for 30 minutes. A quantity of 0.56 g of potassium hydroxide (KOH) pellets was measured and placed in a separate beaker, and a 0.1M KOH solution was prepared. Three drops of phenolphthalein indicator were added to the sample, which was then titrated against the 0.1M KOH until a color change to pink was observed (ASTM D 664).

Sulphur Content

The sulphur content was assessed using energy dispersive X-ray fluorescence spectroscopy. The biodiesel was placed in a disposable plate, which was covered with male and female cells; the sample was then positioned in sulphur testing equipment and allowed to sit for 10 minutes. The X-ray fluorescence spectrometer measured the sulphur content of the biodiesel three consecutive times, and the average was recorded as the sulphur content (ASTM D 5453, 2002).

Ash Content

The sample was ignited and allowed to burn until only ash and carbon were left. Following the cooling process, the residue underwent treatment with sulphuric acid and was heated to 775°C until the oxidation of carbon was fully achieved. The ash was subsequently cooled, treated again with sulphuric acid, and heated at 775°C until a constant weight was reached (ASTM D 874).

Determination of Calorific Value

The calorific value of the biodiesel was assessed using a bomb calorimeter in accordance with the ASTM D2015 standard method. An oxygen bomb was pressurized to 3 MPa using an oxygen container. The bomb was automatically ignited after the temperatures of the jacket and bucket equilibrated to an acceptable level of accuracy (ASTM D 2002).

Sample Size of Vehicles and Generators and Blending

Petrol and diesel were mixed with biodiesel in proportions ranging from B10 to B40. At B0, there was no blending of petrol or diesel with biodiesel, while B5 indicates a mixture of 5% biodiesel and 95% petrol/diesel. At B10, the blend consists of 10% biodiesel and 90% petrol/diesel. The designations B20, B30, and B40 represent blends of 20%, 30%, and 40% biodiesel, respectively, with the remaining percentages being petrol/diesel. The samples listed below were randomly selected based on availability and cooperation from automobile operators.

For diesel-fueled vehicles: Trailer – 6, Tanker – 6. For petrol-fueled vehicles: Motorcycle – 10, Tricycle – 10, Bus – 10, Private Vehicles – 10. For generators: Small Capacity petrol Generators – 10, Large Capacity petrol Generators – 10, Blended Engines, Petrol-biodiesel fueled Small Capacity Generator – 1, Petrol-biodiesel fueled Large Capacity Generator – 1. Diesel-biodiesel fueled Large Capacity Generator – 1, Petrol-Biodiesel fueled Motorcycle – 1.

Equipment Setup and Exhaust Gas Measurement

A gas analyzer (Bacharach portable combustion analyzer 2) was utilized for this study. The instrument weighs 1 kg and can operate for as long as the battery lasts. The gas analyzer consists of a 5-gas analyzer meter, an exhaust probe, and a printer. The meter is equipped with water, a filter, and a protective rubber sleeve. The equipment quantifies the volume percentages of CO, CO2, O2, NO, and NOx present in the exhaust gas. CO2 and O2 emissions are expressed in %s, while CO, NO, and NOx (the combined values of NO and NO2) are reported in ppm. At the beginning of each experiment, the gas analyser was purged to eliminate any trapped air that could potentially skew the results. The filter was

routinely inspected to ensure it remained clean and free from particle blockage. The preparation time prior to testing was approximately seventy seconds. Once ready, the analyser probe was securely attached to the exhaust pipe. The vehicle operator was instructed to let the engine idle for five minutes before taking measurements. Typically, testing one vehicle or generator took about five minutes. For motorcycles, operators were required to ride the motorbike for a distance of 1 km before emissions measurements were conducted (Ogwuche and Obruche, 2020).

RESULTS AND DISCUSSION

Tables 1 and 2 present the findings from the characterization of oil and biodiesel. The viability of the oil for biodiesel production was assessed based on its characterization, with the results for waste oil characterization displayed in Table 1. The peroxide value (PV) recorded at 4.98 mgKOH/g was significantly lower than the standard set by FAO/WHO (2009) for fresh edible oil, which is 10 mEq/kg. The low PV values indicate minimal oxidative rancidity in the oils and suggest a strong presence of antioxidants. Certain antioxidants, such as propyl gallate, may be employed to mitigate rancidity. The low peroxide value indicates that the oils are less likely to deteriorate when utilized as feedstock for biodiesel. The saponification value of the oil serves as an indicator of its propensity to form soap during the trans esterification process. The saponification value recorded was 257.93 mg KOH/g. This value is closely aligned with the standards for quality oils and indicates a strong potential for soap production. It has been noted that saponification values are inversely correlated with the average molecular weight of the fatty acids present in the oil fractions. Oil fractions exhibiting saponification values of 200 mg KOH/g or higher are known to contain low molecular weight fatty acids (Dorado *et al.*, 2003). The iodine value of the feedstock utilized in this research, which indicates the degree of unsaturation, was measured at 9.9 mg I2/100 g of oil. As per Obruche *et al.* (2019), methyl esters intended for use as diesel fuel should have an iodine value below 120 g per 100 g of sample, thus confirming the suitability of this waste cooking oil for biodiesel production. Predojevic (2008) noted that the iodine value is influenced by the origin of the feedstock and significantly affects the tendency of the fuel to oxidize. The refractive index, defined as the ratio of the speed of light in a vacuum to that in a medium, serves as an indicator of the oil's saturation level (El-Sabagh *et al.*, 2011). The analysis of the refractive index revealed that the waste cooking oil, with a refractive index of 1.470, nearly aligns with the ASTM (2002) specifications, which range from 1.476 to 1.479. Furthermore, the kinematic viscosity of the waste cooking oil was found to be within the acceptable standard range of 6.3 to 8.8 m2/s. Additionally, the moisture content of the waste cooking oil was recorded at 0.00%, which is favorable for the transesterification process. Moisture in vegetable oils poses a significant barrier to ester formation due to an increased likelihood of soap formation, necessitating minimal moisture levels for successful transesterification (Fazal *et al.*, 2011). The acid value, which quantifies the presence of free acids in the sample, impacts fuel aging. An acid value of 1.64 mg KOH/g was found to be within the recommended limits, as elevated acid values can lead to catalyst deactivation. Umudi *et al.* (2025) reviewed the acid value requirements for alkaline transesterification has to be reduced to less than 2 mg KOH/g.

Table 1 Results of waste cooking oil Characterization.

Parameters	Obtained Experimental Values
Moisture Content (%)	0.00
Specific gravity	0.99
Free Fatty Acid (%)	0.82
Peroxide Value (mgKOH/g)	4.98
Iodine Value (gI_2/100g)	9.90
Kinematic Viscosity (m^2/s)	7.52
Refractive Index	1.47
Saponification Value (mgKOH/g)	257.93
Acid Value (mgKOH/g)	1.64

The biodiesel derived from waste cooking oil was evaluated for its fuel properties (Table 2), which were then compared to the ASTM D 6751 biodiesel standard and the EU Standard EN 14214 to ascertain its viability as a fuel for engines. Density is a crucial factor for the diesel fuel injection system. A higher density in biodiesel results in a marginally increased mass of fuel delivery, as fuel equipment operates based on a volume metering system. The density of the biodiesel produced (0.90g/cm3) fell within the acceptable range of the EN 14214 standard, although it was slightly above the ASTM D6751 standard. The pour point, which indicates flow properties, was recorded at -3°C. This suggests that the biodiesel produced would perform adequately even in colder conditions. Furthermore, the biodiesel exhibited a low sulfur content of 0.01%, which is advantageous since sulfur in fuel can lead to the formation of acidic sulfur oxides, namely SO2 and SO3. These gases are corrosive and can damage engine components while contributing to environmental pollution. The flash point, defined as the lowest temperature at which fuel produces sufficient vapor to ignite, is notably high for biodiesel, typically exceeding 100oC, in contrast to conventional diesel fuel, which has a flash point of 77oC (Moser, 2000). The biodiesel produced from waste cooking oil methyl ester recorded a flash point of 155oC, meeting the minimum requirements of both EN and ASTM standards, as illustrated in Table 2, and indicating that the biodiesel is not highly flammable. Kinematic viscosity, which measures a fluid's resistance to flow, is another important characteristic. This property is a primary reason why biodiesel is preferred as an alternative fuel over pure vegetable oils and animal fats, which can cause operational issues such as engine deposits when used directly. The kinematic viscosity of the produced biodiesel, measured at 40oC, was 1.9mm2/s, aligning with the biodiesel standards set forth by ASTM D6751, as shown in Table 2.The biodiesel obtained in the study had higher calorific value (41.25MJ/kg), acid value (0.459mgKOH/g) and viscosity (4.72mm^2/s) but lower flash point (139°C) and specific gravity (0.879). This parameter is also significant for assessing the methyl ester content in biodiesel samples, as there exists a correlation between ester content and viscosity; specifically, higher viscosity correlates with lower biodiesel yield. The moisture content of the produced biodiesel, measured at 0.05%, falls within the acceptable range. The water content in biodiesel is crucial as it influences the calorific value and, more importantly, the fuel's shelf life. Biodiesel with elevated water content exhibits notably reduced oxidation stability. A decrease in oxidation stability increases the likelihood of oxidation products

forming during extended storage, which can lead to engine issues due to deposits, particularly affecting the injection system. To mitigate this risk, EN 14214 stipulates a maximum water content of 500 ppm. The calorific value of the biodiesel produced, recorded at 34,400 kJ/kg, is deemed acceptable as it exceeds the European standard for biodiesel, which is 32.9 MJ/kg. However, this biodiesel's calorific value of 34.4 MJ/kg is lower than that of petroleum diesel, which stands at 49.65 MJ/kg. The acid value (AV) serves as a straightforward method for assessing fuel quality. The acid value of the biodiesel derived from waste cooking oil was 0.22 mg KOH/g (refer to Table 2). This finding complies with the maximum AV limit of 0.50 mg KOH/g established by the ASTM D6751 standard. The acid value directly indicates the presence of free fatty acids in biodiesel. A high concentration of free fatty acids can result in corrosion during storage or transportation and may be attributed to water content in the fuel. The ash content was slightly above the acceptable level, and if it accumulates on engine components, it can lead to abrasion. The biodiesel produced in this study exhibited a low iodine value of 13.45 mgI2/100g, which is within the acceptable limit. The results were compared with those obtained by Kean *et al.* (2003) from waste oil methyl esters.

Table 2: Results of Biodiesel Characterization

Parameters	Obtained Experimental Values	Biodiesel (EN14214)Standards	Biodiesel D-6751Standards
Moisture Content (%)	0.05	< 0.05	0.05
Specific Gravity	0.90	0.86-0.9	0.86-0.89
Acid Value(mgKOH/g)	0.22	<0.50	<0.8
Sulphur Content (%)	0.01	< 0.01	< 0.05
Flash Point (^oC)	155	> 101	> 130
Kinematic Viscosity (m^2/s)	1.9	3.5-5	1.9-6
Pour Point (^oC)	-3.00	---	---
Ash Content (%)	0.09	0.02	< 0.02
Iodine Number ($gI_2/100g$)	13.45	120	---
Calorific Value (KJ/Kg)	34400	32900	---

Tables 3 to 14 present the characterization results for the measurements of exhaust gases. The analysis of emissions from various vehicles and generators revealed that O2, CO2, NOx, and CO were released during the combustion of fossil fuels. The results obtained encompass the combination of all vehicle types included in the analysis. These results pertain to vehicles and generators with varying engine types and sizes. For petrol-powered vehicles, emissions from minibuses, private cars, tricycles, and motorcycles were measured, and the average of their emission results is calculated as illustrated in Table 4.2.1, with their percentage emissions depicted in Figure 1

Table 3: Concentrations of gaseous emissions from motorcycles

S/N	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
1	14.5	3011	4.7	3	3
2	17.6	3290	5.8	2	2
3	18.6	2919	3.4	2	2
4	18.5	3371	-	3	3
5	16.2	3320	-	2	2
6	12.7	3406	4.1	6	6
7	9.3	2273	3.3	5	5
8	5.7	3590	4.1	24	24
9	16.6	4031	4.9	2	2
10	11.4	3650	4.6	3	3

Table 4: Concentrations of gaseous emissions from Tricycles

S/N	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
1	19.5	3350	3.5	3	3
2	20.9	1565	3.8	5	5
3	18.5	2981	4.6	2	2
4	20.2	3217	2.3	4	4
5	19.3	1781	4.7	2	2
6	14.6	3017	4.3	6	6
7	11.1	2178	4.9	3	3
8	19.3	1782	4.3	2	2
9	20.4	2415	2.5	5	5
10	13.8	3319	3.5	3	3

Table 5: Concentrations of gaseous emissions from Mini Buses

S/N	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
1	11.9	3325	6.1	32	32
2	14.9	3563	5.1	6	6
3	13.7	3644	5.3	8	8
4	18.3	3123	6.6	34	34
5	12.3	3832	4.9	13	13
6	15.1	3428	5.1	27	27
7	11.9	3861	7.5	9	9
8	11.4	3520	8.4	17	17
9	16.8	3005	6.2	24	24
10	12.6	3816	5.7	30	30

Table 6: Concentration of gaseous emissions from Private Vehicles (small cars)

S/N	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
1	13.2	1598	3.6	43	43
2	18.1	2891	2.4	12	12
3	7.7	2346	3.8	26	26
4	12.6	2274	3.9	16	16
5	9.2	2812	2.9	37	37
6	14.6	1497	3.5	23	23
7	11.2	2654	4.6	14	14
8	19.4	1091	3.3	39	39
9	20.2	1986	-	20	20
10	15.9	2170	3.8	41	41

Table 7: Concentrations of gaseous emissions from Tankers

S/N	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
1	16.00	597	1.5	50	126
2	12.84	705	1.2	17	103
3	13.73	728	1.9	37	113
4	15.64	840	1.5	41	106
5	16.07	671	1.6	53	132
6	16.21	831	1.7	28	108

Table 8: Concentrations of gaseous emissions from Trailers

S/N	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
1	16.31	9 28	1.9	38	102
2	16.28	971	1.1	55	109
3	16.62	729	2.3	46	104
4	16.68	890	1.4	33	89
5	17.20	551	0	49	100
6	18.73	583	0	50	95

Table 9: Concentrations of gaseous emissions from Small Capacity Generators

S/N	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
1	18.5	2847	2.1	29	29
2	14.2	3891	4.8	26	26
3	7.5	2311	7.6	19	19
4	9.1	3248	5.6	33	33
5	14.6	2130	6.4	23	23
6	18.0	1935	1.9	37	37
7	17.4	3271	4.5	16	16
8	12.0	3619	5.1	41	41
9	13.2	2477	6.2	20	20
10	16.8	3039	2.4	32	32

Table 10: Concentrations of gaseous emissions from Large Capacity Petrol Generators

S/N	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
1	15.7	2868	5.4	33	33
2	5.9	4021	10.8	26	26
3	7.3	3029	8.8	41	41
4	16.0	3865	3.2	25	25
5	12.2	1548	5.0	18	18
6	9.2	1955	7.2	45	45
7	13.2	3124	6.3	37	37
8	14.6	2138	5.5	19	19
9	11.0	3081	6.7	39	39
10	8.9	2847	6.9	20	20

Table 11: Concentrations of gaseous emissions from Biodiesel-Petrol Blendfueledsmall capacity generators

Ratio	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
B0	15.5	2847	3.7	29	29
B5	15.1	2802	3.7	24	24
B10	15.3	2730	3.6	16	16

Table 12: Concentrations of gaseous emissions from Biodiesel-PetrolBlend fueled large capacity generator

Ratio	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
B0	12.5	3891	5.2	54	54
B5	13.5	3831	5.1	51	51
B10	14.4	3675	4.5	43	43

Table 13: Concentrations of gaseous emissions from Biodiesel-Petrol Blend fueled Motorcycle

Ratio	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_X (ppm)
B0	11.70	3566	3.0	1	1
B5	10.71	2842	2.9	2	2
B10	11.50	2218	2.7	8	10

Table 14: Concentrations of gaseous emission from Biodiesel-Diesel Blend fueled generator

Ratio	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NOx (ppm)
B0	11.40	1009	1.5	43	77
B10	14.67	900	1.3	51	80
B20	16.23	820	1.0	53	82
B30	15.20	713	--	57	83
B40	16.22	631	--	62	88

The overall trend in emission levels illustrated in Table 15 indicates that minibuses release more CO_2 than personal vehicles, tricycles, and motorcycles. Minibuses exhibited a mean CO_2 value of 6.02%, whereas private vehicles (small cars), tricycles, and motorcycles had mean CO_2 values of 3.53%, 3.84%, and 4.36% respectively. As a result, minibuses accounted for 34% of the total CO2 emissions from these petrol vehicles, while private vehicles, tricycles, and motorcycles contributed 24%, 22%, and 20% respectively, as depicted in Figure 1. The emission of carbon monoxide serves as an indicator of incomplete combustion within the engine and is a significant pollutant. Table 15 presents the levels of carbon monoxide emitted by the four types of automobiles. Minibuses emitted more carbon monoxide than personal vehicles, tricycles, and motorcycles. The mean CO emission values were 3511.7 ppm for minibuses, and 2131.9 ppm, 2560.5 ppm, and 3286.1 ppm for private vehicles, tricycles, and motorcycles respectively. Minibuses represented 31% of the total petrol CO emissions, while private vehicles, tricycles, and motorcycles accounted for 18%, 22%, and 29% respectively, as shown in Figure 1. NOx emissions are also part of the overall emissions since air consists of a mixture of nitrogen and oxygen. When fuel ignites in an engine, certain areas reach temperatures high enough (above 1500°C/2700°F) to oxidize some nitrogen into NOx gases. According to Table 15, among petrol vehicles, private vehicles had the highest mean NOx value at 27.1 ppm, while minibuses, tricycles, and motorcycles emitted 20 ppm, 3.5 ppm, and 5.2 ppm respectively. Figure 1 illustrates that private vehicles contributed 49% and minibuses 36% of the total NOx emissions from petrol vehicles. Tricycles had the lowest NOx emissions, contributing only 6% of the total NOx from petrol vehicles, while motorcycles, contributing 9%, also exhibited significantly lower NOx emissions compared to the others.

In all the petrol vehicles assessed, NO_2 was not detected, indicating that the NOx value is equivalent to the NO value. Literature suggests that the NO_2 fraction is significantly lower in petrol engines. NO_2 is mainly produced in high-temperature gases through the reaction of NO with the HO_2 radical and is rapidly converted back to NO through reactions with O or H radicals (Obruche *et al.*, 2019). NO_2 can remain stable if the decomposition reactions are inhibited by mixing with cooler gases. This scenario is anticipated in diesel engines due to the substantial excess air present in the cylinder, unlike in spark-ignition engines (Heywood, 1998), which aligns with observed data. This finding is also consistent with other research on emissions from petrol and diesel vehicles. Umudi *et al.* (2025) reported that diesel vehicles emitted between 0.94 and 75.2 ($\mu g/m^3$) of NO_2, whereas no NO_2 was detectable in any of the petrol vehicles. When compared to the second European emission (EU 2) standard, which Nigeria adheres to according to the literature, and in contrast to the EU 6 standard utilized in Europe, motorcycles emitted four times (3286.10

ppm) the CO limit of 569.36 ppm set by the EU2 standard for two-wheelers, resulting in an excess of 2716.6ppm CO. The NOx value for motorcycles (5.2 ppm) was below the standard limit for NOx, which is 10.50ppm. Therefore, while the motorcycles studied were not environmentally friendly due to their CO emissions, they could be considered environmentally friendly regarding their NOx emissions when compared to the Nigerian standard. Tricycles emitted 2560.5 ppm of CO, which is 1835.64ppm above the permissible limit of 724.64 ppm for three-wheeled vehicles, but their NOx value (3.5 ppm) remained below the allowable limit of 14.01ppm.

The tricycles examined are not environmentally friendly due to their CO emissions, yet they are considered environmentally friendly regarding their NOx emissions as per Nigerian standards. In contrast, private cars and minibuses emitted CO levels of 2131.9 ppm and 3511.7 ppm, respectively, which surpass the permissible limit of 227.74 ppm for CO. Although there is no established standard for NOx emissions under the EU 2 emission standard for light-duty petrol vehicles, the NOx emissions recorded exceeded the EU 6 permissible limit of 2.10 ppm. Furthermore, there is no CO_2 emission standard in the EU 2 framework. The standards for passenger cars are set at 95 g/km of CO_2, with a phased implementation for 95% of vehicles in 2020 and full compliance required by 2021. For light commercial vehicles, the standard is 147 g/km of CO_2 for the year 2020. Among petrol vehicles, tricycles exhibit the lowest CO_2 emissions; however, their average emission rate of 3.84% (638.592 g/km) exceeds the 147 g/km threshold by 491.592 g/km (ICCT, 2014).

Table 15: Mean concentrations of petrol vehicular emissions

Engines	CO(ppm)	Engine	CO_2(%)	Engine	NOx(ppm)
Motorcycle	3286.1	Motorcycle	4.36	Motorcycle	5.2
Tricycle	2560.5	Tricycle	3.84	Tricycle	3.5
Mini-Buses	3511.7	Mini-Buses	6.02	Mini-Buses	20.0
Small cars	2131.9	Small cars	3.53	Small cars	27.1

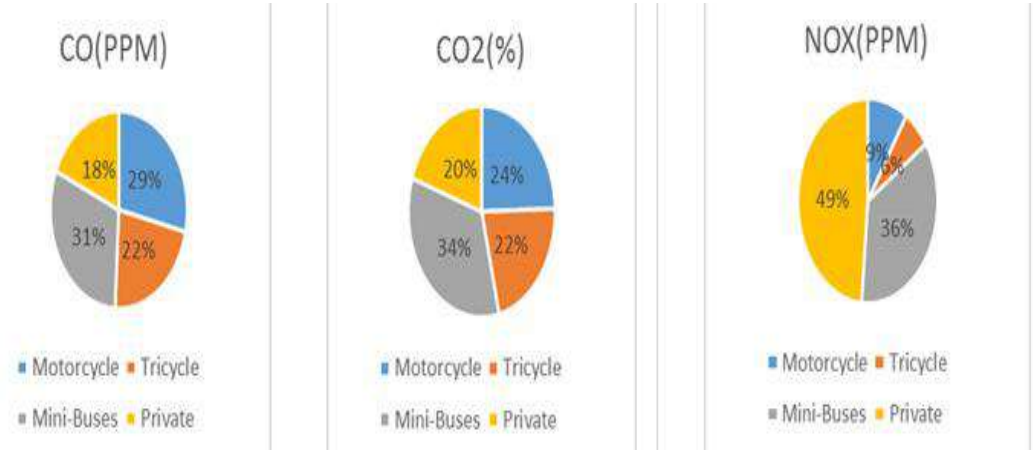


Figure 1: Percentage petrol vehicular emission

CONCUSION

This research indicates that pollution levels in Nigeria are significantly high and are projected to rise further if not addressed. The analysis of tailpipe emissions from vehicles and generators revealed that the highest average concentration of NOx emissions reached 27.1 ppm, CO at 3511.7 ppm, and 6.02% CO2 for petrol engines. In contrast, diesel engines exhibited a peak mean level of NOx at 114.7 ppm, CO at 744.8 ppm, and CO_2 at 1.6%. Diesel vehicles produce more NOx compared to petrol vehicles, whereas petrol engines generate higher levels of CO and CO_2 than their diesel counterparts. Emissions from both small and large capacity generators fall within the range of those from vehicles. These emission levels surpass the second European standard (EU 2 standard) for vehicular emissions, which Nigeria has adopted as its current benchmark.This situation suggests that individuals exposed to these emissions daily are at an increased risk of developing health issues over time as the concentration accumulates in their systems.

Recommendation: Notably, large capacity generators emit lower quantities of harmful CO and NOx compared to small capacity generators. Waste cooking oil, which is abundantly available, serves as an excellent feedstock for biodiesel production. Blending petrol or diesel with biodiesel derived from this feedstock has been shown to reduce exhaust emissions. The biodiesel-diesel blend decreased CO2 and CO emissions in diesel generators but resulted in an increase in NOx emissions. Conversely, the biodiesel-petrol blend lowered CO, CO_2, and NOx emissions in petrol generators, although it raised NOx emissions in petrol motorcycles. This indicates that the use of biodiesel-blended petrol is advantageous for both small and large capacity petrol generators, but it may lead to higher NOx emissions in biodiesel-blended diesel generators and petrol motorcycles.

REFERENCES

Abeokuta, O.J, Uriri, S.A, Obruche, E.K, Okurame, O (2025). Hydrochemical Assessment of Borehole Water Quality in Eku, Delta State, Nigeria. Journal of Science, Technology and Environmental Studies,1(2):17-25

ACEA, EUROPIA, European Commission. (1995). Effect of Fuel Qualities and Related Vehicle Technologies on European Vehicle Emissions. An Evaluation ofExisting Literature and Proprietary Data, Final Report, Brussels

ASTM International. (2002). Standard test method for oxidation onset temperature of hydrocarbons by differential scanning calorimetry (E-2009-02). Annual Book of Standards, section 12.10, ASTM International, West Conshohocken, pp. 734-738.

Dorado, M.P., Ballesteros, E., Arnal, J.M. Gomez, J. and Lopez F.J., (2003). Exhaust Emissions from a Diesel Engine Fuelled with Transesterified Waste Olive Oil Fuel, 82, pp 1311–1315.

Ekpo Ekokodu Rose, Erienu Obruche Kennedy, and Abiye Clement. Marcus (2025). Spatial and Temporal Variations in the Concentrations of Polycyclic Aromatic Hydrocarbon, in Ambient Air From Three Different Locations in River State, Nigeria. *International Journal of New Chemistry*, 12 (4), 567-580

El-Sabagh, S.M.; Keera, S.T. and Tama, A.R. (2011). The characterization of biodiesel fuel from waste frying oil. Energy Source, Part A .J. 33 401-409.

Ekpo, R.E., Marcus, A.C., and Obruche E.K. (2023). Spartial and Temporal Variations in the Concentration of

Particulate Matter in Ambient Air from three Different Locations in River State, Nigeria. International Journal of Scientific Research in Chemical Science,10(4):32-38

EPA. (2000). Air Quality Criteria for Carbon Monoxide. U.S. Environmental Protection Agency, National Center for Environmental Assessment. June, 2000. EPA 600/P-99/001F.

Erienu Obruche Kennedy, Itodo Adams, Wuana Raymond and Sesugh Ande (2022). Polycyclic Aromatic Hydrocarbons in Harvested Rainwater in Warri and Agbarho, Nigeria. *Bulletin of chemical society of Ethiopia*, 36(4): 27-35.

FAO/WHO (2009). Report of the 21st session of the Codex Alimentarius Committee on fats and oils. Kola Kinabalu, Malaysia, 16 – 20 February 2009.

Fazal, M.A., Haseeb, A.S.M.A. and Masjuki, H.H., (2011). Biodiesel Feasibility Study: an Evaluation of Material Compatibility; Performance; Emission and Engine Durability. Renew Sust Energy Rev, 15 (2), 1314–1324.

Ikechukwu S. Chikwe, Odioko M. Obianuju, Onadje F. Ovwighose, Apuyor K. Efe, Onwugbuta G. Chukwuemeka, Chikwe Oluchukwu B., Anyanwu Gogo C, Stanley Sotonye, Etus Patrick Chimuanya, Joseph N. Barnabas, Erienu Obruche Kennedy.(2026). Remediation of Surface Water Polluted by Mining Effluent Discharges: Environmental Impacts and Treatment Methods in South-South Region, Nigeria. International journal of computational research in science and technology, 2(1),1 – 21

International Energy Agency., (2006). Energy and CO_2 Emissions trends in the transport sector. World Energy Outlook, 2006 Edition, pp 30-71.

IPCC., (1996). Revised IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual'. Inter Governmental Panel on Climate Change, Bracknell, USA. pp 1-8.

Itodo, A. U., Wuana, R. A. Erhabor, O. D., Obruche, E. K. and Agbendeh, Z. M.(2021). Evaluating the Effects of Roofing Materials on Physicochemical Properties of Harvested Rainwater in Warri, Delta State, Nigeria. Chemical Society of Nigeria Journal, Kano, 12(1): 234-245

Kean, A.J., Harely, R.A. and Kendall, G.R., (2003). Effect of Vehicle Speed and Engine Load on Motor Vehicle Emissions. Environmental Science and Technology 37, pp 3739-4628

Kennedy.(2025) Degradation Efficiencies of the Total Petroleum Hydrocarbons (TPHs) in the Soil Amended with Palm Bunch Ash and Tween 80 in Ibenomo L.G.A, Akwa Ibom State. International Journal of Chemistry and Chemical Processes,11(5):1-20 10.56201/ijccp.vol.11.no5.2025.pg1. 21

Obruche E. K, Emakunu S.O, Ugochukwau G. C (2025). Rainwater Harvesting: Microbial and Chemical Water Quality Assessment in Warri District. Mosogar Journal of Science Education,10(1):36-45

Obruche E. K, Ogwuche C.E, Erhabor O.D and Mkurzurum.C (2019).Investigating Corrosion

Inhibition Effects of *Tagetes Erecta L*. Leaf Extrac on Aluminium in Acidic Medium. *Global Scientific Journals*, 7 (1): 1-17

Ogwuche C.E and Obruche E.K. (2020). Physio-chemical analysis of palm oils (*elaeis guineensis*) obtained from major markets in agbarho, unenurhie, opete, ughelli and evwreni town, Delta state, Nigeria. *International journal of trend in scientific research and development*,4(2):56-60

Ugochukwu Gladys Chioma, Ataine Theresa Ifeyinwa and Erienu Kennedy Obruche (2025). Determination of the Physicochemical Properties of Soil Amended with Cassava Mill Effluent in Mosogar Area of Delta State. Mosogar Journal of Science Education,10(1):81-89

Umudi E. Q., Obruche E. K., Sani M. I., Onwugbuta G. C., Aghemwenhio I.S., Ikechukwu S. C., Clark P. D., Essiet A.G., Eresanya O.I., Ibe M.C. and Hashimu. A. (2025). Evaluation of Polycyclic Aromatic Hydrocarbons (PAHs) Contents of Fishes, Waters and Sediments of Rivers Niger: Human Health Risk Assessment. Journal of Basics and Applied Sciences Research,3(5),187-199. https://dx.doi.org/10.4314/jobasr.v3i5.20

Umudi Ese Queen, Ese Ekanem , Sani Mamman Ibrahim, Onwugbuta Godpower Chukwuemeka , Suleiman Abdulmajid, Magashi Luper, Udo Idongesit , Ikechukwu Chikwe Odontimi Nimighaye , Essiet Gordon , Chinedu Okechukwu, Brown Amieye Bright and Erienu Obruche

PALYNOLOGICAL AND PHYSICOCHEMICAL ASSESSMENT OF FRESHWATER ECOSYSTEM CHANGES IN SELECTED WATER BODIES OF BENUE STATE, NIGERIA

[1*]Okoh, Thomas., [1]Okpara, Priscilla Onyinyechi., [1]Olasan, Joseph Olalekan., [1*]Edinoh, Daniel Ojomugbo., [1]Muje, Godiya Simon and [1]Owoicho, Susan Ochanya

[1]Department of Plant Science and Biotechnology, College of Biological sciences, Joseph Sarwuan Tarka University, Benue State Nigeria

*Corresponding Author's Email: edinohdaniel1@gmail.com

ABSTRACT

Aquatic ecosystems are dynamic environments whose ecological integrity can be influenced by both natural and anthropogenic factors. This study evaluated ecosystem changes associated with pollens in selected water bodies in Benue State, Nigeria. Water and sediment samples were collected from five locations: Middle Core, Pila Community, Special Science School, Ichwa Community and River Benue. Standard palynological techniques, including acetolysis and light microscopy were employed to recover, identify and characterize pollen grains while selected physicochemical parameters of surface and bottom waters were determined using standard analytical procedures. The study identified pollen grains belonging to major plant families including Fabaceae, Asteraceae, Poaceae, Pinaceae, Ocystaceae, and Chlorophyceae, exhibiting considerable variation in size, shape, aperture type and exine ornamentation, indicative of diverse reproductive and ecological adaptations. Surface water exhibited electrical conductivity values ranging from 61.4–113.5 µS/cm, total dissolved solids (TDS) from 30.6–100.7 mg/L, temperatures between 30 and 35°C, and pH values of 6.6–7.1, whereas bottom waters recorded higher conductivity (71–285 µS/cm), TDS (35.1–110.3 mg/L), and slightly alkaline pH (7.3–7.5). The observed physicochemical conditions remained within acceptable limits for freshwater ecosystems and were conducive to pollen preservation and aquatic biological productivity. Variations in pollen assemblages reflected the influence of surrounding terrestrial vegetation and environmental conditions, while differences between surface and bottom water characteristics suggested ongoing sediment–water interactions. The findings demonstrate that pollen analysis, when integrated with physicochemical assessment, provides an effective approach for monitoring ecosystem changes and evaluating environmental quality in freshwater systems. The study recommends continuous palynological and water quality monitoring to support biodiversity conservation and sustainable management of aquatic ecosystems.

Keywords: Palynology, Pollen Grains, Aquatic Ecosystem, Physicochemical Parameters, Freshwater, Ecosystem Monitoring.

INTRODUCTION

Freshwater ecosystems are among the most productive and biologically diverse ecosystems on Earth, providing essential ecological services such as potable water supply, fisheries, irrigation, flood regulation, nutrient cycling, recreation, and habitat for aquatic organisms. These ecosystems also play a critical role in supporting food security, public health, and socioeconomic development, particularly in developing countries where communities depend heavily on natural water resources (UNESCO, 2024). Despite their ecological and economic significance, freshwater ecosystems are increasingly threatened by anthropogenic activities, including rapid urbanization, agricultural intensification, industrial discharges, deforestation, sand mining, and climate change, all of which alter water

quality and disrupt ecological processes (IPBES, 2019; UNEP, 2021).

Nigeria possesses an extensive network of rivers, streams, lakes, ponds, and wetlands that support domestic, agricultural, and industrial activities. However, many freshwater systems are experiencing progressive degradation arising from untreated wastewater disposal, agricultural runoff, indiscriminate refuse dumping, and land-use changes. In Benue State, where agriculture constitutes the major livelihood of the population, freshwater bodies receive substantial inputs of fertilizers, pesticides, sediments, and organic wastes from surrounding farmlands and settlements. These inputs often modify the physicochemical characteristics of water, reduce biodiversity, promote eutrophication, and ultimately impair ecosystem functioning (Federal Ministry of Water Resources [FMWR], 2021; UNEP, 2021).

Assessing ecological changes in freshwater environments requires the integration of biological and physicochemical indicators. While physicochemical analyses provide information on the current condition of water, biological indicators reflect cumulative environmental changes over time. Among biological indicators, pollen grains and spores (palynomorphs) have become valuable tools for reconstructing environmental conditions because of their resistance to degradation, taxonomic specificity, and ability to record changes in surrounding vegetation and land-use patterns (Giesecke *et al.,* 2019). Palynological investigations have therefore gained increasing recognition in environmental monitoring, palaeoecology, forensic science, and biodiversity assessments.

Palynology, the scientific study of pollen grains, spores, and other acid-resistant organic-walled microfossils, provides important information about vegetation dynamics, climatic variability, sediment transport, and ecosystem disturbance. Pollen deposited in freshwater sediments originates from surrounding terrestrial vegetation as well as aquatic plants, making it an effective proxy for evaluating ecological changes within a watershed. Variations in pollen assemblages often reflect alterations in vegetation composition caused by agriculture, urban development, deforestation, invasive species, or climatic fluctuations (Reille, 1998; Giesecke *et al.*, 2019). Consequently, palynological analysis complements conventional water quality assessment by revealing both present and historical environmental changes.

Physicochemical properties such as temperature, pH, electrical conductivity, turbidity, dissolved oxygen, biochemical oxygen demand, total dissolved solids, nutrients, and heavy metals remain fundamental indicators of freshwater quality. These parameters directly influence aquatic biodiversity, microbial activity, nutrient cycling, and ecosystem productivity. Alterations in these variables often signal pollution, eutrophication, habitat degradation, or other environmental disturbances. The World Health Organization (WHO, 2022) and the Food and Agriculture Organization (FAO, 2020) emphasize routine monitoring of these parameters to ensure the sustainable management of freshwater resources for domestic and agricultural use.

The integration of palynological and physicochemical assessments provides a more comprehensive understanding of freshwater ecosystem dynamics than either approach alone (Birks and Birks, 2016). While physicochemical analyses identify immediate environmental conditions, pollen assemblages preserve evidence of longer-term ecological responses to natural and anthropogenic disturbances. Combined assessments therefore improve ecological interpretation, facilitate environmental

monitoring, and support evidence-based conservation planning (Giesecke *et al.*, 2019).

Benue State, located within the Guinea Savannah ecological zone of North-Central Nigeria, is traversed by several rivers and streams, including the River Benue and its numerous tributaries. These water bodies support domestic water supply, irrigation, fisheries, transportation, and diverse aquatic habitats. However, increasing population growth, agricultural expansion, urban development, and other human activities have intensified pressure on these freshwater ecosystems. Although several studies have investigated the physicochemical characteristics and pollution status of Nigerian freshwater bodies, relatively few have incorporated palynological evidence to evaluate ecosystem changes, particularly in Benue State. This knowledge gap limits a holistic understanding of ecological alterations and their driving factors.

The present study therefore seeks to integrate palynological and physicochemical analyses to evaluate freshwater ecosystem changes in selected water bodies of Benue State, Nigeria. The findings are expected to provide baseline ecological information for environmental monitoring, biodiversity conservation, pollution assessment, and sustainable freshwater resource management. Furthermore, the study will contribute to the growing body of knowledge on the application of palynology as a complementary tool for environmental assessment in tropical freshwater ecosystems.

MATERIALS AND METHODS

Study Area

The Study was conducted in Makurdi, Benue State Nigeria. Benue State is located in the North-Central geopolitical zone of Nigeria and is characterized by a diverse ecological setting, prominently featuring the River Benue, which is a major tributary of the River Niger. The area experiences a tropical wet and dry climate with two distinct seasons: the rainy season (April to October) and the dry season (November to March), with annual rainfall ranging between 1,200 mm and 1,800 mm (Alegbeleye *et al.,* 2019). The River Benue provides a rich aquatic ecosystem, which supports a variety of biota including plankton, aquatic plants, and microorganisms. Its basin also receives input from agricultural and urban runoff, which may influence the abundance and diversity of polynomorphs in the system.

Figure 1: Map showing the Study Area (Makurdi, Benue State) (Odeyemi *et al.*, 2021)

Method of Sample Collection

Water and sediment samples were collected from the five selected ponds located at Special Sciences, River Benue, Ichawa Community, Middle Core, JOSTUM and Pila using a stratified sampling approach. Water samples were collected in sterile polyethylene bottles, while sediment samples were obtained with an Ekman grab sampler, preserved in cool boxes, and transported to the laboratory for analysis (Ekanem and Udo, 2020).

Physicochemical Analysis of Water Sample

Physicochemical parameters, including pH, temperature, electrical conductivity (EC), total dissolved solids (TDS), nitrate, phosphate, and ammonium, were measured using portable equipment and standard APHA procedures to evaluate water quality and its influence on polynomorph preservation and distribution (APHA, 2017; Okoye *et al.*, 2022).

Palynological Analysis

Sediment samples were dried, sieved, treated with hydrochloric acid (HCl) and hydrofluoric acid (HF), and processed by acetolysis. The prepared slides were mounted with glycerin jelly and examined under a light microscope to identify and quantify pollen, spores, and other organic-walled microfossils (Mertens *et al.*, 2021).

Acetolysis Procedure

Acetolysis was carried out using the modified Erdtman method, in which samples were treated with acetic anhydride and concentrated sulfuric acid, followed by washing and centrifugation to obtain clean residues for microscopic examination (Faegri and Iversen, 1989; Suganuma *et al.*, 2023).

Method of Identification of Pollen and Spores

Recovered pollen and spores were identified based on morphological features such as size, shape, aperture type, and exine ornamentation using standard pollen atlases, taxonomic keys, and published reference materials (Adeonipekun *et al.*, 2018; Sowunmi and Akintola, 2020)

Characterization of Shapes and Sizes of Pollen and Spores

Measurements of pollen and spore dimensions were made using a calibrated micrometer eyepiece. The major parameters assessed included polar axis, equatorial diameter, and shape descriptors (e.g., spheroidal, prolate, oblate, triangular) (Zonneveld *et al.,* 2019).

Data Analysis

Quantitative data from physicochemical parameters and palynological counts were analyzed using SPSS Version 26.

RESULTS

Pollen Morphology

Table 1 shows clear variations in the morphological characteristics of pollen from the Ocystaceae, Fabaceae, Asteraceae, Chlorophyceae, Finaceae, and Poaceae families. Pollen size ranged from 10–180 µm, with differences in shape, exine ornamentation, aperture type, and colour among the families. These variations reflect the taxonomic diversity of the examined taxa and their adaptations to different pollination mechanisms, including water, insect, and wind pollination.

Table 1: Pollen Morphology of Different Aquatic Organism

FAMILY	POLLEN SIZE	POLLEN SHAPE	EXINE ORNAMENTATION	NUMBER OF APERTURE	COLOR OF POLLEN
Ocystaceae (green algae)	18um	Oval	Nil	25pores	Green
Fabaceae (Leguminosae)	Medium20um	spherical	Tectate-columelate	tricolpate	cream
Asteraceae (sunflower)	83long-34wide	spherical	spiniouse	tricolpate	goldenbrown
Chlorophyceae (green algae)	180um	Spheroidal	echinate	colporate	Yellowish brown
Finaceae(conifers)	10-19um	Irregular	Scabrate-reticulate	monolete	brown
Asteraceae(sunflower)	Medium	Spheroidal	echinate	tricolporate	Lightyellow
Poaceae(grass)	20-40um	Spheriodal	psilate	monoporate	Light yellow
Poaceae(grass)	15-40um	Slightly oval	Thin, smooth	monoporate	Yellowish brown

Figure 2: Ocystaceae (Green algae)

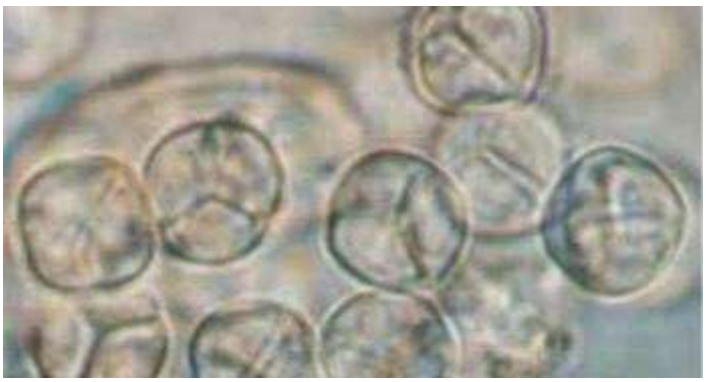


Figure 3: Fabaceae (Leguminosae)

Figure 4: Asteraceae (sunflower)

Figure 5: Chlorophyceae (green algae)

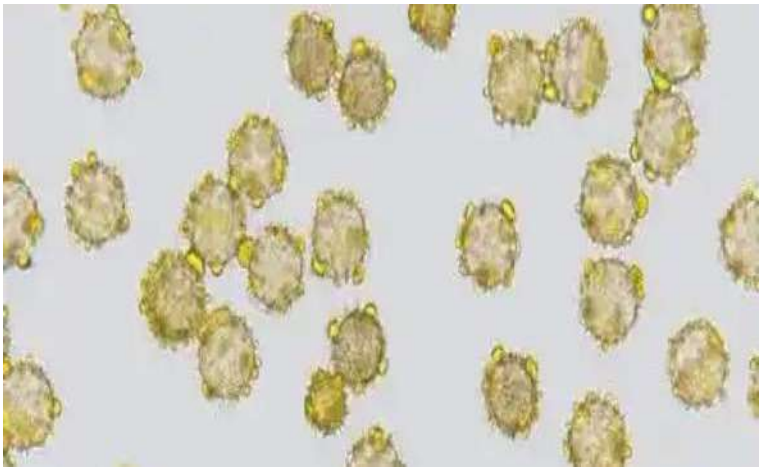


Figure 6: Finaceae(conifers)

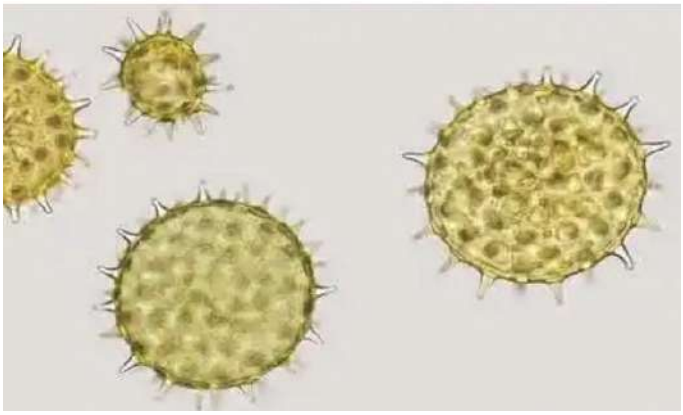


Figure 7: Asteraceae (sunflower

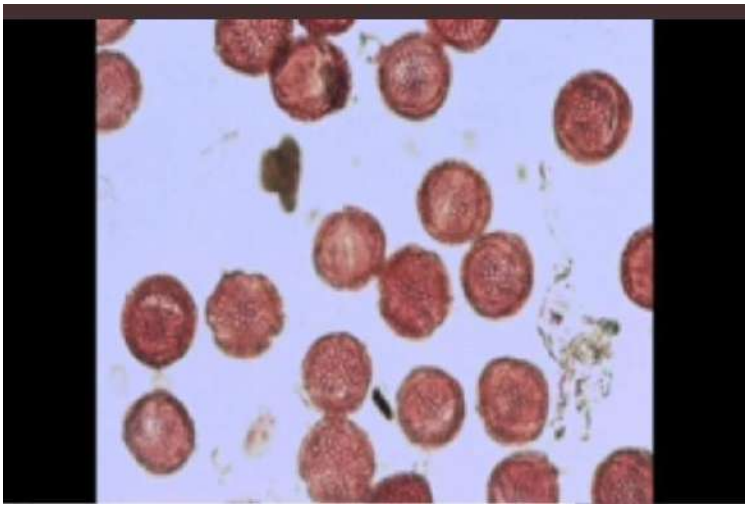


Figure 8: Poaceae

Figure 9: Poaceae (grass)

Figure 10: Poaceae (Grass)

Physicochemical Properties of Surface Water

The physicochemical properties of water showed slight variations across the five locations. Electrical conductivity ranged from 61.4–113.5 µS/cm, with Middlecore recording the highest value and River Benue the lowest. TDS followed a similar pattern, ranging from 30.6–100.7 mg/L, indicating low dissolved solids. Temperature varied between 30–35°C, with River Benue recording the highest value. pH ranged from 6.6 to 7.1, indicating neutral to slightly acidic conditions, with the lowest values observed in River Benue and Special Science School.

Table 2: Physicochemical Properties of Surface Water

S/N	GPS	LOCALITY	ELECTRICAL CONDUCTIVITY	TDS	TEMPERATURE	pH
1	7.78771°N, 8.61925°E	Middle core	113.5,110.5	100.7,100.	30	7.1
2	7.74300°N, 8.66077°E	Pila community	84.5,84.6	41.8,41.8	31	7.1
3	7.78600°N, 8.56077°E	Special science school	83.1,82.6	41.4,41.2	31	6.6
4	7.77859°N, 8.61135°E	Ichwa community	94.0,93.9	46.7	30	7.1
5	7.74200°N, 8.55076°E	River Benue	61.4,61.9	30.6,30.6	35	6.6

Physicochemical Properties of Bottom Water

The physicochemical characteristics of bottom water varied across the five locations. TDS was highest in Pila Community (110.3 mg/L) and lowest in River Benue (35.5 mg/L), indicating higher dissolved substances in community areas. Temperature ranged from 29–35°C, with the highest value recorded at Middlecore and the lowest at Special Science. Electrical conductivity also varied considerably, reaching its highest value in Ichwa Community (285 µS/cm) and remaining lowest in River Benue (71–74 µS/cm), reflecting differences in ionic concentration. pH values ranged from 7.3 to 7.5 across all sites, indicating slightly alkaline and relatively stable bottom water conditions.

Table 3: Physicochemical Properties of Bottom Water

S./N	LOCALITY	TDS	TEMPERATURE	ELECTRICAL CONDUCTIVITY	PH	GPS
1	Middlecore	100.7,100.4	35	217,219	7.4	7.78771°N, 8.61925°E
2	Pila community	110.3,110.3	30	224,226	7.5	7.74300°N, 8.66077°E
3	Special science	104.2,104.4	29	215,214	7.5	7.78600°N, 8.56077°E
4	Ichwa community	103.8	31	285,285	7.3	7.77859°N, 8.61135°E
5	River benue	35.5,35.1	30	74.3,71.0	7.3	7.74200°N, 8.55076°E

DISCUSSION

The findings in Tables 1, 2 and 3 provide valuable insights into the morphological diversity of pollen grains from different plant families and the physicochemical characteristics of associated aquatic environments. Together, these parameters reflect the interrelationship between plant reproductive adaptations and environmental quality, particularly in freshwater ecosystems where these species may thrive.

The pollen characteristics presented in Table 1 show notable variations across families, indicating evolutionary adaptations to different pollination mechanisms and ecological conditions. The family Ocystaceae (green algae) exhibited small, oval-shaped pollen grains (18 µm) with numerous pores (25) and a green coloration. The absence of exine ornamentation suggests a simpler structural design, typical of algal spores or gametes adapted to aquatic environments where water currents aid dispersal rather than wind or insects. These observations align with those of Agashe and Caulton (2019), who reported that most green algae possess non-ornamented, porous walls to facilitate buoyancy and water-mediated fertilization.

The Fabaceae (Leguminosae) family produced medium-sized (20 µm), spherical pollen with a tectate-columellate exine pattern and tricolpate apertures, consistent with dicotyledonous plants that rely on entomophilous (insect-mediated) pollination. The cream color indicates the presence of sporopollenin and lipids that attract pollinators, as also observed by Olowokudejo *et al.* (2020) in Nigerian legume species. Similarly, Asteraceae (sunflower) pollen exhibited larger, spiny (spinulose) or echinate surfaces, reflecting adaptations for adhesion to pollinators such as bees. The recorded pollen size (83 µm long, 34 µm wide) corresponds with the findings of Kumar *et al.* (2021), who identified large, echinate, tricolpate pollen in Helianthus annuus (sunflower), enhancing attachment efficiency during pollination.

The Chlorophyceae (green algae) pollen grains were spheroidal, large (180 µm), and echinate, with colporate apertures and yellowish-brown coloration. This may indicate an intermediate adaptation between aquatic and aerial dispersal forms. Large, echinate exines in algae-like forms have been linked to evolutionary transitions from aquatic to semi-terrestrial environments (Nair and Thomas, 2022). The Pinaceae

(conifers) pollen was smaller (10–19 µm), irregular in shape, and had scabrate-reticulate ornamentation with a monolete aperture an adaptation for anemophilous (wind) pollination. The brown pigmentation and exine pattern support findings by Ali *et al.* (2020), who noted that conifer pollen has rough, thick walls that resist desiccation and mechanical damage during wind dispersal.

The Poaceae (grasses) family showed monoporate, smooth (psilate) to thin exine patterns with spherical or slightly oval grains (15–40 µm), reflecting wind pollination efficiency. Similar patterns were documented by Ogbu and Eze (2021), who found that the simplicity of Poaceae pollen morphology minimizes air resistance and enhances long-distance dispersal. The color variations from light yellow to yellowish brown indicate different stages of maturity and chemical composition.

Overall, the diversity in pollen morphology across taxa mirrors the ecological and evolutionary strategies of each family, where exine ornamentation, size, and aperture type are directly linked to their mode of pollination and habitat adaptation.

The water quality data in Table 2 and 3 reveal spatial differences between surface and bottom layers across all sampling sites (Middle Core Jostum, Pila, Caps, Ichwa, and River Benue). Electrical Conductivity (EC) values were consistently higher in the bottom layers than at the surface, indicating an accumulation of dissolved ions from sediment interactions and organic matter decomposition. For instance, EC in Middle Core Jostum increased from 113.5 µS/cm at the surface to 219 µS/cm at the bottom, while Ichwa Community recorded the highest EC (285 µS/cm) at the bottom. These findings are in agreement with Eneji *et al.* (2018) and Adeleke and Jimoh (2023), who both observed higher conductivity in deeper waters of River Benue and the Lower Niger Basin due to mineral leaching and limited water circulation.

TDS (Total Dissolved Solids) followed a similar trend, increasing with depth, suggesting the presence of higher concentrations of dissolved salts and organic residues in bottom waters. Such patterns indicate that sediment–water exchange processes are major contributors to the ionic composition of these aquatic systems (Okoro *et al.,* 2022).

Temperature readings ranged between 29°C and 35°C, with minimal variation between depths, suggesting a well-mixed thermal profile typical of tropical freshwater systems where solar radiation and shallow depth promote uniform temperature distribution. These values are within the optimal range for aquatic organisms, as supported by Abdulrahman *et al.* (2020), who recorded similar thermal conditions (28–34°C) in the River Kaduna basin.

The pH ranged between 6.6 and 7.5 across all sites, reflecting near-neutral to slightly alkaline conditions. Surface waters in Caps and River Benue were slightly acidic (pH 6.6), possibly due to organic acid runoff or decaying vegetation, while bottom layers were slightly alkaline (pH 7.3–7.5), influenced by sediment buffering and microbial activity. This agrees with Ezekiel *et al.* (2021), who found similar depth-dependent pH variations in Imo River.

Integrating the results from both tables, it can be inferred that the pollen-producing plants are likely thriving in relatively healthy freshwater systems. The physicochemical parameters observed moderate EC, TDS within permissible limits (<500 mg/L), stable temperature, and near-neutral pH support favorable conditions for plant and algal growth, hence enabling viable pollen production and dispersal. As Onyema *et al.* (2023) suggested, aquatic plants health is directly linked to water quality stability,

influencing pollen morphology and reproductive success.

CONCLUSION

The study reveals clear interrelationships between pollen morphology and aquatic environmental quality. Pollen grains from various plant families displayed significant morphological diversity, highlighting their evolutionary adaptations to different pollination mechanisms. Concurrently, physicochemical parameters such as EC, TDS, temperature, and pH were within the for freshwater ecosystems, signifying moderately good water quality. The results collectively suggest that these environmental conditions sustain diverse plant taxa and ensure effective reproductive cycles.

Recommendations

It is therefore recommended that;

1. Sustained Environmental Monitoring: Continuous assessment of water quality and palynological diversity is recommended to detect ecological changes resulting from anthropogenic activities.

2. Pollution Management: Efforts should be made to minimize agricultural and domestic runoff to preserve water quality and ensure optimal conditions for aquatic vegetation.

3. Integrated Studies: Future research should integrate palynological and physicochemical data seasonally to assess long-term ecological dynamics.

4. Conservation Awareness: Local communities should be sensitized on the importance of maintaining clean water systems to sustain biodiversity and ecosystem productivity.

REFERENCES

Abdulrahman, M. A., Ibrahim, A. B., and Yusuf, S. O. (2020). Physicochemical assessment of selected freshwater ecosystems in the River Kaduna Basin, Nigeria. *Journal of Environmental Water Quality, 15*(2), 112–124.

Adeleke, O. T., and Jimoh, A. A. (2023). Vertical variation of water quality parameters in selected freshwater ecosystems of the Lower Niger Basin. *Nigerian Journal of Aquatic Sciences, 18*(1), 56–69.

Adeonipekun, P. A., Olowokudejo, J. D., and Akinsoji, A. (2018). *Pollen Flora of West African Plants*. University of Lagos Press.

Agashe, S. N., and Caulton, E. (2019). Morphological adaptations of freshwater algal spores and pollen analogues. *International Journal of Palynology, 43*(2), 87–99.

Alegbeleye, O. O., Ojo, A. O., and Musa, Y. A. (2019). Climatic characteristics and hydrological features of the River Benue Basin, Nigeria. *Journal of Tropical Environmental Studies, 12*(3), 145–157.

Ali, M. A., Khan, R. S., and Hassan, T. M. (2020). Exine ornamentation and dispersal adaptations of conifer pollen. *Palynological Research Journal, 28*(1), 33–47.

American Public Health Association (APHA). (2017). Standard methods for the examination of water and wastewater (23rd ed.). American Public Health Association.

Birks, H. J. B., and Birks, H. H. (2016). How have studies of ancient DNA from sediments contributed to the reconstruction of Quaternary floras? *New Phytologist, 209*(2), 499–506. https://doi.org/10.1111/nph.13657

Ekanem, E. E., and Udo, J. E. (2020). Standard procedures for sampling freshwater sediments and surface

water in tropical environments. *African Journal of Environmental Monitoring, 14*(4), 201–214.

Eneji, I. S., Adakole, J. A., and Sha'Ato, R. (2018). Seasonal variations in selected physicochemical properties of River Benue, Nigeria. *Journal of Water Resources and Environmental Engineering, 10*(2), 81–94.

Faegri, K., and Iversen, J. (1989). Textbook of pollen analysis (4th ed.). John Wiley and Sons.

Federal Ministry of Water Resources. (2021). *National Action Plan for the Revitalization of Nigeria's Water Supply, Sanitation and Hygiene Sector*. Abuja, Nigeria.

Food and Agriculture Organization. (2020). The state of world fisheries and aquaculture 2020: Sustainability in action. FAO. https://doi.org/10.4060/ca9229en

Giesecke, T., Brewer, S., Finsinger, W., Leydet, M., and Bradshaw, R. H. W. (2019). Patterns and dynamics of European vegetation change over the last 15,000 years. *Journal of Biogeography, 46*(5), 1021–1035. https://doi.org/10.1111/jbi.13548

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). (2019). Global assessment report on biodiversity and ecosystem services. IPBES Secretariat.

Kumar, P., Sharma, R., and Singh, V. (2021). *Comparative pollen morphology of Helianthus annuus and related Asteraceae species*. *Journal of Plant Systematics and Evolution, 59*(4), 412–425.

Mertens, K. N., Johnson, M. A., and Williams, S. D. (2021). Laboratory methods for palynological preparation of freshwater sediments. *Review of Palynological Techniques, 19*(2), 95–110.

Nair, R. P., and Thomas, K. J. (2022). Evolutionary significance of echinate pollen in aquatic and semi-aquatic plants. *Botanical Evolution Journal, 37*(1), 18–30.

Odeyemi, O. A., Adeyinka, A. T., and Salisu, M. B. (2021). Land use patterns and freshwater ecosystem dynamics in Benue State, Nigeria. *Environmental Monitoring in Africa, 16*(2), 66–79.

Ogbu, C. N., and Eze, P. C. (2021). Pollen morphology and wind dispersal efficiency in selected Poaceae species. *African Journal of Plant Sciences, 15*(6), 178–190.

Okoro, I. C., Umeh, E. C., and Nwachukwu, P. O. (2022). Sediment-water interactions and total dissolved solids in tropical freshwater systems. *Environmental Pollution Studies, 24*(3), 210–224.

Okoye, J. O., Nwankwo, C. I., and Bello, A. M. (2022). Influence of physicochemical parameters on aquatic biodiversity in selected Nigerian inland waters. *Nigerian Journal of Environmental Biology, 17*(1), 25–39.

Olowokudejo, J. D., Adeonipekun, P. A., and Aina, D. O. (2020). Comparative pollen morphology of selected Nigerian Fabaceae species. *Nigerian Journal of Botany, 33*(2), 115–129.

Onyema, I. C., Akinyemi, O. A., and Ibrahim, M. T. (2023). Water quality and reproductive ecology of aquatic macrophytes in tropical freshwater ecosystems. *African Journal of Aquatic Ecology, 21*(1), 51–67.

Sowunmi, M. A., and Akintola, S. L. (2020). *Atlas of West African pollen and spores* (2nd ed.). Nigerian Botanical Society.

Suganuma, Y., Matsumoto, T., and Kondo, H. (2023). Advances in acetolysis techniques for pollen preparation and microscopic analysis. *Journal of Palynological Methods, 45*(1), 15–29.

UNESCO. (2024). United Nations World Water Development Report 2024: Water for Prosperity and Peace. UNESCO.

United Nations Environment Programme. (2021). Making Peace with Nature: A scientific blueprint to tackle the climate, biodiversity and pollution emergencies. UNEP.

World Health Organization. (2022). *Guidelines for drinking-water quality* (4th ed., incorporating the second addendum). WHO.

Zonneveld, K. A. F., Marret, F., and Versteegh, G. J. M. (2019). Morphometric characterization of pollen and spores for environmental reconstruction. *Palynology, 43*(3), 341–356.

EVALUATION OF SOIL PHYSICOCHEMICAL AND HEAVY METAL INDICES AROUND ALUMACO FABRICATION AREAS IN ABRAKA, DELTA STATE, NIGERIA

Egboduku, W.O., Udo, M.W., Onokpasa, D., Okonigbo, B.D., and *Agbogidi, O.M.
Department of Botany, Faculty of Science, Delta State University, Abraka, Delta State, Nigeria
*Corresponding Author's Email: omagbogidi@yahoo.com

ABSTRACT

Rapid urbanization and expanding metal fabrication activities have increased the risk of heavy metal contamination of soils, posing serious threats to soil fertility, agricultural productivity, environmental quality, and public health. This study evaluated the physicochemical properties and heavy metal concentrations of soils surrounding aluminium fabrication workshops in Abraka, Delta State, Nigeria. Soil samples were collected from three locations around aluminium fabrication sites, composited, and analyzed using standard methods prescribed by AOAC (2012). Physicochemical analysis showed that the soils were predominantly sandy, moderately acidic (pH 6.70), and characterized by low organic matter (0.76%) and total nitrogen (0.03%), indicating poor soil fertility. However, appreciable levels of essential macronutrients, including available phosphorus (41.8 mg kg^{-1}), calcium (4.97 mg kg^{-1}), and magnesium (6.07 mg kg^{-1}), were recorded. Heavy metal analysis revealed elevated concentrations of nickel (647.71 mg kg^{-1}), lead (26.80 mg kg^{-1}), and iron (14.82 mg kg^{-1}) relative to the control soil and recommended FAO/WHO permissible limits. Nickel exhibited the highest concentration, substantially exceeding acceptable thresholds, while cobalt (0.022 mg kg^{-1}), mercury (0.09 mg kg^{-1}), and arsenic (0.12 mg kg^{-1}) were detected at trace levels. The elevated concentrations of heavy metals indicate substantial soil contamination associated with aluminium fabrication activities and suggest a potential risk of metal uptake by plants, bioaccumulation within the food chain, and adverse ecological and human health effects. The study concludes that aluminium fabrication operations have significantly altered soil quality in the study area and recommends routine environmental monitoring, improved waste management practices, and the adoption of phytoremediation techniques to mitigate heavy metal contamination and restore soil health.

Keywords: Aluminium Fabrication, Soil Contamination, Environmental Health, Phytoremediation, Heavy Metals.

INTRODUCTION

Our ecosystems depend on the soil to sustain plants, store minerals, and filter water. However, the soil frequently becomes contaminated with heavy metals and undergoes chemical alterations in areas where human activity entails intensive labor, such as metal fabrication. Metals such as lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), and nickel (Ni) are frequently released into nearby soil from fabrication processes, painting, metal cutting, and improper waste disposal (Onobredefe *et al.,* 2024; Eyenub *et al.,* 2020). These metals' behavior is influenced by the characteristics of the soil, such as pH, organic matter, electrical conductivity (EC), and cation exchange capacity (CEC). According to Ofem *et al.,* (2024) and Onobredefe *et al.*, (2024), they have an impact on whether metals remain trapped in the soil or become accessible to plants and groundwater. Elevated amounts of Zn, Cu, Pb, and other metals have been found in soils close to scrap dumps and workshops in Abraka and other parts of Delta State, indicating significant pollution (Akpoveta *et al.,* 2010). Despite the fact that metal

production hubs are common in urban areas, including the Alumaco zones in Abraka, relatively little research has been done on the soils in the vicinity of these locations. Since these places may expose adjacent citizens and agricultural fields to contaminants without our knowledge, a new, location-specific analysis is desperately needed. An essential part of the terrestrial ecosystem, soil serves a variety of purposes beyond only anchoring plants. By providing vital nutrients, moisture, and oxygen, it serves as a life-supporting medium for terrestrial organisms, particularly plants. Furthermore, soil acts as a natural detoxification and filtering system, absorbing contaminants like heavy metals and either immobilizing or changing them into less dangerous forms (Onobredefe *et al.,* 2024). However, the constant inflow of contaminants, particularly from man-made sources like manufacturing and industrial operations, might exceed its filtration and buffering capabilities. As time passes, this contamination may change microbial communities, impact soil fertility, lower agricultural output, and endanger human health by way of the food chain (Okon and Ogiri, 2024). Even while certain heavy metals, such as iron (Fe), zinc (Zn), and copper (Cu), are necessary micronutrients for both plants and animals, high amounts of these metals can be harmful. The production of aluminum contributes by releasing paint leftovers, metallic dust, and wastewater that contains metal particles. Once in the soil, the pH, redox potential, texture, and organic matter content all have an impact on the intricate interactions that these metals go through. They can remain dissolved and mobile, bind with organic materials, precipitate as insoluble compounds, or be adsorbed onto clay minerals. Because they are more bioavailable, mobile metals are more likely to be absorbed by plants and contaminate groundwater (Sanyaolu *et al.,* 2023). Lead (Pb) and cadmium (Cd) are two examples of metals that are especially persistent and can contaminate soil for decades.

Aluminium fabrication (commonly referred to as Alumaco fabrication in Nigeria) processes contributes to socio-economic development and urban infrastructure, it also introduces a range of pollutants into the environment, especially in unregulated settings like informal workshops or roadside industries (Laniyan *et al.,* 2023). Aluminium toxicity in plants leads to inhibited root development**,** nutrient deficiency**,** chlorosis**,** and stunted growth (Chibuike and Obiora, 2018). The presence of aluminium and lead in the rhizosphere also limits the uptake of essential minerals like calcium, magnesium, and phosphorus, leading to poor plant health and reduced yields (Adegbite *et al.,* 2022). In edible crops, this contamination poses human health risks due to the bioaccumulation of metals beyond acceptable limits. Similar results where documented by Otukam *et al.,* (2025) on a study on the environmental accumulation of trace metals, including heavy metals (Pb, Cu, Zn, Cr, and Fe), in four vegetables. According to the study, plants use their roots to absorb these metals from the contaminated soil. These trace metals gradually build up in plant tissues, become concentrated, and become toxic to organisms at higher trophic levels.

MATERIALS AND METHOD

The research was conducted in Abraka, situated in Ethiope East Local Government Area of Delta State, Southern Nigeria. The study location is located between latitutde 5° 45′ and 5° 5 0′N and longitude 6° and 6° 15′E. It lies within the tropical rainforest zone, characterized by high humidity, substantial rainfall, and distinct wet and dry seasons. The average annual temperature ranges from 25°C to 30°C, and the area receives an average annual rainfall of

approximately 3.098 mm with mean monthly rainfall ranging from 28.8mm. The soil temperature in this area is about 28°C and soil pH ranging from 4.5-8 (Achuba and Ja-anni, 2018).

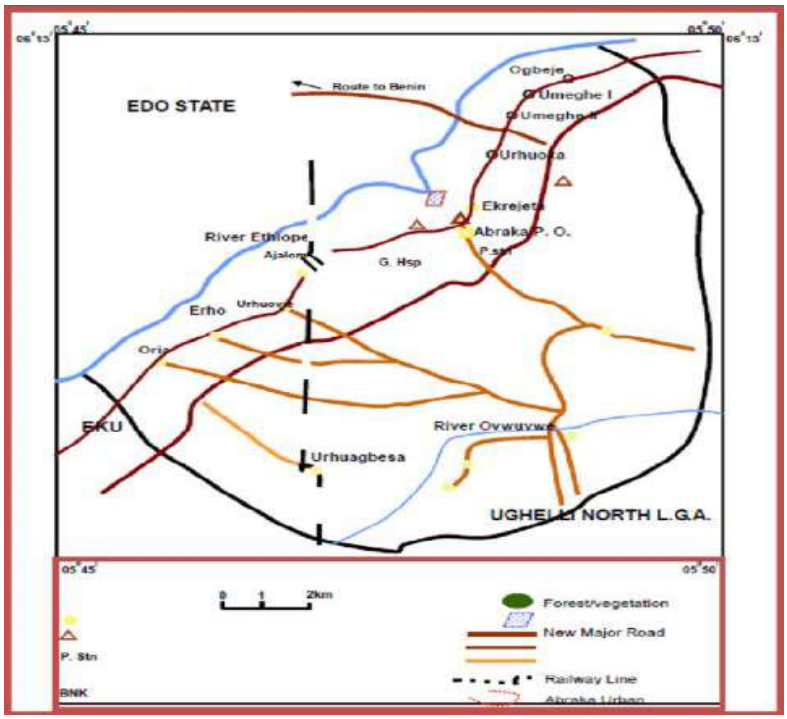


Figure 3.1: Map showing the study area, Abraka, Delta State
Source: Ozabor and Obaro (2016)

Sample Collection and Preparation

Soil samples were collected from three active aluminium fabrication workshops located in different parts of Abraka. Each sampling site was selected based on proximity to fabrication activity and visible signs of metal accumulation. From each location, surface soil samples were collected at a depth of 0–20 cm using a clean stainless-steel auger to minimize contamination. At each site, multiple sub-samples were collected and combined to form a single composite sample per site. The three composite samples were then homogenized to form one bulk representative sample for laboratory analysis. Following collection, samples were transferred into labeled, clean polyethylene bags and transported to the laboratory. In the laboratory, soil samples were air-dried at ambient temperature to eliminate moisture without altering chemical composition. After drying, samples were gently crushed using a ceramic mortar and pestle to break down clumps. The crushed soil was sieved through a 2 mm mesh to ensure uniformity in particle size. Prepared samples were stored in airtight, contamination-free containers for subsequent physicochemical and heavy metal analysis.

Physicochemical parameters analyzed included soil texture, soil color, soil odor, soil organic matter, bulk density, total porosity, pH. Heavy metals (Mn, Fe, Co, Pb, Ni, Zn, As, Cr, Cu).

Analyses of soil physicochemical properties and heavy metal content were conducted

using standardized procedures outlined by the Association of Official Analytical Chemists (AOAC, 2012).

RESULTS AND DISCUSSION

Table 1 and 2 present the physicochemical parameters of the soil

Table 1 Soil Physicochemical Parameters

S/N	Parameters	Contaminated Soil (mg/kg)	Control Soil (mg/kg)
	Physical Parameters		
1	Soil Texture-Sand	79%	69%
	Clay	11%	12%
	Silt	10%	19%
2	Soil Color	Yellowish grey	-
3	Electrical Conductivity	5.76	0.28
4	Soil Odor	Nice earthly smell	-
5	Soil Organic Matter	0.76	0.54
6	Water Holding Capacity	11.00	50.6
7	Moisture Content	10.5	13.5
8	Bulk density	1.30	1.48
9	Total Porosity	3.98	43.56
	Chemical Parameters		
1	pH	6.70	6.45
2	Calcium (Ca^{2+})	4.97	5.40
3	Magnesium (Mg^{2+})	6.07	3.96
4	Phosphorus (P)	41.8	57.2
5	Nitrogen (N)	0.03	0.03

Table 2 Heavy metals in the soil

S/N	Heavy Metals	Contaminated Soil (mg/kg)	Control Soil (mg/kg)	WHO/FAO Limit (mg/kg)
1	Manganese (Mn)	0.57	-	2000
2	Iron(Fe)	14.82	0.058	50000
3	Cobalt(Co)	0.022	-	50
4	Lead(Pb)	26.8	1.308	60
5	Nickel(Ni)	647.71	-	50
6	Zinc(Zn)	14.61	0.229	300
7	Arsenic(As)	0.12	-	20
8	Chromium(Cr)	0.20	0.015	100
9	Copper(Cu)	3.00	-	100
10	Mercury(Hg)	0.09	-	2

DISCUSSION

The Soil Texture of the contaminated soil was composed of 79% sand, 11% clay, and 10% silt, while the control soil consisted of 69% sand, 12% clay, and 19% silt. This indicates that the contaminated soil is more sandy in nature compared to the control. A higher sand fraction generally reduces water-holding capacity and nutrient retention, which may explain the lower water-holding

capacity of the contaminated soil. Soil Color and Odor, the contaminated soil was yellowish-grey in color with a nice earthy smell. The yellowish-grey appearance of the contaminated soil may be due to anthropogenic inputs from aluminum fabrication activities, which influence soil mineral composition. Electrical Conductivity (EC), the contaminated soil recorded an EC of 5.76, much higher than the control value of 0.28. This suggests a significant increase in soluble salts within the contaminated soil, possibly due to deposition of metal ions and industrial residues. High EC levels can affect plant root physiology and microbial activity. Soil Organic Matter (OM), organic matter in the contaminated soil (0.76 mg/kg) was higher than the control (0.54 mg/kg). This suggests that the contaminated site may have received organic inputs, possibly from plant litter, waste disposal, or industrial effluents. Increased OM improves soil fertility and cation exchange capacity, although excessive contamination could alter its decomposition. Water Holding Capacity (WHC), the contaminated soil exhibited a low WHC (11.0%) compared to the control (50.6%). This reduction is likely due to the high sand fraction, which promotes rapid drainage and reduces the soil's ability to retain moisture. Low WHC adversely affects plant growth, especially during dry conditions. Moisture Content was lower in the contaminated soil (10.5%) compared to the control (13.5%). This trend aligns with the sandy nature and low WHC of the contaminated soil. Bulk Density and Porosity**,** bulk density of the contaminated soil (1.30) was slightly lower than the control (1.48). Interestingly, total porosity was drastically reduced in the contaminated soil (3.98) compared to the control (43.56). This suggests compaction and loss of pore spaces, possibly from industrial deposition and reduced organic matter stabilization. Such conditions hinder root penetration and limit aeration. The pH of contaminated soil (6.70) was slightly more acidic than the control (6.45). Both values fall within the near-neutral range, suitable for nutrient availability. However, even small pH shifts can influence the mobility and bioavailability of heavy metals. Macronutrients like Calcium was found to be lower in contaminated soil (4.97 mg/kg) compared to control (5.40 mg/kg), suggesting depletion due to industrial leaching. Magnesium, higher in contaminated soil (6.07 mg/kg) than control (3.96 mg/kg), possibly due to deposition from industrial residues. Phosphorus, reduced in contaminated soil (41.8 mg/kg) compared to control (57.2 mg/kg), indicating nutrient depletion or fixation by heavy metals. Nitrogen, both soils recorded equal values (0.03 mg/kg), showing no notable influence of contamination on nitrogen levels. Agbogidi and Ogbe (2025) reported that crude oil contamination of soil significantly reduced cassava performance, largely due to the alteration of key soil physicochemical properties such as soil pH, nutrient composition, and organic matter. This is consistent with the present study, where the contaminated soil exhibited variations in pH, organic matter (0.76 compared to 0.54 in the control), and electrical conductivity (5.76 compared to 0.28 in the control). These changes indicate that contamination disrupts soil quality, thereby creating unfavorable conditions for crop growth and development. Similarly, Agbogidi *et al.,* (2023) showed that starch wastewater adversely affected maize growth in Abraka by altering soil chemical properties, particularly nitrogen and phosphorus levels, which aligns with the reduced phosphorus (41.8 compared to 57.2 in the control) and stable nitrogen content (0.03 in both soils) observed in this study. Taken together, the findings of Agbogidi *et al.,* reinforce the evidence that contamination alters the physicochemical balance of soil, leading to poor soil fertility and potential

crop performance challenges in the study area."

Heavy Metals analyzed are Manganese (Mn), contaminated soil recorded Mn at 0.57 mg/kg. This concentration is far below the FAO/WHO permissible limit of 2000 mg/kg, indicating no immediate threat of Mn toxicity. Iron (Fe) concentration was 14.82 mg/kg in contaminated soil compared to 0.058 mg/kg in the control. While elevated in contaminated soil, the value remains far below the permissible limit of 50,000 mg/kg. The increase suggests inputs from aluminum fabrication byproducts. Cobalt (Co) detected at 0.022 mg/kg in the contaminated. This value is far below the FAO/WHO threshold of 50 mg/kg. Lead (Pb) concentration was 26.8 mg/kg in contaminated soil compared to 1.308 mg/kg in the control. Although below the FAO/WHO permissible limit of 60 mg/kg, the nearly 20-fold increase in contaminated soil indicates significant anthropogenic enrichment, raising long-term ecological and health concerns. Nickel (Ni) present in contaminated soil recorded an extremely high Ni concentration of 647.71 mg/kg. This far exceeds the FAO/WHO permissible limit of 50 mg/kg, indicating severe Ni contamination and potential toxicity to plants and soil biota possibly due to the result of aluminiun fabrication activities. Zinc (Zn) levels were 14.61 mg/kg in contaminated soil versus 0.229 mg/kg in the control, both far below the permissible limit of 300 mg/kg. While elevated, Zn may pose future threat to soil health if not properly monitored. Arsenic (As), measured at 0.12 mg/kg in contaminated soil is far below the FAO/WHO permissible limit of 20 mg/kg. Chromium (Cr), contaminated soil contained 0.20 mg/kg, compared to 0.015 mg/kg in the control. Although elevated, this is far below the permissible limit of 100 mg/kg. Copper (Cu) recorded at 3.00 mg/kg in contaminated soil and below the FAO/WHO limit of 100 mg/kg. Mercury (Hg), detected at 0.09 mg/kg in contaminated soil and below the FAO/WHO limit of 2 mg/kg.

In summary, among the heavy metals analyzed, Nickel (Ni) recorded the highest concentration (647.71 mg/kg), far above the permissible limit of 50 mg/kg, suggesting it is the most critical pollutant in the study area. In contrast, Cobalt (Co) had the lowest concentration (0.022 mg/kg), well below the permissible limit. This comparison highlights the severity of Ni contamination in aluminum fabrication sites in Abraka.

CONCLUSION

This research has shown that aluminium fabrication activities significantly alter the physicochemical quality of soil in Abraka. Although some parameters such as pH, Ca, and N were relatively stable, others such as electrical conductivity, bulk density, water holding capacity, and porosity were adversely affected, reducing soil quality and productivity. Furthermore, the accumulation of Nickel and Lead above permissible thresholds highlights the risk of heavy metal contamination in the studied area. Therefore, aluminium fabrication practices in Abraka contribute to soil degradation and may pose ecological and public health hazards if left unchecked. This underscores the urgent need for proper waste management and monitoring strategies in the area.

RECOMMENDATIONS

1. Environmental regulatory agencies should enforce strict guidelines on industrial waste disposal and impose penalties for non-compliance to deter unsafe practices.

2. Operators of aluminium fabrication workshops should adopt environmentally friendly methods, including proper disposal of metal residues and a routine soil monitoring should be carried out in and around fabrication sites to detect early signs of contamination and ensure compliance with permissible standards.

3. Awareness campaigns should be organized for local communities and artisans to educate them on the environmental and health implications of heavy metal pollution.

REFERENCES

Achuba, F.I and Ja-anni, M.O (2018). Effect of abattoir waste water on metabolic and antioxidant profiles of cowpea seedlings grown in crude oil contaminated soil. *International Journal of Recycling Organic waste in Agriculture*, 7:59-66.

Adegbite, M. O., Ojo, S. A., and Adefolalu, D. O. (2022). Aluminium toxicity and nutrient interactions in crops grown on acid soils in southwestern Nigeria. *Nigerian Journal of Soil and Environmental Research*, 21(2):113–125.

Agbogidi, O. M., and Ogbe, O. (2025). Performance of cassava (Manihot esculenta Crantz) as affected by crude oil contamination of soil. *Journal of Science Research and Reviews*, 2(2), 63-69.

Agbogidi, O. M., Enujeke, C. E., Okpewho, O. P., Efobo, M., Ogbemudia, C. O., and Edokpiawe, S. (2023). Effects of starch wastewater on the performance of maize (Zea mays L.) in Abraka, Delta State, Nigeria. *FUDMA Journal of Sciences*, 7(4):47-50.

Akpoveta, O. V., Osakwe, S. A., Okoh, B. E., and Otuya, B. O. (2010). Physicochemical characteristics and heavy metal levels in soils near metal scrap dumps in Abraka and Agbor, Delta State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 14(4):57–60.

Association of Official Analytical Chemists (AOAC). (2012). *Official Methods of Analysis* (19th ed.). AOAC International.

Chibuike, G. U., and Obiora, S. C. (2018). Heavy metal polluted soils: Effect on plants and bioremediation methods. *Applied and Environmental Soil Science*, 2018, 1–12.

Eyenubo, O. B., Peretomode, O., Egharevba, F., and Osakwe, S. A. (2020). Assessment of heavy metal pollution from e-waste dumping in Abraka, Delta State, Nigeria. *Arid Zone Journal of Engineering, Technology and Environment*, 16(4), 123–132.

Food and Agriculture Organization of the United Nations and World Health Organization. (2001). *Codex Alimentarius Commission, Food Additives and Contaminants*. Joint FAO/WHO Food Standards Programme.

Laniyan, T. A., Ajayi, S. O., and Idowu, O. E. (2023). Soil heavy metal load near small-scale aluminium fabrication hubs in Nigeria. *Environmental Monitoring and Assessment*, 195(2):119.

Ofem, J. O., Kefas, G., and Abam, T. K. S. (2024). Assessment of heavy metals in soils around industrial zones in Warri and Effurun, Delta State, Nigeria. *Journal of Environmental Science and Technology*, 18(2):95–105.

Ofem, K. I., Kefas, P. K., and Abam, P. O. (2024). Soil health implications of heavy metals in Southeast Nigerian agricultural soils. *Environmental Monitoring and Assessment*, 196, 38.

Okon, A. N., and Ogiri, J. O. (2024). Soil contamination from aluminium fabrication activities in Port Harcourt, Nigeria. *Nigerian Journal of*

Environmental Research, 21(1):33–44.

Onobredefe, J. H., Maju-Oyovwikowhe, E. G., and Kinrin-Ola, J. O. (2024). Heavy metal contamination in soils around the Delta Steel Company, Aladja, Nigeria. *Journal of Energy Technology and Environment*, 6(4):93–106.

Otukam, N. T., Agbodjoh, O. M., Otuakam, E. A., and Agorom, I. G. (2025). Trace metal contents of vegetables in Ogbedigbo Afor, Delta State, Nigeria. *Science World Journal*, 20(1):367-372.

Ozabor, F and Obaro, H.N. (2016). Health effects of poor waste management in Nigeria: a case study of Abraka, in Delta state. *International Journal of Environment and waste Management*, 18(3):195-204

Sanyaolu, A. A., Eze, V. C., and Adedeji, M. O. (2023). Influence of metal fabrication on soil physicochemical properties in Ogun State, Nigeria. *Journal of Applied Environmental Management*, 15(4):201–213.

GEOSPATIAL ASSESSMENT OF BIOMASS RESIDUES FOR RENEWABLE ENERGY AND ECOLOGICAL SUSTAINABILITY IN NASARAWA STATE, NIGERIA

***[1]Abubakar Suleiman, [2]Adamu Bello Suleima, [1]Anyubaga Salim Bitus, [2]Fatima Umar Abdulhamid**
Ahamdu Bello University Zaria, Nigeria
Federal University of Lafia, Nigeria
*Corresponding Author's Email: b3lllo.as@gmail.com

ABSTRACT

The mounting energy shortfall and rising environmental challenges linked to reliance on fossil fuels have amplified the necessity of investigating sustainable renewable energy options. Using Geographic Information System (GIS)-based spatial modeling techniques, this study evaluated the availability of agricultural biomass residues and their bioenergy potential in Akwanga, Wamba, and Nasarawa Eggon Local Government Areas of Nasarawa State, Nigeria. Secondary data were utilized, including crop production statistics from 2020 to 2022, Sentinel-2 imagery, and Digital Elevation Model (DEM) data for the analysis. The Residue-to-Product Ratio (RPR) method was used to estimate the amount of crop residues and their energy potential. Additionally, ArcGIS Model Builder and Multi-Criteria Decision Analysis (MCDA) were utilized to find appropriate locations for bioenergy plant development. The findings showed that around 14,004.46 tonnes of agricultural residues could be produced in the study area, yielding an estimated energy potential of roughly 200,934.69 MJ/year. While Wamba LGA generated the most biomass residue, Akwanga LGA was recognized as the best site for a bioenergy plant because of its advantageous terrain, accessibility, and availability of biomass. The greatest portion of the total energy potential derived from cassava residues. The research shows that agricultural residues are a feasible renewable energy source that can decrease waste, lessen greenhouse gas emissions, and improve environmental sustainability. It thus advocates for greater investment in biomass energy technologies, educating farmers about residue management, and incorporating GIS-based decision-support systems into the planning and development of renewable energy in Nasarawa State.

Keywords: Renewable Energy, Agricultural Biomass Residues, Bioenergy Potential, Waste-to-Energy, Residue-to-Product Ratio, Environmental sustainability.

INTRODUCTION

Despite the ongoing increase in global energy demand, numerous developing nations, Nigeria included, grapple with chronic energy shortages and a significant reliance on fossil fuels. This scenario worsens climate change and greenhouse gas emissions. This has led to an increasing worldwide interest in alternative, renewable, and carbon-neutral energy sources. Biomass, especially agricultural crop residues, presents a promising avenue. Biomass is defined as any organic material, whether living or dead, that has a biological origin, but excludes fossil fuels and peat. It encompasses wood, energy crops, organic waste from municipalities and industries, and agricultural by-products like stalks, straws, husks, peelings, and shells. These resources can be transformed into biofuels, biogas, or biomethane

(International Renewable Energy Agency [IRENA], 2009). Beyond being carbon neutral, bioenergy reduces fossil fuel dependency and enhances energy security (Hanif *et al.,* 2020). Esmaeili and Farhadi (2020), concluded in their work that all liquid and solid wastes from human activities are termed residual biomass, which is generated across agricultural, industrial, commercial, and residential areas.

In spite of this potential, significant amounts of crop residues in Nigeria are either subjected to open burning or allowed to decompose in the fields. This gives rise to two significant environmental issues: the emission of methane during the decomposition process and the generation of carbon monoxide from open burning (Bharti *et al.,* 2021). Thus, effective residue management is crucial for both renewable energy generation and safeguarding the environment. Waste-to-Energy (WtE) strategies that convert these residues into energy can reduce waste, help fight climate change, promote environmental sustainability, and address energy supply gaps.

On a global scale, the production of crop residues is significant and increasing. Cherubin *et al.,* (2018) calculated that the global production of crop residues rose from 3,803 million tons (MT) in 2003 to 5,011 MT in 2013, marking a 31.7% increase. According to Hiloidhari and Baruah (2014), India has an annual dry biomass total of 686 MT, with 234.5 MT (34.2%) available for bioenergy after domestic and agricultural uses, as noted by Cardoen *et al.,* (2015b). In Africa, research has validated similar potentials. According to Di-Fraia *et al.,* (2020), residual biomass could satisfy 14% of the thermal demand in Italy's Campania region. Gabisa and Gheewala (2018) reported an annual figure of 550 PJ derived from Ethiopian crop residues, whereas Mboumboue and Njomo (2018) estimated that 42,317.1 kt of residues in Cameroon yielded 251.3 TJ. In Nigeria, Elisha *et al.,* (2021) estimated that groundnut residues alone in Bogoro LGA could yield 215,725.8 tonnes with an energy potential of 676,181 MJ.

However, the absence of dependable, detailed geographical data on the availability of biomass resources presents a significant obstacle to the uptake of bioenergy in Nigeria (Ukoba *et al.,* 2023). Two approaches exist for biomass estimation: demand-driven and resource-focused. The resource-focused approach which considers actual biomass types such as agricultural residues and their byproducts is the most widely used globally (Simonyan and Fasina, 2013). This study adopts that approach.

Geographic Information System (GIS) modeling provides a powerful framework for resource-focused assessment. Modeling is a set of rules and procedures for representing a phenomenon or predicting an outcome (Environmental Systems Research Institute [ESRI], 2018). In a GIS environment, a map is a miniature representation of part of the real world and is the most common model. The ArcGIS Model Builder can automate processes such as resource estimation, multi-criteria decision analysis, and suitability mapping. According to Mitchell (2012), representing a part of the real world allows studies and simulations to be conducted on the model rather than the real world, enabling testing of scenarios. For biomass assessment, the representation of residue concentration and quantity is a form of modeling, and tools such as weighted overlay can be designed within Model Builder to establish required procedures. This approach has been successfully applied in landscape assessment by Schaller and Mattos (2009) and soil erosion modeling by Hidayat and Andajali (2018).

In Nasarawa State, Nigeria, agricultural activities generate considerable crop residues from cassava, maize, rice, sorghum, groundnut, and yam. However, no comprehensive GIS-based study has quantified the energy potential of these residues or identified suitable locations for bioenergy plants. This study, therefore, focuses on three Local Government Areas (Akwanga, Wamba, and Nasarawa Eggon), utilizing crop production statistics (2020–2022), residue-to-product ratios (RPR), Digital Elevation Model (DEM), and Sentinel-2 10m resolution imagery within an ArcGIS Model Builder environment to assess and evaluate residual biomass availability for energy production in Nasarawa State, Nigeria, using GIS-based modeling by estimating the quantity of crop residues and their corresponding bioenergy potential using the residue-to-product ratio method. The study also Implements a GIS-based model using weighted overlay analysis to determine suitable locations for siting a bioenergy plant in the study area.

MATERIALS AND METHODS

Source of Data

Annual production of crops data used for the study were obtained from Nasarawa State Agricultural Development (NADP) from 2020-2022. To select and estimate the quantity of residues generated, the residue-to-product ratio (RPR) method was used. The Residue-to-Product Ratio (RPR) values of different crops and their respective heating values were obtained from published literature.

Estimating the Residue and Bioenergy Potential

The quantity of crop residues was estimated using the residue-to-product ratio (RPR) method. The theoretical biomass potential (TBP) and total energy potential (TEP) were calculated using Equations (1) and (2):

$$\mathbf{TBP} = \Sigma\,[CP_{(i)} \times RPR_{(i)} \times (1 - M)] \quad \ldots\ldots\ldots\ldots (1)$$

$$\mathbf{TEP} = \Sigma\,[TBP_{(i)} \times LHV_{(i)}] \quad \ldots\ldots\ldots\ldots (2)$$

Where:

- $CP_{(i)}$ = Crop production of crop type (tonnes)
- $RPR_{(i)}$ = Residue-to-product ratio of crop type
- M = Moisture content (decimal)
- $TBP_{(i)}$ = Theoretical biomass potential of crop type (tonnes)
- $LHV_{(i)}$ = Lower Heating Value of crop type (MJ/ tonnes)
- i = the index number representing a specific crop.

Thus, TBP is what gave rise to TEP using the crop production data.

GIS Model Implementation Using Various Weighted Criteria

A weighted overlay tool was used to assemble all the factor maps to produce the final map which was automated by ArcGIS model builder in ArcGIS 10.6.1 environment. First, criteria factors were processed using Euclidean Distance and Reclassification techniques in spatial analyst tools of ArcGIS 10.6.1. Weighted overlay was used to process the weighted value from the AHP of Multi Criteria Decision Analysis to generate the final suitability map. In addition, certain factors such as qualifiers and restrictions were considered during the analysis.

RESULTS AND DISCUSSION

This study estimated the potential for producing bioenergy from various crop residues sources and GIS was used to model suitable locations for bioenergy plant. The estimate of the studied biomass residue resources and the corresponding bioenergy potential are presented in the following sections.

Estimated Bioenergy potential

The estimated bioenergy potential for all the crop residues in the study area is shown in Tables 1, 2 and 3. Result in table 1 shows the estimated theoretical bioenergy potential that can be used to generate energy from the available crop residues. It was observed that cassava (stalk) residues have the highest residues with an energy potential of 17,052.47MJ, and the least is maize (Husk) with an energy potential of 530.75MJ. The total bioenergy potential of Akwanga LGA is estimated at 45,497.09MJ which includes all the crop residue potentials in the study area. These results partly align with that of Tanyi *et al.,* (2020) which reported that the crop residues with the highest energy potential in Cameroon are plantains, palm oil, maize, sorghum, and cassava. The high energy content crops can be attributed to their high production quantities and heating values of their residues. It also agrees with Tolessa (2023) which reported that maize residue potential has 293PJ per year accounting for 29% of the total residues of 836PJ in Ethiopia.

Table 1: Amount of energy that can be generated from each crop residue in Akwanga Local Government Area, Nassarawa State, Nigeria

Crop type	Crop Residues	Residues Amount	Estimated Energy (MJ)
Maize	Stalk	326.23	6,413.68
	Cob	52.23	850.30
	Husk	34.11	530.75
Rice	Straw	217.37	1,919.37
	Husk	356.86	4,603.49
Sorghum	Straw	78.48	1,020.24
Cassava	Stalk	805.97	13,693.43
	Peelings	711.15	9,316.06
Groundnut	Shell/Husks	49.49	836.38
	Straw	220.99	3,359.04
Yam	Peelings	278.45	2,954.35
	Total Energy	**3131.33**	**45,497.09MJ**

Results in Table 2 show the estimated theoretical bioenergy potential that can be used to generate energy from the available crop residues, it was observed that cassava residues have the highest residues with an energy potential of 82,712.68MJ, and Maize residue (Husk) with 443.30MJ of bioenergy potential is crop with the lowest residue. The total bioenergy potential of Wamba LGA is estimated at 102,882.24MJ which includes all the crop residue potentials in the study area. Similar studies by Elisha *et al.,* (2021) and Ukoba (2024) estimated the potential of groundnut crop residue which accounted for 215,725.8 tonnes with an energy potential of 676,181 MJ in Bogoro LGA of Bauchi State. The high energy content crops can be attributed to their high production quantities and heating values of their residues.

Crop type	Crop Residue	Residues Amount	Estimated Energy (MJ)
Maize	Stalk	272.51	5,357.54

	Cob	43.64	710.45
	Husk	28.49	443.30
Rice	Straw	253.57	2,239.02
	Husk	416.28	5,370.01
Sorghum	Straw	53.76	698.88
Cassava	Stalk	1871.87	31,803.07
	Peelings	3886.23	50,909.61
Groundnut	Shell/Husks	32.92	556.34
	Straw	147.01	2,234.55
Yam	Peelings	200.18	2,123.90
	Total Energy	**7206.46**	**102,882.24MJ**

Result in Table 3 shows the estimated theoretical bioenergy potential that can be used to generate energy from the available crop residues. It revealed that cassava residues have the highest residues with an energy potential of 23,315.55MJ, and maize (Husk) with 610.73MJ is the lowest residue. The total bioenergy potential of Nasarawa Eggon LGA is estimated at 52,555.361MJ which includes all the crop residue potentials in the study area. Based on this, it is established that crop residues have huge energy potentials. Likewise, Gabisa and Gheewala (2018) reported that crop residues in Ethiopia can produce 550 PJ accounting for 34% of the total crop residues in the country. Similarly, Mboumboue and Njomo (2018) found that a total of 251.3TJ of bioenergy potential can be generated from 42,317.1kt of residues in Cameroon.

Table 2: Amount of energy that can be generated from each crop residue in Wamba Local Government Area, Nassarawa State

Crop type	Crop Residue	Residues Amount	Estimated Energy (MJ)
Maize	Stalk	375.36	7,379.57
	Cob	60.11	978.59
	Husk	39.25	610.73
Rice	Straw	373.58	3,298.71
	Husk	613.31	7,911.69
Sorghum	Straw	99.34	1,291.42
Cassava	Stalk	816.69	13,875.56
	Peelings	720.61	9,439.99
Groundnut	Shell/Husks	64.89	1,096.641
	Straw	289.75	4,404.2
Yam	Peelings	213.78	2,268.26
	Total Energy	**3666.67**	**52,555.361MJ**

GIS-Based Model Implementation

Figure 1, shows the process by which the model was created for the study area using the ArcGIS model builder to generate result by automating the process. Different layers with their corresponding values were used as input, and the model was automated. This method is similar to that of Schaller and Mattos (2009) and Hidayat and Andajali (2018) which used ArcGIS model builder to automate the process of landscape assessment and soil erosion. The result of the model is presented in Figure 2.

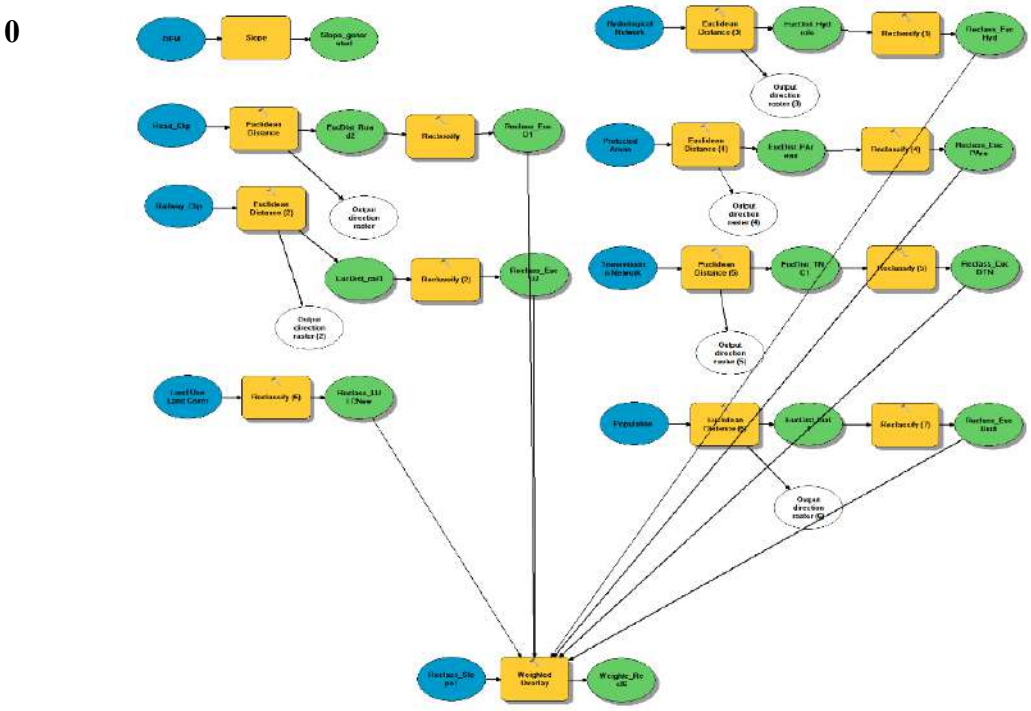


Figure 1: Steps and procedure adopted during the model implementation.

Result in Figure 2 show the model output, total unsuitable area account for 3.34%, lowest suitable area account for 81.25%, low suitable area account for 226.92%, moderately suitable area account for 94.41% and highly suitable area account for 9.44% of the study area. It is evident that Akwanga LGA has the largest area suitable for situating bioenergy plant. The attributing factors that made Akwanga LGA with a large expanse of land suitable for bioenergy plant is because of its moderate level terrain, road networking and population density.

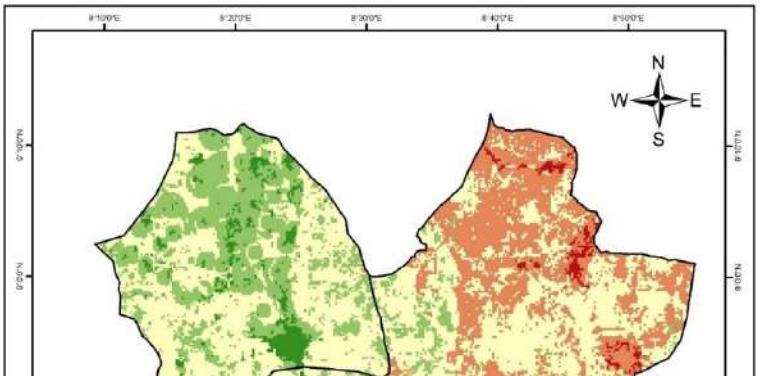


Figure 2: Final model suitability map of the study area

CONCLUSION

This study assessed residual biomass availability for energy production in Wamba, Nasarawa Eggon and Akwanga LGAs of Nasarawa State, Nigeria. It was observed that cassava had the highest residue with 8812.8 tonnes, followed by maize 1231.93tonnes and yam 629.41 tonnes. The study estimated the bioenergy potential using the residue-to-product ratio method of estimating the potential of crops in energy production. It was estimated that the crops in the study area have the potential of generating 200,934.691MJ of energy. The crop with the highest energy potential was cassava with 129,037.72MJ and the crop with the least energy potential was Maize (Husk) residue with 1,548.78MJ of energy. Based on the final suitability model, it was observed that unsuitable area covers about 3.34% and highly suitable area for bioenergy production covers 9.44% in the study area. Akwanga LGA was observed to have the large area for situating a bioenergy plant. Overall, this study provides valuable data and insights on the abundant biomass resources and crop residues that can be used for energy production in the study area. Exploiting these energy potentials will go a long way in contributing to clean, smart, and sustainable energy thereby combating and reducing the rate of carbon emission.

REFERENCES

Bharti, A., Paritosh, K., Mandla, V. R., Chawade, A., and Vivekanand, V. (2021). GIS application for the estimation of bioenergy potential from agriculture residues: An overview. *Energies, 14*(4), Article 898. https://doi.org/10.3390/en14040898

Cardoen, D., Joshi, P., Diels, L., Sarma, P. M., and Pant, D. (2015). Agriculture biomass in India: Part 2. Post-harvest losses, cost and environmental impacts. *Resources, Conservation and Recycling, 101*, 143–153. https://doi.org/10.1016/j.resconrec.2015.06.002

Cherubin, M. R., Oliveira, D. M. D. S., Feigl, B. J., Pimentel, L. G., Lisboa, I. P., Gmach, M. R., Varanda, L. L., Morais, M. C., Satiro, L. S., Popin, G. V., De

Paiva, S. R., Dos Santos, A. K. B., De Vasconcelos, A. L. S., De Melo, P. L. A., Cerri, C. E. P., and Cerri, C. C. (2018). Crop residue harvest for bioenergy production and its implications on soil functioning and plant growth: A review. *Scientia Agricola, 75*(3), 255–272. https://doi.org/10.1590/1678-992X-2016-0459

Di Fraia, S., Fabozzi, S., Macaluso, A., and Vanoli, L. (2020). Energy potential of residual biomass from agro-industry in a Mediterranean region of southern Italy (Campania). *Journal of Cleaner Production, 277*, Article 124085. https://doi.org/10.1016/j.jclepro.2020.124085

Elisha, K. E., Bello, A. A., Dandakouta, H., Ejilah, R. E., and Habou, D. I. (2021). *The application of GIS model as a location selector for biomass gasification plant in Bogoro Local Government Area, Bauchi, Nigeria.*

Environmental Systems Research Institute. (2018). *ArcGIS Pro documentation and GIS modeling concepts*. ESRI.

Esmaeili, H., and Farhadi, M. (2020). Prognosis of access to biomass residue resources in rural areas to provide energy for villagers. *SN Applied Sciences, 2*(3), Article 2201. https://doi.org/10.1007/s42452-020-2201-x

Gabisa, E. W., and Gheewala, S. H. (2018). Potential of bio-energy production in Ethiopia based on available biomass residue. *Biomass and Bioenergy, 111*, 77–87. https://doi.org/10.1016/j.biombioe.2018.02.009

Hanaki, K., and Portugal-Pereira, J. (2018). The effect of biofuel production on greenhouse gas emission reductions. In K. Takeuchi, H. Shiroyama, O. Saito, and M. Matsuura (Eds.), *Biofuels and sustainability: Holistic perspectives for policy-making* (pp. 53–71). Springer. https://doi.org/10.1007/978-4-431-54895-9_6

Hanif, I., Raza, S. M. F., Gago-de-Santos, P., and Abbas, Q. (2020). Fossil fuels, foreign direct investment, and economic growth have triggered CO_2 emissions in emerging Asian economies: Some empirical evidence. *Energy, 171*, 493–501.

Hidayat, D. P. A., and Andajani, S. (2018). Development of land erosion model using ModelBuilder GIS (Case study: Citepus Watershed). *MATEC Web of Conferences, 147*, Article 03003. https://doi.org/10.1051/matecconf/201814703003

Hiloidhari, M., and Baruah, D. C. (2014). GIS mapping of rice straw residue for bioenergy purpose in a rural area of Assam, India. *Biomass and Bioenergy, 71*, 125–133. https://doi.org/10.1016/j.biombioe.2014.10.018

International Renewable Energy Agency. (2009). *Bioenergy from agricultural residues and waste: Technology brief*. International Renewable Energy Agency.

Mboumboue, E., and Njomo, D. (2018). Biomass resources assessment and bioenergy generation for a clean and sustainable development in Cameroon. *Biomass and Bioenergy, 118*, 16–23. https://doi.org/10.1016/j.biombioe.2018.08.002

Mitchell, A. (2012). *Modeling suitability, movement, and interaction*. ESRI Press.

Owusu, P. A., and Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Engineering, 3*(1), Article 1167990. https://doi.org/10.1080/23311916.2016.1167990

Pant, D., Misra, S., Nizami, A. S., Rehan, M., van Leeuwen, R., Tabacchioni, S., Goel, R., Sarma, P., Bakker, R., Sharma, N., Kwant, K., Diels, L., and Elst, K. (2019). Towards the development of a biobased economy in Europe and India. *Critical Reviews in Biotechnology, 39*(6), 779–799. https://doi.org/10.1080/07388551.2019.1618787

Schaller, J., and Mattos, C. (2009). ArcGIS ModelBuilder applications for landscape development planning in the region of Munich, Bavaria. *Digital Landscape Architecture, 2009*, 43–52.

Simonyan, K. J., and Fasina, O. (2013). Biomass resources and bioenergy potentials in Nigeria. *African Journal of Agricultural Research, 8*(40), 4975–4989. https://doi.org/10.5897/AJAR2013.6726

Tanyi, R. J., and Adaramola, M. S. (2023). Bioenergy potential of agricultural crop residues and municipal solid waste in Cameroon. *AIMS Energy, 11*(1), 31–46. https://doi.org/10.3934/energy.2023002

Ukoba, M. O., Diemuodeke, E. O., Briggs, T. A., Imran, M., Owebor, K., and Nwachukwu, C. O. (2023). Geographic information systems (GIS) approach for assessing the biomass energy potential and identification of appropriate biomass conversion technologies in Nigeria. *Biomass and Bioenergy, 170*, Article 106726. https://doi.org/10.1016/j.biombioe.2023.106726

THE ROLE OF INDIGENOUS KNOWLEDGE IN BIODIVERSITY CONSERVATION IN EKITI STATE, NIGERIA. A CASE STUDY OF ERIJINYAN AND ILAWE COMMUNITIES

Itodo Racheal Chinenyenwa
School of Sciences, Federal College of Education, Ilawe Ekiti,
Ekiti State, Nigeria
Correspondence: onahracheal1996@gmail.com

ABSTRACT

Indigenous Knowledge (IK) represents a cumulative body of knowledge, practice, and belief, evolving through adaptive processes and transmitted intergenerationally about the relationships between living beings and their environments. This study examines the multifaceted role of Indigenous Knowledge in biodiversity conservation in Ekiti State, Nigeria, a case study of Erijinyan and Ilawe Communities employing a mixed-methods approach that combines key informant interviews and focus group discussions. Key informant interviews with 100 participants includes traditional rulers, chiefs and elders, spiritual leaders, and recognized knowledge holders, this Interviews explored: types of indigenous knowledge related to biodiversity; specific conservation practices; changes observed over time; challenges facing knowledge transmission. 100 people participated in focus group discussions that was conducted, 50 per participating community. Groups were stratified by age and gender to facilitate open discussion, discussions explored are the collective memory of traditional practices, current application of indigenous knowledge, community perspectives on conservation challenges; and visions for future conservation. This paper synthesizes evidence demonstrating that IK contributes significantly to conservation outcomes through sacred ecological practices, customary governance systems, traditional resource management, and biocultural approaches. The study identifies five key mechanisms through which IK operates: spiritual and cultural practices creating de facto protected areas; traditional resource management systems maintaining ecosystem resilience; indigenous-led monitoring frameworks; and knowledge integration with scientific approaches. Despite these contributions, IK faces significant threats from cultural erosion, modernization pressures, policy marginalization, and inadequate legal protections. This paper argues for the urgent integration of IK into formal conservation policy, recognition of indigenous rights and sovereignty, and development of equitable partnership models that respect indigenous data sovereignty and leadership. The findings underscore that effective, just, and sustainable biodiversity conservation in Nigeria must center indigenous peoples as knowledge holders and rights-holders, not merely stakeholders.

Keywords: Indigenous Knowledge, Traditional Ecological Knowledge, Biodiversity Conservation, Nigeria, Biocultural Diversity, sustainable biodiversity conservation

INTRODUCTION

The global biodiversity crisis, characterized by unprecedented rates of species extinction and ecosystem degradation, demands innovative and inclusive approaches to conservation. Nigeria, as one of Africa's most biodiverse nations, faces particular challenges with forest loss, wetland degradation, and species decline across its varied ecosystems ranging from mangrove swamps in the Niger Delta to savannas in the north and tropical forests in the southeast (Adekunle *et al.*, 2023; Federal Ministry of Environment, 2021). For decades,

mainstream conservation in Nigeria has been dominated by top-down approaches that often excluded local and indigenous communities, sometimes forcibly evicting them from ancestral lands in the name of protecting nature (Ite and Adams, 2020; Ogar *et al.*, 2021). Biodiversity is the cornerstone of life on Earth, encompassing the variety of all living organisms, their genetic diversity, and the ecosystems they form. As global environmental challenges such as habitat loss, climate change, and species extinction intensify, it becomes imperative to explore multiple approaches to conserve biodiversity.

One such approach, often overlooked in mainstream conservation discourse, is the knowledge held by indigenous communities. Indigenous knowledge refers to the cumulative and dynamic body of practices, beliefs, and understandings developed by indigenous peoples through direct interaction with their natural surroundings (Berkes, 2018). In the rural and sub-urban areas where the natural environments, biodiversity and resources are under serious threat, the cultural taboos and their sanctions can help to reduce the abuse on their immediate environments. The mitigation of reckless exploitation of the natural resources is noticeable in the indigenous people's farming systems, hunting, and care for the land, forests, wild life, trees and streams. This fact is as buttressed by Ngara and Remigios (2013).

However, a growing body of evidence demonstrates that indigenous peoples in Nigeria have been effective stewards of biodiversity for millennia, maintaining ecosystem health through sophisticated knowledge systems and cultural practices (Borokini *et al.*, 2022; Eneji *et al.*, 2022). From the Erijinyan and Ilawe Communites it was ascertained that indigenous knowledge systems have sustained biodiversity while supporting human livelihoods (Nwoko and Iwuji, 2024; Ohwo *et al.*, 2023).

Indigenous Knowledge, otherwise called 'local or traditional/native knowledge is defined as "a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (Berkes, 2018). This knowledge is characterized as local, community-owned, intergenerational, holistic, and embedded in cultural practices, languages, and worldviews rather than written texts (Mauro and Hardison, 2020). Indigenous knowledge systems (IKS) are a body of knowledge, or bodies of knowledge of the indigenous people of particular geographical areas that they have survived on for a very long time. IKS is local knowledge that is unique to a given culture or society (Mapara, 2009). IKS is built by societies through generations of living in close contact with nature. It includes norms, taboos, a system of classification of natural resources, a set of empirical observations about the local environment and a system of self-management that governs resource use (Fonjong, 2008).

Unlike Western scientific approaches that often seek to separate humans from nature, IK in Nigeria typically embraces relational worldviews in which humans are integral parts of ecosystems with reciprocal responsibilities toward other species and the environment (Gbadegesin and Gbadamosi, 2023). The rising interest in IK among researchers and policymakers in Nigeria is driven by several factors: recognition of the long-standing relationship between indigenous peoples and their environments; the comprehensive knowledge accumulated over generations to guide social-ecological

systems; the demonstrated resilience of indigenous communities in facing environmental changes; and the failure of conventional conservation approaches to halt biodiversity decline (Okafor *et al.*, 2023; Ogar *et al.*, 2021). Furthermore, international frameworks such as the Convention on Biological Diversity and Nigeria's National Biodiversity Strategy and Action Plan increasingly acknowledge the essential role of indigenous peoples in achieving conservation targets (CBD, 2022; Federal Ministry of Environment, 2021).

This study is motivated by the recognition and the adherence to indigenous knowledge systems in the conservation and preservation of biodiversity in Ekiti State. The terms 'biodiversity' is used synonymously to refer to conservation, preservation, protection and sustainable use of particular plant and animal species. This research is done in order to establish benefits that will be derived by present and future generations from indigenous conservation and preservation of the biodiversity. As such, the aim of this study therefore, is to examine the types of indigenous knowledge related to biodiversity; specific conservation practices; changes observed over time; challenges facing knowledge transmission reflected in Erijiyan and Ilawe Communities of Ekiti State, Nigeria.

Conceptual Framework: Understanding Indigenous Knowledge Systems

Systematic review of the literature reveals that Indigenous Knowledge in Nigeria possesses several defining characteristics that distinguish it from Western scientific knowledge. Research by Okafor *et al.* (2023) working in Igboland, Ohwo *et al.* (2023) studying Delta State communities, and Gbadegesin and Gbadamosi (2023) examining national policy frameworks, converge on key attributes:

Community- owned, locally grounded and context-specific

Indigenous knowledge in Nigeria is deeply rooted in particular places, ecosystems, and communities. The knowledge of mangrove management among the Ogoni differs fundamentally from the forest conservation practices of the Igbo or the savanna resource management of Hausa-Fulani pastoralists (Adekunle *et al.*, 2023; Eneji *et al.*, 2022). This specificity emerges from generations of observation, experimentation, and adaptation to local environmental conditions. Ngara and Remigios (2013) investigated the Shangwe religious and cultural practices which are meant to save the extinction of vegetation and particular animals in the then Gokwe District in the Midlands Province in Zimbabwe.

Most importantly, these practices were linked to Nevana, the Shangwe rain making god. It emerged from the study that snakes symbolised the ancestral beings. Consequently, it was a taboo for the Shangwe to kill them. The belief in these symbolic snakes was a favourable factor which necessitated their annual increase in numbers. The study established that certain sacred hills were places of abode for gods and spirits. Also, echoes of music and dance used to be heard on the following day after Mukwerera rainmaking performances. Furthermore, it was found out that the community members were culturally not allowed to fell trees from these sanctified hills and they [hills] grew into thick forests.

Thus, the Shangwe indigenous knowledge system was utilised not only to protect wild animals and deforestation; it was a tool that intensively combated soil erosion as well. Unlike privatized knowledge in Western systems, IK in Nigeria is typically held collectively by communities, transmitted through participation in cultural practices, storytelling, and relationships with elders and

knowledge holders (Mauro and Hardison, 2020). The Okpe people of Delta State, for example, maintain collective ownership of knowledge about traditional festivals, language, and medicinal practices (Ohwo *et al.*, 2023).

Holistic, Integrated, Intergenerational and dynamic

Indigenous knowledge is transmitted across generations but evolves through adaptive processes as communities respond to environmental changes (Berkes, 2018). Research with indigenous youth in Southern Nigeria by Nwoko and Iwuji (2024) reveals complex dynamics of knowledge transmission in contexts of rural-urban mobility, where young people both preserve traditional knowledge and adapt it to contemporary challenges. The Igbo concept of Ala (earth goddess) exemplifies this integration, where land is not merely a resource but a sacred entity with moral authority (Okafor *et al.*, 2023)

Sacred and ethical

For many Nigerian indigenous peoples, knowledge about the environment is inseparable from ethical responsibilities and spiritual relationships (Borokini *et al.*, 2022). Sacred groves, totemic species, and ritual practices encode conservation ethics within cultural systems that are often more effective than formal regulations because they are internally motivated (Ite and Adams, 2020).

Biocultural Diversity in the Nigerian Context

The concept of biocultural diversity has emerged as a powerful framework for understanding indigenous conservation in Nigeria. Biocultural approaches recognize that biological diversity and cultural diversity are interdependent and co-evolved, with losses in one domain often accompanied by losses in the other (Maffi, 2021). Nigeria's extraordinary ethnic diversity with over 250 ethnic groups parallels its ecological diversity, suggesting deep historical relationships between cultural and biological systems. Research by Nwoko and Iwuji (2024) across ten states in Southern Nigeria revealed that indigenous communities perceive and value their relationships with nature through multiple dimensions: material contributions (food, medicine, construction materials); non-material contributions (cultural identity, spiritual relationships, aesthetic values); and regulating contributions (climate regulation, water purification, erosion control). This holistic understanding contrasts with narrow economic valuations of ecosystem services and highlights the deep cultural embeddedness of indigenous conservation. The Ogoni people's relationship with their mangrove ecosystem exemplifies biocultural interdependence. According to studies by Adekunle *et al.* (2023) and the Environmental Rights Action (2022), mangrove forests provide not only material resources for fishing and harvesting but also cultural identity, spiritual sites, and the foundation of Ogoni cosmology. This integrated relationship has sustained both the ecosystem and the culture for centuries.

Sacred Groves and Traditional Conservation Areas

Sacred groves represent one of the oldest forms of biodiversity conservation in Nigeria. Research by Borokini *et al.* (2022) documented over 1,000 sacred groves across southern Nigeria, ranging in size from small patches of less than one hectare to extensive forest areas exceeding 100 hectares. These groves are protected through spiritual beliefs, customary prohibitions, and social sanctions that regulate access and resource use. Okafor *et al.* (2023) conducted comprehensive studies of sacred groves in Igboland, documenting their ecological significance.

Their research found that sacred groves harbor rare and endemic species, maintain genetic diversity, protect water sources, and serve as reference ecosystems for understanding natural vegetation patterns. The Osun-Osogbo Sacred Grove, a UNESCO World Heritage Site, exemplifies the conservation value of such areas, protecting the last remnant of high forest in Osun State while maintaining cultural and spiritual practices (Osun State Tourism Board, 2023).

However, Borokini *et al.* (2022) note that sacred groves face mounting threats from religious conversion, urbanization, agricultural expansion, and weakening of traditional institutions. Their survey across southwestern Nigeria found that approximately 30% of documented sacred groves had been significantly degraded or completely lost over the past five decades.

Policy and Legal Frameworks

Nigeria's policy framework for biodiversity conservation has historically marginalized indigenous knowledge. The National Park Service Act and various forestry laws established protected areas through exclusionary approaches that displaced indigenous communities (Ite and Adams, 2020). However, recent policy developments show growing recognition of indigenous contributions. The National Biodiversity Strategy and Action Plan (2021-2025) explicitly acknowledge the role of indigenous and local communities in conservation and calls for their participation in protected area management (Federal Ministry of Environment, 2021). The National Policy on the Environment (2022) includes provisions for recognizing traditional knowledge in environmental management (Gbadegesin and Gbadamosi, 2023). Despite these policy advances, implementation remains limited. Ogar *et al.* (2021) found that indigenous communities continue to be excluded from decision-making processes affecting their territories, and traditional knowledge remains marginalized in formal conservation planning. The absence of legal frameworks protecting indigenous knowledge from appropriation and misuse further undermines indigenous-led conservation (Mauro and Hardison, 2020).

MATERIALS AND METHODS

Research Design

This study employed a mixed-methods approach that combines key informant interviews and focus group discussions. Key informant interviews with 100 participants includes traditional rulers, chiefs and elders, spiritual leaders, and recognized knowledge holders, this Interviews explored: types of indigenous knowledge related to biodiversity; specific conservation practices; changes observed over time; challenges facing knowledge transmission. 100 people participated in focus group discussions that was conducted, 50 per participating community. Groups were stratified by age and gender to facilitate open discussion, discussions explored are the collective memory of traditional practices, current application of indigenous knowledge, community perspectives on conservation challenges; and visions for future conservation. The design incorporated systematic literature review, key informant interviews, focus group discussions, and field observations, following established methodologies for indigenous knowledge research (Berkes, 2018; Chilisa, 2020).

Study Area

Ekiti State, one of the thirty-six states of the Federal Republic of Nigeria was carved out of the former Ondo State on 1st October 1996. It has sixteen local government areas, with Ado Ekiti as the capital. The word “Ekiti” or “okiti” denotes a mound. This is derived from the rugged mountainous

topography of the State. The state is largely agrarian, employing about 75% of the State working population. The State is one of the largest producers of rice, kolanut, palm oil and cocoa in the country. They also produce crops like cassava, yam, cocoyam, maize, cowpea, citrus, plantain and fruits like cashew, mango and orange. Tourism is another source of income for the state. Notable among its tourist attractions is the Ikogosi Warm and Cold Springs. The State is also the watershed and source of some prominent rivers such as Ero, Ose and Ogbese. This location is selected based on documented presence of indigenous conservation practices, accessibility, security considerations, and expressed willingness of communities to participate (Nwoko and Iwuji, 2024; Ohwo *et al.*, 2023).

Erijiyan Ekiti:
Erijiyan Ekiti is close to Ikogosi and Erio. The town is located within the Ekiti West Local Government Area. Other settlements in Erijiyan Ekiti Community include: Asa Oloro, Abuja Camp, Surulere, Oriokuta Camp, Kajola Camp, Ajebamidele, Araromi Oke, Aro, Surulere, Ajayi Oke, Ajayi Odo, Temidire Camp, Orisumibare Camp, Ajebamidele and Kosubu Town. The people of Erijiyan Ekiti, apart from farming, also engage in trading activities, selling farm products like yams, rice, vegetables like tete, ila, amunututu, adodo, odu, sokoyoto, ebolo, ewuro and tomatoes. They sell traditional cloths such as aso ofi, agbada, gbariye, kembe, dandogo, fila gobi, abeti aja, kente, dye cloths like adire of different shades and colours. The people also sell cash products like cocoa, coffee, rubber and palm oil. These commodities are sold in large quantities to the itinerant traders from Ado-Ekiti, Ilesa, Ibadan, and Lagos. Their trading activities take them beyond Erijiyan Ekiti frontiers especially on the town's market days. The people of Erijiyan Ekiti are mostly Muslims and Christians while some are still Traditional Religionists.

Ilawe-Ekiti:
The town is located within the Ekiti South-West Local Government Area. Ilawe-Ekiti is nestled in a valley surrounded by granite hills, making it a naturally fortified town. The town is historically unique for never having shifted its original site since its 13th-century founding by immigrants from Ile-Ife and later Benin. It is internally divided into 8 major traditional quarters: Okebedo, Okeemo, Irorin, Aaye, Okepa, Okeloye, Iro, and Adin. Farming is the primary occupation, engaging a large majority of the populace. Many professionals, including civil and public servants, also partake in agricultural activities. Other prevalent trades in the community include lumbering, pottery, and traditional mat weaving. Commerce is highly active, anchored by the central Ojulawe market, which operates every five days. They are nicknamed "The Home of Banana," Ilawe-Ekiti is widely recognized as one of the largest producers of banana and plantain in Nigeria, trading over three million bunches of bananas annually. Alongside bananas and plantains, the town's agrarian economy thrives on the production of cash crops such as cocoa, oil palm, and kola nut. The community's religious landscape is a mix of traditional Yoruba beliefs, Christianity, and Islam. Historically, the inhabitants strongly practiced traditional Yoruba religion, revering deities like Ogun, Orunmila, and Orinlase. Today, Christianity and Islam are widely practiced, existing alongside deep-rooted cultural traditions and indigenous beliefs.

Sampling Strategy
A sample of 100 participants which includes traditional rulers, chiefs and elders, spiritual leaders, and recognized knowledge holders are selected for key informant interviews and

focus group discussions. 50 per participating community, Groups were stratified by age and gender to facilitate open discussion, discussions explored are the collective memory of traditional practices, current application of indigenous knowledge, community perspectives on conservation challenges; and visions for future conservation. The design incorporated systematic literature review, key informant interviews, focus group discussions, and field observations, following established methodologies for indigenous knowledge research (Berkes, 2018; Chilisa, 2020).

Data Collection Methods

Key Informant Interviews

Semi-structured interviews were conducted with 25 key informants from each of the communities making a total of 50 key informant interviewers. Informants included traditional rulers (n=10), chiefs and elders (n=20), spiritual leaders (n=10), and recognized knowledge holders (n=10). Interviews explored: types of indigenous knowledge related to biodiversity; specific conservation practices; changes observed over time; challenges facing knowledge transmission; and recommendations for supporting indigenous conservation.

Interviews were conducted in local language (Yoruba) or Nigerian Pidgin English based on participant preference, using trained interpreters from within communities. Each interview lasted 10-15 minutes.

Focus Group Discussions

Focus group discussions were conducted, one per participating community, with 25 participants each (total n=50). Groups were stratified by age and gender to facilitate open discussion: male elders (n=5 groups), female elders (n=10 groups), male youth (n=15 groups), female youth (n=20 groups). Discussions explored: collective memory of traditional practices; current application of indigenous knowledge; intergenerational differences in knowledge and practice; community perspectives on conservation challenges; and visions for future conservation.

Focus groups lasted 10-15 minutes and were conducted in local languages with facilitation by trained community researchers. Discussion guides were developed iteratively based on emerging findings from interviews.

Field Observations

Transect walks and site visits were conducted to the “Odo-Erin” and the forest the abode of “Osa-Erin” the goddess in Erijiyan Ekiti, Agbetaleta rock in Ilawe-Ekiti and they are identified by participants as sites of indigenous conservation practice.

Ethical Considerations

This research adhered to rigorous ethical protocols for indigenous knowledge research (Kovach, 2021; UN Declaration on the Rights of Indigenous Peoples, 2007).

Free, Prior and Informed Consent: Community entry protocols were followed in each community, beginning with visits to traditional rulers and council of chiefs to explain research objectives and seek permission. Individual informed consent was obtained from all participants, with consent processes conducted in local languages and using both written and oral formats for participants with limited literacy.

Community Engagement and Reciprocity: Research objectives and methods were developed in consultation with community advisory groups in each community. Preliminary findings were shared with communities through feedback sessions, and community input was incorporated into final interpretations. Each participating community received a summary report in accessible language and format.

RESULTS

Mechanisms of Indigenous Knowledge in Biodiversity Conservation

The research identified five primary mechanisms through which Indigenous Knowledge contributes to biodiversity conservation across Nigeria.

Sacred and Spiritual Practices Creating De Facto Protected Areas

The Sacred Grove

The grove talks about the environmental concerns through rituals and disciplined observance of the mores and instructions of their ancestors while the practice of periodic festivals and rituals such as Oro-Ologun constantly reminds the citizens about their deity and her principles of protecting the ecosystem. Oro-Ologun festival usually takes place sometimes in June/July. Sacrifices are offered yearly or periodically and/or at the request of the worshippers from within and abroad. At the grove money, ‘ekuru”, “eko”, cock, sheep and goats are offered as rituals. “Akara kengbe” (Beans cakes) will be abundantly prepared. After the residents had eaten enough, the remaining “akara kengbe” will be thrown to the Odo-Erin. This will serve as special food for the aquatic and terrestrial animals living within and around the stream and the adjoining forest. As part of the festival, the “Abore” will dance seven times round the particular spot where the Osa-Erin temporary resides while the festival lasts. Libations will be poured. Virgin girls will wear beads round their heads, necks, ankles and waists while dancing. Prayers will be said for rain or friendly weather or on behalf of sick children and adults. In addition, a number of the juju priests have their powers associated with this goddess spirit.

An elder from the community explained:

"These forests belong to our ancestors and the deities. No one can cut a tree there without facing the consequences not just from the community but from the spirits. Even during the civil war, people sought refuge in these groves because they knew they would be safe from harm." (Interview, Male Elder, Ilawe-Ekiti, May 2025)

Agbetaleta Rock

The Agbetaleta (or Agbele) rock formation in Ilawe-Ekiti is a towering, mysterious natural monument that astonishingly resembles a woman carrying a child on her back and balancing a heavy load on her head. According to local folklore, the rock was once a human woman who was turned to stone by divine punishment after she was caught stealing food from a village drying site during a time of famine. It was found that species like rat, lizard, snake etc. still retain their habitat thereby sustaining biodiversity conservation. This mountain serves important role to the survival of plants and animals in this ecosystem.

Locals call it "Agbele," which roughly translates in Yoruba to “carrying a child,” and its striking silhouette stands as a reminder of the legend. When standing at its base, the massive granite formation's posture, the child's shape, and the balanced load are all said to be perfectly captured at the exact moment of the curse. The site has attracted the attention of tourism boards, including visits from officials mapping out Ekiti State’s natural heritage.

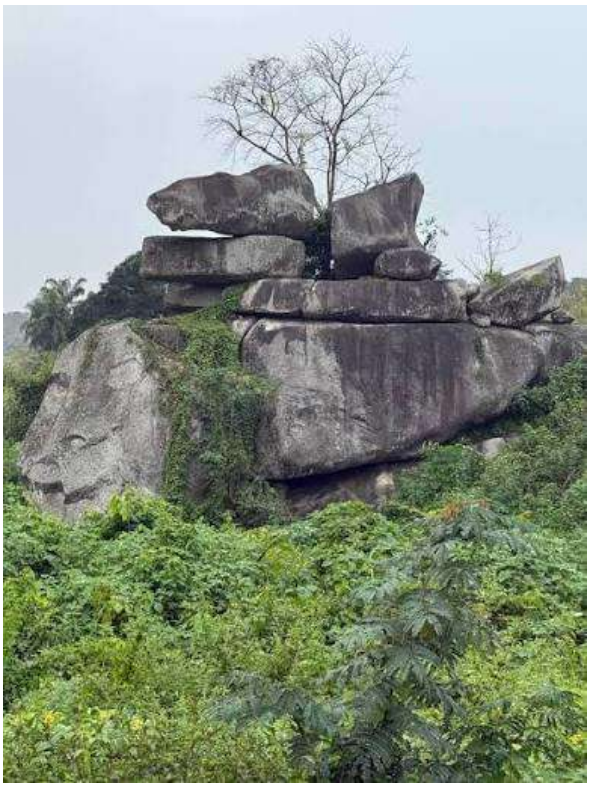


Figure 1: The Agbetaleta rock of Mystery

Traditional Resource Management Systems

In Erijiyan Ekiti, there is a particular stream named Odo-Erin. The stream takes it source from Oke-Aye, a settlement in the neighbourhood. This stream transverses through the entire ancient town. This stream provides the residents with the needed water for domestic purposes such as drinking, cooking, washing and cleaning. Apart from these domestic purposes, it serves important role to the survival of plants and animals in this ecosystem. More importantly, the stream is seen as having magical powers of healing certain ailments like headache, pain and stomach upset. The stream is often conceived as capable of bringing earthly bliss and good fortune. The indigenes of Erijiyan Ekiti conceived this stream as the abode of a certain goddess named "Osa-Erin". This goddess is seen as powerful and benevolent. According to oral traditions, this goddess had helped them win certain inter-tribal wars in the past centuries. This goddess is also regarded as capable of giving barren women children. It is the belief of the indigenes and residents of Erijiyan that fishes and other aquatic animals in this stream are the children of this goddess. Killing these fishes is regarded as killing the offsprings of the goddess. Even to the people of Erijiyan Ekiti, fishing or harvesting of any aquatic animals in the stream is well prohibited. It has been established that no matter how long the fishes harvested from these streams are subjected to cooking they remain fresh.

Indigenes were made to believe this ancestress will punish any person who attempts to demystify these traditionally sanctioned mores or destroys this environment. In order not to be punished by this goddess, certain sacrifices must be made. The culprit will be made to pay certain fines (such as money, cock, goat or sheep) before the yeye abore (the traditional priestess)

could appease the goddess. As such, resource exploitation through activities such as farming, hunting, and tree cutting are prohibited along the stream. Although “Odo-Erin” Stream is relatively small in terms of its depth and volume of water therein contained, it is of biological importance owing to its potential biodiversity conservation. Indigenous communities maintain sophisticated resource management systems that regulate harvesting and maintain ecosystem productivity. Traditional fishing practices in Erinjiyan and Ilawe communities incorporate seasonal closures, gear restrictions, and species-specific prohibitions.

An Erinjiyan fisher described:

"We know when the fish are spawning, and we stop fishing in those areas during that time. Our fathers taught us that if you catch a pregnant fish, you are killing tomorrow's food. We also have certain net sizes that allow the small fish to escape only the big ones are taken." (Focus Group Participant, Ekiti State, May 2025) These practices align remarkably with fisheries science principles, as confirmed by a fisheries biologist on the research team: "What we're seeing is indigenous knowledge that has arrived at the same conclusions as modern fisheries science through generations of observation. The closed seasons correspond precisely with peak spawning periods for commercially important species, and the mesh size restrictions are optimal for sustainable yield." (Research Team Member, Personal Communication, 2024)

Intergenerational Knowledge Transmission

The continuity of indigenous conservation depends on effective knowledge transmission across generations. However, findings reveal complex dynamics of transmission and adaptation. Youth participants demonstrated variable knowledge levels. A young Ekiti man from one of the communities noted: "I know that certain trees are protected, but I don't always know why. My grandfather could tell you which tree cures which sickness and which ones you must never cut. I went to school in the city, so I missed learning many of these things. But now I'm back, and I'm trying to learn from the elders before they are gone." (Focus Group Participant, Ekiti State May 2025)

The forest adjoining (space around) Odo-Erin in Erijiyan Ekiti, Ekiti West Local Government Area typifies a pristine vegetation that has not been disturbed for several decades a (see Plate 1). Several species of plants such as Palm trees (Arecaceae spp), Raffia palm, (Raphia spp), Elephant grass (Pennisetum purpureum) and Reeds (Phragmite spp) amongst others flourished in this forest. This is similar to the finding of Rim-Rukeh, Irerhievwie and Agbozu (2013) found out that the location of the trees at Useifrun and Ujevwu communities respectively is regarded as a sacred place where trees and plants were allowed to grow undisturbed. Reptiles, birds and animals could have free living without fear of poaching or interference by man. This forest at Erijiyan Ekiti is also sacred and hence no axe may be laid to any tree, no branch broken, no firewood gathered, no grass burnt; and wild animals which have taken refuge there may not be molested. Residents were also prevented from constructing buildings and/or erecting physical structures within certain distance away from the stream.

Oral literature has it that harvesting or tapping of the palm tree and/or the raffia palms in the forest is strictly forbidden. If an attempt is made to tap the palm trees, the local belt (Igba) used will turn into a ‘snake’ and bite the person that makes such attempt.

If the culprit survives the venom of 'the snake' abore (the priestess) is the only one who can affect rescue through sacrifices and rituals (ebo ati etutu). Cock, sheep, goat and other things may be offered as restitution for demystifying the goddess, while prayers will be offered for the well-being of the offender. These inadvertent principles of conserving and preserving the ecosystem were meant to preserve the watershed and the surrounding forest. Invariably, this stems the rate at which percolation and evapotranspiration occurred. This will also have a reductionist effect on the washing away of the fertile topsoil.

The vegetation cover also keeps the stream water cool and fresh for drinking. Other plants that thrive in this undisturbed vegetation include the Shea butter (old name: Butyrospermum, new name: Vitellaria paradoxa), Locust Beans (Parkia biglobosa), Araba (Pihostigma reticulata) and "Akintola taku" (Chromolaena odoratum). Although these plants are strictly protected in the community however, religious use of these plant resources is allowed. The use of barks, leaves, twigs and roots of these plants that are medicinal and efficacious in the treatment of both familiar and strange illnesses is also not prohibited.

Figure 2: The Erinjiyan Scared fish river; The stream and the adjoining forest; the temporary abode of "Osa-Erin".

Indigenous knowledge used in conserving the biodiversity

Indigenous knowledge in the form of beliefs and taboos is effectively used in conserving the water resources and the biodiversity. The indigenous knowledge identified through the PRA are summarised as follows:

1. It is taboo to fish or catch any aquatic species in the stream. They belief that tempering with aquatic resources attracts the wrath of the 'sprits' and gods and that anybody attempting that must have life misfortunes.
2. It is also a taboo in the community to fell down a tree within about a kilometre radius from the stream. Even the falling of the tree is caused by natural course like wind, it has to be allowed to decompose without anybody tempering with it.
3. The stream water is belief to have medicinal values; as such they use it to cure certain diseases.

4. The stream site is considered as a ritual center where some spiritual practices peculiar to the community are carried out. Many people visit the stream to receive diverse kind of spiritual help from the water and offer sacrifices to the 'spirits' by slaughtering animals at the site and receive their petitions answered. The residents so much believe this spiritual healing that even people from other communities visit the river to receive spiritual help too.

Threats to Indigenous Knowledge and Conservation

Cultural and Religious Change

The spread of Christianity and Islam has undermined spiritual beliefs that underpin conservation. Across the communities, participants reported that conversion to world religions leads to abandonment of traditional practices. A Yoruba elder explained: "When people become born-again Christians, they are told that our traditional ways are pagan and evil. They cut down sacred groves to build churches. They pour libations no more. The spirits depart, and the forest goes with them." (Interview, Male Elder, Ekiti State, May 2025). Quantitative data from participant surveys revealed that 68% of respondents under 40 are identified as Christian or Muslim, compared to 32% of those over 60, indicating rapid religious transition with implications for knowledge transmission.

Modernization and Economic Pressures

Market integration and economic pressures drive practices that contradict traditional conservation ethics. Commercial logging, poaching for bushmeat trade, and agricultural expansion were frequently cited as threats. An Erinjiyan fisher described the dilemma: "We know we should not catch the small fish, but the buyers in the city don't care. They will buy anything. And if I don't sell to them, someone else will. The hunger is real. Our traditional rules worked when everyone followed them, but now with so many people and so much demand, it is hard." (Focus Group Participant, May 2025)

Policy Marginalization

Despite policy rhetoric, indigenous knowledge remains marginalized in formal conservation. Protected area management plans rarely incorporate traditional practices, and indigenous communities are excluded from decision-making. A community leader in Ilawe-Ekiti noted: "They created a national park on our land, and now we cannot enter to collect medicine or perform our ceremonies. They say it is to protect the forest, but the forest was fine when we were caring for it. Now without our presence, poachers come at night, and the forest suffers. But we cannot say anything because we are not part of the management." (Interview, Community Leader, May 2025)

DISCUSSION

Synthesis of Findings

This study provides comprehensive evidence that Indigenous Knowledge plays a vital role in biodiversity conservation across Nigeria. The five identified mechanisms—sacred spiritual practices, traditional resource management, intergenerational transmission, indigenous monitoring, and knowledge integration—operate synergistically to maintain ecosystem health while supporting cultural continuity. The finding that sacred groves harbor significantly higher biodiversity and confirms the conservation value of spiritually protected sites.

CONCLUSION

This comprehensive study has demonstrated that Indigenous Knowledge plays an indispensable role in biodiversity conservation across Nigeria. Through sacred groves that protect forest remnants,

traditional resource management that sustains fisheries and agrobiodiversity, intergenerational transmission that maintains stewardship capacity, indigenous monitoring that detects environmental change, and emerging partnerships that weave knowledge systems, indigenous peoples continue to sustain biodiversity while maintaining cultural vitality. The indigenous people have their own taboos which work well for them and these taboos need to be promoted for the benefit of the present and future generations in preserving and conserving natural ecosystem. These working IKS could be transferred to other traditional settings in other geopolitical zones in Nigeria and in other countries.

The indigenous knowledge in the forms of strong beliefs and taboos imbibed by the community no doubt has significant impacts on man environment relationship. By these actions the community, knowingly or unknowingly, making an attempt at sustainable use of the environmental resources. The taboo on fish catch and other aquatic species had allowed them to flourish thereby preventing them from being extinct. As observed in the field, the species roam in the water freely to the admiration of the observers; thus provides a potential for ecotourism and a good site for aquatic research.

The prohibition of cutting down trees within a kilometre radius of the stream has significant implication on sustainable forest resources management and conservation in that apart from preserving the trees to flourish, other species that use the trees as habitat are also protected. Such a scenario creates a microclimate different from the surrounding environment, where the modified climate due to the thick vegetation and available moisture enabled introduction of crops that are usually cultivated in more humid forest zones. No wonder cash crops is grown in the area. Allowing fallen trees (with all the components like the leaves) to decompose replenishes the soil and encourage microbial activities essential for maintaining soil nutrient balance.

The perception that the stream water had curative value might have negative implication on water quality since the belief is not based on scientific empiricism. It could be wrong impression of good water quality. However, on the positive side the value attached to the stream water is a good omen for conservation and sustainable usage. The fact that the stream is attached with certain spiritualities and that people from other communities visit the site to seek spiritual healings is an indication of common heritage being appreciated. The attraction of people from other places is an indication of ecotourism potentials.

Recommendations

Community Recommendations

Participants articulated clear recommendations for supporting indigenous conservation:

Recognition of land rights: Communities consistently emphasized that secure tenure is essential for conservation. A Community leader stated: "If we don't own our land, we cannot protect it. Give us title to our mangroves, and we will guard them with our lives."

Respect for traditional governance: Participants called for recognition of traditional institutions in conservation governance. An Ilawe chief insisted: "The government should work through our traditional councils, not around them. We know our people and our land."

Support for intergenerational transmission: Communities requested resources for documentation and teaching of indigenous knowledge. A youth participant proposed: "Create programs where elders can teach young people in schools and communities. Pay the elders for their time for their knowledge is valuable."

Protection from appropriation: Communities demanded legal frameworks to prevent misappropriation of their knowledge. A Yoruba priestess stated: "Our knowledge is sacred, not a commodity. There should be laws that protect it, like copyright for our culture."

Partnership not extraction: Communities emphasized the importance of genuine partnerships. An Ilawe community representative concluded: "Don't just come to take our knowledge and leave. Work with us, respect us, share the benefits. Then we can protect the forest together."

Finally, Government and other conservation agencies should encourage communities still having and practicing traditional system of resources management. This can be done through positive motivation and incentives. Corporate bodies, private individuals and non-governmental organisations should be involved in the sponsorship of traditional festivals that are associated with the conservation of the environment. This will create awareness on the need for the sustainable use of natural resources. In a nutshell, indigenous knowledge systems should help save the interests of the locals and ultimately, their land.

REFERENCES

Adekunle, V. A. J., Olagoke, A. O., and Ogundele, F. O. (2023). Biodiversity conservation in Nigeria: The role of indigenous knowledge in mangrove ecosystem management. *Journal of Environmental Management, 325, 116-134.*

Berkes, F. (2018). Sacred ecology (4th ed.). Routledge.

Borokini, T. I., Babalola, F. D., and Amusa, T. O. (2022). Sacred groves in southwestern Nigeria: Status, threats and conservation prospects. *International Journal of Biodiversity and Conservation, 14(3), 112-128*.

Chilisa, B. (2020). Indigenous research methodologies (2nd ed.). SAGE Publications.

Convention on Biological Diversity (CBD). (2022). Global Biodiversity Outlook 5. Secretariat of the Convention on Biological Diversity.

Eneji, C. V. O., Gubo, Q., and Okpiliya, F. I. (2022). Indigenous knowledge and agricultural biodiversity conservation in Cross River State, *Nigeria. Journal of Sustainable Agriculture, 46(4), 389-406*.

Environmental Rights Action. (2022). Mangrove restoration and community resilience in Ogoniland. ERA Publication Series.

Federal Ministry of Environment, Nigeria. (2021). National Biodiversity Strategy and Action Plan 2021-2025. Federal Government of Nigeria.

Fonjong, L. N., (2008). Gender roles and practices in natural resource management in the North West

province of Cameroon. Local Environment, 13(5): 461-475.

Gbadegesin, A., and Gbadamosi, A. (2023). Mainstreaming indigenous knowledge in Nigeria's environmental policy: Challenges and opportunities. *Environmental Policy and Governance, 33(2), 145-162.*

Ite, U. E., and Adams, W. M. (2020). Forest conservation in Nigeria: History, current status and future directions. In B. Child and C. MacKenzie (Eds.), African conservation: Past, present and future (pp. 189-214). Oxford University Press.

Maffi, L. (2021). Biocultural diversity conservation: A global sourcebook. Earthscan Publications.

Mapara, J., (2009). Indigenous knowledge systems in Zimbabwe: Juxtaposing postcolonial theory. *The Journal of Pan African Studies, 3: 139-155.*

Mauro, F., and Hardison, P. D. (2020). Traditional knowledge of indigenous and local communities: International debate and policy initiatives. *Ecological Applications, 10(5), 1263-1269.*

Nwoko, C. O., and Iwuji, M. C. (2024). Indigenous knowledge systems and biodiversity conservation in Southern Nigeria: A mixed-methods study. Nigerian Journal of Environmental Studies, 22(1), 45-67.

Ogar, E., O'Gar, T., and Bassey, A. (2021). Conservation, indigenous peoples and the struggle for environmental justice in Nigeria. *Journal of Political Ecology, 28(1), 234-256.*

Ohwo, O. A., Agbogidi, O. M., and Ekpoh, I. J. (2023). Indigenous knowledge and sustainable fisheries management in Delta State, Nigeria. Fisheries Management and Ecology, 30(3), 278-295.

Okafor, J. C., Okeke, S. E., and Nwosu, C. M. (2023). Sacred groves of Igboland: Biodiversity, cultural significance and conservation challenges. *Journal of Ethnobiology and Ethnomedicine, 19(1), 45-62.*

Osun State Tourism Board. (2023). Osun-Osogbo Sacred Grove: Management plan 2023-2028. Osun State Government.

EFFECTS OF IRRIGATION REGIME, ORGANIC, INORGANIC MINERAL SOURCE AND INFLUENCE OF CLIMATE CHANGE ON GROWTH AND YIELD OF SWITCHGRASS *(Panicum virgatum L.)* IN SOKOTO NIGERIA

[1]ABDULLAHI, A.A., [2] TAMBARI, U., [3]BALARABE, I.U., [2] ADILI, I.S.

[1]Department of Biology Federal College of Education Gidan Madi, Sokoto

[2]Department of Environment, Shehu Shagari University of Education, Sokoto

[3]Department of Agriculture, Federal College of Education Gidan Madi, Sokoto

Corresponding Author's Email: adamuabdullahi50@gmail.com

ABSTRACT

The effects of organic, in organic fertilizer and irrigation regime on yield parameters of P. virgatum in upland and low land areas in Sokoto, Nigeria were assessed. Four levels of nitrogen (0, 25, 50 and 75 kg N ha^{-1}), three rates of farmyard manure (0, 5 and 10 t ha^{-1}) and three irrigation regimes (w_2, w_4 and w_6) were set up as split – plots design. Farmyard manure and irrigation regimes were combined and allocated as the main plots, while nitrogen rates were assigned to the sub – plots and each replicated three times. The influences of climate change on Switchgrass growth and yield are spatially heterogeneous and vary depending on ecotype. Data collected were analysed using statistical package for Social Science (SPSS) version 16. Analysis of variance (ANOVA) was carried out and significant mean were separated using Duncan's New Multiple Range Test (DNMRT). Result revealed that raising nitrogen rate from 50 to 75kg N ha^{-1}, farmyard manure rate from 5 – 10 t ha^{-1} or irrigation intervals from 2 to 4 days did not show a significant ($p>0.05$) increase in yield components evaluated. Dry matter accumulation was significantly ($p<0.05$) affected by irrigation regime in both locations and 2 days interval irrigation had the highest dry matter yield. A significant interaction between nitrogen and manure application was observed only at upland in 2024/2025 and a combination of 75kg N ha^{-1} and 10 t ha^{-1} manure produced the highest value in all the parameters evaluated. The study suggests that 50kg N ha^{-1} with 5 t ha^{-1} of farmyard manure and 2 days irrigation interval gave the highest yield. A combination of 50kg n ha^{-1} with 5 t ha^{-1} of farmyard manure and 2 days irrigation interval were found to be optimum for growth and yield of Switchgrass under both locations in Sokoto, Nigeria. Switchgrass production under climate change should be in cooperated into planning for current and feature sustainable crop yield production.

Keywords: Switchgrass, Irrigation, Farmyard Manure, Nitrogen Fertilizer, Climate Change.

INTRODUCTION

Switchgrass (*Panicum virgatum L.)* is a perennial grass native to North America, where it occurs naturally from55ºN in Canada, United States and Mexico. It is one of the dominant species of the Central North America tall grass pairies used primarily for soil conservation (USDA and NRCS, 2008), forage production (Stegelmerier *et al.,* 2007), game cover (Bies, 2006), as an ornamental grass (Samson, 2007) and more recently as a biomass crop for ethanol fiber, electricity and heat production (Hastings and Prince, 2007). Switchgrass can yield a variety of useful fuels such as synthetic gasoline and diesel fuel, methanol methane gas, hydrogen as well other chemical by-products useful for making fertilizers, solvent and plastics (Bransby, 2005). However, the potential of switchgrass as bio fuel feedback in Nigeria has not exploited. There is currently no information on the potential impact of large-scale switchgrass growth and production on the

natural resources and the environment. For example, certainly surrounds the effective use of water by the crop and the lack of information on the basic agronomies dictated that research be undertaken to develop a capacity for predicting impacts of large-scale planting of switchgrass in Nigeria.

Nitrogen availability is one of the most crucial factors in determining crop yield (Carpenter-Boggs *et al.,* 2000) and it increases the population of soil microorganisms (Ladd *et al.,* 1994; Smolander *et al.,* 1994; Entry *et al.,* 1996). Franzluebber *et al.,* (1998) suggested that an integrated soil fertility management practice, which incorporates organic and inorganic sources, is needed to increase the productivity of low activity clay soils. A deficiency of nitrogen results in yellowing of leaves, slow and stunted growth and excess nitrogen may increase crop susceptibility to pest and disease attack (Brice *et al.,* 1997). Irrigation is used on full season agronomic crops to provide a dependable yield every year. It is also on crops where water stress affects the quality of the yield which brings increased yield and allows double cropping and intercropping.

Soil and plant carbon sequestration is a practical way to mitigate Co_2 emission (Kucharik, *et al.*, 2001). Soil sequestration in the Switchgrass field does not occur only in the top soil. Liebig, *et al.*, 2004) show that Switchgrass soils below30cm can also effectively sequester soil organic carbon and not prone to mineralisation and erosion. Net ecosystem Co_2 exchange (NEE) is the result of imbalance between total primary production (GPP) and ecosystem respiration (Re) which can affect carbon dynamic and budget (Liebig, *et al.*, 2004).

Switchgrass could provide a major solution in helping achieve major emission reduction targets. Overall, Switchgrass pellets can reduce greenhouse gas emissions by about 90% when compared with using an equivalent amount of energy in the form of fossil fuels. Switchgrass can also reduce greenhouse gas emissions by increasing the carbon stored in landscapes through increased carbon storage in roots and soil organic matter. It has been found that land conversion to switchgrass on crop planting has led to 40 tonnes/ha of CO2 being stored compared to conventional land use. Therefore, reducing agriculture's carbon emissions is a crucial issue. Switchgrass a biofuel crop that improve soil quality, promote nutrient cycling and carbon fixation, and can produce large quantities of high carbon biomass. Compared with fossil fuels biofuel crops have greater advantages in energy utilization. Furthermore, Switchgrass requires less maintenance and input can be adaptable to marginal soils. The objectives of this work are to investigate the effects of organic, inorganic nutrients and varying irrigation regimes on growth and yield parameters of switchgrass and discusses the potential contribution of Switchgrass in carbon sequestration and greenhouse gas emission reduction.

MATERIALS AND METHODS

Collection of materials and experimentation: Seeds of switchgrass were sourced from the United State of America (USA) through Sokoto Energy Research Centre, Usmanu Danfodiyo University, Sokoto, Nigeria on a Pure Live Seed basis (PLS). The seeds were kept in big labelled paper envelop and stored in metal cabinets in the University herbarium. Field experiments were conducted during 2023/2024 and 2024/2025 dry seasons at both upland and lowland areas. Sokoto is located on latitude 13º.01N and longitude 05º.15E and lies at an altitude of 350m above sea level (Kowal and Knade, 2002). The temperature averages ranges from 27 – 40º C in April and 18ºC in December – January. The state falls in the Sudan Savanna agro-ecological zone of

Nigeria. Treatments consist of three rates of manure as farmyard manure (0, 5 and 10t ha^{-1}fym). Four rates of nitrogen fertilizer (0, 25, 50 and 75kg N ha^{-1}) and three irrigation regimes (W_2, W_4 and W_6) for watering every two, four and six days respectively. The treatments were laid out in split-plot design and replicated three times. Manure rates and irrigation regimes were combined and allocated as the main plots, while nitrogen levels were assigned to the sub-plots. The gross plot size had a dimension of 4 x 3m ($12m^2$) consisting of 36 plots, the net plot size was x$2m^2$ ($2m^2$) and the total area of the experimental sites was $10,000m^2$.

Experimental sites were ploughed, harrowed, levelled and plots demarcated manually. Seed beds of 4 x 3 were prepared. Irrigation channels were laid out to convey water and drain away the excess. One meter leeway was left between blocks. Seeds were sown by direct seeding using a spacing of 1 x 1m at 0.5 – 1.0cm planting depth according to Ontario Ministry of Food Agriculture and Rural Affairs (OMAFRA) guidelines for forage crops. Five seeds were sown per hole and later thinned to 3 plants per hole.

Nitrogen fertilizer in form of urea (0, 25, 50 and 75kg N ha^{-1}) was applied through ring application method in two equal doses according to the treatments, the first dose was applied after the first weeding (2 WAP), while the second dose was applied by top dressing (6 WAP). Different rates of farmyard manure (0, 5 and 10t h^{-1}) as per treatment were applied during land preparation. The seedlings were subjected to 3 watering regimes i.e. W_2, W_4 and W_6 indicating watering every two, four and six days respectively. Weeding was carried out manually at two Weeks After Sowing (WAS) and subsequently after every two weeks to maintain weed free fields. Harvesting was done manually and was taken at the late boot stage of the development and tied into small bundles.

Data collection and Analysis: Three plants were randomly tagged from the inner rows of each plot and were used for the evaluation of growth and yield parameters. Number of inflorescences was recorded by counting from the three tagged plants. The inflorescence count recorded was taken at 13 WAS and the average count recorded. Days to 50% flowering were determined when 50% of the plant's population in a particular treatment flowered. Number of seeds per plant was counted at harvest from the 3 tagged plants for each treatment. The seeds were threshed, counted and average per plant determined. Cumulative seed weight per plant was extrapolated to kg ha^{-1} times number of plant per hectare. Shoot and dry matter accumulation was taken at the end of the experiment; shots of the plants were harvested. Fresh and dry weights were taken to estimate the dry matter accumulation. The shoots were placed on an oven Gallenkamp (model IH-150) and dried at 70^oC for 72h. The dried materials were weighed separately on (Sartorius model P. 163) weighing balance. Data collected were analysed using Statistical Package for Social Science (SPSS) version 16. Analysis of variance (ANOVA) was carried out and significant mean were separated using Duncan's New Multiple Range Test (DNMRT).

RESULT

Effect of nitrogen, farmyard manure and irrigation regimes on number of inflorescences of switchgrass is presented in Table 1 and 2. Results revealed a significant effect ($p<0.05$) of nitrogen application on number of inflorescences. At lowland location and in both 2023/2024 and 2024/2025 growing seasons, the number of inflorescences per plant increased with increase in nitrogen rates. In 2023/2024, the highest number of inflorescence (58.26) was obtained in plants treatment with 75kg N ha^{-1} (Table 1). In 2024/2024 growing season N

rates significantly affected the number of inflorescence (table 2). At upland location in both seasons, control had the lowest number of inflorescences with 47.58 and 48.85 inflorescence per plant for the 2023/2024 and 2024/2025 growing seasons respectively.

The result on the effect organic nitrogen, farmyard manure and irrigation regimes on number of seeds per plant is depicted in table 1 and 2. Number of seeds per plant was significantly,

Table 1: Effect of Nitrogen, Farmyard manure and Irrigation regime on yield parameters at upland and lowland location in 2023/2024

Treatment	Number of Inflorescences		No of Seeds per Plant		Fresh Weight (g)		Dry Weight (g)	
	Lowland	Upland	Lowland	Upland	Lowland	Upland	Lowland	Upland
Nitrogen (kg/ha^{-1})								
0	50.56^{c}	47.58	202.04^{b}	167.00	2.68^{c}	1.94^{b}	1.28	0.75
25	54.48^{b}	48.85	203.78^{ab}	168.19	3.08^{b}	2.39^{a}	1.35	0.98
50	54.96^{b}	50.26	205.11^{a}	171.04	3.42^{a}	2.47^{a}	1.36	0.99
75	58.26^{a}	50.04	204.44^{a}	171.37	3.42^{a}	2.49^{a}	1.37	0.99
SE±	1.00	0.85	1.09	2.28	0.12	0.12	0.10	0.13
Significance Level	*	Ns	*	ns	*	*	Ns	Ns
Manure ($t\ ha^{-1}$)								
0	51.86^{b}	47.47^{b}	202.08^{b}	168.36	2.77^{b}	2.11	1.23	0.87
5	55.22^{a}	50.47^{a}	203.89^{a}	169.33	3.19^{a}	8.12	1.37	0.93
10	56.61^{a}	51.03^{a}	204.56^{a}	170.70	3.30^{a}	2.44	1.42	0.98
SE±	0.97	0.64	0.97	2.01	0.12	0.12	0.09	0.11
Significance Level	*	*	*	ns	*	Ns	Ns	Ns
Irrigation Regime (weeks)								
0	55.81^{a}	50.97^{a}	204.72^{a}	170.72	3.39^{a}	2.71	1.38	1.11^{a}
2	54.83^{a}	49.58^{ab}	204.08^{a}	169.81	3.03^{b}	8.04	1.38	0.87^{b}
4	53.06^{b}	48.42^{b}	202.02^{b}	167.67	2.85^{b}	1.92	1.08	0.79^{b}
SE	1.05	0.70	0.96	2.00	0.12	0.12	0.08	0.11
Significance Level	*	*	*	ns	*	Ns	Ns	*
Interactions								
NxM	*	Ns	ns	ns	ns	Ns	Ns	ns
Nxl	Ns	Ns	ns	ns	ns	Ns	Ns	ns
Mxl	Ns	Ns	ns	ns	ns	Ns	Ns	ns
NxMxl	Ns	Ns	ns	ns	ns	Ns	Ns	ns

Means in a column with different superscripts are significant different ($P<0.05$), * significant at 5% levels, ns = not significant. AE± - standard error of means.

Table 2: Effect of Nitrogen, Farmyard manure and Irrigation regime on yield parameters at upland and lowland location in 2024/2025

Treatment	Number of Inflorescences		No of Seeds per Plant		Fresh Weight (g)		Dry Weight (g)	
	Lowland	Upland	Lowland	Upland	Lowland	Upland	Lowland	Upland
Nitrogen (kg/ha^{-1})								
0	50.56^{c}	47.58	202.04^{b}	167.00	2.68^{c}	1.94^{b}	1.28	0.75
25	54.48^{b}	48.85	203.78^{ab}	168.19	3.08^{b}	2.39^{a}	1.35	0.98
50	54.96^{b}	50.26	205.11^{a}	171.04	3.42^{a}	2.47^{a}	1.36	0.99
75	58.26^{a}	50.04	204.44^{a}	171.37	3.42^{a}	2.49^{a}	1.37	0.99
SE±	1.00	0.85	1.09	2.28	0.12	0.12	0.10	0.13
Significance Level	*	Ns	*	ns	*	*	Ns	Ns
Manure (t ha^{-1})								
0	51.86^{b}	47.47^{b}	202.08^{b}	168.36	2.77^{b}	2.11	1.23	0.87
5	55.22^{a}	50.47^{a}	203.89^{a}	169.33	3.19^{a}	8.12	1.37	0.93
10	56.61^{a}	51.03^{a}	204.56^{a}	170.70	3.30^{a}	2.44	1.42	0.98
SE±	0.97	0.64	0.97	2.01	0.12	0.12	0.09	0.11
Significance Level	*	*	*	ns	*	Ns	Ns	Ns
Irrigation Regime (weeks)								
0	55.81^{a}	50.97^{a}	204.72^{a}	170.72	3.39^{a}	2.71	1.38	1.11^{a}
2	54.83^{a}	49.58^{ab}	204.08^{a}	169.81	3.03^{b}	8.04	1.38	0.87^{b}
4	53.06^{b}	48.42^{b}	202.02^{b}	167.67	2.85^{b}	1.92	1.08	0.79^{b}
SE	1.05	0.70	0.96	2.00	0.12	0.12	0.08	0.11
Significance Level	*	*	*	ns	*	Ns	Ns	*
Interactions								
NxM	*	Ns	ns	ns	ns	Ns	Ns	Ns
Nxl	Ns	Ns	ns	ns	ns	Ns	Ns	Ns
Mxl	Ns	Ns	ns	ns	ns	Ns	Ns	Ns
NxMxl	Ns	Ns	ns	ns	ns	Ns	Ns	Ns

Means in a column with different superscripts are significant different (P<0.05), * significant at 5% levels, ns = not significant. AE± - standard error of means.

(p<0.05) higher in lowland location both in 2023/2024 and 2024/2025 growing seasons (Table 1, 2). The highest number of seeds per plant were recorded with the highest nitrogen rate (75kg ha^{-1} in both years. The lowest number of seeds per plant was obtained with control in both 2023/2024 and 2024/2025 growing seasons. results revealed that increase in the N rate from 25 to 75kg ha^{-1} markedly increased number of seeds per plant.

Application of manure significantly (p<0.05) increase number of seeds in both seasons and locations. The lowest \number of seeds per plant was obtained in the control treatments

in the two seasons and the highest manure rate (10t ha^{-1}) had the highest number of seeds per plant for both seasons and locations. Irrigation frequency significantly ($p<0.05$) increases number of seeds per plant at lowland location in both seasons. Two days irrigation interval had the highest number of seeds per plant in both 2008/2009 and 2009/2010 growing seasons. At upland location in both seasons similar trend was observed (Table 1, 2).

Seed yield was significantly ($p<0.05$) affected by manure rates at lowland location in both the growing seasons. At upland location in 2023/2024 and 2024/2025 growing seasons, results indicate a significant ($p<0.05$) increase in seed yield due to manure application. The result showed that increasing manure rate from 5 to 10 t ha^{-1} did not result in significant increases in seed yield. However, the values obtained for the seed yield from plots treated with manure differed significantly ($p<0.05$) from those obtained in the control (Table 1, 2).

Effect of nitrogen, farmyard manure application and irrigation regimes on days to 50% flowering is presented in Table 1 and 2. Results revealed that the effect of nitrogen in days to 50% flowering was significant ($p<0.05$). at the upland location in both 2023/2024 and 2024/2025 growing seasons, the control treatments had 50% flowering earlier than the nitrogen treated plots.

The effect of nitrogen on fresh weight was significant ($p<0.05$) for both seasons (Table 1, 2). The highest mean fresh weight was recorded with 75kg N ha^{-1} for the two growing seasons. However, there were no significant difference between treatments given 75kg N ha^{-1} and treatments that received 50kgN ha^{-1} in both growing seasons. The effect of farmyard manure was significant ($p<0.05$) in dry matter accumulation in both seasons and locations as shown in Table 1 and 2.

Table 3: Interaction of Nitrogen, farmyard manure and irrigation regime on days to 50% flowering of Switchgrass at lowland location in 2023/2024

	Farmyard manure (t ha^{-1})								
	0			**5**			**10**		
	Irrigation regime (days)			**Irrigation regime (days)**			**Irrigation regime (days)**		
Nitrogen (kg ha^{-1})	2	4	6	2	4	6	2	4	6
0	100.0	100.7[c]	102.0	103.0	103.0	103.0	104.0	104.0	104.0
25	105.0	105.0[b]	105.0	106.0	106.0	106.0	107.0	107.0	107.0
50	107.0	107.0[a]	107.0	108.0	108.0	108.0	109.0	109.0	109.0
75	107.0	107.0[a]	108.0	108.0	108.0	108.0	109.0	109.0	109.0
SE±		0.33							

Y Means in a column with different superscripts are significantly different ($p<0.05$) using DMRT a 5% level, SE: Standard error of means.

Interaction of nitrogen, manure and irrigation regime was significant ($p<0.05$) on days to 50% flowering at both lowland and upland location and in all the growing seasons (Table 3).

Climate change affects switchgrass in the following specific ways.

1. **$C0_2$ Fertilization:** Higher carbon dioxide levels in the air help the plant

make food faster. Switchgrass uses a special C_4 pathways to turn sunlight into energy. This makes it very good at using extra $C0_2$ to grow faster and bigger while using less water.

2. **Yield Risk:** While switchgrass is tough, severe weather still hurts its growth and yield. If a long drought hits during its main growing season, the plant will reduce far less biomass for biofuel.

3. **Heat and Drought Stress:** Very hot weather and dry soil can hurt growth. When it gets too hot, the plant closes tiny holes in the leaves (called stomata) to save water. This stops the plant from taking in $C0_2$, which slows down growth and yield.

4. **Soil Carbon Storage:** Switchgrass helps remove greenhouse gases from the air. It traps this carbon deep in the soil inside its massive root system. Similarly, when the weather gets too hot, soil microbes eat this carbon and release it into the air. This means the plant traps less carbon than it normally would.

DISCUSSION

Nitrogen plays a vital role in the vegetative growth of plants. It encourages the development of early inflorescence and allows more flower and seed formation (Masters *et al.,*, 1993). This could have been the possible reason for the higher number of inflorescences per plant with nitrogen application. This is in agreement with the findings of Brejda (2000) and Masters *et al.,* (1993). The highest number of inflorescences obtained with 2 days irrigation could be as a result of absence of water deficit thus maintaining continuous growth and development which is in line with the finding of Samson (2008) and Alexandrova *et al.,* (1996). The response of seeds per plant to nitrogen rates could be attributed to the contribution made by nitrogen in the nutritional status of the soil which favoured plant growth and development. The nutrient deficient crop would produce less seeds out of which many will shrink and become infertile. This is probably the reason for obtaining higher seed number with increase in nitrogen rates. The increase number of seeds per plants as affected by manure application could be due to its contribution in to the nutritional status of the (Reeves, 1997). The highest number of seeds per plant recorded in 2- and 4-days irrigation intervals could be related to the availability and water use efficiently of the crop (Samson, 2008).

The application of 50kg N ha^{-1} appeared to produce the best yield in both seasons, suggesting it to be the appropriate rate for seed production at Sokoto. The response of seed yield of switchgrass to nitrogen obtained is in conformity with the findings of John *et al.*, (1998) who reported that switchgrass respond to moderate level of nitrogen fertilizers application. Seed yield of 320kg ha^{-1} across all treatments and seasons was reported by Masters *et al.*, (1993). Some commercial seed fields in North-eastern U.S.A. also reported seed yield average 224kg ha^{-1} of pure live seed with 112kg N ha^{-1} Switchgrass yield of 390kg ha^{-1} in Kansas (Sanderson *et al.*, 2004) and 700kg ha^{-1} in Missouri (John *et al.*, 1998) were reported. The increased seed yield of switchgrass as a result of nitrogen application may be attributed to an increased photosynthetic area exhibited as a result of good vegetative growth.

The increase in seed yield of switchgrass with increase in farmyard manure application conforms with the finding of Masters *et al.*, (1993) who reported that seed yield of switchgrass is only obtained on soils which are well supplied with organic material and essential nutrients. The marginal difference

in seed yield, due to the different rates of farmyard manure, exhibited in both the seasons suggested that switchgrass require a moderate level of farmyard manure application. Akoun (2005) also confirm that manure increases the nutrient status of a soil, which leads to increase in yield. Seed yield differences between various irrigation regimes, seasons and across locations probably resulted from differences in irrigation intervals, which may have affected pollination and seed set.

The reason for the increase in time taken to attain 50% flowering with increase in nitrogen rate may be attributed to the important role nitrogen played in the vegetative growth (Thomson, 1996). This therefore, prolonged the flowering stages which conformed to the findings of Selim *et al.*, (1993). The longer time taken by manure treatment to reach 50% flowering could be due to contributions made by manure to the fertility status of the soil. Manure is known to increase soil fertility which in turn prolongs vegetative growth period and maturity of crops (Reeves, 1997). The differences in the dry matter yield with varying irrigation days may be due to the fact that water stress reduces dry matter accumulation of vegetative component of switchgrass. Furthermore, the yield parameters of switchgrass in lowland areas were higher than that of the upland areas. It was also observed that lowland soils had higher concentration of electrical conductivity, organic carbon, total nitrogen, sodium, calcium, magnesium and cation exchange capacity than upland soils. The higher content of these moisture and minerals in the lowland soil compared to upland soils probably accounts for the higher yield performance of switchgrass in lowland areas.

Climate change alter switchgrass growth and yield through rising $C0_2$ and shifting temperatures. Increased $C0_2$ boosts growth via the C_4 phitosynthesis pathway, and drought. Warming extends growing seasons and lower crop yields. Similarly, extreme heat and unpredictable rainfall can cause wild swings in yearly crop yields, lower water availability, stunting plant development and reducing long term soil carbon storage. As a bioenergy crop, switch-grass also fight climate change by storing large amounts of carbon in the soil.

CONCLUSION

The results of this study revealed that the combination of nitrogen at the rate of 50kg ha^{-1}, 5 t ha^{-1} farmyard manure and 2 days irrigation intervals were the optimum conditions for switchgrass yield in Sokoto, Nigeria. Increasing the nitrogen, farmyard manure rates or irrigation intervals above these levels led only to a marginal increase in yield. Changes in soil organic carbon or net ecosystem caused by switchgrass production have a positive effect on climate change. These results highlight the influences of climate change on Switchgrass yield are spatially heterogenous and vary depending on the location. Understanding how Switchgrass yields will be affected by future change in climate is important for achieving a sustainable crop production.

Although short term measures shows that soil organic carbon can be significantly increased by perennial biomass production, a long-term measure is required to assess the dynamic of soil organic carbon. Knowledge of spatial distribution of suitable area for Switchgrass production under climate change should be incorporated into planning of current and future suitable Switchgrass production.

Effect of climate change on the growth and the yield of switchgrass, lower crop yields due to water scarcity caused by drought, heat waves and flooding. Greenhouse gases significantly affect climate change.

REFERENCES

Akoun, J., 2005. Effect of planting density and manure on the yield and yield components of the common onion (*Allium cepa L)* var. Nsukka Red. *Nig. J. Horticultural Sci.,* 9:43 – 48.

Alexandrova, K.S., Denchev, P.D. and Conger, B.V. 1996. *In vitro* development of inflorescences from Switchgrass nodal segments. *Crop. Sci.,* 36: 175 – 178.

Bies, L., 2006. The biofuels explosion: Is green energy good for wildlife? Wildlife Soc. Bull., 34: 1203 – 1205.

Bransby, D. 2005. Switch grass profile. Bioenergy Feedstock Information Network (bfin), OakRidge National Laboratory. Pp: 40 – 47. https//bioenergy.ornlgov/papers/misc.switchggrass-profile.httml.

Brejda, J.J. 2000. Fertilization of native Worm-Season grasses. In: Native Warm Season Gasses: Research Trends and Issues Anderson, B.E. and K.J. Moore (Eds. CSSA, Madison, WI., pp: 177 – 2000.

Brice, J.L. Currah, A., Mahins and Bancrott, R., 1997. Onions Storage in the Tropics: A Practical Guide to Method of Storage and their Selection. National Research Institute, Chatha, UK., pp: 4 – 6.

Carpenter-Boggs, L., Pikull, J.L., Vigil, M.F. and Riedell, W.E. 2000. Soil nitrogen mineralization influenced by crop rotation and nitrogen fertilization. Am. *J. Soil Sci. Soc.,* 64: 2038 – 2045.

Entry, J.A., Mitchell, C.C. and Beckman, C.B. 1996. Influence of management practices on soil organic matter, microbial biomass and cotton yield in Alabama's Old Rotation Biol. Fertility *Soils*, 23:353 – 358.

Franzluebber, K., Hossner, L.R. and Juo, A.S.R. 1998. Integrated Nutrient Management for Sustained Crop Production in Sub-Saharan Africa. Soil Management CRSP/TopSoils/Texas A and M University, USA., pages 50.

Hastings, C. And Prince, E.C., 2007. Local capacity and emerging opportunities for bioenergy production. Hastings stewardship council and Elorin, Eastern lake Ontario *Regional Innovation Network*. Pp:6 – 7.

John, J.B., Moser, L.E. and Vogel, K.P. 1998. Evaluation of switchgrass rhizosphere microflora for enhancing seedling yield and nutrient uptake. *Agron. J*., 90:753 – 758.

Kucharic, C.J., Brye, K.A., Norman, J.M., Foley,J.A., Gower, S.Tand Bundy,L.G.(2001). Measurements and modelling of carbon and nitrogen cycling in agroecosystems of Southern Wisconsin: potential for SOC sequestration during the next 50 years. *Ecosystem.*4:237- 258.

Kowal, J.M. and Knabe, D.T. 2002. An Agroclimatological Atlas of the Northern States of Nigeria. Ahmadu Bello University Press, Zaria, Nigeria, pp:128.

Ladd, J.N., Amato, M., Zhou, L. And Schultz, J. E. 1994. Differential effects of rotation, plant residue and nitrogen fertilizer on microbial biomass and organic matter in an Australian alfisol. Soil Biol. *Biochem*., 26: 21 – 831.

Liebig, M.A., Johnson, H.A., Hanson, J.D., and Frank, A.B. (2004). Soil carbon under Switchgrass stands and cultivated cropland. Biomass Bioenergy.28:347 – 354.

Ma, Z., Wood,C.W., and Bransby, D.L.(2008). Soil management impacts on soilcarbon sequestration by

Switchgrass. *Biomass Bioenergy*.18:469 – 477.

Masters, R.A., Mitchell, R.B., Vogel, K.P. and Waller, S.S. 1993. Influence of improvement practice on big blustem and indiangrass seed production in tall grass prairies. *J. Range Manage*., 46: 183 188.

McLaughlin, S., Bouton, J., Bransby, D., Conger, B. And Ocumpaugh, W. *Et al.*, 1999. Developing Switchgrass as a Bioenergy Crop. In: Perspectives on New Crops and New Uses, Janick, J. (Ed.) ASHS Press, Alexandria, VA, USA, pp: 282 -299.

Reeve, D.W., 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil Tillage Res*., 43: 131 – 167.

Samson, R., 2007. Switchgrass production in Ontario: A management guide. Resource efficient Agricultural production (REAP), Canada.

Samson, R., 2008. Switchgrass L Living solar battery for the prairie. http://eap.mcgill.ca/MagRack/SF/Fall%2091%20L.htm.

Sanderson, M.A., Brink, G., Higgins, K. And Naugle, D. 2004. Alternative uses of Warm-Season Forage Grasses. In: Warm-Season (c_4) Grasses. Moser, L.E. (Ed.) ASA and CSSA, Madison, WI., pp: 389 – 416.

Selim, S.M.A., Rokba, M.R., Hassan, M.R. and Hussain, M.A. 1993. Effect of sowing dates, nitrogenous and potassium fertilization on reselle plant. *Egypt J. Hortic*, 20: 87 – 96.

Smolander, A., Kurka, A., Kitunen, V. and Malkonen, E. 1994. Microbial biomass c and N and respiratory activity in soil of repeatedly limed and N-and P-fertilized Norway spruce stands. *Soil Biol. Biochem.*, 26: 957 – 962.

Stegelmeier, B.L., Elmore, S.A., Lee, S.T., James, L.F. and Gardner, D.R. *et al.*, 2007. Switchgrass (*Panicum virgatum*). Toxicity in Rodents, sheep, Goats, and Horses. In: Poisonous Plant: Global Research and Solutions, panter, K. (Ed.) CABI Publishing, New York USA., pp: 113 -117.

Thomson, D.J., 1996. The seasons, global temperature and progressions. *Science*, 268: 57 – 68.

Tian, G., Kolawole, G.O., Kong, B.T. and Kirchoff, G. 2000. Nitrogen fertilizer replacement indexes of legume cover crop in the derived savanna of West Africa. *Plant Soil*, 224: 287 – 296.

USDA and NRCS, 2008. Plants profile for *Panicum virgatum* (Switchgrass). United State Department for Agriculture, Natural Resources Conservation Services, Washington, DC, USA., pp;35 – 65.

ASSESSMENT OF DEFORESTATION IMPACT ON LIVELIHOOD OF RURAL DWELLERS IN ETCHE LOCAL GOVERNMENT AREA OF RIVERS STATE, NIGERIA

Amadi, G. O, Nnadi, P.C, Augustus, M. U.
Department of Forestry Environment, Rivers State, Rivers State University,
Nkpolu/Oroworukwo, Port Harcourt, Nigeria
Corresponding Author's Email: picaso1ng'@yahoomail.com

ABSTRACT

Deforestation remains one of the major environmental challenges in rural communities, threatening forest ecosystems and the livelihoods of people who depend on forest resources for their socioeconomic well-being. This study assessed the impact of deforestation on the livelihoods of rural dwellers in Etche Local Government Area, Rivers State, Nigeria. Specifically, the study examined the demographic characteristics of residents, assessed the status of the forest, identified the causes and consequences of deforestation, and evaluated strategies for reducing deforestation in the study area. Primary data were collected through a structured questionnaire and oral interviews. A total of 100 questionnaires were randomly administered across communities in Okehi, Igbo, Mba, Ozuzu, and Ulakwo clans, and all were successfully retrieved, representing a 100% response rate. Data were analyzed using descriptive statistics. The findings revealed that all respondents (100%) indicated that substantial portions of the forest had been converted to other land uses. The major causes of deforestation were infrastructure development (30%), overdependence on forest resources (13%), overpopulation (10%), and agricultural expansion (3.5%). The major consequences included climate change (38%), loss of biodiversity (36%), environmental degradation (20%), and flooding (3%). Respondents identified the most effective strategies for reducing deforestation as the establishment of forest monitoring teams (27%), prohibition of indiscriminate harvesting of forest products (26%), reforestation programmes (14%), and public awareness and sensitization campaigns (11%). The study concludes that deforestation has significantly altered forest ecosystems and negatively affected the livelihoods of rural dwellers in Etche Local Government Area. It therefore recommends strengthening forest governance, promoting reforestation initiatives, enforcing sustainable forest management policies, and intensifying environmental education to ensure the sustainable utilization and conservation of forest resources.

Keywords: Deforestation, Rural Livelihoods, Forest Degradation, Sustainable Forest Management, Etche Local Government.

INTRODUCTION

Deforestation is one of the indiscriminate anthropogenic activities contributing to erosion, flooding, loss of soil nutrients, poor agricultural produce, global warming, climate variability, climate change and desertification (Audu, 2013; Mfon *et al.*, 2014).

Deforestation has global consequences, primarily because of the influence on carbon exchange (Alamu and Agbeja, 2011) and it accounts for 87 percent of total carbon emission in Nigeria. With more CO2 in the atmosphere, more of the sun's radiation is reflected to earth, instead of space, and this causes average temperature to rise (Mfrekemfon and Konwea, 2014). In this way, deforestation is a major issue when it

comes to global warming (Ogbuene, 2010). Health problems associated with global warming include heat stroke, climate stress on agriculture predisposing to malnutrition, increase in the number of malaria-carrying mosquitoes putting 65% of the world population on the risk of malaria infection. These increase morbidity and mortality rate (Mfrekemfon and Konwea, 2014). Many developing countries, like Nigeria, are suffering from serious environmental degradation primarily because of the rapid growth in population which has not only brought about gross encroachment and damage to natural forest, wildlife, land, water and even air but has also brought unacceptable quality of life conditions in the human community environment (Oduntan *et al.*, 2013).The forest reserve in Nigeria is estimated to cover about 10 million hectares, which accounts for more than 10% of land area approximately 96.2 million of ha (Ikuomola *et al.*, 2016).

However, Nigeria has the worst deforestation rate in the world which is attributed to her increasing population with high poverty level. The annual rate of deforestation in Nigeria is 3.5% which is approximately 350,000-400,000 hectares per year (Mfrekemfon and Konwea, 2014); resulting in more than 50% loss of primary forests in the past decades through unsustainable logging, agriculture, as well as fuel wood collection (Mfon *et al.*, 2014). Some policy measures were put in place by government such as ban on logging (1975), Annual Afforestation (1988), National Forest Action Plan (NFAP) (2005), educating farmers about dangers of environmental degradation, providing farmers with high yielding varieties of crop and irrigation equipment. In spite of these policy measures, deforestation continued to increase at alarming rate (Ibrahim *et al.*, 2015). The Federal Ministry of Environment, (2006) also reported that the first ever National Forestry Act has been evolved to back the policy and have since been presented to the Council for ratification and to be passed into law (Ojekunle, 2014).

Nevertheless, in recent times the area marked as forest lands have been decreasing steadily due to the indiscriminate felling of trees and activities of illegal loggers which have continued in virtually every part of the country (Alamu and Agbeja, 2011; Ikuomola *et al.*, 2016). This research has focused on deforestation in one of the rural areas because over 60% of Nigerian population lives in rural communities and depend largely on agriculture, cottage industries and other forms of informal and small-scale natural resources exploitation activities, for rural household income. These activities are often unsustainably carried out, given the paramount motivation to increase household income (Mfon *et al.*, 2014).

Nigeria has a population of over 170 million people with an average population growth rate of 2.5%, while a large percentage (70.8%) are living in abject poverty, below $1 per day with 0.826 metric tons carbon dioxide emissions per capital per year. With this population growth and without economic growth or technological advancement the high rate of deforestation is unavoidable (Mohammed, 2014). Nigerians have always depended on the forest for their survival, economic development, as well as environmental amelioration. However, only half-hearted efforts have been made to control deforestation, leading to the almost destruction of Nigerian forests. Therefore, sustainable development is yet to be achieved (Mfon *et al.*, 2014).

The main cause of deforestation in tropical forests is clearing for agriculture to feed the growing population or (to a lesser degree) to earn foreign exchange from export (Oduntan *et al.*, 2013). Also, the economy of fuel wood market is booming as a household preferential choice of energy because of its

qualities: availability, accessibility, affordability, source reliability, flexibility, and taste (Mohammed, 2014); without realizing that a substantial amount of carbon stored in the vegetation in the dry zones averaging about 30 tons per hectare, declines when the vegetation is depleted. Carbon rich soils are found in dry zones hence the destruction of these trees has a very powerful effect on the carbon cycle and boosts the greenhouse effect as a result of the depletion of carbon (Alamu and Agbeja, 2011).The use of fuel wood is currently gaining more popularity among the medium and high income earners in urban centres such as Makurdi, Kaduna, Kano, Lokoja, Ibadan, Sokoto, Ilorin, Jalingo and Minna among others due to the scarcity and cost of kerosene as well as local gas (Audu, 2013). A consequence of the rapid increase in human populations, settlements, and encroachments globally is the concomitant rapid decline in biological diversity, with significant shifts in species community composition and severe disruption to established food webs, which are directly tractable to land-use change and deforestation (Aaron *et al.*, 2016).

Deforestation is a major problem occurring in many parts of Nigeria and the most serious affected region is the less endowed northern part of the country with the forests and game reserves being intensively and extensively exploited. As a global challenge, tropical deforestation has gained greater impetus in policy and research. Mahapatra and Kant (2003) stated that since the early 1980s, policy makers have responded to tropical deforestation with various bilateral and multilateral initiatives such as Tropical Forestry Action Plan, International Tropical Timber Organization and Forest Principles. They also indicated that there is increasing research on various dimensions of tropical deforestation by many scientists, such as Mfon, *et al.* (2014) on challenges of deforestation in Nigeria and the Millennium Development Goals, Ogbuene, (2010) on environmental consequences of rainfall variability and deforestation in Southeastern Nigeria, Aliyu *et al.* (2014) on Impacts of deforestation on socioeconomic development of Akwanga and Nasarawa state, and Ojekunle (2014) on the effects and linkages of deforestation and temperature on climate change in Nigeria. The impact of deforestation has really affected the means of providing the necessities of life for the rural dwellers in Etche. In spite of the various research conducted on deforestation, little or no research has been carried out on The Impact of Deforestation on Livelihood of Rural Dwellers in Etche Local Government Area, Rivers state, Nigeria.

There is enough evidence that the whole world is facing an environmental crisis on account of heavy deforestation. For several years, there has been remorseless of destruction which must be put under control to avoid some bad consequences associated with deforestation. Nobody knows exactly how much of the world rainforests have already been destroyed and continue to be razed each year. Data is often imprecise and subject to differing interpretations. However, this research work will focus on the consequences of deforestation on the rural house hold income especially as observed in Etch Local Government Area in Rivers State.

Objectives

i. Establish the demographic information of residents around the study area
ii. Investigate the status of the forest in the study area.
iii. Determine the causes of deforestation and consequences on livelihood of rural dwellers in the study area.
iv. Determine the strategies for reducing deforestation.

MATERIALS AND METHODS

Study Area

This research was carried out in Etche, Rivers State. Etche is a Local Government Area (LGA) in Rivers State, Nigeria, named after the Etche (Echie) people of Southern Nigeria. The Etche are a sub-group of the Igbo people and they speak a dialect of the Igbo language. It is within Latitude 4° 59' 27.00" N and Longitude 7° 03' 16.00" E.

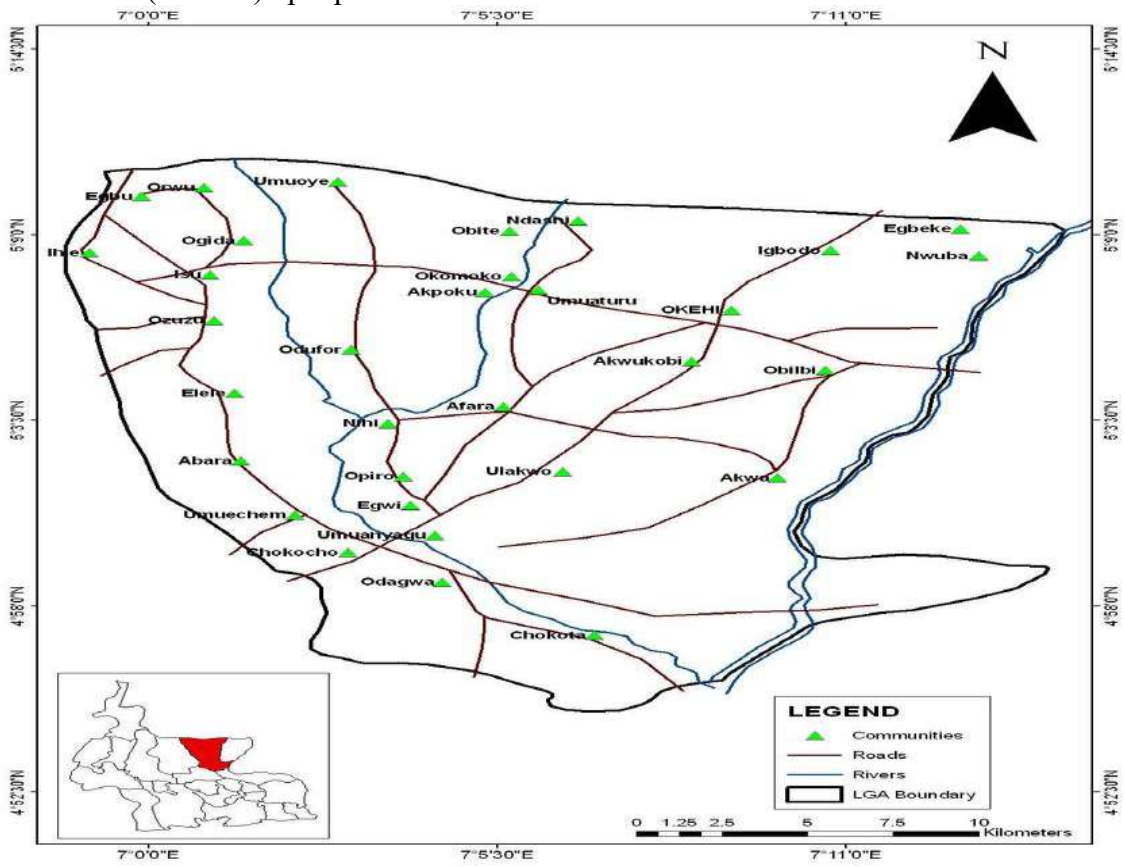


Figure 1: Map of Etche Local Government Area showing the Selected Communities in Rivers State, Nigeria

Data Collection

Data was collected with the aid of a well-structured questionnaire in the study area. The data for the study was collected through primary sources. The primary sources of data involve collection of fresh data that are non-existing. Nachmaise and Nachmaise (2009) posit that primary data describes how data usually obtained through questionnaire, interviews or observation. This source of data provides information in relative to the study. Its sources include questionnaire and direct oral interview that will be conducted in the area.

Distribution of questionnaires

A total of One hundred copies of questionnaires was randomly distributed in the research area which includes Communities in Okehi clan, Igbo group, Mba clan, Ozuzu and Ulakwo clan and a total of one hundred copies were retrieved.

Establish the demographic information of residents around the study area

The questions in the questionnaire were structured to elicit information about the respondents.

Investigation of Forest status in the study area.

The status of the forest in Etche Local Government Area was investigated using questionaires to elicit information.

Causes and consequences of deforestation on livelihood in the study area

Causes of deforestation were investigated with the used of questionnaire possible causes

Determine the strategies for reducing deforestation

This was achieved using information gotten from the respondents in the study area.

Data Analysis

The data upon which the research was based were collected using simple random sampling and results are presented using descriptive statistics with the use of frequency, percentage, table, charts and figures.

RESULTS

Establishment of Demographic Information of Respondents around the Study Area.

In table 1, the demographic characteristics of the respondents in the study area are displayed. From the table it is observed that Christian religion (78%) is more than Islam (1%), Traditional worship (15%) and Pagan is (2%). The male respondents are (50%) and female (50%). Respondents age 18-30 is (18%), 31-43 is (21%), 44-56 is (37%) and 57 and above is (26%). 25% of respondents are single and 37% are married, 21% are divorced while 16 are widow(er). Showing that the percentage of married respondents is higher than single, divorced and widow(er)

Status of the forest in the study area

Information gotten from the respondent on whether the forest is still intact as they first saw it is in Figure .1. The figure shows that one hundred percent (100 %) of the respondent in the study area are of the opinion that their forest is not intact. Figure .2 shows that 91% are of the opinion that the forest is depleted while sparsely populated and extinct is 9% and 0% respectively. Figure .3 shows that 100% affirmed that forest land has been converted to other purposes.

Causes of deforestation in the study area

Figure.4 shows that the causes of deforestation include infrastructure with 30%, over population with 10%, conversion to farmland 35%, over dependence 13% and uses for other purposes 12%. Figure .5 shows the information gotten from the respondents about the frequency at which some rural dwellers fell trees. 19% were of the opinion that it is carried out daily, 63% weekly, 16 % monthly and yearly 2% respectively.

Consequences of deforestation on livelihood of rural dwellers in the study area

Figure 6 shows the consequences of deforestation on livelihood of rural dwellers in the study area are as follows ; erosion 3%, environmental degradation 20%, loss of species/biodiversity is 36%, Climate change is 38% and flooding 3%.

Strategies for reducing deforestation

. The strategies are as follows, carrying out awareness/sensitization program 11%, reforestation 14%, placement of monitoring team 27%, encouraging substitutes 22% and prohibition of indiscriminate harvesting 26%.

Table 1: personal characteristics of the respondents

Variable	Frequency	Percentage (%)
Religion		
Christian	78	78
Islam	1	1
Traditional worship	15	15
Pagan	2	2
Sex		
Male	50	50
Female	50	50
Age		
18-30	16	16
31-43	21	21
44-56	37	37
57 and above	26	26
Marital Status		
Single	16	16
Married	21	21
Widow(er)	37	37
Divorce	25	25
Level of Educational		
Primary	9	9
Secondary	77	77
Tertiary	13	13
None	1	1
Occupation		
Contractor	1	1
Farmer	46	46
Students	23	23
Self-employ	22	22
Civil servants	12	12

Table 2: Respondents response on condition of the forest

Variable	Frequency	Percentage
Yes	0	0
No	100	100
Undecided	0	0

Source: Field study, 2022

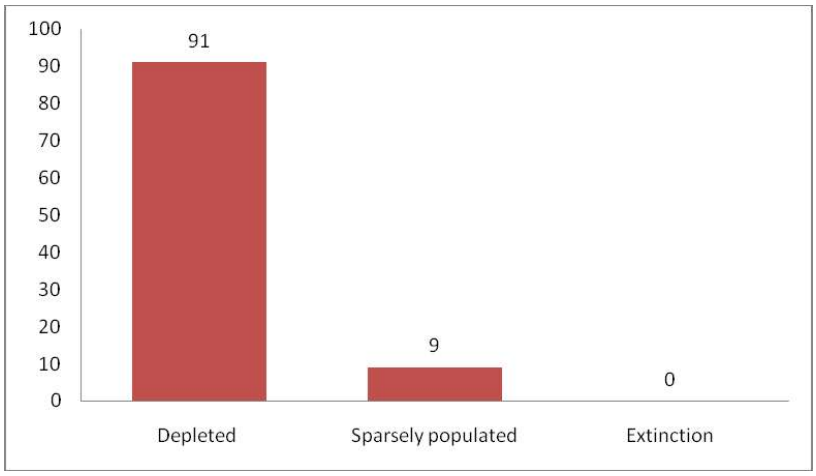


Figure 1: Description of the Forest in the study area

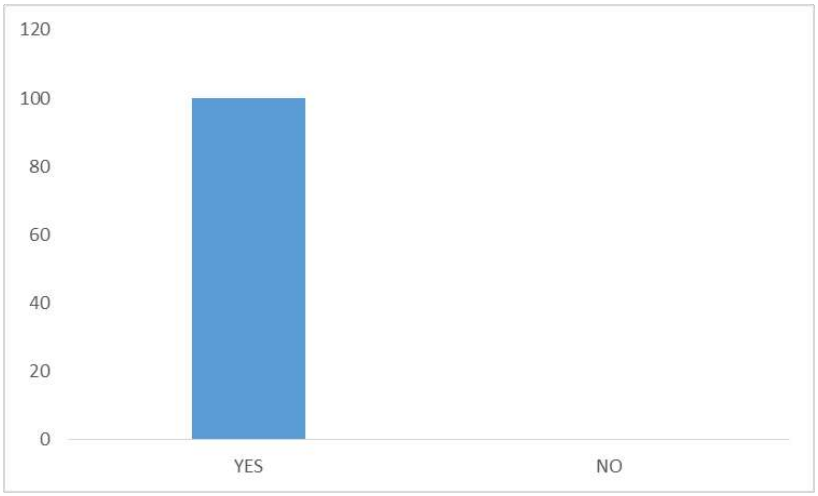


Figure 2 Respondents on Conversion of forest land

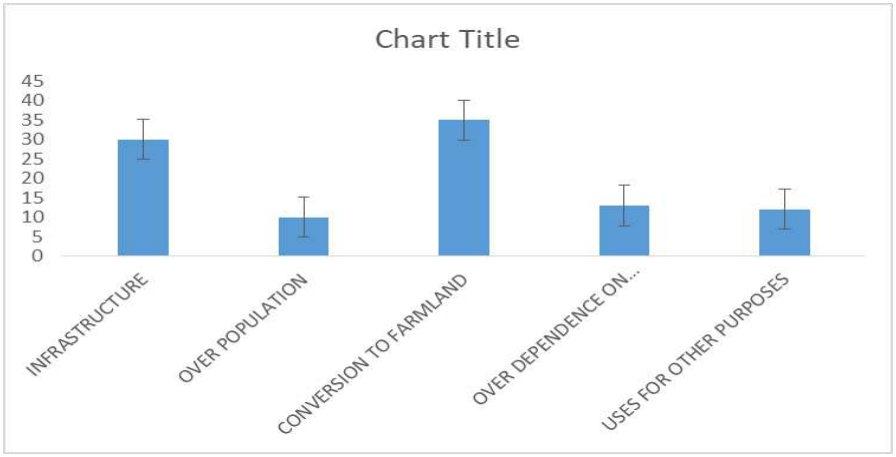


Figure 3.: Causes of Deforestation in the study area

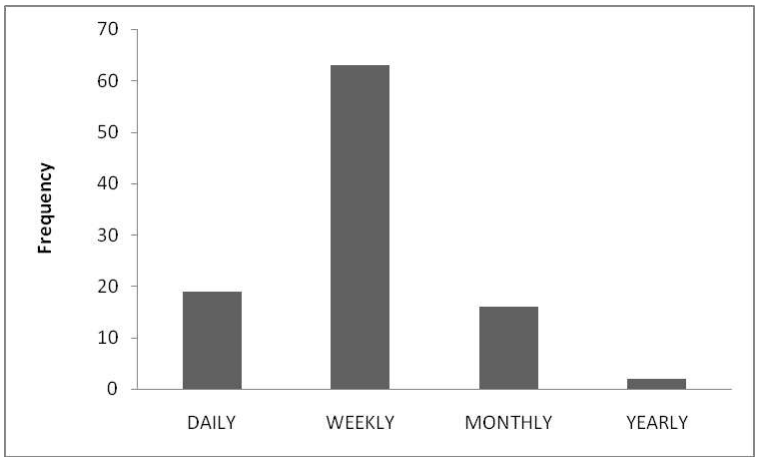


Figure .4: Frequency of how trees are often fell

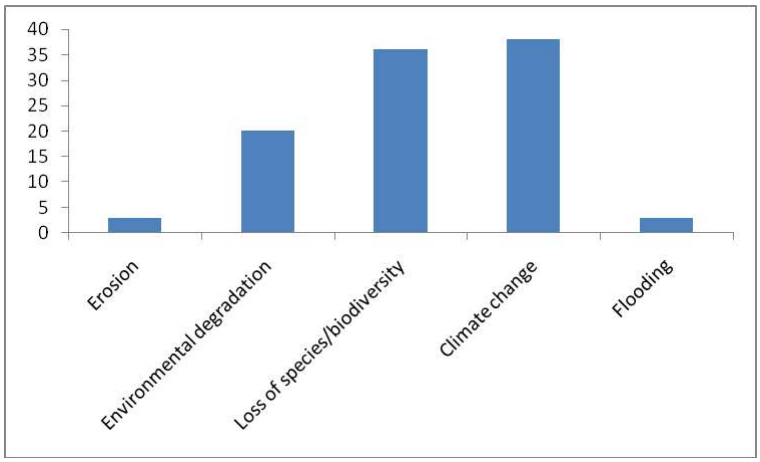


Figure 5: Effect of deforestation in the study area

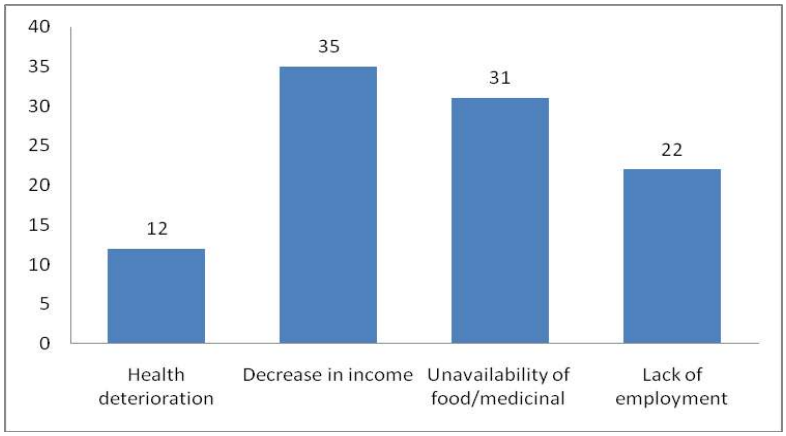


Figure 6: Effect of deforestation on livelihood

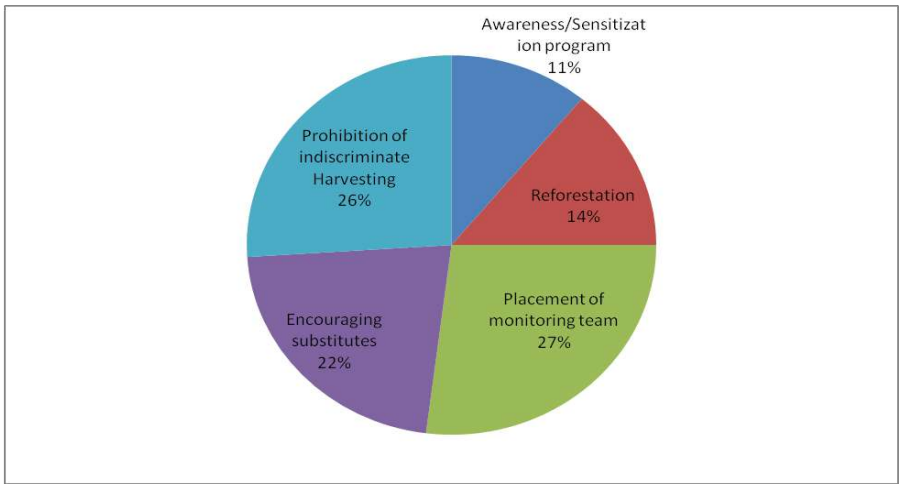


Figure 7: Remedies to reduce deforestation

DISCUSSION

The study revealed that a higher percentage (91%) of the respondents indicated that the Forest has been depleted while (9%) indicated that the Forest is sparely populated. This shows that the forest in the study area is depleted.

The result of the conversion of deforestation to other use in the study area reveals that 100% of the respondents indicated that most forest land has been converted to other use in the study area. This research agrees with the report of Pearce and Brown (1994) that one of the major causes of deforestation is as a result of conversion to other use such as agriculture, infrastructure, resident buildings etc.

It was also observed that there are various causes of deforestation in the area which are infrastructure (30%), overpopulation (10%), conversion to farmland (35%), over dependent (13%) and uses for other purpose (12%). This research shows that most of the rural dwellers converted the Forest land to farmland which is the major cause of deforestation in the area. This finding agrees with the report of (Myers, 1994 ; Anon, 1991) which stated that about 60 percentage of the clearing of tropical moist forests is for agricultural settlement.

Also, the frequency at which rural dwellers fell trees in their area which include daily 19%, weekly 63%, monthly 16% and yearly 2%. this shows that rural dwellers fell trees mostly on weekly basis. This research agrees with the report of Ajayi, S. and Ilem E. E (2015) which stated that over fifty trucks of wood leave the northern axis of Cross River State weekly before the advent of the task force.

The result of the effects of deforestation on rural dwellers which reveals that 38% % of the respondents indicated loss of species and biodiversity as effects of deforestation in rural dwellers in the study area that deforestation activities in the study area have reduced the wild species of both plants and animals, some of which are of great economic importance, these in turn affects the local community and reduce the quality of life. The result conforms to the findings of Magala (2015) who found that biological diversity and animal species are threatened due to loss of wildlife habitats and degradation of water-shed areas, hence leading to deterioration of the quality of life and reduction of options for development. The result further reveals that 36% of the respondents indicated climate change. This implies that deforestation negatively affect the climate in the study area and consequently affects agriculture, crop

harvest, which tells greatly on the livelihood of the people. This agrees with the findings of Chomitz et al, 2007) which stated that deforestation affects wind flow, water vapour flows and absorption of solar energy thus clearly influencing local and global cliamte. 20% of the respondents indicated environmental degradation as the effect of deforestation, 3% indicated erosion as an effect of deforestation and 3% also indicated flooding as an effect of deforestation.

Finally 27% of the respondents indicated placement of monitoring team as strategies for reducing deforestation. Furthermore, 14% of respondents agreed to reforestation as an effective means of reducing deforestation. According to the findings, respondents have some knowledge of reforestation programs which were not fully implemented and supervised. Respondents expressed a belief in this strategy if it will be fully enacted. This agrees with Warren (2017) who posited that another solution to deforestation is to plant more trees to replace those already lost. 22% expressed their interest in encouraging substitute, 26% on prohibition of indiscriminate harvesting and 11% indicated awareness/sensitization program as a means of reducing deforestation.

CONCLUSION

Conclusively, the study revealed the drastic negative effects deforestation has on rural dwellers, ranging from climate change, loss of species biodiversity, flooding, erosion to environmental degradation. Most rural dwellers depend on farm and off– farm activities to create or generate all the necessities of life in order to sustain their life. Forest resources are one of the major resources on which most of the communities depend on to generate necessities for their family. This results in resource over exploitation and ultimately deforestation with dire consequences on man and the environment.

Recommendation

1. There should be policy regulating forest resources harvesting.
2. There should be a policy on wood harvest from forests, restricting both rural and non-rural based people from illegal logging. Strict regulations by Government and Nongovernmental organizations should be enacted to reduce deforestation.
3. Advertising campaigns for sensitization of the local community on the unfriendly effects of deforestation should be encouraged.
4. Policies and strategies that aim at improving the welfare of rural livelihood and natural resource conservation should give attention to alternative livelihood sources and discourage forest depletion.

REFERENCES

Alamu, L.O. and Agbeja, B.O. (2011). Deforestation and endangered indigenous tree species in south-west Nigeria. International journal of biodiversity and conservation, 3(7); 291-297. PAT 2020; 16 (2):33-45 ISSN: 0794-5213; Abah et al; Effects of Deforestation on Rural Household Income 43

Aliyu, A., Modibbo, M.A., Medugu, N.I and Ayo, O. (2014), Impacts of deforestation on socio-economic development of Akwanga Nasarawa state. International journal of science, environment and technology, 3(2); 403-

Audu, E.B. (2013). Fuel wood consumption and desertification in Nigeria. International journal of Dun.science and technology, 3(1); 1-5. . .

Chomitz, K.M., Bugs, P., Luca, G.D., Thomas, T.S. and Wertz-Kanounnik,

O.S. (2007). At logger heads? Agricultural expansion, poverty reduction and environment in the tropical forests. World Bank policy research report. World Bank Washington DC.

Mfon, P., Akintoye, O.A., Mfon, G., Olorundami, T., Ukata, S.U. and Akintoye, T.A. (2014). Challenges of deforestation in Nigeria and millennium development goals. International journal of environment and bioenergy, 9(2);76-94.

Mfrekemfon, P.I. and Konwea, P.E. (2014). Deforestations, environmental sustainability and health implication in Nigeria: A review. International journal of science, environment, 3(2); 502-517.

Mohammed Al-amin (2014). Domestic energy crisis and deforestation challenges in Nigeria. Journal of environmental and earth science, 4(2); 94-99.

Myers, N. (1994.); Tropical deforestation: rates and patterns. In: The Causes of Tropical of Tropical Deforestation. The economic and statistical analysis of factors giving rise to the loss of the tropical forest, eds. Brown, K. and Pearce, D. pp 27-40. UCL Press. .

Oduntan, O.O., Soaga, J.A.O., Akinyemi, A.F. andOjo, S.O. (2013). Human activities pressure and its threat on forest reserves in yewa division of ogun state, Nigeria. Journal of environmental research and management, 4(5); 260-267.

Ogbuene, E.B. (2010). Environmental consequences of rainfall variability and deforestation in southeastern Nigeria. International journal of water and soil resources', 1 (1-3): 100-115.

Ojekunle, O.Z. (2004). The effects and linkages of deforestation and temperature on climate change in Nigeria. Global journal of science frontier research: environment and earth science.

Pearce, D. and Brown, K. (1994). Saving the world's tropical forests. In: The Causes of Tropical of Tropical Deforestation. The economic and statistical analysis of factors giving rise to the loss of the tropical forest, eds. Brown, K. and Pearce, D. pp 2-26. UCL Press.

HABITAT RESTORATION STRATEGIES FOR ENHANCING BIODIVERSITY AND ECOLOGICAL NETWORKS: A REVIEW

Olatidoye, O. R.

Forestry Research Institute of Nigeria, Jericho Hills, Ibadan. Nigeria
Corresponding Author's Email: olaremiolatidoye@gmail.com

ABSTRACT

Ecosystems are under growing stress resulting from human activities including deforestation, pollution, climate change, and resource overuse, this makes restoring degraded ecosystems a crucial worldwide challenge. In order to restore degraded landscapes in a sustainable and environmentally sound manner, habitat restoration strategies would play crucial roles in this process. The concepts of habitat restoration are explained by ecological integrity, target species identification, and long-term sustainability. Native species are very successful at reestablishing ecological services and promoting biodiversity because they have developed in particular areas over millennia and are particularly adapted to local environmental conditions. Another important element that promotes cooperation between locals, environmental groups, governmental organizations and contributes to the social and financial advantages of restoration efforts is community-based conservation strategies. In order to guarantee the resilience and sustainability of ecosystems for future generations, this paper examines fundamental these restoration strategies in relation to a variety of factors, including landscape connectivity and ecological corridors, technological tools, monitoring and evaluation, and challenges encountered in the restoration process. It also highlights the necessity of continued investment in these strategies.

Keywords: Ecological network, Ecological integrity, Monitoring, Sustainability, Biodiversity Conservation

INTRODUCTION

The variety of life on Earth is represented by biodiversity, which includes differences within species, between species, and between ecosystems. It serves as the basis for ecosystem functioning and offers a variety of ecological services (Mitchell, 2005) that promote environmental sustainability and human well-being (McDonald *et al.* 2016). Healthy ecosystems sustain food production systems, control the climate, clean water, and preserve soil fertility. Additionally, biodiversity supports social stability, economic growth, and cultural values. However, growing anthropogenic pressures and environmental changes are posing unprecedented potential threats to world's biodiversity (Shafroth *et al.* 2005).

Ecological networks that support biodiversity are disrupted as ecosystems become more fragmented due to habitat loss (Lambeck and Hobbs, 2002; Potter, 2016), resulting in instability to ecosystem functioning. Growing awareness of the extent of land degradation and its concerning effects on human well-being has prompted ongoing efforts to combat this worldwide phenomenon. Restoring habitat has become a key tactic for ecosystem recovery and biodiversity preservation. According to the Society for Ecological Restoration (SER 2004; Gann *et al.* 2019), ecological restoration is the process of helping a degraded, damaged, or destroyed ecosystem recover; It has drawn more attention since it is one of the most widely used solutions to land degradation maintaining and restoring ecosystems and their services (EU, 2011). Under these stressful circumstances, plant recovery after harm is extremely challenging, and this is true for both natural regeneration

and restoration. Competition is more intense and stress levels are lower in moist environments. Lands in arid regions are extremely vulnerable to human disturbance and degradation (Rundel, 1998). Restoration activities improve ecosystem resilience and aid in the regeneration of ecological networks by reconstructing natural habitats and reuniting fragmented landscapes (Pocock *et al.* 2012). Because it highlights how interrelated ecosystems are, the idea of ecological networks has drawn more attention in conservation science. As a foundation for management strategies, this entails a transparent and verifiable examination and evaluation of abiotic conditions, natural habitats, and species (Van der Molen *et al.* 2011).

Complex relationships between organisms and their surroundings, such as food webs, mutualistic interactions, and nutrient cycles, make up ecological networks. Ecosystems lose their ability to operate efficiently when these networks are interrupted. Therefore, restoring habitat is essential to strengthening ecological ties and enhancing the stability of biodiversity. McDonald, 2004; Dilworth *et al.,* 2000).

The long-term preservation and improvement of our natural and cultural heritage, as well as the management, planning, and conservation of landscapes, can be facilitated by the use of native species in habitat restoration. Additionally, planting native plants helps prevent the spread of invasive alien species and strengthen ecosystem resilience to climate change (Lake, 2013). In order to improve and offer suggestions for sustainable methods of habitat restoration, this article discussed a general process of habitat restoration that centers on goal setting, linking goals to target species, and prioritizing actions based on the set goals and typical constraints encountered.

Principles of Habitat Restoration

A number of ecological principles that are intended to guarantee the proper recovery of damaged ecosystems serve as the foundation for habitat restoration. The ability of ecosystems to preserve their original composition, structure, and functions is referred to as ecological integrity. The goal of restoration efforts is to create environments that enable ecosystems to operate similarly to how they did in past times. This entails reestablishing the hydrological processes, vegetation structure, soil conditions, and species interactions that sustain biodiversity (McDonald *et al.* 2016). Prior to habitat restoration, a focal or target species or group of species must be identified in order to direct the process and optimize conservation benefits within the framework of regional objectives (Dale *et al.* 2000; Scott *et al.* 2001; Groves *et al.* 2002).

Using native species in restoration efforts is a key component of habitat restoration (Nagler *et al.* 2011). Native plants and animals are crucial to preserving ecological balance since they are suited to the local environment conditions (Walker, 2006). Introducing native species promotes interactions including pollination, seed distribution and aids in the reconstruction of natural communities (Bateman *et al.* 2013). On the other hand, the introduction of non-native species may cause invasive species issues (Boitani *et al.* 2007) and disturb ecological connections (Johnson *et al.* 2010). As a result, protection and reintroduction of native plants and animals are usually given top priority in restoration initiatives; this initiative emphasizes the restoration of ecosystem functioning (Paxton *et al.* 2011). By enhancing habitat quality and encouraging species interactions, effective restoration techniques utilizing native species seek to restore these functions (Block *et al.* 2001). Another important factor in habitat restoration is long-term sustainability. Climate variability is also one of the

environmental changes that continuously affect ecosystems, which are dynamic. Thus, adaptive management techniques and future environmental conditions must be taken into account in restoration initiatives (Evans *et al.* 2013). Adaptive management entails ongoing observation, assessment, and modification of restoration techniques in response to ecological input. With this strategy, restoration professionals may adapt to changing circumstances and gradually enhance restoration results.

Participatory Restoration Approach

Land restoration done through a participatory manner makes all parties involved create contractual and partnership connections. "Participation is a dynamic, functional, and pragmatic approach in which development agents and populations combine their knowledge, their know-how, and their willingness in concerted actions of partnership in order to sustainably improve the management of these actions." (Gallard and Koné, 1994). This idea encourages restoration professionals to acknowledge that locals play an important role in the development, planning, execution, and assessment of restoration initiatives. Local and indigenous knowledge can offer important insights into species behavior, ecological dynamics, and sustainable resource management techniques. In fact, local communities are perceived as passive beneficiaries rather than true collaborators, and they rarely have a significant role in the decision-making process related to natural resource management (Wily 2002).

Restoration initiatives can produce more successful and culturally relevant results by fusing scientific research with traditional knowledge systems (Battisti, 2003). According to Light (2000), ecological restoration has a possibility for democracy. This concept demonstrates the inclusive context of ecological restoration. Therefore, a genuine recovery initiative needs to involve the public. According to Davis and Slobodkin (2003), some authors view restoration as a value-based endeavor that ought to focus on supporting the restoration of ecosystem features and services that are beneficial to humans. Community-based conservation strategies promote cooperation between local citizens, environmental groups, and governmental institutions. These projects frequently integrate traditional ecological knowledge that has been established over generations via direct engagement with natural surroundings. (Davis and Slobodkin, 2004; Hobbs *et al.* 2004). As a relatively new idea, participatory forest management encounters institutional and political challenges (Derak *et al.* 2017).

However, the need for involvement in restoration projects is becoming more widely acknowledged worldwide (McDonald *et al.* 2016). In order to ensure the coherence, depth, and continuity of efforts to combat desertification, the United Nations Convention to Combat Desertification (UNCCD)-Ninth Conference of Parties emphasized the necessity of cooperation between the general public, local governments, research institutes, and international financing agencies (UNCCD 2009).

Employment opportunities are frequently created by restoration projects in fields like habitat monitoring, tree planting, and ecological tourist development. These financial rewards promote sustainable livelihoods and local involvement (Van Driesche and Van Driesche 2002). Environmental education programs linked to restoration projects can also raise public understanding of environmental stewardship and biodiversity conservation. Strong institutional support and inclusive decision-making procedures are necessary for effective community participation (Hobbs *et al.* 2004). Recognizing the population's

ability to take charge and make choices regarding the creation and execution of initiatives and programs that affect their current and future lives is the essence of population participation. Interveners must therefore acknowledge locals as important partners and stakeholders. They shouldn't see them as merely project objectives or a way to carry out decisions made without their input. The five steps of the participatory restoration approach are as follows: (1) Define restoration goals and objectives; (2) create restoration planning; (3) Put strategies and measurements into action; (4) assess and track; and (5) make iterative, successive adjustments.

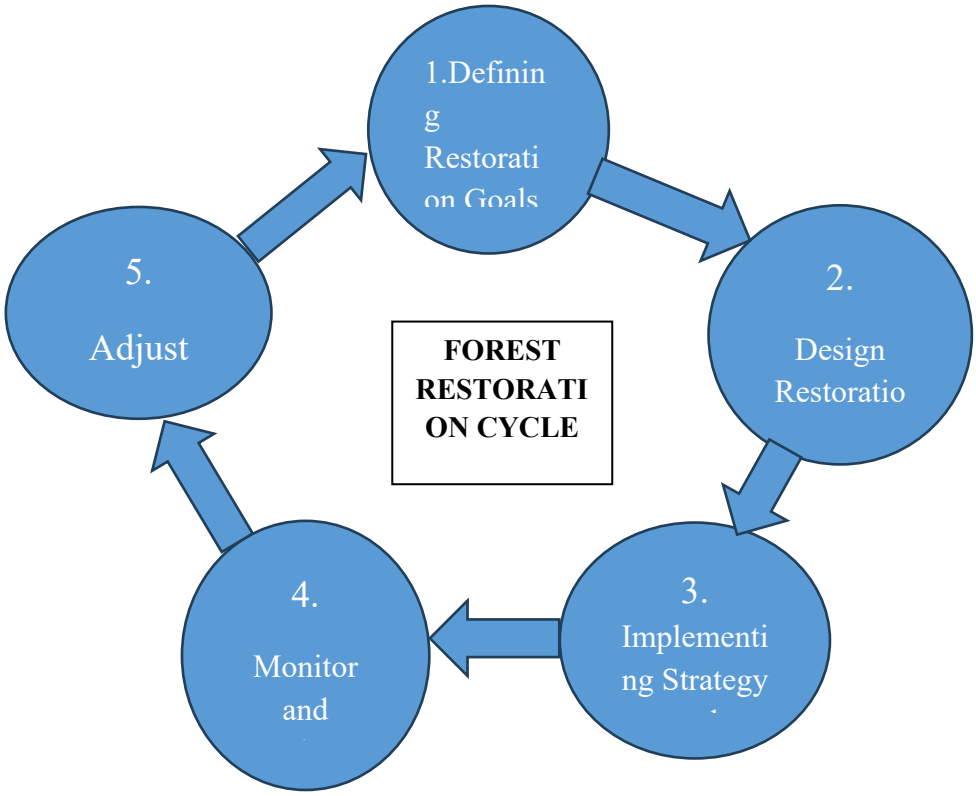


Figure 1: Forest Restoration Cycle

Stakeholder engagement in restoration planning and design should involve local community members, owners, managers, and pertinent authorities both at the beginning of the project and during its lifespan; It is necessary to establish baseline inventories, identify reference ecosystems, have a clear vision, goals, and objectives, analyze and prioritize logistics and restoration methods, and prescribe restoration treatments. Hobbs (2004, 2007)

All treatments are implemented in a way that supports and safeguards the possibility for both natural and assisted recovery while also being responsive to natural processes. The outcomes of monitoring should guide the application of adaptive management (Roni *et al.* 2015). In line with the prior practice, this approach foresees unanticipated ecological reactions and corrective activity modifications.

Monitoring adheres to precise targets, quantifiable goals, and objectives determined during planning and design. It is crucial to report and share evaluation findings and progress with important stakeholders and the

general public. The management body is in charge of continuing maintenance and post-completion monitoring; adjustment entails post-implementation maintenance. Surveillance and communication should be continuously compared to a suitable reference model. (Gann and others, 2019).

Ecological Corridors and Landscape Connectivity

Maintaining connectivity between ecosystems is just as essential for preserving ecological networks as restoring individual habitats is for biodiversity conservation. The ability of organisms to freely migrate between habitat patches within a landscape is referred to as landscape connectivity (Dilworth *et al.* 2000; McDonald 2004). Long-term population survival depends on species' ability to spread, migrate, and preserve genetic variety. These natural migration patterns are frequently disrupted by habitat fragmentation brought on by roads, urban development, and agricultural expansion (Debinski and Holt 2000; Hobbs 2002), isolating populations and raising the danger of extinction (Devoto *et al.* 2012). In order to overcome habitat fragmentation, ecological corridors are frequently employed as a conservation approach. These corridors are safeguarded routes that link remote habitats and make it easier for wildlife to travel between ecosystems. Forest strips, river systems, grassland belts, and other natural landscapes that permit animals to move across fragmented ecosystems safely can all be considered corridors (Wender *et al.* 2004).

Ecological corridors boost biodiversity stability and ecosystem resilience by encouraging species dispersal and genetic exchange. By preserving ecological interactions, landscape connectivity also enhances ecosystem functioning. Predator-prey relationships, pollination networks, and seed dispersal methods frequently rely on a species' capacity to migrate across different types of environments. These relationships can be reinforced and reestablished when ecological corridors are created.

Consequently, ecological networks become more resilient and able to adjust to environmental shifts, such as variations in the climate (Montoya *et al.* 2012). One of the main concerns of contemporary conservation research is the incorporation of connectivity planning into habitat restoration initiatives. In order to determine priority sites for corridor development, conservation planners are increasingly using landscape modeling and spatial analysis methods. It is possible to reconstruct biological networks at the regional and landscape levels by combining habitat restoration with connectivity conservation.

Technological Tools for Restoring Habitats

Technology has made it much easier to design, carry out, and monitor habitat restoration project. In order to evaluate restoration results and assess ecosystem conditions, modern conservation research is depending more and more on digital technologies and data-driven methodologies. For instance, researchers may monitor vast landscapes and identify changes in vegetation cover, land use patterns, and ecosystem health using remote sensing technology. Prioritizing restoration locations and identifying degraded habitats are made easier with the help of satellite photography and aerial surveys.

Geographic Information Systems (GIS) are essential for the analysis of spatial data pertaining to habitat connectivity and biodiversity. Researchers can assess landscape fragmentation, map species distributions, and create ecological corridors that facilitate wildlife migration using GIS techniques. Predicting how ecosystems will react to restoration initiatives is another

growing application of ecological modeling and simulation approaches. These models can direct decision-making processes by identifying possible results of various restoration techniques. (Liquete *et al.* 2015).

Predictive models, for instance, can calculate the potential effects of restored habitats on species populations, ecosystem services, and climate resilience. Restoration evaluation efforts are being further enhanced by biodiversity monitoring technologies like environmental DNA (eDNA) analysis, video traps, and sound sensors. In restored ecosystems, these instruments enable researchers to monitor species presence, behavior, and population trends. Continuous monitoring offers input for bettering management techniques and assists in determining whether restoration goals are being accomplished. Technological advancements will become more important in assisting evidence-based habitat restoration initiatives as they develop.

Monitoring and Evaluation

To ensure that restoration programs are carried out appropriately and are yielding the desired results, monitoring and assessment are crucial (Senapathi *et al.* 2015; FAO, 2016). Additionally, it guarantees the effective and efficient utilization of program and project resources. In order to assist practitioners in identifying appropriate indicators of restoration success, the Society for Ecological Restoration Primer lists nine essential characteristics of successful restoration: (1) similar diversity and community structure when compared to the reference ecosystems; (2) presence of indigenous species; (3) presence of functional groups that can allow long-term stability; (4) suitable physical environment to sustain the biological component's ability to reproduce; (5) normal functionality; (6) integration with its surrounding landscape; (7) absence or significantly reduced threats to its integrity and health; (8) adequate resilience; and (9) self-sustainability (Society for Ecological Restoration International Science and Policy Working Group 2004).

Challenges in Habitat Restoration

The efficiency of restoration efforts is constrained by a number of limitations, despite the fact that habitat restoration is increasingly acknowledged as a crucial conservation tactic. The complex structure of ecological systems and the ambiguity surrounding ecosystem recovery processes are two of the main concerns, numerous environmental factors, such as soil properties, species interactions, climate, and human activity, have an impact on ecosystems. Because of this, it can be challenging to forecast restoration results, especially in severely damaged areas (Egan and Howell, 2001).

Another major obstacle to large-scale restoration initiatives is financial limitations. The design, execution, monitoring, and long-term upkeep of habitat restoration frequently necessitate large financial outlays. Conflicts over land usage also provide difficulties for habitat restoration initiatives. Careful planning and stakeholder interaction are necessary to strike a balance between conservation goals and economic development goals (Lake, 2007). Habitat restoration is made more difficult by climate change (Burkle *et al.* 2013). Because environmental circumstances are constantly changing, restoration techniques based on past ecosystem conditions would not always be appropriate for future climate scenarios (Bijlsma *et al.* 2019). Therefore, adaptive management strategies that take climate unpredictability into account and provide flexible adjustments over time must be incorporated into restoration initiatives.

Prospects for Future Habitat Restoration

The creation of extensive ecological restoration programs that concentrate on rehabilitating entire landscapes rather than individual ecosystems is a possible option. In the future, it will be necessary to integrate restoration initiatives with ecological connectedness, ecosystem resilience, and regional biodiversity conservation goals with sustainable land management practices (Smallwood 2001). The future of habitat restoration will also be shaped by the increasing utilization of multidisciplinary research and cooperative partnerships. To create all-encompassing restoration plans, scientists from disciplines including ecology, environmental economics, sociology, and climate science must collaborate.

Effective restoration efforts will require cooperation between governments, academic institutions, conservation groups, and local populations.

Global environmental programs that support ecosystem restoration are becoming more well-known as instruments to combat climate change and biodiversity loss (Smallwood 2001). These programs encourage nations to fund restoration projects that promote environmental resilience and sustainable development. Governments can improve ecosystem sustainability and biodiversity protection by coordinating restoration initiatives with national environmental policy and global conservation objectives.

Recommendations for Habitat Restoration

To enhance habitat restoration, the following suggestions are offered:

- In the early phases of restoration planning, contact native plant nurseries and suppliers to make sure the right plant species are available in the expected amounts for planting.
- Ensure an adequate water supply for maximum efficiency
- To address anticipated climate changes and limited water supply, use native drought-tolerant woody and herbaceous species in restoration plantings.
- Preserve and maintain native vegetation strands that could be vital sanctuaries in places affected by non-native species.

CONCLUSION

In order to combat biodiversity loss and reconstruct ecological networks in degraded ecosystems, habitat restoration has emerged an essential strategy. By reestablishing species populations, restoring ecological processes that promote environmental sustainability, and recovering ecosystem structure, restoration projects seek to reverse these trends. Rebuilding ecological networks and promoting species migration depend heavily on the creation of ecological corridors, landscape connectivity projects, native species planting, and monitoring.

By encouraging sustainable management practices and enhancing monitoring capabilities, technology advancements and community involvement further increase the efficacy of restoration efforts. Overcoming obstacles calls for integrated initiatives that incorporate community involvement, policy backing, scientific research, and adaptive management techniques. Restoring degraded ecosystems and safeguarding biodiversity for future generations is made possible through the process of habitat restoration.

REFERENCES

Bateman, H. L., Paxton, E.H., Longman, W.S.2013, Tamarix as Wildlife Habitat. Chapter 10, pages 168-188

Battisti, C. (2003). Habitat fragmentation, fauna and ecological network planning: Toward a theoretical conceptual framework. *Italian Journal of Zoology,* 70(3), 241 247.

Bijlsma, R.J., Agrillo, E., Attorre, F., Boitani, L., Brunner, A., Evans, P., Foppen, R., Gubbay, S., Janssen, J.A.M., Kleunen, A. van, Langhout, W., Noordhuis, R., Pacifici, M., Ramirez, I., Rondinini, C., Roomen, M. van, Siepel, H., Winter, H.V. (2019). Defining and applying the concept of Favourable Reference Values for species and habitats under the EU Birds and Habitats Directives: technical report. Service contract No. 07.0202/2015/715107/SER/ENV.B.3 financed by the European Commission. Wageningen: Wageningen Environmental Research, (Wageningen Environmental Research report 2928) edepot.wur.nl/469035

Block, W. M., Franklin, A. B., Ward, J. P., Ganey, J. L. and G. C. White J. L. (2001). Design and implementation of monitoring studies to evaluate the success of ecological restoration on wildlife. *Restoration Ecology* 9:293–303.

Boitani, L., Falcucci, A., Maiorano, L., and Rondinini, C. (2007). Ecological networks as conceptual frameworks or operational tools in conservation. *Conservation biology*, 21(6), 1414-1422.

Burkle L, Marlin, J. and Knight T. (2013). Plant-pollinator interactions over 120 years: Loss of species, co-occurrence, and function. *Science* 339(6127): 1611–1615.

Clewell, A. and Aronson, J. (2007). Ecological restoration: principles, values and structure of an emerging profession. Island Press (eds.), Washington D.C.

Dale, V. H., Brown, S., Haeuber, R. A., Hobbs, N. T., Huntly, N., Naiman, R. J., Riebsame, W. E., Turner, M. G. and Valone, T. J. (2000). Ecological principles and guidelines for managing the use of land. *Ecological Applications* 10:639–670.

Davis, M. A. and Slobodkin, L. B. (2004). The science and values of resto ration ecology. *Restoration Ecology* 12:1–3.

Davis M.A. and Slobodkin L.B., (2003). The science and values of restoration ecology. *Restoration Ecology* 11: 1-3.

Derak, M., Cortina, J., Taiqui, L. and Aledo, A. (2017). A proposed framework for participatory forest restoration in semiarid areas of North Africa. *Restoration Ecology* S1: S18-S25; doi: 10.1111/rec.12486.

Devoto, M., Bailey, S., Craze, P., and Memmott, J. (2012). Understanding and planning ecological restoration of plant–pollinator networks. *Ecology letters*, 15(4), 319-328.

Dilworth, R., Gowdie, T. and Rowley, T. (2000). Living landscapes: the future landscapes of the Western Australian wheatbelt? *Ecological Management and Restoration* 1:165–174.

EU (2011). Our life insurance, our natural capital: an EU biodiversity strategy to 2020. Com(2011)244, European Commission.

Evans, D. M., Pocock, M. J., and Memmott, J. (2013). The robustness of a network of ecological networks to habitat loss. *Ecology letters*, 16(7), 844-852.

FAO. 2016. Policy Analysis Paper: Mainstreaming of Biodiversity and Ecosystem Services With A Focus On Pollination. http://www.fao.org/3/a-i4242e.pdf

Gallard, J. and Koné P., (1994). Appui au programme de développement de la

foresterie rurale au Sénégal. Manuel de formation. Rome, 50 p.

Gann, G.D., McDonald, T., Walder, B., Aronson, J., Nelson, C.R., Jonson, J., Hallett, J.G., Eisenberg, C., Guariguata, M.R., Liu, J., Hua, F., Echeveria, C., Gonzales, E., Shaw, N., Decleer, K. and Dixon, K.W. (2019). International principles and standards for the practice of ecological restoration. Second edition. *Ecological Restoration* 27(S1): S1–S46. www.ser.org/page/ SERStandards

Groves, C. R., Jensen, D. B., Valutis, L. L., Redford, K. H., Shaffer, M. L., Scott, J. M., Baumgartner, J. V., Higgins, J. V. Beck, M. W. and Anderson, M. G. (2002). Planning for biodiversity conservation: putting conservation science into practice. *Bioscience* 52:499–512.

Hobbs, R. J. (2004). Restoration ecology: the challenge of social values and expectations. *Frontiers in Ecology and the Environment* 2:43–44.

Hobbs, R. J. (2007). Setting effective and realistic restoration goals: key directions for research. *Restoration Ecology* 15:354–357.

Johnson, M., Magill, R., and Riper, C. (2010). Yellow-billed cuckoo distribution and habitat associations in Arizona, 1998-1999. The Colorado Plateau IV; Integrating Research and Resources Management for Effective Conservation. Uniersity of Arizona Press, Tucson.

Lake, P. S. (2013). Resistance, Resilience and Restoration. *Ecological Management and Restoration*, 14: 20–24. doi:10.1111/emr.12016

Lake, P. S., Bond, N., and Reich, P. (2007). Linking ecological theory with stream restoration. *Freshwater biology*, 52(4), 597-615.

Lambeck, R. J., and Hobbs, R. J. (2002). Landscape and regional planning for conservation: issues and practicalities. Pages 360–380 in K. Gutzwiller, editor. Concepts and applications of landscape ecology in biological conservation. Springer Verlag, New York.

Light, A., (2000). Contemporary Environmental Ethics From Metaethics to Public Philosophy. *Metaphilosophy* 33(4): 426-449.

Liquete, C., Kleeschulte, S., Dige, G., Maes, J., Grizzetti, B., Olah, B., and Zulian, G. (2015). Mapping green infrastructure based on ecosystem services and ecological networks: A Pan European case study. Environmental Science and Policy, 54, 268 280.

McDonald, T, Gann, G. D., Jonson, J. and Dixon, K. W. (2016). International standards for the practice of ecological restoration – including principles and key concepts. Society for Ecological Restoration, Washington, D.C. pp. 47.

McDonald, T. 2004. The Wilderness Society's Wild Country program. *Ecological Management and Restoration* 5:87–97.

Mitchell, S. C. (2005). How useful is the concept of habitat? a critique. *Oikos* 110:634–638.

Nagler, P. L., Glenn, E. P., Jamevich, C. S., and Shafroth, P. B. (2011). Distribution and abundance of saltcedar and Russian olive in the Western United States, *Critical*

Reviews in Plant Sciences 30:508-523

Paxton, E. H., Thiermer, T. C., and Sogge M. K. (2011). Tamrisk biocontrol using tamarisk betles: potential consequences for riparian birds in the South-western United States. *The Condor* 113: 255-265

Pocock, M. J., Evans, D. M., and Memmott, J. (2012). The robustness and restoration of a network of ecological networks. *Science,* 335(6071), 973-977.

Potter, A. E. (2016). Periodic status review for Taylor's Checkerspot in Washington. Washington Department of Fish and Wildlife, Olympia, Washington. 16 iii pp.

Roni, P., Beechie, T., Pess, G and Hanson, K. (2014). Wood placement in river restoration: fact, fiction, and future direction. *Canadian Journal of Fisheries and Aquatic Sciences*, 2015, 72(3): 466-478, https://doi.org/10.1139/cjfas-2014-0344.

Rundel, P.W., (1998). Landscape Disturbance in Mediterranean-Type Ecosystems: an Overview. In: P.W. Rundel, G. Montenegro, and F.M. Jaksic (eds), Landscape Disturbance and Biodiversity in Mediterranean-Type Ecosystems. Springer Berlin Heidelberg. Berlin, Heidelberg, pp. 3-22.

Scott, T. A., Wehtje, W. and Wehtje, M. (2001). The need for strategic planning in passive restoration of wildlife populations. Restoration Ecology 9:262–271.

Senapathi, D., Biesmeijer, J. C., Breeze, T. D., Kleijn, D., Potts, S. G. and Carvalheiro, L. G. (2015). Pollinator conservation — the difference between managing for pollination services and preserving pollinator diversity. *Current Opinion in Insect Science*, 12, 93–101.

The SER International primer on ecological restoration. Society for Ecological Restoration International, Tuscon, Arizona

Shafroth, P. B., Cleverly, J. R., Dudley, T. L., Taylor, J. P., Riper, C. V., Weeks, E, P., and Stuart, J. N., (2005). Control of Tamris in the western United States: implication for water salvage, wildlife use, and riparian restoration. *Environmental Management* 35:231-246

Smallwood, K. S. (2001). Linking habitat restoration to meaningful units of animal demography. *Restoration Ecology* 9:253–261. UNCCD- The United Nations Convention to Combat Desertification. (2009). Ninth session of the conference of the parties (COP 9). 21 September-2 October 2009.

Van Driesche, J., and Van. Driesche, R. (2000). Nature out of place. Island Press, Washington, D.C.

Van Zadelhoff, F. J. (1981). Nederlandse Kustduinen. Geobotanie (Dutch coastal dunes. Geobotany, in Dutch with English Summary). Pudoc, Wageningen

Wender, B, Harrington, C. and Tappeiner, J.C. (2004). Flower and Fruit Production of Understory Shrubs in Western Washington and Oregon. Northwest Science, Vol. 78, No. 2. p. 124-140.

Wily L.A., 2002. Gestion forestière participative en Afrique: un aperçu des progrès et des pro blèmes. Second

international workshop on par ticipatory forestry in Africa: Defining the way forward: sustainable livelihoods and sustainable forest management through participatory forestry. 18-22 February 2002 Arusha, United Republic of Tanzania, pp. 331-339.

RELEVANCE OF TROPICAL WETLANDS TO AGRICULTURE AND ITS CHALLENGES: A REVIEW

Abdullahi Kamal[1] and Umar Aminu Mohammed[1]
[1]Department of Biological Sciences, Sa'adu Zungur University, Bauchi State.
*Corresponding Author's Email: Kamalabdullahi@basug.edu.ng

ABSTRACT

Wetlands are distinct ecosystems characterized by the presence of water, either permanently or seasonally, which influences the soil and supports unique vegetation. The Ramsar Convention categorizes wetlands into marine and coastal wetlands (e.g., mangroves, coral reefs), inland wetlands (e.g., rivers, peat lands, lakes), and artificial wetlands (e.g., reservoirs, irrigation canals). Wetlands provide numerous ecological services, including: Flood Control, Groundwater Replenishment, Storm Protection, Nutrient Retention, Sediment and Heavy Metal Traps. Wetlands are under severe pressure from human activities, with 87% of known inland wetlands lost, especially in tropical regions. Major threats include: Anthropogenic Activities, Agricultural Expansion, Climate Change, and Biodiversity Loss. To protect wetlands, sustainable management strategies include: Constructed Wetlands, balancing Conservation and Human Needs, Policy and Awareness Initiatives, Scientific Research and Monitoring. Wetlands are critical ecosystems that provide essential services for both nature and human societies. However, they face increasing threats from human activities and climate change. Effective conservation strategies, informed policies, and sustainable practices are necessary to safeguard these ecosystems for future generations. Some of the challenges facing tropical wetlands includes: Wetland Degradation and Habitat Loss, Climate Change and Rising Sea Levels, Pollution and Eutrophication, Overexploitation of Wetland Resources, Invasive Species Encroachment, and Water Diversion and Hydrological Changes, while solution to those challenges can be through: Policy and Legal Frameworks, Community Based Wetland Management, Education and Awareness Campaigns and Restoration and Rehabilitation Programs. In conclusion, wetlands are indispensable for agriculture, providing critical ecosystem services that sustain food production and rural livelihoods.

Keywords: Tropical Wetlands, Wetland Management, Agriculture, Environmental Challenges, Irrigation Agriculture.

INTRODUCTION

Wetlands have been defined by a lot of ecologist, environment biologist and hydro-biologist but the mostly conventional definition is that of Ramsar Convention, signed in 1970, described wetlands are areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or "owing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters (Nyman, 2011; Husnain *et al.,* 2022). Similarly, A wetland is a distinct ecosystem that is inundated by water, either permanently or seasonally, where oxygen-free processes prevail (Keddy, 2010; Fagorite *et al.,* 2019). The primary factor that distinguishes wetlands from other land forms or water bodies is the characteristic vegetation of aquatic plants, adapted to the unique hydric soil (Butler, 2010). More so, Wetland is generally defined as areas that are strongly influenced by the water regime, tidal movements of rivers or seas, inundation due to rainfall or shipping "flooding, "at to basin topography, poor drainage, waterlogged, and problem soils such as acid sulfate soil, saline

soil, and peat soil. Wetland is a unique ecosystem which highly dependent on surface water existence (Husnain *et al.,* 2022).

Another definition that is also widely accepted is that of (Allaby, 2010) who define wetlands as any open water habitats and periodic or permanently waterlogged land areas, as well as lakes, rivers, and estuarine and freshwater marshes. Habitats found in the wetland, notably bog areas and marsh, are susceptible to destruction because the water could be drained and reclaimed for irrigation or production of woody trees, in some cases it could also be drained for pest control, such as eliminating breeding grounds for malaria-carrying mosquitoes, or modified for water supply, flood control, hydroelectric power schemes and waste disposal (Bridgewater, 2008).

Scientist from various discipline are engaged in studying the uniqueness of wetlands due to the global attention it is presently receiving. For instance Ramsar Convention on Wetlands, adopted in 1971 and as of December 2002 has 1230 wetland sites located in six regions which are North America, Europe, Africa, Asia, Neotropics (an ecozone covering the Caribbean, Central America and South America), and Oceania are acknowledged as wetlands of international significance (John, 2002). Though, many more wetlands are likely to be recognise and documented because many countries have just started identifying wetlands (Hettiarachchi, Morrison, and McAlpine, 2015).

The purposeful value of wetlands rest on their size and location within the landscape, as well as their interaction to neighboring water areas (Mitsch and Gossilink, 2000). Wetlands are usually natural or artificial in some cases it could be a mixture of the two. Scientist generally agreed that the existence of wetlands is as a result of precise hydrology, soil type, and vegetation and animal communities, and that their purpose rely on the context of their virtual placement in the ecosystem (Campbell, Cole, and Brooks, 2002).

A small number of attempts have been made to calculate the economic value of the goods and services offered by wetlands. Even though the precision and exactness of these efforts may be arguable, they have merit because it emphasize and draw attention to the massive economic significance (Bergstrom, Stoll, Titre, and Wright, 1990). Preceding estimates include: between US$8,977 and US$17,000 (1983) for the goods and services offered by each acre of Louisiana wetlands (Costanza, Farber, and Maxwell, 1989), and between US$19 million and US$70 million per year for a 45±mile stretch of the Platte River, Colorado (de Groot *et al.,* 2012). Presence and functioning of wetlands in developing countries can be critical for agricultural and extractive economies (Heimlich, Wiebe, Claassen, Gadsby, and Robert, 1998).

Ramsar wetland classification

The Convention on Wetlands (http://www.ramsar.org) is "the intergovernmental treaty that provides the framework for the conservation and wise use of wetlands and their resources." Also known as the Ramsar Convention, this collection of contracting parties has done much for the international recognition of wetland importance and protection. The mission of the International Convention on Wetlands is for "the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world." Under the Ramsar Convention, a classification system for wetland types was developed, providing a broad framework for wetland

identification and management (Wasserman and Dalu, 2022).

Based on that wetland is divided into three main groups, these are:

i. **Marine and coastal wetlands**: These comprise the coral reefs, tidal flats, estuaries, mangrove forests, open coasts and coastal lagoons.
ii. **Inland wetlands:** These consist of seasonal and permanent rivers, permanent and seasonal lakes and ponds, inland deltas and floodplains, marshes, peat lands and freshwater swamp forests.
iii. **Artificial wetlands:** These are reservoirs, barrages and dams, aquaculture ponds, wastewater treatment ponds and irrigation canals, ditches and rice fields, excavations and borrow pits (Johnston *et al.,* 2008; Wasserman and Dalu, 2022).

Significance of wetlands

Wetlands offered significances to plants, animals as well as the humans. Some of the significances include the followings as described by fagorite *et al.,* (2019);

i. Storage reservoirs and flood protection

According to Ramsar, (2011), the floodplains of major rivers act as natural storage reservoirs, enabling excess water to spread out over a wide area, which reduces its depth and speed. Wetlands close to the headwaters of streams and rivers can slow down rainwater runoff and spring snowmelt so that it doesn't run straight off the land into water courses. This can help prevent sudden, damaging floods downstream (Ramsar, 2011). Notable river systems that produce large spans of floodplain include the Nile River, the Niger river inland delta, (the Zambezi River flood plain), (the Okavango River inland delta), (the Kafue River flood plain)(the Lake Bangweulu flood plain] (Africa), Mississippi River (USA), Amazon River (South America), Yangtze River (China), Danube River (Central Europe) and Murray-Darling River (Australia) (Fagorite *et al.,* 2019).

ii. Groundwater replenishment

The surface water which is the water visibly seen in wetland systems only represents a portion of the overall water cycle which also includes atmospheric water and groundwater. Wetland systems are directly linked to groundwater and a crucial regulator of both the quantity and quality of water found below the ground (Fagorite *et al.,* 2019). Wetland systems that are made of permeable sediments like limestone occur in areas with highly variable and fluctuating water tables especially have a role in groundwater replenishment or water recharge. Sediments that are porous allow water to filter down through the soil and overlying rock into aquifers which are the source of 95% of the world's drinking water. Wetlands can also act as recharge areas when the surrounding water table is low and as a discharge zone when it is too high. (Fagorite *et al.,* 2019). Karst (cave) systems are a unique example of this system and are a connection of underground rivers influenced by rain and other forms of precipitation. These wetland systems are capable of regulating changes in the water table on upwards of 130 m (430 ft) (Fagorite *et al.,* 2019).

iii. Shoreline stabilization and storm protection

The Wetland types used are mangroves, coral reefs, salt marsh. Tidal and inter-tidal wetland systems protect and stabilize coastal zones. Coral reefs provide a protective barrier to coastal shoreline. Mangroves stabilize the coastal zone from the interior and will migrate with the shoreline to remain adjacent to the boundary of the water. The main conservation benefit these systems have against storms and storm surges is the ability to reduce the speed and height of waves and floodwaters (Fagorite *et al.,* 2019).

iv. Nutrient retention

Wetlands cycle both sediments and nutrients balancing terrestrial and aquatic ecosystems. A natural function of wetland vegetation is the up-take, storage, and (for nitrate) the removal of nutrients found in runoff from the surrounding soil and water (UNEP, 2011). In many wetlands, nutrients are retained until plants die or are harvested by animals or humans and taken to another location, or until microbial processes convert soluble nutrients to a gas as is the case with nitrate (Fagorite *et al.,* 2019).

v. Sediment and heavy metal traps

Precipitation and surface runoff induces soil erosion, transporting sediment in suspension into and through waterways. These sediments move towards larger and more sizable waterways through a natural process that moves water towards oceans. All types of sediments which may be composed of clay, sand, silt, and rock can be carried into wetland systems through this process. Wetland vegetation acts as a physical barrier to slow water flow and trap sediment for short or long periods of time. Suspended sediment often contains heavy metals that are retained when wetlands trap the sediment. In some cases, certain metals are taken up through wetland plant stems, roots, and leaves (Fagorite *et al.,* 2019).

Distribution of wetlands

There are more than 12.1 million km2 of projected wetland area on the planet, with 54 percent constantly flooded and 46 percent flooded seasonally. The Ramsar List of Wetlands of International Importance, which includes protected areas (2,300 sites), covers 13-18% of the world's wetland area (UNCC, 2018). The Pantanal, which covers more than 42 million acres and is located in South America, is the world's largest wetland. Renuka Lake in India (49.42 acres) is the world's smallest wetland (Vasmathi *et al.,* 2023). Furthermore, the estimated wetland area on earth is between 7 to 9 million km^2 which is 4±6 percent of the Earth land surface (Mitsch and Gosselink 2000). As reported by Giri *et al.,* (2010) worldwide distribution of mangroves, Asia recorded 41% as the highest, followed by Africa which recorded 21% then North and Central America which recorded 15%, Oceania and Australia recorded 12%, while South America recorded the least which is 11%. Although wetlands cover only about 0.25% of the land surface of the Earth's, 3% of the global stocks of soil carbon and a 20% of peat carbon are found in tropical peat lands (Page *et al.,* 2004; Page and Banks, 2007). More than 20 Mha peat lands are located in Indonesia (WI 2003, 2004, 2006), and the estimated carbon stocks is approximately 55 petagrammes carbon (Jaenicke *et al.,* 2008). A lot of islands are located in Indonesia which amount to 17000 which makes Indonesia the home for the quarter of world's mangroves. In the last three decades more than half of these coastal forests were lost, reducing the size from 4.2 Mha in 1982 to 2 Mha in 2000 (Giri *et al.,* 2010).

Wetland threats

Wetlands are dynamic and often complex ecosystems which provide a variety of beneficial services to humans and yet remain ecologically sensitive (Turner *et al.,* 2000;

Wasserman and Dalu, 2022). Regardless of their sensitivity, wetlands are exploited and overexploitation has consequently led to degradation and loss of these ecosystems (Skowno *et al.,* 2019; Sievers *et al.,* 2018). Most wetlands are under threat primarily from a variety of human activities (Gren *et al.,* 1994; Dalu *et al.,* 2017). The remaining natural wetlands cover only a fraction of their original area and have been progressively declining around the world through drainage, road construction, agriculture, grazing, mining, de-vegetation, damming flow, dumping, dredging, and urban development, among others (Wasserman and Dalu, 2022). Presently, these activities are particularly pervasive in the tropical areas, given economic development dynamics in these often low- and middle-income regions. Globally, approximately 87% of known inland wetland systems have been lost, with rates of loss having been greatest during the late 20th century (Joosten, 2010; Davidson, 2014). Major declines have also been observed in forested and tropical peatlands during this time (Joosten, 2010; Davidson, 2014). Artificial wetlands (i.e., artificial reservoirs' and rice paddies) have increased since the 1970s, but this is mostly due to conversion of natural wetlands (Davidson *et al.,* 2018) and these homogenized environments are typically less biodiversity. For example, wetland conversion to rice paddy fields is among the leading causes of current wetland loss in Asia, estimated at about 5000 km2 per year (Gopal, 2013). The mounting pressures on wetlands in tropical regions of the world and the small fraction of protected wetlands call for urgent action. Many populations of wetland dependent species are exhibiting long-term declines and are threatened with extinction based on recent assessments. The International Union for Conservation of Nature (IUCN) Red List highlighted that of the over 19,500 wetland dependent species globally, approximately 25% are threatened with extinction and about 25% and 6% of inland wetland dependent species are globally threatened and critically endangered, respectively, from over 18,000 taxa assessed (Collen *et al.,* 2014; Ramsar Convention on Wetlands, 2018; Wasserman and Dalu, 2022). At a finer spatial scale, global threat levels of wetland dependent species vary greatly across different regions. Globally threatened freshwater taxa percentages vary between 20% and 37% across different biogeographic realms (i.e., areas with a broadly similar evolutionary history) (Collen *et al.,* 2014), with the highest threats being recorded in the tropics (Wasserman and Dalu, 2022).

Effect of Anthropogenic activities on wetlands

Wetlands are among the world's hotspots for biological diversity (MEA (Millennium Ecosystem Assessment), 2005; Eneyew and Assefa, 2021). They support a high concentration of birds, mammals, reptiles, amphibians, fish and invertebrate species (Eneyew and Assefa, 2021). They are also an important storehouse for genetic sources. Despite providing habitats for aquatic life, wetlands are severely threatened ecosystems on our planet (MEA, 2005). More than 33% of global wetlands had been lost in the first two decades of 21st (Hu *et al.,* 2017; Eneyew and Assefa, 2021). Anthropogenic activities influence wetland function and health. These activities could potentially result in wetland loss, where wetland areas are converted into non-wetland areas (i.e. there is a loss of function), or wetland degradation, where wetland function becomes impaired due to human activities (Maltby and Acreman, 2011; Mitchell, 2013; Melly, 2016).

Many wetlands have been drained or dredged for housing developments and agriculture, or even to prevent mosquitos breeding (Barbier *et al.,* 1997; Maltby and Acreman 2011; Melly, 2016). Overgrazing or removal of

vegetation as well as paved surfaces in urban areas increase surface run-off and lower the water table level (Arnold and Gibbons, 1996; Mitchell, 2013). Alien vegetation and groundwater extraction can also place a strain on the water resources (Millennium Ecosystem Assessment 2005, Junk *et al.,* 2013). Pollution of ground and surface waters from urban or rural developments can severely impact the quality of water entering wetlands (Turner *et al.,* 2000, Junk *et al.,* 2013; Melly, 2016), which in turn could affect the overall health of the wetland ecosystem.

Unsustainable harvesting of wetland resources (for example, plants and other aquatic organims) can also negatively impact wetland ecosystems (Barbier *et al.,* 1997, Millennium Ecosystem Assessment 2005). Tourism and recreational activities can also have an effect on wetlands (Melly, 2016). On larger systems, power boating, off-road vehicles, fishing, hunting and abstraction of water can place a strain on wetland resources (Burger *et al.,* 1995, Millennium Ecosystem Assessment 2005). On smaller systems, even small amounts of human activity can result in significant disturbances to the surrounding vegetation or fauna in the wetland (Meyer *et al.,* 2003; Melly, 2016).

Moreover, wetland degradation or a change in wetland function can be associated with increased nutrient inputs (particularly phosphorus and nitrogen) into a system from agricultural, industrial or sewage sources (Rossouw *et al.,* 2005; Corry, 2012; Melly, 2016). This nutrient-enrichment leads to increased algal growth and reed growth, which consequently reduces the amount of available oxygen in the water column, and leads to changes in the wetland community structure (Rossouw *et al.,* 2005; Corry, 2012).

Another possible cause of human-induced wetland degradation is a lack of knowledge on how these complex systems function (Turner *et al.,* 2000; Schuyt 2005; Melly, 2016). This effect is compounded in smaller, more ephemeral systems which are less 'obvious' to untrained people and are consequently seen as less important (Meyer *et al.,* 2003, Blackwell and Pilgrim, 2011). As a result, they tend to be encroached on or affected before their existence is known or the impact of a particular activity is understood (Semlitsch 2000; Meyer *et al.,* 2003). Consequently, this often results in the failure to predict or manage regional anthropogenic activities on the surrounding wetlands because of the lack of information on the complex spatial relationships between the ground and surface water, surrounding land use and wetland vegetation (Turner *et al.,* 2000; Schuyt, 2005; Melly, 2016).

Recently, various empirical studies have been conducted to investigate the reasons why wetlands have vanished and their biodiversity have lost. The findings of several studies indicated that biological invasion, hydrological disconnection of water sources, urban expansion, climate change, sedimentation, excessive exploitation of biological resources, agricultural intensifications, water extraction and construction of roads and dams are the factors for the loss of wetland biodiversity (Assefa *et al.,* 2021; Gatti, 2016; He *et al.,* 2015; Kuiper *et al.,* 2014; Laurance *et al.,* 2012; Mitchell, 2013; Rebelo *et al.,* 2011; Seki *et al.,* 2018; Wu *et al.,* 2019; Xie *et al.,* 2010). Furthermore, the analysis of wetland biodiversity revealed the loss of floristic plants, macrophytes and macroinvertebrates.

As reported by Wood and van Halsema, (2008), the factors that contributed to the degradation of the study wetland biodiversity are diverse. Eneyew and Assefa, (2021), however, reported that extraction of wetland water for a city water supply and plant irrigation, farmland expansion, eucalyptus tree plantation, overgrazing and, unregulated and overuse of Cyprus papyrus were found to be the major anthropogenic activities that resulted in the degradation of biodiversity in the wetland area studied. As mentioned previously, functioning wetlands provide a wide array of ecosystem services. Therefore, wetland resources need to be sustainably used to ensure that future generations will have access to the goods and services supplied the wetlands before there is an irreversible impact on wetland function (van der Duim and Henkens, 2007; Melly, 2016). An important component of sustainable use is understanding the spatial and temporal scales of the anthropogenic (and ecological) stressors on a system which should be part of a spatially applicable decision-making processes (Danz *et al.,* 2007, Minaya *et al.,* 2013).

Impact of agricultural activities on wetland ecosystems

Convection on Wetlands, (2022) revealed that agricultural practices and systems interact with wetlands in many ways. At catchment and river-basin scales agriculture can have delayed interactions with wetlands through system-wide changes in water use, sediment movement, changes in biota and increased pollutants, leading to an overall degradation at landscape scale. Impacts also occur at the wetland-scale, directly by land conversion, water extraction, drainage, nutrient inputs, erosion, soil degradation and harvest of biota. All these interactions can lead to changes in the ecological character of a wetland and the possible permanent loss of its benefits to people, emphasizing the need for sustainable agriculture (Wood and van Halsema, 2008; Ramsar Convection on Wetlands, 2021). Some of the impact of agricultural activities on wetland regions as described by Convection on Wetlands, (2022) includes;

i. Land conversion

During the 20th century, the use of the earth's land surface by humans has expanded dramatically. The proportion of natural land decreased from 70.1 to 46.5%. At the same time, crop and grazing lands increased from 27.2 to 46.5% of total land area (UNCCD, 2017). The current global extent of wetlands is estimated at between 1.5-1.6 billion ha (Davidson and Finlayson, 2018).

Due to land conversion, the extent of natural wetlands declined by 35% between 1970-2015, where data exist, while human-made wetlands, including rice paddy fields and reservoirs, increased by +233% (Darrah *et al.,* 2019). The rate of decline of natural wetlands during the same period (-0.78% per year) was more than three times higher than natural forests (-0.24% per year), and by 2015, global rates of wetland loss increased to -1.6% (Darrah *et al.,* 2019). The proportion of wetland loss attributable to agriculture has not been calculated globally. However, various studies indicate that agricultural development is often the primary cause of wetland loss (Mao *et al.,* 2018; Patino and Estupinan-Suarez, 2016; Robertson *et al.,* 2019).

Wetland conversion for agriculture also causes greenhouse gas emissions and climate change (Ramsar Convection on Wetlands, 2021). Globally, wetlands form only about 5-8% of the land surface but hold about 30% of the total soil carbon store, with peat wetlands and coastal wetlands being particularly important for carbon storage (UNCCD, 2017; Moomaw *et al.,* 2018; Ramsar Convention on Wetlands, 2018). Drainage of wetlands for agricultural development causes soil oxidation and major greenhouse gas (GHG)

emissions, as well as lost capacity for continued carbon sequestration and storage (Moomaw *et al.,* 2018). This is particularly important for wetland types that store large amounts of carbon, such as peatlands and forested wetlands.

ii. Contaminants; Nutrients, Fertilizers and Pesticides

Water pollution is caused by excessive fertilizer use, application of pesticides, salinization from agricultural drainage water and contamination by animal manure and slurries (FAO/ IWMI, 2018; Convection on Wetlands, 2022). Fertilizer use increased steadily around the globe in the period 1960-1990, with the largest growth rates in consumption In Asia, Latin America and Africa (Convection on Wetlands, 2022). After 1990 this growth has slowed down, especially in Europe and North America. In the developing countries the growth continued but at a slower rate. Total use (consumption) of fertilizer is now about 109 and 41 million tonnes of N and P, respectively, with Asia consuming roughly half of that. Fertilizer use in the other regions is much lower.

High use of fertilizer within or near wetlands increases surface water and groundwater inputs of nitrogen and phosphorus to wetland ecosystems resulting in nutrient enrichment that can have significant ecological effects, including eutrophication, increased productivity of invasive species, higher rates of nutrient leaching and shifts in species composition (Verhoeven *et al.,* 2006). The application rate of fertilizers (kg/ha) also increased, to a global average of 70 kg/ha of nitrogen and 26 kg/ha of phosphorus in 2018. There are large regional differences, with the highest application rates in eastern and southern Asia and northern and western Europe, and the lowest in western, central and eastern Africa and in central Asia (Ramsar Convection on Wetlands, 2021). In some regions, nutrient use efficiency has the potential to be improved through the adoption of agroecology/regenerative agriculture practices (FAO, 2018b; Lal, 2020) or other low input agricultural practices (Wu and Ma, 2015).

Pesticide accumulation in wetlands is of growing global concern as pesticide residues can pollute the aquatic environment through direct run-off and leaching and are often toxic to fish and other aquatic species (FAO/IWMI, 2018). Furthermore, pesticides contaminate food sources and can be toxic to people, presenting a significant threat to human health (FAO/IWMI, 2018). Total pesticide use increased in the period 1990-2012 from 2.3 to about 4.1 million tonnes. Since then, pesticide use stabilized. In most regions, half or more of total pesticide use consists of herbicides. Application rates of pesticides are highest (> 12 kg/ha per year) in eastern Asia and also high (4-5 kg/ha) in Western Europe and South America (Convection on Wetlands, 2022).

iii. Water Use, Drainage and Flow Diversion

Agriculture is responsible for around 70% of global freshwater withdrawals, and despite increasing competition in demand for water, agriculture withdrawals continue to increase (FAO, 2020). Agricultural water use in different regions ranges from 28 to 76 % of total water withdrawals depending on the level of economic development. In large areas of Asia, northern Africa, Australia, and the Americas, agriculture intensification disproportionality drives high water stress affecting people and wetlands (FAO, 2020). Land drainage and river flow diversion for agriculture also modify natural water flow paths with often negative impacts on wetland hydrology and functioning.

The total area of drained agricultural land in the world is over 200 million ha (Schultz *et al.,* 2005), and in many regions this supports

productive farmland, including in deltas of major rivers such as the Mekong and Ganges (Ramsar Convection on Wetlands, 2021). About 34% of farmland in Northwestern Europe and 17-30% in the USA is drained to remove excess water and prevent water logging (Gramlich *et al.,* 2018).

iv. Erosion and soil degradation

Sediment is supplied to wetlands from wind or water erosion through natural sediment transport processes, as well as from human-induced changes in land or water management, including agriculture (Convection on Wetlands, 2022). Land conversion and farm practices (e.g., tilling and harvesting) can lead to a significant increase in erosion and soil degradation. In arable and intensively grazed lands rates of soil erosion are 100 to 1,000 higher than natural erosion rates, and far higher than rates of soil formation (Montgomery, 2007; UNCCD, 2017). With high inputs and deposition of sediment to wetlands, nutrients and other chemical compounds are also transported, which can affect the ecological functioning of streams and rivers, floodplains, lakes and forested wetlands. Nutrient losses from soil degradation also lead to increased rates of fertilizer application at high economic and environmental costs (UNCCD, 2017).

Soil erosion by water induces annual fluxes of 23-42 Mt of nitrogen and 14.6-26.4 Mt of phosphorus from agricultural land, much of which contaminates freshwater ecosystems (FAO/ITPS, 2015).

v. Extraction of biota

Another major risk to wetlands is from over-harvesting or exploitation of biota (Millennium Ecosystem Assessment, 2005).The harvesting of vegetation and animals is a direct outcome of agriculture in wetland ecosystems. Extraction may occur as vegetation clearance, when wetlands are drained for pasture or other land uses, leading to loss of biodiversity (Convection on Wetlands, 2022). In wetland-based farming systems, extraction of biota is ongoing, as harvest of vegetation, fish or other biota from wetlands. This often provides fodder for livestock, but also for a range of other purposes including medicine, construction, handicrafts, furniture, and fuel (Convection on Wetlands, 2022).

vi. Wetland extent and biodiversity continues to decline

Wetlands are one of the world's ecosystems most in decline (Ramsar Convection on Wetlands, 2021).The extent of loss of wetlands and the decline of biodiversity is documented in the *Global Wetland Outlook* with much of this due to the impacts of the expansion and intensification of agriculture globally (Ramsar Convention on Wetlands, 2018). Since 1900 a loss of 64-71% of the wetland area has occurred (Davidson, 2014), and around 35% since 1970 (Darrah *et al.,* 2019).

vii. Water scarcity

Water scarcity is a global concern for wetlands and people (FAO, 2020) that are felt locally, but needs to be dealt with at catchment, national as well as international scales. In many regions of the world, river basins, which are critical to maintain groundwater levels and the overall water cycle, are under water stress due to agricultural withdrawals (Convection on Wetlands, 2022). As noted in the 2020 assessment on food and agriculture "almost one-sixth of the world's population lives in areas with very high severe drought frequency or very high water stress. Water requirements will only increase owing to population and economic growth, dietary changes and climate change*"* (FAO, 2020). This illustrates the tension between providing water to support agriculture, while maintaining environmental flows to

wetlands. Wetlands are still often not considered as part of the overall water resources network, with a consequent lack of awareness that loss of wetland connectivity can contribute to water scarcity, as well as to floods (Convection on Wetlands, 2022).

viii. Water pollution and soil erosion

Water pollution, including excessive amounts of nutrients and pesticides in water and wetland soils, degrades the ecological character of wetlands (Convection on Wetlands, 2022).The synthesis report on food and water pollution (FAO/IWMI, 2018) was unequivocal, stating "population growth, changes in calorie intake and diets have increased the demand for a wider variety of foods, including more meat and dairy products, and led to an increased water footprint in terms of water quality. Where the resulting agricultural intensification is not well managed, its benefits for society are often accompanied by significant environmental and health costs, in particular through water pollution".

Further, the loss of organic soils and associated nutrients due to land erosion is a significant concern for agricultural production, reducing crop yields and increasing fertilizer and water use (Convection on Wetlands, 2022). The annual economic cost of global soil erosion has been estimated to be USD 33-60 billion for nitrogen fertilizer application and USD 77-140 billion for phosphorus (FAO/ITPS, 2015).

Climate Change effect on Wetlands

Climate change refers to statistically quantifiable changes in the climate that persist for an extended period, and refers to both natural and human-induced changes (IPCC, 2014; Melly, 2016). As in the case of different countries, climate change could result in increased temperature, changing rainfall patterns (mostly a reduction in rainfall) and more extreme rainfall patterns such as droughts and floods (Mitchell 2013, IPCC, 2014). These changes would result in an increased net water loss to systems, which could potentially result in a reduction in the number and/or size of ephemeral wetlands (Erwin, 2009; Junk *et al.,* 2013; Melly, 2016). Ephemeral ecosystem functions could be altered because the abiotic and biotic components of the system are strongly influenced by the timing of the hydrologic regime (as well as the amount of surface water input) (Erwin, 2009; Junk *et al.,* 2013). This is partially due to their rapid evaporation rates and their shallow depths (Erwin, 2009; Johnson *et al.,* 2010; Melly, 2016).

A reduction in rainfall could also result in the overall reduction of wetland areas over a landscape, thereby potentially affecting overall wetland connectivity (Erwin, 2009, Johnson *et al.,* 2010). These changes in rainfall patterns could also potentially result in a greater disturbance to the ecosystem structure, making them less resilient to further impacts (whether human or naturally induced) (Erwin, 2009, Junk *et al.,* 2013). Climate change can potentially compound the effects of human activities on wetlands (Melly, 2016). The negative effects of overexploitation of wetland resources due to various socio-economic factors (population growth, poverty etc.) can be exacerbated by drought (Turner *et al.,* 2000; Junk *et al.,* 2013). For example, freshwater availability is already limited in southern Africa, and this is expected to worsen with a reduction in precipitation and increasing population pressures for freshwater supplies (IPCC, 2014).

The increase in extreme weather events can put wetland systems under increased strain and possibly reduce the ability for the systems to withstand previously sustainable levels of human activity (Erwin 2009, Junk *et al.* 2013). Other effect of climate change to wetlands ecosystems comprised of;

i. Seawater Level Rise

Global warming causes the melting of glaciers in the Polar Regions, thereby increasing the volume of ocean water in significant quantities and then raising the global sea level. The climate model using RCP (Representative Concentration Pathways) model scenarios predicts an average sea level rise of 26-98 cm (minimal emission scenario) to 93-243 cm (high emission scenario) in the year 2100 (Kopp *et al.,* 2017). This seawater level rise threatens low-lying areas including coastal wetlands and small islands in different countries with substantial wetland ecosystems to be in danger of sinking (Husnain *et al.,* 2022).

Coastal wetland areas that have been used as residential and crop cultivation areas are vulnerable areas that are prone to sinking and are no longer able to be inhabited and produce agricultural products (Husnain *et al.,* 2022). With the vast area of agricultural coastal wetland in Indonesia (Ritung *et al.,* 2020), the loss of them affects the problem of food security. Moreover, seawater level rise threatens hydrological functions, wildlife habitats, and human civilization in wetlands (Kopp *et al.,* 2017; Martinez-Megías and Rico, 2022; Adyasari *et al.,* 2021). When the sea level rises gradually towards the predicted level, it will be accompanied by an increase in salinity, both by increasing salt concentrations in groundwater and soils and the salinity penetration to the mainland (Forster *et al.,* 2011; Wassmann *et al.,* 2009; Husnain *et al.,* 2022). Crops will experience stress due to increased salinity and further interfere the crop growth and yields.

ii. Temperature Increases

The increase in air temperature due to global warming has an impact on increasing the risk of drought in wetlands (Husnain *et al.,* 2022). The existence of wetlands depends on the availability of water, considers very vulnerable to the risk of drought. It was detected that a third of the global wetland area had been lost in 2009, with mostly happened in Asia (Hu *et al.,* 2017; Husnain *et al.,* 2022).

The loss of wetland is caused by hydrological drought due to water abstraction and drainage for agricultural use (Li *et al.,* 2021). Aerobic conditions in the soil surface layer are very important to favor the growth of crop roots.

Global wetland shrinkage occurs at a rate of 1% per year (Davidson and Finlayson, 2018) and possibly gets worse due to meteorological drought of climate change (Dai, 2013). Water loss from soil causes oxygen penetration into the wetland and subsequently accelerates organic matter decomposition and increases acidity. Decomposition of organic matter releases GHGs which is dominated by CO2, causing an increase in GHG concentrations in the atmosphere. In general, drought in wetlands causes environmental damage (Stirling *et al.,* 2020). In wetlands with marine physiography, this drought accelerates the water evaporation and exposes the iron sulfide of pyrite in the soil layer to oxygen, and drops the acidity down to < 3 pH (Anda *et al.,* 2009). The roots of crops are mostly failed to survive in such low pH. The extreme acid solution possibly contaminates the lower areas and deteriorates the damage to the ecosystem (Stirling *et al.,* 2020).

iii. Emissions from wetland

Potential emissions from wetlands mainly come from the release of above and below-ground C-stocks (Husnain *et al.,* 2022). Emissions from aboveground carbon stocks occur when land uses with high carbon stocks, such as primary forests, are converted to land use types with relatively low carbon stocks. Agriculture does not always cause the release of carbon stock, as some agricultural areas are developed on lands with a relatively low carbon stock If shrubs are converted to plantations, this conversion likely results in

net carbon sequestration (Susanti and Dariah, 2014; Agus, 2013). Carbon stocks depend not only on plant type but also on soil fertility and climatic factors. Carbon in peatlands and mangroves is primarily stored as belowground carbon pools and is unstable, which means it can quickly decompose if its natural conditions change, i.e., under aerobic conditions (Rieley *et al.,* 2008; Agus *et al.,* 2013; Husen *et al.,* 2014; Maswar and Dariah, 2014).

iv. Emission from organic soil decomposition

A part to the relatively larger use of peatlands is because the potential emissions from peatlands are much higher than other swamplands due to the higher (below ground) carbon stock of peatlands (Husnain *et al.,* 2022). According to Agus and Subiksa, (2008), carbon stocks in peatlands range from 300-6,000 t C ha^{-1}, while mineral soils are only 30-300 t C ha^{-1}. Various studies on different countries'' peatlands have resulted in widely varying emissions data. This is partly due to different measurement methods. Previously, the value of GHG emissions from drained peatlands was based on subsidence measurements, as has been done by Couwenberg *et al.,* (2010), Couwenberg and Hooijer, (2013) , Aich *et al.,* (2013) and (Husnain *et al.,* 2022).

The use of subsidence data to estimate emission levels has several drawbacks, i.e. there are other factors such as shrinkage and compaction that have not been carefully considered. However, the phenomenon of bouncing back (Anwar *et al.,* 2020) is also an obstacle in estimating emissions based on subsidence. Therefore, the effects of climate change illustrate the need for extensive wetland research that can be used to establish appropriate management strategies. This type of research begins with baseline knowledge on the number of wetlands, size, position in the landscape and the influence of surrounding anthropogenic activities. Combined with knowledge obtained on wetland functioning, the vulnerability of wetlands can also be more accurately assessed (Melly, 2016).

Management for Sustainable Development

The UN Millennium Ecosystem Assessment determined that environmental degradation is more prominent within wetland systems than any other ecosystem on Earth (Davidson *et al.,* 2018). Constructed wetlands are used to treat municipal and industrial wastewater as well as storm water runoff. They may also play a role in water-sensitive urban design (Fagorite *et al.,* 2019). The major management practices to ensure sustainable development includes;

i. Constructed wetlands

The function of most natural wetland systems is not to manage wastewater. However, their high potential for the filtering and the treatment of pollutants has been recognized by environmental engineers that specialize in the area of wastewater treatment (Fagorite *et al.,* 2019). These constructed wetland systems are highly controlled environments that intend to mimic the occurrences of soil, flora, and microorganisms in natural wetlands to aid in treating wastewater effluent. Constructed wetlands can be used to treat raw sewage, storm water, agricultural and industrial effluent. They are constructed with flow regimes, micro-biotic composition, and suitable plants in order to produce the most efficient treatment process (Fagorite *et al.,* 2019). Other advantages of constructed wetlands are the control of retention times and hydraulic channels (Brix, 1993). The most important factors of constructed wetlands are the water flow processes combined with plant growth. Constructed wetland systems can be surface flow systems with only free-floating macrophytes, floating-leaved macrophytes, or submerged

macrophytes; however, typical free water surface systems are usually constructed with emergent macrophytes (Vymazal and Kröpfleova, 2008). Subsurface flow-constructed wetlands with a vertical or a horizontal flow regime are also common and can be integrated into urban areas as they require relatively little space (Hoffmann *et al.,* 2011).

ii. Balancing wetland conservation with the needs of people

Wetlands are vital ecosystems that provide livelihoods for the millions of people who live in and around them. The Millennium Development Goals (MDGs) called for different sectors to join forces to secure wetland environments in the context of sustainable development and improving human wellbeing (Fagorite *et al.,* 2019). A three-year project carried out by Wetlands International in partnership with the International Water Management Institute found that it is possible to conserve wetlands while improving the livelihoods of people living among them. Case studies conducted in Malawi and Zambia looked at how dambos wet, grassy valleys or depressions where water seeps to the surface can be farmed sustainably to improve livelihoods. Mismanaged or overused dambos often become degraded, however, using a knowledge exchange between local farmers and environmental managers, a protocol was developed using soil and water management practices (Fagorite *et al.,* 2019).

Project outcomes included a high yield of crops, development of sustainable farming techniques, and adequate water management generating enough water for use as irrigation. Before the project, there were cases where people had died from starvation due to food shortages. By the end of it, many more people had access to enough water to grow vegetables. A key achievement was that villagers had secure food supplies during long, dry months. They also benefited in other ways: nutrition was improved by growing a wider range of crops, and villagers could also invest in health and education by selling produce and saving money (Ramsar, 2008). Other possible ways to tackle the anthropogenic impact, climate impact and effect of agricultural activities associated with the wetlands includes;

i. Enlighten people and the decision makers on the contribution of wetlands to the global economy in order to gain support its sustainable use and conservation.
ii. Key out the beneficiaries of wetlands services so as to attract investments and ensure sustainable financial incentives for the maintenance and restoration of its services.
iii. Sponsor and encourage research that will fill the gap on the level of withdrawals that will be adequate for use and that will not affect the environment negatively.
iv. Encourage an annual biodiversity assessment of all ramsar sites in order to have a resourceful fact sheets that will enable decision makers to act appropriately.
v. Ensure an environmental impact assessment is properly carried out before any major irrigation or damming project is executed.
vi. Nevertheless, this is the crucial question determining the likelihood of coexistence of ecological resources and irrigated agriculture with restoration where needed. identify the users and beneficiaries of wetland services to attract investments and secure sustainable financial streams and incentives for the maintenance, or restoration, of these services (i.e., make users pay and ensure that local people receive a proper share of the benefits);and

vii. Increase awareness about the many benefits of wetlands to human well-being and ensure that wetlands are better taken into account in economic welfare indicators (e.g., in Gross National Product (GNP) calculations) and pricing mechanisms (through internalization of externalities).

Challenges Facing Wetlands and Their Solutions

Wetlands are among the most productive yet vulnerable ecosystems in the world. Despite their ecological and economic significance, they face various challenges primarily due to human activities and climate change. Below are some key challenges and their possible solutions.

Challenges Facing Wetlands

i. Wetland Degradation and Habitat Loss

Over 35% of wetlands have been lost globally since 1970 due to human induced degradation (Davidson and Finlayson, 2018). Conversion of wetlands into agricultural land, urban areas, and infrastructure projects has led to habitat destruction (Ramsar Convention on Wetlands, 2021).

ii. Climate Change and Rising Sea Levels

Climate change is altering rainfall patterns, increasing temperatures, and causing sea level rise, which threatens coastal wetlands (Husnain *et al.,* 2022). Rising temperatures lead to higher evaporation rates, reducing water availability in wetlands (IPCC, 2014).

iii. Pollution and Eutrophication

Agricultural runoff, industrial waste, and domestic sewage introduce excessive nutrients and pollutants into wetlands, causing eutrophication and reduced water quality (FAO/IWMI, 2018). Accumulation of pesticides, heavy metals, and plastics disrupts wetland biodiversity (Verhoeven *et al.,* 2006).

iv. Overexploitation of Wetland Resources

Wetlands provide essential resources, including timber, fish, and medicinal plants, but overharvesting leads to habitat degradation and species decline (Millennium Ecosystem Assessment, 2005). Excessive groundwater extraction lowers wetland water tables, leading to loss of hydrological functions (Ramsar Convention on Wetlands, 2021).

v. Invasive Species Encroachment

Invasive plant and animal species, such as water hyacinth (*Eichhornia crassipes*) and *Lantana camara*, disrupt wetland ecosystems by outcompeting native species and altering habitat structure (Gopal, 2013). Some invasive species contribute to excessive sedimentation and nutrient accumulation, leading to reduced biodiversity (Dalu *et al.,* 2017).

vi. Water Diversion and Hydrological Changes

The construction of dams, irrigation canals, and drainage systems alters natural water flow, affecting wetland hydrology (FAO, 2020). Hydrological disconnection caused by urban development prevents wetlands from receiving sufficient water for their ecosystem functions (Davidson *et al.,* 2018).

Sustainable Solutions for Wetland Conservation

To ensure long-term sustainability, wetland conservation efforts must involve governments, local communities, and international organizations.

i. Policy and Legal Frameworks

Strengthen wetland protection laws and ensure effective enforcement (Turner *et al.,* 2000).

Increase funding for Ramsar designated wetlands and expand international cooperation (Ramsar Convention, 2018). Implement strict land use policies to prevent unregulated conversion of wetlands (Robertson *et al.,* 2019). Promote ecological restoration programs to recover degraded wetlands (Darrah *et al.,* 2019). Establish buffer zones and mangrove restoration projects to protect coastal wetlands from rising seas (Forster *et al.,* 2011). Promote climate resilient wetland management strategies, such as integrating wetlands into climate adaptation plans (Ramsar Convention, 2018).

ii. Community Based Wetland Management

Engage local communities in wetland conservation through participatory approaches (Melly, 2016). Provide incentives for sustainable landuse practices that benefit both wetlands and local economies (van der Duim and Henkens, 2007).

Implement buffer strips and constructed wetlands to filter pollutants before they reach wetland ecosystems (Moomaw *et al.,* 2018). Implement alternative livelihoods to reduce dependence on wetland resources (UNCCD, 2017).

iii. Education and Awareness Campaigns

Increase public awareness of wetland benefits and threats through education programs (Semlitsch, 2000). Train farmers, fishers, and local stakeholders on sustainable wetland management (Blackwell and Pilgrim, 2011). Promote sustainable agricultural practices, including organic farming and controlled fertilizer application (Wu and Ma, 2015). Introduce sustainable harvesting policies and community-based conservation programs to regulate wetland resource use (FAO, 2020).

iv. Restoration and Rehabilitation Programs

Conduct reforestation programs for degraded wetlands, particularly mangroves and peatlands (Page *et al.,* 2004). Implement wetland monitoring programs using satellite imagery and field surveys (Joosten, 2010). Establish early detection and rapid response programs to control invasive species (Sievers *et al.,* 2018). Promote biological control measures using natural predators or competitors to manage invasive species (Giri *et al.,* 2010). Implement integrated water resource management (IWRM) strategies that consider wetland needs in water allocation (Schuyt, 2005). Restore natural flow regimes through dam removal or ecological water releases (Mitchell, 2013).

CONCLUSION

In conclusion, wetlands are indispensable for agriculture, providing critical ecosystem services that sustain food production and rural livelihoods. Protecting and managing wetlands wisely is essential not only for ensuring agricultural productivity but also for preserving biodiversity, mitigating climate change, and securing water resources for future generations. Sustainable agricultural practices that balance food production with wetland conservation will be key to maintaining the long-term benefits that these ecosystems offer. Wetlands play a crucial role in supporting agricultural productivity and sustainability. As natural water reservoirs, they regulate water availability for irrigation, acting as buffers against drought and excessive flooding.

Their capacity to retain and filter water helps maintain soil moisture, which is essential for crop cultivation, particularly in regions with erratic rainfall patterns. Furthermore, wetlands act as natural nutrient sinks, improving soil fertility and enhancing agricultural yields by recycling essential nutrients such as nitrogen and phosphorus. In

addition to providing water and fertile land for farming, wetlands also support aquatic food production, including fisheries and aquaculture, which serve as vital sources of protein and livelihood for millions of people worldwide. The buffering role of wetlands in flood control protects farmlands from erosion and crop loss, reducing the risks associated with extreme weather events. Moreover, wetland dependent agro-ecosystems, such as floodplain farming and rice paddies, demonstrate the symbiotic relationship between wetlands and sustainable food production. However, the overexploitation and conversion of wetlands for agriculture have led to significant environmental degradation, threatening both wetland ecosystems and agricultural sustainability. The loss of wetlands due to drainage, excessive irrigation, pollution, and land conversion has resulted in soil depletion, loss of biodiversity, and increased vulnerability to climate change impacts. Sustainable wetland management practices, including integrated water resource management, conservation agriculture, and wetland restoration, are essential to ensure that wetlands continue to support agricultural production while maintaining their ecological integrity.

REFERENCES

Adyasari, D. Pratama, M.A. Tegun, N.A. Sabdaningsih, A. Kusumaningtyas, M.A. and Dimova, N. (2021) Anthropogenic impact on Indonesian coastal water and ecosystems: Current status and future opportunities. *Marine Pollution Bulletin*, **171**, 112689.

Agus, F. (2013). Konservasi tanah dan karbon untuk mitigasi perubahan iklim mendukung keberlanjutan pembanguan pertanian. *Pengembangan Inovasi Pertanian*, **6**(1): 23-33.

Aich, S. McVoy, C.W. Dreschel, T.W. and Santamaria, F. (2013). Estimating soil subsidence and carbon loss in the Everglades Agricultural Area, Florida using geospatial techniques. *Agriculture, Ecosystems and Environment*, **177**: 124-133.

Allaby, M. (2010). *A Dictionary of Ecology Oxford Reference*. *Oxford University Press, USA; 4 edition (July 15, 2010)*. https://doi.org/10.1093/acref/9780199567669.001.0001

Anwar, S. Sumawinata, B. Pulunggono, H.B. Sadono, D. Taniwiryono, D. Siswanto, Widiastuti, H. and Sabiham, S. (2020). *Laporan Akhir Penelitian Tahun II, Faktor Emisi Lahan Gambut yang Didrainase untuk Kelapa Sawit*. Fakultas Pertanian, IPB dan Badan Pengelola Perkebunan Kelapa Sawit (BPDPKS).

Arnold Jr., C.L., and Gibbons, C.J. (1996). Impervious surface coverage: the emergence of a key environmental indicator. *Journal of the American Planning Association,* **62**(2)**,** 243-258.

Assefa, W.W., Eneyew, B.G., Wondie, A. (2021). The impacts of land-use and land-cover change on wetland ecosystem service values in peri-urban and urban area of Bahir Dar City, Upper Blue Nile Basin, Northwestern Ethiopia. *Ecological Processes*. **10**, 39.

Barbier, E.B., Acreman, M.C., and Knowler, D. (1997). Economic valuation of wetlands: a guide for policy makers and planners. Ramsar Convention Bureau, Gland, Switzerland, p. 116.

Blackwell, M.S.A. and Pilgrim, E.S. (2011). Ecosystem services delivered by

small-scale wetlands. *Hydrological Sciences Journal,* **56**(8)**,** 1467-1484.

Burger, J., Kerlinger, P., Cordell, H.K., Decker, D.J., Cole, D.N., Landres, P., Smith, E.N., Brett, J., Larson, R. and O'Shea, T. (1995). *Wildlife and recreationists: coexistence through management and research*, Island Press, Washington, D.C., p. 389.

Campbell, D. A., Cole, C. A., and Brooks, R. P. (2002). A comparison of created and natural wetlands in Pennsylvania, USA. *Wetlands Ecology and Management*, **10** (1), 41–49.

Collen, B., Whitton, F., Dyer, E.E., Baillie, J.E., Cumberlidge, N., Darwall, W.R. (2014). Global patterns of freshwater species diversity, threat and endemism. *Global Ecology and Biogeography*, **23**, 40-51.

Convention on Wetlands. (2022) *Policy Brief No. 6: Transforming agriculture to sustain people and wetlands*. Gland, Switzerland: Secretariat of the Convention on Wetlands.

Corry, F. (2012). Development of a tool for assessment of the environmental condition of wetlands using macrophytes. *Wetland Health and Importance Research Programme*. Report Number: TT 436/12, Water Research Commission, Pretoria, p. 434.

Dai, A. (2013). Increasing drought under global warming in observations and models. *Nature Climate Change*, **3**, 52–58.

Dalu, T., Wasserman, R.J., Dalu, M.T.B. (2017). Agricultural intensification and drought frequency increases may have landscape-level consequences for ephemeral ecosystems. *Global Change Biology*, **23**, 983-985.

Danz, N.P., Niemi, G.J., Regal, R.R., Hollenhorst, T., Johnson, L.B., Hanowski, J.M., Axler, R.P., Ciborowski, J.J., Hrabik, T. and Brady, V.J. (2007). Integrated measures of anthropogenic stress in the US Great Lakes basin. *Environmental management,* **39**(5)**,** 631-647.

Darrah, S.E. *et al.,* (2019). Improvements to the Wetland Extent Trends (WET) index as a tool for monitoring natural and human-made wetlands. *Ecological Indicators*, **99**: 294-298.

Davidson, N. and Finlayson, C.M. (2018). Extent, regional distribution and changes in area of different classes of wetlands. *Marine and Freshwater Research*, **69**, 1525–1533.

Davidson, N.C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research,* **65**(10)**,** 934-941.

De Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services*, **1**: 50-61.

Eneyew, B. G., and Workiye, W. A. (2021). Anthropogenic effect on wetland biodiversity in Lake Tana Region: A case of Infranz Wetland, Northwestern Ethiopia. *Environmental and Sustainability Indicators,* **12**: 100158.

Erwin, K.L. (2009). Wetlands and global climate change: the role of wetland restoration in a changing world. *Wetlands Ecology and Management,* **17**(1)**,** 71-84.

Fagorite, V. I., Odundun, O. A., Iwueke1, L. E., Nwaigbo, U. N. and Okeke, O.C. (2019). Wetlands; A review of their classification, significance and management for sustainable development. *International Journal of Advanced Academic Research Sciences, Technology and Engineering*, **5**, (3): Pp; 24-38.

FAO. (2018b). *The 10 elements of agroecology: Guiding the transition to sustainable food and agricultural systems*. FAO, Rome, Italy.

FAO. (2020). *The State of Food and Agriculture 2020. Overcoming water challenges in agriculture*. Rome. https://doi. org/10.4060/cb1447en

FAO/ITPS. (2015). *Status of the World's Soil Resources (SWSR) Main Report*. FAO and Intergovernmental Technical Panel on Soils, Rome

FAO/IWMI. (2018). *More people, more food, worse water? A global review of water pollution from agriculture* (ed. by Mateo-Sagasta J., Marjani Zadeh, S. Turral, H.). Food and Agriculture Organization of the United Nations, Rome; and International Water Management Institute/CGIAR Water Land and Ecosystems research program, Colombo.

Forster, P.M. Andrews, T. Good, P. Gregory, J.M. Jackson, L.S. and Zelinka, M. (2012). Evaluating adjusted forcing and model spread for historical and future scenarios in the CMIP5 generation of climate models. Journal of Geophysical Research: *Atmospheres,* **118**, 1139–1150.

Gatti, C.R. (2016). Freshwater biodiversity: a review of local and global threats. *International Journal of Environmental Studies*, **73**, 887–904.

Giri, C., Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J. and Duke, N. (2010). Status and distribution of mangrove forests of the world using Earth observation satellite

Gopal, B. (2013). Future of wetlands in tropical and subtropical Asia, especially in the face of climate change. *Aquatic Sciences*, **75**, 39_61.

Gramlich, A., Stoll, S., Stamm, C., Walter, T., and Prasuhn, V. (2018). Effects of artificial land drainage on hydrology, nutrient and pesticide fluxes from agricultural fields–A review. *Agriculture, Ecosystems and Environment*, **266**, 84-99.

Gren, I.M., Folke, C., Turner, K., Batemen, I. (1994). Primary and secondary values of wetland ecosystems. *Environmental and Resource Economics*, **4**, 55_74.

He, X., Hormann, G., Strehmel, A., Guo, H., Fohrer, N. (2015). Natural and anthropogenic causes of Vegetation changes in Riparian Wetlands Along the Lower Reaches of the Yellow River, China. *Wetlands,* **35**, 391–399.

Heimlich, E., Wiebe, K. D., Claassen, R., Gadsby, D., and Robert, M. (1998). Wetlands and Agriculture: Private Interests and Public Benefits. *International Immunology*, **24**(765), 99.

Hettiarachchi, M., Morrison, T. H., and McAlpine, C. (2015). Forty-three years of ramsar and urban wetlands. *Global Environmental Change*, **32**, 57–66.

Hoffmann, H., Platzer, C., von Münch, E. and Winker, M. (2011). *Technology review of constructed wetlands; Subsurface flow constructed wetlands*

for greywater and domestic wastewater treatment"(PDF). Eschborn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit.

Hu, S., Niu, Z., Chen, Y., Li, L., Zhang, H. (2017). Global wetlands: potential distribution, wetland loss, and status. *Science and Total Environment*, **586**, 319–327.

Husen, E. Salma, S. and Agus, F. (2014) *Peat emission control by groundwater management and soil amendments: evidence from laboratory experiments*. Mitigation and Adaptation Strategies for Global Change https://link.springer.com/article/10.1007/s11027-013-9526-3.

Husnain, M., Setiari, Ma., Ai, D., Sukarman, M., Noor, A. H., and Rahmah, D.Y. (2022). Agriculture on Wetlands: A Fragile System Requiring Wise Management Systems. *Wetland Agriculture*, Chapter **7**. Pp; 73-79.

IPCC (2014). Climate Change 2014: *Synthesis report. Contribution of working groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. In: Pachauri, R. and Meyer, L. (eds.). Report Number: 9291691437, IPCC, Geneva, Switzerland, p. 151.

Jaenicke, J., Rieley, J. O., Mott, C., Kimman, P. and Siegert, F. (2008). Determination of the amount of carbon stored in Indonesian peatlands. *Geoderma*, **147**: 151–158.

Johnson, W.C., Werner, B., Guntenspergen, G.R., Voldseth, R.A., Millett, B., Naugle, D.E., Tulbure, M., Carroll, R.W.H., Tracy, J. and Olawsky, C. (2010). Prairie wetland complexes as landscape functional units in a changing climate. *BioScience,* **60**(2)**,** 128-140.

Johnston, C. A., Shmagin, B. A., Frost, P. C., Cherrier, C., Larson, J. H., Lamberti, G. A., and Bridgham, S. D. (2008). Wetland types and wetland maps differ in ability to predict dissolved organic carbon concentrations in streams. *Science of the Total Environment*, **404**(2–3), 326–334.

Joosten, H. (2010). *The Global Peatland CO_2 Picture. Peatland Status and Drainage Related Emissions in All Countries of the World*. Wetlands International, Ede, The Netherlands.

Junk, W.J., An, S., Finlayson, C.M., Gopal, B., Kvet, J., Mitchell, S.A., Mitsch, W.J. and Robarts, R.D. (2013). Current state of knowledge regarding the world's wetlands and their future under global climate change: a synthesis. *Aquatic Sciences,* **75,** 151-167.

Kopp, R.E., R.M. DeConto, D.A., Bader, C.C., Hay, R.M., Horton, S., Kulp, M., Oppenheimer, D., Pollard, and B.H. Strauss. (2017). Evolving understanding of Antarctic ice-sheet physics and ambiguity in probabilistic sea-level projections. *Earth's Future*, **5**, (12): 1217-1233,

Kuiper, J.J., Janse, J.H., Teurlincx, S., Verhoeven, J.T.A., Alkemade, R. (2014). The impact of river regulation on the biodiversity intactness of floodplain wetlands. Wetland Ecology and Management, **22**, 647–658.

Lal, R. (2020). Regenerative agriculture for food and climate. *Journal of soil and water conservation*, **75**: 123A-124A.

Laurance, S.G.W., Baider, C., Vincent Florens, F.B., Ramrekha, S., Sevathian, J.-C., Hammond, D.S. (2012). Drivers of wetland disturbance and biodiversity impacts on a tropical oceanic island. *Biology and Conservation*, **149**, 136–142.

Li, D., Tian, P., Luo, Y., Dong, B., Cui, Y., and Khan, S. (2021). Importance of stopping groundwater irrigation for balancing agriculture and wetland ecosystem. *Ecological Indicators*, **127**, 107747.

Maltby, E. and Acreman, M.C. (2011). Ecosystem services of wetlands: pathfinder for a new paradigm. *Hydrological Sciences Journal,* **56**(8)**,** 1341-1359.

Mao, D., Luo, L., Wang, Z., Wilson, M.C., Zeng, Y., Wu, B. and Wu, J., (2018). Conversions between natural wetlands and farmland in China: A multiscale geospatial analysis. *Science of the Total Environment*, **634**: 550-560.

Martinez-Megias, C. and Rico, A. (2022). Biodiversity impacts by multiple anthropogenic stressors in Mediterranean coastal wetlands. *Science of the Total Environment*, **818**, 151712.

Maswar, and Dariah, A. (2014). *Teknologi pengelolaan lahan gambu dan sumbangannya terhadap mitigasi gas rumah kaca. Konservasi Tanah Menghadapi Perubahan Iklim. Badan Penelitian dan Pengembangan Pertanian*. Indonesian Agency for Agricultural Research and Development, Hall press. 83–103.

MEA (Millennium Ecosystem Assessment), 2005. *Ecosystems and Human Well-Being: Synthesis*. Washington, DC.

Melly, B. (2016). *Factors influencing wetland distribution and structure, including ecosystem function of ephemeral wetlands, in Nelson Mandela Bay Municipality (NMBM), South Africa*. A Dissertation submitted to the Faculty of Science, Department of Botany Nelson Mandela Metropolitan University Port Elizabeth.

Minaya, V., McClain, M.E., Moog, O., Omengo, F. and Singer, G.A. (2013). Scale-dependent effects of rural activities on benthic macroinvertebrates and physico-chemical characteristics in headwater streams of the Mara River, Kenya. *Ecological Indicators,* **32,** 116-122.

Mitchell, S.A. (2013). The status of wetlands, threats and the predicted effect of global climate change: the situation in Sub-Saharan Africa. *Aquatic Sciences*, **75**, 95–112.

Mitsch, W. J., and Gossilink, J. G. (2000). The value of wetlands: Importance of scale and landscape setting. *Ecological Economics*. https://doi.org/10.1016/S0921-8009(00)00165-8.

Moomaw, W.R., Chmura, G.L., Davies, G.T., Finlayson, C.M., Middleton, B.A., Perry, J.E., Roulet, N. and Sutton-Grier, A.E. (2018). Wetlands in a Changing Climate: Science, Policy and Management. *Wetlands*, **38**, 183-205.

Nyman, J. A. (2011). Wetlands. In *wetlands* (pp. 115–128). https://doi.org/10.1007/978-94-007-0551-7.

Page, S.E. and Banks, C. (2007). Tropical peatlands: distribution, extent and carbon storage uncertainties and

knowledge gaps. *Peatlands International*, **2**: 26–27.

Page, S.E., Wust, R.A.J., Weiss, D., Rieley, J.O., Shotyk, W. and Limin, S. H. (2004). A record of late Pleistocene and Holocene carbon accumulation and climate change from an equatorial peat bog (Kalimantan, Indonesia): implications for past, present and future carbon dynamics, *Journal of Quarternary Science*, **19**(7): 625–635.

Patino, J.E. and Estupinan-Suarez, L.M., (2016). Hotspots of wetland area loss in Colombia. *Wetlands*, **36**: 935-943.

Pengelolaan Berkelanjutan Lahan Gambut dan Peningkatan nilai Nilai eEkonomi. Jakarta 18-19.

Ramsar Convention on Wetlands. (2018). *Global Wetland Outlook: State of the World's Wetlands and their Services to People*. Gland, Switzerland: Ramsar Convention Secretariat.

Ramsar Convention on Wetlands. (2018). Global Wetland Outlook: State of the World's Wetlands and Their Services to People. Ramsar Convention Secretariat, Gland.

Ramsar, (2008). *Good practices and lessons learned in integrating ecosystem conservation and poverty reduction objectives in wetlands*" (PDF). The Ramsar Convention on Wetlands.

Ramsar, (2011). *The Ramsar 40th Anniversary Message for November*". Ramsar Convention Ecosystem Services Benefit Factsheets"

Rebelo, A.G., Holmes, P.M., Dorse, C., Wood, J. (2011). Impacts of urbanization in a biodiversity hotspot: conservation challenges in Metropolitan Cape Town. *South Africa Journal of Botany*, **77**, 20–35.

Rieley, J.O., Wüst, R.A.J., Jauhiainen, J. Page, S.E. Ritzema, H. Wösten, H. Hooijer, A. Siegert, F. Limin, S., Vasander, H., and Stahlhut, M. (2008). *Tropical Peatlands, carbon stores, carbon gas emissions and contribution to climate change processes*. In: M. Strack (ed.) Peatlands and Climate Change. IPS. Saarijärvi. pp. 148-181.

Ritung, S., Suryani, E., Yatno, E., and Subandiono, R.E. (2020). *Pemutakhiran peta sumberdaya lahan rawa. Laporan Akhir*. Biodiversity and Biosystematics of Dry Lands Plants: Bogor.

Rossouw, L., Avenant, M.F., Seaman, M.T., King, J.M., Barker, C.H., de Preez, P.J., Pelser, A.J., Roos, J.C., van Staden, J.J., van Tonder, G.J. and Watson, M. (2005). *Environmental water requirements in non-perennial systems*. Report Number: 1414/1/05, Water Research Commission, Gezina, p. 290.

Schultz, B., Thatte, C.D. and Labhsetwar, V.K., (2005). Irrigation and drainage. Main contributors to global food production. *Irrigation and Drainage*, **54**: 263-278.

Seki, H.A., Shirima, D.D., Courtney Mustaphi, C.J., Marchant, R., Munishi, P.K.T.(2018). The impact of land use and land cover change on biodiversity within and adjacent to Kibasira Swamp in Kilombero Valley, Tanzania. *African Journal of Ecology*, **56**, 518–527.

Sievers, M., Hale, R., Parris, K.M., Swearer, S.E., (2018). Impacts of human-induced environmental change in wetlands on aquatic animals. *Biological Reviews*, **93**, 529-554.

Skowno, A.L., Poole, C.J., Raimondo, D.C., Sink, K.J., van Deventer, H., Van Niekerk, L. (2019). National Biodiversity Assessment. (2018). The Status of South Africa's Ecosystems and Biodiversity. Synthesis Report. South African National Biodiversity Institute, an entity of the Department of Environment, Forestry and Fisheries, Pretoria.

Stirling, E., Fitzpatrick, R.W., and Mosley, L.M. (2020) Drought effects on wet soils in inland wetlands and peatlands. *Earth-Science Reviews,* **210**, 103387.

Susanti, E. and Dariah, A. (2014). *Perubahan penggunaan semak belukar pada lahan gambut ditinjau dari aspek dinamika cadangan karbon tanaman. Dalam Prosiding Seminar Nasional*

Turner, K.R., van den Bergh, C.J.M., Soderqvist, T., Barendregt, A., van der Straaten, J., Maltby, E. (2000). Ecological-economic analysis of wetlands: scientific integration for management and policy. *Ecological Economics*, **35**, 7_23.

UNCCD. (2017). The Global Land Outlook, first edition. https:// doi.org/ISBN: 978-92-95110-48-9

Vasumathi, V., Kalpana, R., Pazhanivelan, S., Priya, M.V., and Pon Arasan, A. (2023). Classification, Distribution, Features, Biodiversity and Functions of Wetlands: A Review. *Agricultural Reviews*, Pp; 1-9.

Verhoeven, J.T., Arheimer, B., Yin, C., Hefting, M.M. (2006). Regional and global concerns over wetlands and water quality. *Trends in Ecology and Evolution*, **21**: 96-103.

Wasserman, R.J., and Tatenda D. (2022). *Tropical freshwater wetlands*: An introduction. Chapter 1, Pp; 1-22.

Wassmann, R., Jagadish, S.V.K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A., Serraj, R., Redona, E., Singh, R.K., and Heuer, S. (2009). Regional Vulnerability of Climate Change Impacts on Asian Rice Production and Scope for Adaptation. In Sparks, editor: *Advances in Agronomy*, **102**, 91-133. ISBN: 978- 0-12-374818-8.

Wood, A., van Halsema, G.E. (2008). *Scoping Agriculture: Wetland Interactions: towards a Sustainable Multiple-Response Strategy*. Rome, Italy.

Wood, A., van Halsema, G.E. (2008). *Scoping agriculture; wetland interactions*. In FAO Water Reports. https://doi. org/10.1016/j.biocon.2015.04.016

Wu, H., Chen, J., Xu, J., Zeng, G., Sang, L., Liu, Q., Yin, Z., Dai, J., Yin, D., Liang, J., Ye, S. (2019). Effects of dam construction on biodiversity: A review. *Journal of Cleaner Production*, **221**, 480–489.

Wu, W., Ma, B. (2015). Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. *Science of the Total Environment*, **512**: 415-427.

Xie, Z., Xu, X., Yan, L. (2010). Analyzing qualitative and quantitative changes in coastal wetland associated to the effects of natural and anthropogenic factors in a part of Tianjin, China. *Estuarine Coastal and Shelf Science*, **86**, 379–386.

CLIMATE CHANGE PERCEPTION AND LIVELIHOOD IMPACTS IN COMMUNITIES SURROUNDING OLOKEMEJI FOREST, OGUN STATE, NIGERIA

[1]*Olajiire-Ajayi, B.L., [1]Ogundana, O.A., [1]Olubayo, O.O and [1]Lameed, T.A.
[1]Forestry and Environmental Technology Department, Federal College of Forestry, Ibadan
*Corresponding Author's Email: jiirebolanle@gmail.com

ABSTRACT

Climate change poses increasing threats to tropical forest ecosystems and the rural communities that depend on them for their livelihoods. This study examined climate change perceptions and their implications for ecosystem services and rural livelihoods in communities surrounding Olokemeji Forest Reserve, Ogun State, Nigeria. Structured questionnaire was administered to 160 households across three forest-adjacent communities: Olokemeji, Adedapo, and Jagunna Ake. Data on socio-demographic characteristics, climate awareness, perceived climate indicators, ecosystem service dependence, and livelihood impacts were analysed using descriptive and inferential statistics. The results revealed generally low levels of climate change awareness among respondents; 44.4% reported low awareness, and only 10.6% demonstrated high awareness. Chi-square analysis showed significant associations between community location and awareness level ($\chi^2 = 12.64$, $p = 0.047$) and between access to climate information and awareness ($\chi^2 = 15.38$, $p = 0.009$). Logistic regression further identified education (OR = 2.43, $p = 0.009$), residency longer than six years (OR = 1.95, $p = 0.020$), access to climate information (OR = 3.06, $p = 0.006$), and residence in Olokemeji community (OR = 1.55, $p = 0.045$) as significant predictors of climate change awareness. Respondents commonly perceived increasing temperatures, erratic rainfall patterns, and prolonged drought as key indicators of climate change, which were linked to declining crop yields, biodiversity loss, and reduced forest resource availability. Despite experiencing these impacts, farmers exhibited comparatively lower conceptual awareness of climate change, suggesting a knowledge–exposure gap. The study concludes that improving climate resilience in forest-dependent communities requires strengthening local extension services, enhancing climate information dissemination, and integrating scientific knowledge with local ecological experience. Policies that support inclusive climate education and sustainable forest management are essential for safeguarding ecosystem services and sustaining rural livelihoods under increasing climate variability.

Keywords: Climate change perception, ecosystem services, rural livelihoods, forest communities, Olokemeji Forest Reserve

INTRODUCTION

Climate change is one of the most significant environmental challenges facing the world today, with severe effects on ecosystems and human livelihoods. Tropical forest ecosystems are particularly vulnerable, as climate variability affects rainfall patterns, temperature regimes, and biodiversity (Onyekuru *et al.,* 2026). Rural communities living near forest reserves depend heavily on ecosystem services such as food production, non-timber forest products, climate regulation, and water resources (Ahammad *et al.,* 2026; Onyekuru *et al.,* 2026). In sub-Saharan Africa, these communities are especially vulnerable because their livelihoods rely largely on rain-fed agriculture and forest resources, yet their capacity to adapt remains limited by weak institutional support and limited access to climate information (Solaja *et al.,* 2025).

In Nigeria, forest reserves in the southwestern rainforest zone are increasingly threatened by deforestation, land-use change, and climate variability (Chunwate *et al.,* 2025). These pressures not only degrade forest ecosystems but also reduce the ecosystem services that support rural livelihoods. Studies across Nigerian ecological zones indicate that farmers in the rainforest region particularly experience erratic rainfall patterns, flooding, increased pest infestation, and high temperatures as key climate challenges (Onyekuru *et al.,* 2026).

Despite growing research on climate change in Africa, limited studies have examined how forest-dependent communities perceive climate change and how these perceptions relate to ecosystem services and livelihood outcomes, particularly in southwestern Nigeria (Ahammad *et al.,* 2026; Chunwate *et al.,* 2025). Although the climate–livelihood relationship has been widely examined globally, with climate variability shown to affect rainfall patterns, natural resource availability, and livelihood outcomes (IPCC, 2022), important gaps exist in the forest ecosystems of southwestern Nigeria, where integrated studies combining climate change studies with systematic analyses of community perceptions remain limited (Fadairo *et al.,* 2021 and Fasona *et al.,* 2015). This impedes the development of locally appropriate adaptation strategies.

This study therefore examines climate change perception and its implications for ecosystem services and livelihoods in communities surrounding the Olokemeji Forest Reserve in Ogun State, Nigeria. Specifically, the study investigates levels of climate awareness, perceived climate change indicators, dependence on forest ecosystem services, and the socio-economic factors influencing climate change awareness. Understanding local perceptions, awareness levels, and experienced impacts of climate change is essential for designing effective adaptation and mitigation strategies (Leal Filho *et al.,* 2021).

MATERIALS AND METHODS

Study Area

The study was conducted in Olokemeji Forest Reserve**,** located in Odeda Local Government Area, Ogun State, southwestern Nigeria (latitude 7°25′N, longitude 3°32′E), at an elevation of 90–140 m above sea level**.** The reserve covers approximately 7,124 ha**,** including 1,088 ha of derived savanna woodland, and is situated about 32 km west of Ibadan (Oyo State) and 35 km northeast of Abeokuta (Ogun State)**.** The terrain is generally undulating**,** with a prominent quartzite ridge on the western side rising above 240 m**,** which influences drainage and creates diverse microhabitats (Akintola *et al.,* 2020).

Soils are derived from Precambrian basement complex rocks**,** mainly banded biotite gneisses with granitoid intrusions, and are overlain by alluvial deposits along streams and floodplains**.** Drainage is typical of forest–savanna transition zones**,** characterized by shallow, seasonal streams that form during the wet season (Ogunleye *et al.,* 2004)**.**

The climate is typical of the tropical savanna (Aw) zone, with distinct wet and dry seasons. Annual rainfall ranges from 1,200–1,300 mm**,** primarily between March and October**,** while the dry season extends from November to February, often accompanied by harmattan winds. Seasonal variations in temperature and humidity significantly influence soil moisture, vegetation growth, and agricultural activities in the surrounding communities (Olubode *et al.,* 2021).

The human population around the reserve is predominantly Egba Yoruba, with Yoruba as the primary language, alongside smaller numbers of Fulani and Hausa migrants. Communities depend

largely on the forest for their livelihoods, engaging in farming, trade in forest products, and other rural activities. Forest resources provide timber, non-timber forest products (NTFPs), and support for agriculture, making them central to both economic and ecological sustainability in the region (TheCable, 2026).

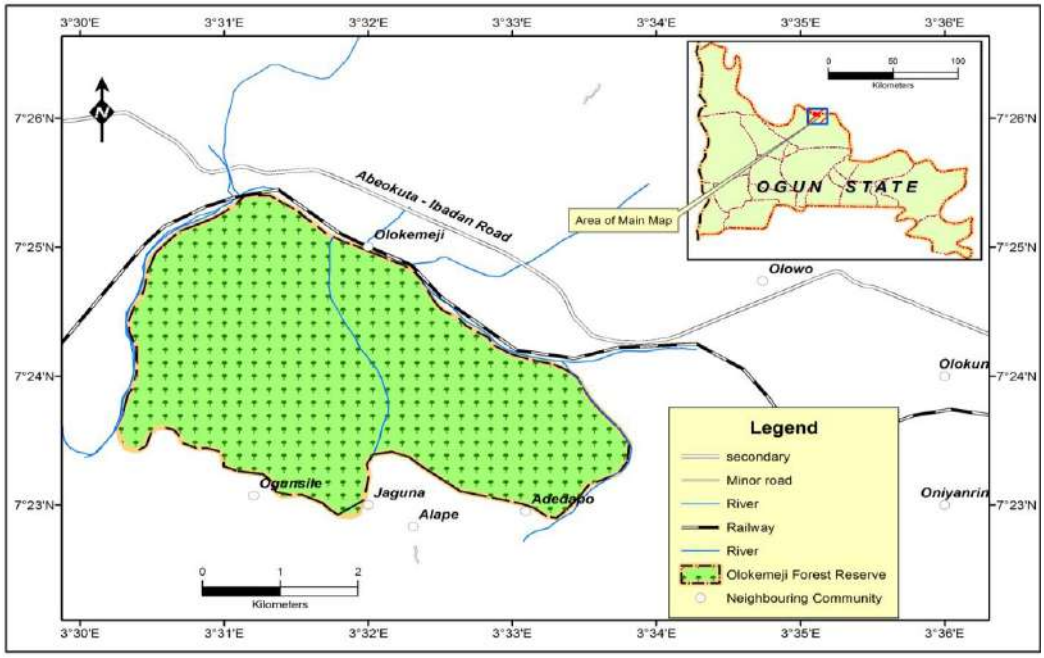


Figure 1: Map of Olokemeji forest reserve showing neighboring communities

Sampling Procedures

The extent and magnitude of benefit that PAs offers communities vary. Therefore, as noted by Mackenzie and Ahabyona (2012), those closer to the reserve tend to feel the impact more. It is on this basis that communities that were within 5km from the Forest reserve were purposively selected

Ten major communities were identified, namely: Ogunsile Camp, Olokemeji, Olowo, Adedapo, Alape, Jagunna Ake, Oniyanrin, Gbagura, Olokun, and Alagba. From these, three communities were purposively selected; Olokemeji, Alape and Jagunna Ake, based on their proximity to the reserve.

Population data for the selected communities for 1996 were obtained from the National Population Commission for Odeda Local Government Area, Ogun State. Using these historical data, population projections for 2024 were computed using the exponential growth formula:

$$P_n = P_o e^{r\,t}$$

Where: P_n = final population (2024 projection),

P_o = initial population,

e = exponential,

r = growth rate at 3.5%,

t = time that is (x-1996) where x is the projection year

Sampling Intensity

Sampling intensity followed the guidelines of Diaw *et al.* (2002), which recommend 10% for populations below 500, 5% for populations below 1,000, and 2.5% for populations above 1,000. Accordingly, respondents were selected proportionally

from the projected populations of the three communities. A total of 160 questionnaires were administered: 72 in Olokemeji, 46 in Alape, and 42 in Jagunna Ake, ensuring adequate representation of households closest to the forest reserve.

Data Collection

Primary data were obtained using structured questionnaires administered to household heads and adult residents. Information collected covered socio-demographic characteristics, climate awareness, perceived climate indicators, ecosystem services provided by forests, and climate change impacts on livelihoods.

Data Analysis

Data were analyzed using descriptive statistics of graphs and tables. Inferential statistics of cross-tabulation was used to examine relationships between communities and climate change awareness, educational level and climate change awareness level. Chi-square (χ^2) tests were further applied to test for significant associations between communities and climate change awareness, educational level and climate change awareness level. Binary Logistic Regression analysis of the determinants of Climate Change Awareness was carried out at $p \leq 0.05$.

RESULTS

Socio-Demographic Characteristics of Respondents by Communities

Figure 2 shows that most of the respondents are middle-aged adults between 40 and 59 years, making up nearly half of the total sample (77 out of 160). This age group is the most represented in all three communities. Younger adults aged 20–39 years also form a substantial portion (53 respondents), while those above 60 years are fewer (30 respondents). Table 3 shows that males constitute the majority of respondents in the surveyed communities. In Olokemeji, 48 respondents are male compared to 24 females, while in Adedapo, 31 are male and 15 are female.

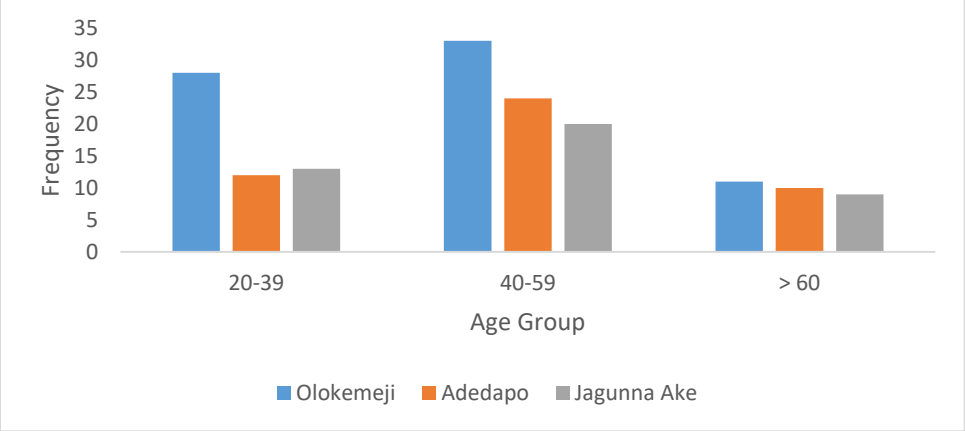


Figure 2: Age distribution of respondents by communities

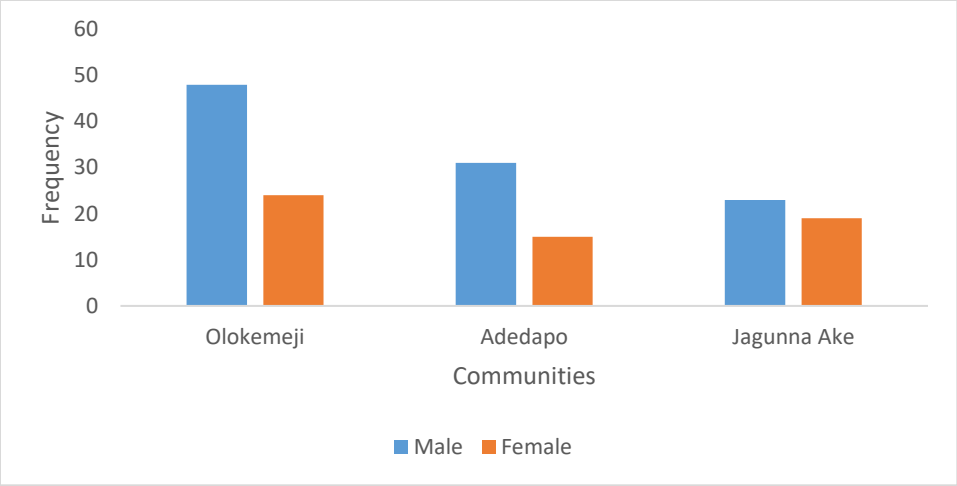


Figure 3: Sex distribution of respondents by communities

The table 1 shows that most respondents have lived in their communities for a long period, particularly more than 11 years (78 respondents). Only a small number (16 respondents) have stayed for 0–5 years. Olokemeji has the highest number of long-term residents (36), followed by Jagunna Ake (22). Table 2 shows that secondary education is the most common educational level among respondents (56 individuals), followed by primary education (43). A considerable number also attained tertiary education (35), while vocational education accounts for 26 respondents.

Table 3 shows variations in household size between the two communities. In Olokemeji, the majority of respondents (48) have small households with fewer than four members. In contrast, Adedapo has more respondents (28) within the medium household size category (5–9 members). Table 4 shows that farming is the dominant occupation across all three communities, particularly in Olokemeji (26 respondents) and Adedapo (18 respondents). Gathering of non-timber forest products (NTFPs) is also common, especially in Olokemeji (19 respondents) and Jagunna Ake (12 respondents). Fishing and trading are moderately represented, while craft activities are least common, with no respondents engaged in craft in Adedapo.

Table 5 presents the distribution of climate change awareness levels across the three study communities. Overall, awareness levels were predominantly low, with 71 respondents (44.4%) reporting low awareness and 28 respondents (17.5%) indicating no awareness of climate change. Only 17 respondents (10.6%) demonstrated high awareness. Across communities, Olokemeji had the highest number of respondents with low awareness (33), while Jagunna Ake had the highest proportion of respondents with no awareness (10 out of 42, representing 23.8% of that community).

Table 1: Length of Residency of Respondents Across Communities

	Residency		
Communities	**0-5**	**6 -11**	**> 11**
Olokemeji	9	27	36
Adedapo	5	21	20
Jagunna Ake	2	18	22

Table 2: Educational Level of Respondents Across Communities

	Educational Level			
Communities	**Primary**	**Secondary**	**Tertiary**	**Vocational**
Olokemeji	18	26	15	13
Adedapo	16	13	9	8
Jagunna Ake	9	17	11	5

Table 3: Household Size Distribution of Respondents Across Communities

	Household size		
Communities	**< 4**	**5 - 9**	**> 10**
Olokemeji	48	16	8
Adedapo	12	28	6
Jagunna Ake	18	11	13

Table 4: Occupational Distribution of Respondents Across Communities

	Occupation				
Communities	**Farming**	**Fishing**	**Gathering NFTP**	**Craft**	**Trading**
Olokemeji	26	12	19	3	12
Adedapo	18	9	13	0	6
Jagunna Ake	12	8	12	4	6

Table 5: Distribution of Climate Change Awareness Levels Across Communities

	Level of Climate Change awareness			
Communities	**High Level**	**Middle level**	**Low Level**	**No Ideal**
Olokemeji	7	22	33	10
Adedapo	6	12	20	8
Jagunna Ake	4	10	18	10

Access and available source of information on Climate change

Table 6 presents respondents' access to climate change information across the three study communities. Overall, access was high, with 142 respondents (88.8%) reporting that they have access to climate change information, while only 18 respondents (11.2%) indicated no access. Across communities, Olokemeji had the highest absolute number of respondents with access (65 out of 72), representing 90.3% of that community. Adedapo followed with 40 respondents (87.0% of the community), while Jagunna Ake had 37 respondents (88.1% of the community) reporting access.

Table 7 presents the primary sources through which respondents access climate change information across the three communities. Government sources were the most frequently cited channel overall, with 74 respondents (46.3%) obtaining climate information from government agencies, extension services, or public institutions. Non-governmental organizations (NGOs) were the second most common source,

reported by 46 respondents (28.8%), followed by social networks; including family, friends, and community members mentioned by 40 respondents (25.0%).

Table 8 presents the frequency of perceived climate change indicators reported by respondents across the three study communities. Increased temperature was the most frequently reported indicator overall, cited by 42 respondents (26.3%), followed closely by erratic rainfall pattern (35 respondents, 21.9%) and prolonged drought (34 respondents, 21.3%). These three indicators together accounted for nearly 70% of all responses, suggesting that rising temperatures and rainfall variability are the most conspicuous manifestations of climate change to local communities. Unpredictable planting season (21 respondents, 13.1%) and increased rainfall intensity (19 respondents, 11.9%) were moderately reported, while decreased rainfall was the least recognized indicator (9 respondents, 5.6%).

Table 9 shows how the different communities perceive the benefits they receive from the forest. People in Olokemeji mostly value the forest for food production, showing a strong reliance on it for their daily needs. In Adedapo, climate regulation stands out, suggesting that residents are more aware of the role of the forest in improving environmental conditions. Jagunna Ake shows a fairly balanced view, recognizing food, NTFPs, and climate regulation almost equally.

Table 10 shows how respondents in Olokemeji, Adedapo, and Jagunna Ake perceive the effects of climate change on forest resources, agriculture, and general infrastructure. In all the communities, the majority indicated "Yes," reflecting a widespread belief that climate change is negatively influencing these sectors. The impact is most strongly felt in agriculture, especially in Olokemeji.

Table 6: Access to Climate Change Information Across Communities

Communities	Yes	No
Olokemeji	65	7
Adedapo	40	6
Jagunna Ake	37	5

Table 7: Sources of Climate Change Information Across Communities

Sources of information			
Communities	**Govt**	**NGO**	**Social Network**
Olokemeji	29	24	19
Adedapo	22	13	11
Jagunna Ake	23	9	10

Table 8: Perceived Climate Change Indicators Across Communities

	Communities		
Climate change manifestation	**Olokemeji**	**Adedapo**	**Jagunna Ake**
Prolonged Drought	15	12	7
Increased Temperature	22	9	11
Increased Rainfall intensity	8	6	5
Erratic Rainfall Pattern	16	10	9
Decreased Rainfall	4	1	4
Unpredictable planting season	7	8	6

Table 9: Perceived Ecosystem Services Provided Across Communities

	Ecosystem Services Provided by Forest				
Communities	Food Production	NTFPs	Climate Regulation	River Protection	Biodiversity Conservation
Olokemeji	32	12	13	5	10
Adedapo	8	9	15	6	8
Jagunna Ake	9	10	11	4	8

Table 10: Perceived Impact of Climate Change on Ecosystem Services and Livelihood Sectors Across Communities

	Climate change and its impact on Ecosystem services								
	Forest Resources			Agriculture			General Infrastructure		
Communities	Y	N	R	Y	N	R	Y	N	R
Olokemeji	60	8	4	65	7	0	59	7	6
Adedapo	42	3	1	39	6	1	42	2	2
Jagunna Ake	39	2	1	40	1	1	38	4	0

Table 11 reveals key climate change indicators observed by respondents in Olokemeji, Adedapo, and Jagunna Ake. Shifting growing seasons, frequent drought/flooding, disappearance of plant and animal species, and reduction in crop yield were among the most commonly reported indicators, particularly in Olokemeji.

Tables 12a and 12b present the relationship between communities and climate change awareness. Table 12a shows that most respondents across Olokemeji, Adedapo, and Jagunna Ake have low to medium awareness, with fewer individuals reporting high awareness or no knowledge of climate change. Table 12b shows the Chi-square test, indicating a statistically significant association between community and awareness level ($p = 0.047$), suggesting that climate change awareness varies across the different communities.

Tables 13a and 13b examine the relationship between educational level and climate change awareness. Table 13a shows that respondents with **t**ertiary education tend to have higher awareness, while those with primary or vocational education are mostly in the low or no-idea categories. Table 13b presents the Chi-square results, indicating a statistically significant association between educational level and climate change awareness ($p = 0.026$), suggesting that higher education is linked to greater awareness of climate change.

Table 14 presents the binary logistic regression results identifying factors that influence climate change awareness. Higher education, longer residency, access to information, and being from Olokemeji significantly increase the likelihood of awareness. Farming occupation was not statistically significant. The model explains 41% of the variance and correctly classifies 73.6% of respondents, highlighting key social and informational determinants of climate change awareness.

Table 11: Perceived Climate Change Indicators Across Selected Communities

Indicators	Olokemeji	Adedapo	Jagunna Ake
Shifting growing season	70	39	39
Reduction in crop yield	69	43	41
Biodiversity loss	42	32	29
Erratic Rainfall	52	45	35
Disappearance of some plant and animal species	74	29	25
Decrease in abundance of Forest Resources	65	44	41
Severe Erosion	67	28	28
Frequent Drought/ Flooding	78	32	30

Table 12a: Cross-tabulation of Community and Climate Change Awareness Level

Community	High (%)	Medium (%)	Low (%)	No Idea (%)	Total
Olokemeji	7 (9.7)	22 (30.6)	33 (45.8)	10 (13.9)	72
Adedapo	6 (13.0)	12 (26.1)	20 (43.5)	8 (17.4)	46
Jagunna Ake	4 (9.6)	10 (23.8)	18 (42.9)	10 (23.8)	42
Total	17	44	71	28	160

Table 12b. Chi-square Test between Community and Climate Change Awareness

Test	Value	df	p-value
Pearson Chi-Square	12.64	6	0.047*
Likelihood Ratio	13.21	6	0.039
N of Valid Cases	160		

*Significant at $p \leq 0.05$

Table 13a. Educational Level and Climate Change Awareness

Education	High	Medium	Low	No Idea
Primary	3	14	23	16
Secondary	7	20	18	11
Tertiary	6	9	8	3
Vocational	1	1	7	4

Table 13b. Chi-Square Test between Educational Level and Climate Change Awareness

Test Statistic	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	18.91	9	0.026*
Likelihood Ratio	19.47	9	0.021
Linear-by-Linear Association	6.82	1	0.009
N of Valid Cases	151		

* Significant at $p \leq 0.05$

Table 14: Binary Logistic Regression Analysis of Determinants of Climate Change Awareness

Predictor Variable	B	S.E.	Wald	Odds Ratio (Exp(B))	95% CI for Exp(B)	p-value
Education (Secondary and above)	0.89	0.34	6.85	2.43	1.26 – 4.70	0.009*
Residency (> 6 years)	0.67	0.29	5.41	1.95	1.11 – 3.42	0.020*
Access to information	1.12	0.41	7.46	3.06	1.37 – 6.82	0.006*
Farming occupation	-0.58	0.31	3.52	0.56	0.30 – 1.03	0.061
Community (Olokemeji)	0.44	0.22	4.01	1.55	1.01 – 2.38	0.045*
Constant	-2.13	0.58	13.47	—	—	0.000

Model Statistics

Model Fit Indicator	Value
−2 Log Likelihood	148.2
Nagelkerke R^2	0.41
Classification Accuracy	73.6%
N	160

* Significant at $p \leq 0.05$

DISCUSSION

This study provides evidence that communities surrounding the Olokemeji Forest Reserve are already experiencing noticeable climate-related environmental changes that affect both ecosystem services and rural livelihoods. The findings demonstrate that local perceptions of climate change are closely linked to the dependence of these communities on forest resources and rain-fed agricultural systems. This is consistent with research from across West Africa showing that farmers possess detailed, experience-based knowledge of rainfall variability (Badiane *et al.*, 2026; Gbedo *et al.*, 2026).

The predominance of low to moderate climate change awareness among respondents suggests that adaptive capacity within the study area remains limited. The statistically significant association between community location and awareness levels ($\chi^2 = 12.64$, $p = 0.047$) indicates that awareness is unevenly distributed across the forest communities. This variation reflects differences in exposure to climate risks, access to information, and socio-economic characteristics. Within the framework of socio-ecological systems (SES), such disparities influence the vulnerability and resilience of communities to environmental change (Stojetz *et al.*, 2026). Access to climate information emerged as the most influential factor determining climate change awareness. Respondents with access to information were significantly more likely to demonstrate higher awareness levels. This finding supports existing research indicating that access to reliable environmental information improves risk perception and strengthens adaptive behaviour (Global EbA Fund, 2026; United Nations Environment Programme, 2025). Effective communication channels, including extension services, government agencies, and community

networks, therefore play a critical role in improving local climate literacy.

Education also significantly influenced climate change awareness (χ^2 = 2.43, p = 0.009). Respondents with higher levels of formal education were more likely to understand and interpret environmental changes within the context of climate variability. There was also significant association between education and the perception of reduced crop yields (χ^2 = 12.34, p < 0.05). This implies that education enhances the ability of individuals to process environmental information, engage with institutional support systems, and adopt adaptive strategies. This finding aligns with studies that identify education as an important form of human capital that improves climate risk understanding and adaptive capacity (Covitt *et al.*, 2025).

Length of residency also contributed significantly to climate change awareness (χ^2 = 1.95, p = 0.020). Long-term residents were more likely to perceive environmental changes due to their accumulated local ecological knowledge and prolonged exposure to climate variability (Ballew *et al.*, 2020; Gbedo *et al.*, 2026). Such experiential knowledge is an important component of climate risk perception. However, experiential knowledge alone may not be sufficient to promote effective

adaptation unless it is supported by formal climate information and institutional support (Badiane *et al.*, 2026; United Nations Environment Programme, 2025).

The occupational structure of the communities reveals a complex pattern of vulnerability. Farmers reported strong perceptions of declining crop yields (χ^2 = 9.87, p < 0.05) and changing rainfall patterns, reflecting their high sensitivity to climate variability. Nevertheless, farming occupation was not a significant predictor of overall climate change awareness in the regression model (OR = 0.56, p = 0.061). This suggests the presence of a knowledge–exposure gap, where individuals who experience climate impacts most directly may not have adequate access to formal climate information (Hansen *et al.*, 2019; Stojetz *et al.*, 2026). Consequently, farmers may observe environmental changes without fully connecting them to broader climate change processes.

Respondents also reported several environmental indicators of climate change, including increasing temperatures, erratic rainfall patterns, prolonged droughts, and shifts in planting seasons. These observations correspond with regional climate projections for West Africa, which indicate increasing temperature trends and greater rainfall variability (Okali, 2026). Scientific attribution studies have confirmed that human-driven climate change has made seasonal downpours across the Niger basin 5-20% more intense, directly affecting agricultural systems (Okali, 2026). Such environmental changes have direct consequences for agricultural productivity, biodiversity, and forest resource availability. The findings further indicate that communities rely heavily on forest ecosystem services for food production, non-timber forest products, and environmental regulation (Gbedo *et al.*, 2026). Climate-related disruptions to these services therefore have significant implications for rural livelihoods. In response to environmental pressures, households may diversify their livelihood strategies by increasing reliance on forest products or alternative economic activities. While this diversification can provide short-term coping benefits, it may also increase pressure on forest ecosystems and potentially undermine long-term ecological sustainability. Over time, this can create a cycle where efforts to cope with environmental change unintentionally increase pressure on natural resources. Such

interactions are common in SES, where human responses to environmental stress can sometimes reduce the long-term resilience of ecosystems and the communities that depend on them (Folke *et al.*, 2021; Intergovernmental Panel on Climate Change, 2022).

Age and gender were not significantly related to climate change awareness in this study. This suggests that structural factors such as education, access to information, and connection to institutions play a more important role in shaping how people understand climate risks than demographic characteristics alone. In other words, people's level of knowledge and the information available to them may influence their awareness more strongly than their age or gender. Similar patterns have been reported in climate perception studies, which show that access to knowledge and information often has a stronger influence on awareness than basic demographic factors (van der Linden *et al.*, 2020).

Consequently, it is important to integrate scientific climate knowledge with local ecological knowledge so as to strengthen community resilience (Badiane *et al.*, 2026; Community Forests

International, 2026). Enhancing adaptive capacity in forest-dependent communities requires not only technological solutions but also improved governance, institutional support, and equitable access to climate information (Ford Foundation, 2026; Global EbA Fund, 2026).

CONCLUSION AND RECOMMENDATIONS

This study demonstrates that forest-dependent communities surrounding the Olokemeji Forest Reserve are already experiencing the impacts of climate variability on ecosystem services and rural livelihoods. Although many respondents reported observable environmental changes such as erratic rainfall, increased temperatures, declining crop yields, and biodiversity loss, overall climate change awareness remains relatively low. Education, access to climate information, and length of residency were identified as key determinants of climate change awareness. In contrast, occupation and demographic characteristics played a less significant role. The results reveal a knowledge–exposure gap, where individuals who experience climate impacts most directly (particularly farmers) often lack access to formal climate information and adaptation resources. Strengthening climate resilience in forest communities therefore requires improved dissemination of climate information, enhanced extension services, and policies that support climate education and community-based learning. Integrating scientific climate knowledge with local ecological knowledge can help communities better understand environmental change and adopt appropriate adaptation strategies.

The study recommends sustainable forest management policies, inclusive information systems, and stronger institutional support mechanisms. These are essential for maintaining ecosystem services and securing rural livelihoods in the face of increasing climate uncertainty.

REFERENCES

Ahammad, R., Tomscha, S. A., Baudron, F., Eddy, I. M. S., Fromstein, M., Gergel, S. E., Abdoulaye, R., Asaha, S., Duriaux-Chavarría, J.-Y., Foli, S., Gumbo, D., Mumba, K. Y., Leonald, L., Rowland, D., van Vianen, J., and Sunderland, T. C. H. (2026). Forest visitation and utilization along agricultural intensification gradients. *Frontiers in Forests and Global Change*, 8, 1646882. https://doi.org/10.3389/ffgc.2025.1646882

Akintola, O.O., Bodede, A.I., Smart, M., Adebayo, A. G and Sulaiman, O. N. (2020). Assessment of Soil Properties in Olokemeji Forest Reserve, Nigeria. *Journal of Bioresources Management*,7(3):73-84

Badiane, A., Kasanoski, D. S., Mendes, O., Bonnet, M.-P., and Sá, R. M. (2026). Landscapes of uncertainty: Mangrove rice farmers' perceptions of rainfall variability and climate change adaptation in three coastal regions of Guinea-Bissau, West Africa. *Agricultural Water Management*, 324, 110120. https://doi.org/10.1016/j.agwat.2026.110120

Ballew, M. T., Leiserowitz, A., Roser-Renouf, C., Rosenthal, S., Kotcher, J., Marlon, J., Lyon, E., Goldberg, M., and Maibach, E. (2020). Experience with extreme weather and climate change belief. *Nature Climate Change, 10*(4), 322–327. https://doi.org/10.1038/s41558-020-0715-1

Chunwate, B. T., Marchant, R. A., Jew, E. K. K., and Stringer, L. C. (2025). Understanding local perspectives on the trajectory and drivers of gazetted forest reserve change in Nasarawa State, North Central Nigeria. *Land*, 14(7), 1450. https://doi.org/10.3390/land14071450

Community Forests International. (2026). Zanzibar Women Leadership in Adaptation (ZanzAdapt) [Project description]. Global Affairs Canada. Retrieved March 11, 2026, from https://w05.international.gc.ca/projectbrowser-banqueprojets/project-projet/Generatexml/P011941001

Covitt, B. A., Frank, N., Bestor, A. G., DeBiasio, S. G., Edmo, T., Kaiser, J., Lachapelle, P., Longknife, D. C., Jr., Wethington, N., and Saha, R. (2025). ResilienceMT: Partnering with rural and tribal communities to cultivate youth climate resilience engagement. *Connected Science Learning*, 7(4), 102–114. https://doi.org/10.1080/24758779.2025.2525830

Diaw, K., Blay, D. and Adu-Anning, C (2002). Socio-economic Survey of Forest Fringes Communities: Krokosua Hills Forest Reserve. A Report submitted to the Forestry Commission of Ghana. 86p.

Fadairo, O., Olajuyigbe, S., Osayomi, T., Adelakun, O., Olaniyan, O., Olutegbe, S., and Adeleke, O. (2021). Climate Change, Rural Livelihoods, and Ecosystem Nexus: Forest Communities in Agroecological zones of Nigeria. In W. Leal Filho *et al.* (Eds.), *African Handbook of Climate Change Adaptation* (pp. 1169-1192). Springer. https://doi.org/10.1007/978-3-030-45106-6_155

Fasona, M. J., Oloukoi, G., Olorunfemi, F. B., Elias, P. O., and Adedayo, V. T. (2015). Aspects of natural resource use and adaptation to climate change in the Nigerian Savanna. In A. Gbadegesin *et al.* (Eds.), *Frontiers in Environmental Research and Sustainable Environment in the 21st Century* (pp. 323-342). Ibadan University Press.

Ford Foundation. (2026, March 7). *Ford Foundation grantees advance climate justice across West Africa.* The Guardian Nigeria.

https://guardian.ng/news/ford-foundation-grantees-advance-climate-justice-across-west-africa/

Global EbA Fund. (2026). EbA-enhanced Climate Field Schools for Climate Resilience (EECCLiRe). Retrieved March 11, 2026, from https://globalebafund.org/project/eba-enhanced-climate-field-schools-for-climate-resilience-eecclire/

Gbedo, F. S., Houéhanou, T. D., Assogbadjo, A. E., and Glèlè Kakaï, R. (2026). Local ecological knowledge and forest inventories reveal Afzelia africana Sm. decline in Benin, West Africa. *Trees, Forests and People*, **23**, 101097. https://doi.org/10.1016/j.tfp.2025.10109

Hansen, J. W., Vaughan, C., Kagabo, D. M., Dinku, T., Carr, E. R., Körner, J., and Zougmoré, R. B. (2019). Climate services can support African farmers' context-specific adaptation needs at scale. *Frontiers in Sustainable Food Systems, 3*, 21. https://doi.org/10.3389/fsufs.2019.00021 (Frontiers)

Leal Filho, W., Oguge, N., Ayal, D., Adeleke, L., and da Silva, I. (Eds.). (2021). African handbook of climate change adaptation. *Springer*. https://doi.org/10.1007/978-3-030-45106-6

Mackenzie C.A and Ahabyona, P (2012). Elephants in the garden: financial and social costs of crop raiding. *Ecological economics* **75**,72-82

Olubode, S. O., Taiwo, D. M., and Woghiren, A. I. (2021). Floristic structure of some selected plots in Olokemeji Forest Reserve, Ogun State, Nigeria. *FUTY Journal of the Environment*, 15(1), 65–72.

Ogunleye, A. J., Adeola, A. O., Ojo, L. O., and Aduradola, A. M. (2004). Impact of farming activities on vegetation in Olokemeji Forest Reserve, Nigeria. *Global NEST Journal, 6*(2), 131–140. https://doi.org/10.30955/gnj.000253 (Global NEST Journal)

Okali, K. D. (2026, March 1). *Extreme flooding and intensifying rainfall variability in Nigeria*. EnviroNews Nigeria. https://www.environewsnigeria.com/extreme-flooding-and-intensifying-rainfall-variability-in-nigeria/

Onyekuru, N. A., Marchant, R., Platts, P., Chukwuone, N., Mukaila, R., Omeje, E., and Ajaero, C. (2026). Ecoregional assessment and mapping of climate change impacts and adaptation strategies among farmers across Nigeria. *Mitigation and Adaptation Strategies for Global Change* 31(2), 2. https://doi.org/10.1007/s11027-025-10281-2

Solaja, S. O., Bamiro, O. M., Ayeni, M. D., Awe, T. E., Faronbi, O. A., and Okonta, O. (2025). Mobile agricultural information and climate change adaptation strategies: Insight from smallholder farmers in Kwara, Nigeria. In 2025 Landmark University International Conference SEB4SDG. Landmark University Repository.

Stojetz, W., Ronzani, P., Pinay, J., d'Errico, M., and Brück, T. (2026). Shocking social safety: Evidence from violence and drought in North-east Nigeria. Food Policy, **138**, 103005. https://doi.org/10.1016/j.foodpol.2025.103005

TheCable. (2026, January 16). OLOKEMEJI: A Nigerian forest, once stripped bare, provides new livelihoods. Accessed 27th February from https://www.thecable.ng/olokemeji-a-nigerian-forest-once-stripped-bare-provides-new-livelihoods/

United Nations Environment Programme. (2025, October 3). *Bridging gaps: Technology, communities, and sustainable funding in the Congo Basin. Congo Landscapes*. https://www.congolandscapes.org/news/bridging-gaps-technology-communities-and-sustainable-funding-congo-basin

van der Linden, S., Leiserowitz, A., Feinberg, G., and Maibach, E. (2015). The scientific consensus on climate change as a gateway belief. *PLOS ONE, 10*(2), e0118489. https://doi.org/10.1371/journal.pone.0118489

SPATIAL ASSESSMENT AND TEMPORAL DYNAMICS OF ABOVE- AND BELOWGROUND BIOMASS AND CARBON STOCKS IN THE KANAWA FOREST RESERVE, GOMBE STATE, NIGERIA

Yuguda[1], UA, Saka[2], MG, Dishan[2], EE, Bello[3], MB and Abba, HM[1]
[1]Department of Plant Sciences, Gombe State University
[2]Department of Forestry and Wildlife Management, Modibbo Adama University
[3]Department of Geography and Environmental Management, Gombe State University
Corresponding Author's Email: uayuguda@gsu.edu.ng

ABSTRACT

Forest biomass is a critical component of global decarbonization strategies, yet spatially explicit data on aboveground (AGB) and belowground biomass (BGB) remain scarce in West African savanna ecosystems. This study aimed to quantify biomass and carbon stocks in the Kanawa Forest Reserve (KFR), Nigeria, and develop robust remote sensing models for their spatial estimation. Field inventories were conducted across 10 systematic 1-ha plots. AGB and BGB were estimated using IPCC-compliant allometric equations (root-to-shoot ratio = 0.26; carbon fraction = 0.47). Multi-temporal Landsat 8 OLI imagery (2020–2024) was processed to derive vegetation indices (NDVI, SAVI, ARVI). Non-linear regression models were calibrated and validated, with uncertainty quantified via Monte Carlo analysis and model selection guided by the Akaike Information Criterion (AIC). The reserve exhibited pronounced spatial heterogeneity. Total plot-level AGB was 1,257.09 Mg ha^{-1} (590.83 Mg ha^{-1} carbon), and BGB was 326.85 Mg ha^{-1} (153.62 Mg ha^{-1} carbon), yielding an aggregate biomass of 1,583.94 Mg ha^{-1}. The inverse-transformed ARVI model yielded the highest predictive accuracy (Adj. R^2 = 0.889; CV = 7.21%), successfully overcoming spectral saturation. Multi-year raster analysis revealed a net decline of 4.40% in mean landscape AGB between 2020 and 2024. Despite its protected status, KFR is experiencing gradual biomass erosion, likely due to anthropogenic disturbances. The validated inverse-transformed spectral modeling framework provides a highly scalable, cost-effective monitoring, reporting, and verification (MRV) architecture, offering a critical empirical baseline for Nigeria's REDD+ commitments and the operationalization of the Climate Change Act of 2021.

Keywords: Aboveground biomass, Carbon sequestration, Spatial modeling, Remote sensing, REDD+, Sudan-Guinea Savanna

INTRODUCTION

Climate change has increased the importance of accurate forest biomass and carbon accounting for climate mitigation and ecosystem management (Bouchene *et al.,* 2021; Manduna and Fundira, 2022). Recent assessments by the Intergovernmental Panel on Climate Change (Intergovernmental Panel on Climate Change [IPCC], 2023) emphasize the escalating frequency and severity of climate-induced phenomena, including floods, desertification, extreme heatwaves, and coastal alterations. Forest biomass contributes substantially to terrestrial carbon storage and national climate mitigation programmes (Forfora *et al.,* 2024).

Forest ecosystems comprise both aboveground and belowground living biomass, alongside decomposed litter and soil organic matter. Aboveground biomass (AGB) encompasses all living vegetation—both woody and herbaceous—situated above

the soil surface, including stems, branches, bark, seeds, and foliage (Johnston *et al.,* 2021). Tree AGB constitutes the largest terrestrial carbon pool and is highly susceptible to deforestation and degradation (Mohd Zaki and AbdLatif, 2017). The sensitivity of forest biomes to climate extremes, such as droughts and heavy precipitation, profoundly influences standing biomass and carbon fluxes (Reichstein and Carvalhais, 2019). How these carbon sinks will respond to increasingly erratic rainfall remains uncertain. Evaluating the role of forests in the carbon cycle necessitates precise quantification of forest biomass, typically expressed as the dry weight of living organisms (Temesgen *et al.,* 2015).

Accurate assessment and spatial mapping of biomass are fundamental for carbon stock quantification, climate change impact assessment, and the strategic placement of bioenergy processing facilities (Kumar and Mutanga, 2017). AGB estimates form the foundation of national carbon inventories and international carbon trading schemes. Carbon markets require long-term, dynamic data on the 'live' aboveground biomass component, which is highly responsive to disturbances such as fire, logging, storms, and land-use changes. Because AGB continuously fluctuates and significantly influences atmospheric carbon fluxes, its continuous monitoring is imperative (Kumar and Mutanga, 2017). To qualify for REDD+ (Reducing Emissions from Deforestation and Forest Degradation) remuneration, nations must accurately estimate carbon stocks and emissions across all significant land-cover transitions (Bos *et al.,* 2019).

Plant biomass is recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS, 2016) and serves as a critical input for the United Nations' REDD+ program and Earth system models (Herold *et al.,* 2019). Spatially continuous maps of plant biomass are therefore essential for reducing uncertainties in the global carbon cycle, particularly in regions lacking ground-based or airborne LiDAR data. The assessment of AGB and carbon stocks is vital for evaluating carbon sequestration potential and guiding environmental management strategies (Yani *et al.,* 2025). Various methodologies have been employed globally to assess these metrics. For instance, in the Eastern Himalayas, forest inventories combined with Landsat data revealed significant biomass losses over 30 years due to land-cover changes (Sharma *et al.,* 2022). Similarly, Keawsomsee and Tongleamnak (2024) utilized Planet NICFI satellite data with Random Forest regression to assess biomass, achieving high accuracy ($R^2 = 0.77$; RMSE = 65.98 Mg/ha).

While AGB is frequently monitored, belowground biomass (BGB) remains a critical, and under sampled component of forest carbon pools (Mokany *et al.,* 2006). Accurate BGB evaluation is essential for estimating total ecosystem carbon stocks and informs carbon sequestration potential, soil stability, and nutrient cycling, all of which are vital for REDD+ implementation and sustainable forest management (Henry *et al.,* 2009). Since the mid-20th century, global climate research has increasingly focused on reducing terrestrial carbon sources and enhancing sinks to mitigate the impacts of CO_2 enrichment (Gupta, 2016; Kumar *et al.,* 2017). Forest biomass is a key biophysical parameter for modeling terrestrial carbon dynamics and predicting forest responses to rising global temperatures (IPCC, 2014; FAO and ICRAF, 2019).

The United Nations Framework Convention on Climate Change (UNFCCC) REDD+ program collaborates with developing countries to promote forest carbon conservation as a mechanism for reducing greenhouse gas emissions (Kralicek *et al.,* 2017). The expanding carbon trade has

driven numerous policies requiring precise biomass and carbon stock estimations to underpin implementation strategies (Temesgen *et al.,* 2015). Accurate estimation of forest AGB and its temporal changes is essential for understanding the global carbon cycle (Houghton, 2005). Monitoring AGB dynamics supports political decisions regarding forest conservation and quantifies the impact of anthropogenic activities on terrestrial carbon stocks (Bojinski *et al.,* 2014; Williams *et al.,* 2013).

In Nigeria, the enactment of the Climate Change Act (2021) underscores the national commitment to strengthening climate action and evolving a domestic carbon market (Ajayi, 2022). The Act establishes the National Council on Climate Change (NCCC) to implement climate action plans, aiming for low greenhouse gas emissions and sustainable green growth. The Act also empowers the Council to oversee carbon taxation and emissions trading, creating an enabling environment for carbon investors (PwC, 2023). Despite these policy advancements, a significant paucity of data on carbon sequestration in Nigerian natural and reserved forests hinders the country's ability to optimize carbon credit gains through mechanisms like the Clean Development Mechanism (CDM) and REDD+. Specifically, there is limited information regarding AGB dynamics under varying disturbance regimes and climatic conditions in the Kanawa Forest Reserve (KFR).

Recent methodological advancements have focused on producing temporally and spatially explicit biomass maps using remote sensing (Araza *et al.,* 2023). High-resolution satellite imagery and airborne LiDAR enable fine-scale monitoring of forest structure, allowing researchers to track biomass fluctuations driven by natural and anthropogenic disturbances (Zhang *et al.,* 2021). However, the extent to which these technologies improve our understanding of AGB changes in heterogeneous savanna ecosystems remains underexplored. Therefore, this study aims to determine the aboveground and belowground biomass of the Kanawa Forest Reserve, assess the carbon sequestered, and develop robust spatial models to map these carbon stocks, thereby providing critical baseline data for regional climate mitigation strategies.

MATERIALS AND METHODS

Study area

Kanawa Forest Reserve lies in the Yamaltu-Deba Local Government Area of Gombe State in north-eastern Nigeria. It is located in the southern Sudan Savanna between latitude 9°15'00"N and 10°18'30'N, longitude 11°18'10" E. and 11°22'09" E., and elevation 336-390m.

The forest was gazetted as a forest reserve in 1953 and covered 53 hectares with its shallow V-shaped drainage, the topography is primarily undulating (Mohammed *et al.,* 2015).

The two distinct seasons that make up the climate are the dry season, which runs from November to March, and the rainy season, which runs from April through October. The yearly total of the rainfall pattern falls between 658 and 923 mm. The annual mean temperature is between 32.2 and 32.8°C. The vegetation of the study area is a mosaic made up of dense Sudan Savanna vegetation especially around the hilly part of the reserve and marshy, riparian, lowland rainforest vegetation near the Poli stream, grassland with tall grasses and tropical thorn forests, in the drier part of the forest (Abba *et al.,* 2015). KFR is dominated by Sudan and Guinea savanna transitional vegetation, with a high diversity of herbaceous species, including *Cymbopogon citratus* and *Hyparrhenia rufa*. Woody species like *Afzelia africana* and *Isoberlinia doka* provide critical ecosystem services (Abba *et al.,* 2015). The reserve also

acts as a biodiversity hotspot, with its flora supporting various avifaunal populations (Tali *et al.,* 2022).

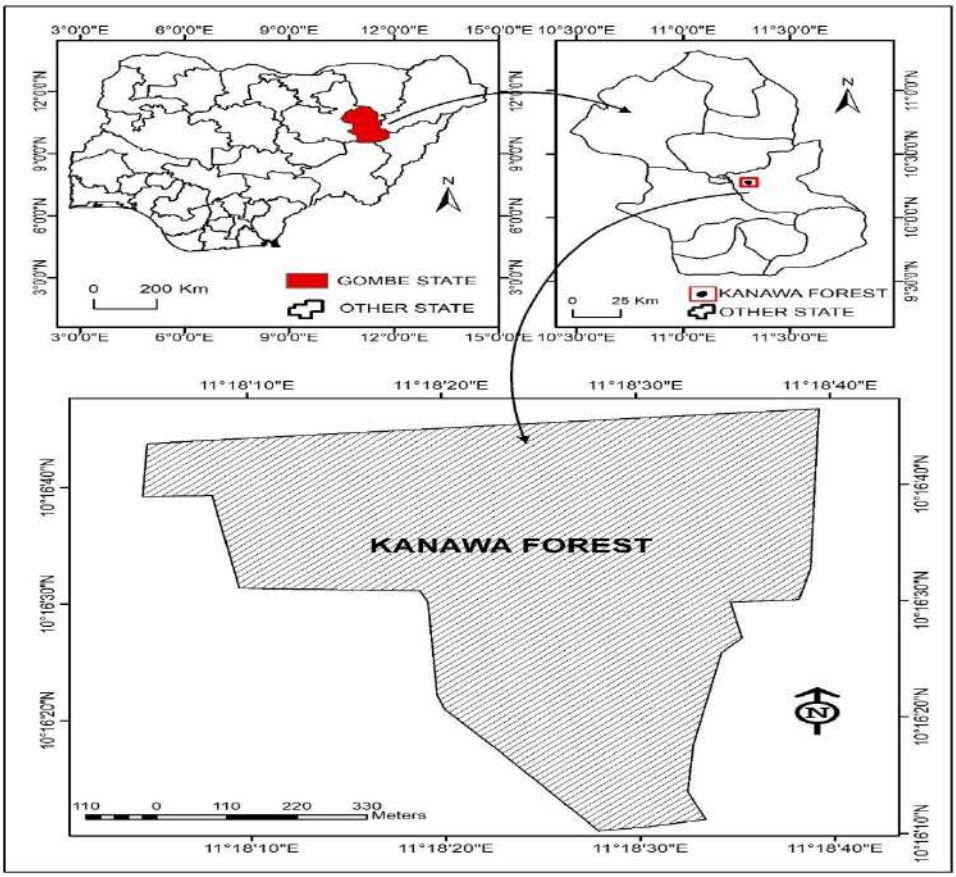


Figure 1: Kanawa Forest Reserve (Source: GIS Lab, Gombe State University)

Data collection and Sampling Techniques

A total of 10 plots were established across the study area. This sample size was determined based on minimum sampling intensity for biomass and carbon estimation in areas with low to moderate tree density (Rügnitz *et al.,* 2009). Systematic sampling method was employed to ensure that plots were representative of the variation within each study site (Ravindranath and Madelene, 2008) and the plots were placed at fixed and equal intervals (100 m). Each sampling plot has an area of 100 m × 100 m (1 hectare), corresponding to 11 pixels of Landsat 8 per sample plot. Within each sampling plot four grids of 20m × 20m were nested in four corners for trees and 5m × 5m subplots for shrubs species (Bordoloi *et al.,* 2021) and another 1m × 1m subplots for litter (Fig. 2).

Aboveground biomass (AGB) data were derived from systematic field inventories of woody vegetation and litter components within each sampling unit. Diameter at breast height (DBH) and total height, were recorded for all woody individuals. To ensure

comprehensive sampling across structural layers, vegetation was categorized by size: shrubs and saplings (1–9 cm DBH) and mature trees (≥ 10 cm DBH) were independently assessed within the designated plot. DBH was measured using a diameter tape at 1.3 m above ground level for trees. For shrubs and small trees, stem diameter was measured at the most representative position near the base or at the point of primary branching, depending on the growth form of the plant. Total plant height was determined using a clinometer. The litter was collected by establishing 0.5 m × 0.5 m quadrants within a 1 m × 1 m subplot and weighing the samples (Asrat *et al.,* 2022). Tree necromass <5 cm in diameter or <50 cm in length, non-decomposed plant materials, crop residues, unburned leaves and branches, roots, and partly decomposed dark litter was gathered from randomly selected 0.5 m × 0.5 m quadrants (Asrat *et al.,* 2022).

Aboveground biomass (AGB) was used to estimate belowground biomass (BGB) by using allometric equations that establish a relationship between the two. The belowground biomass (BGB) was calculated by multiplying above-ground biomass by 0.26 being the root to shoot ratio (Ma *et al.,* 2021; Sukhbaatar *et al.,* 2023).

Aboveground and belowground biomass estimation and carbon stock analysis

Aboveground and belowground biomass were estimated from field-measured vegetation attributes using generalized allometric procedures consistent with the Intergovernmental Panel on Climate Change guidelines. For trees, aboveground biomass (AGB) was estimated using the IPCC (2006, 2019) generalized allometric model, in which biomass was expressed as a function of diameter at breast height (DBH) and total tree height. The coefficients $a$and b applied in the model were adopted from the multi-species equation developed by Henry *et al.* (2009) for savannah and agro-landscape vegetation. Tree carbon stock was subsequently derived by multiplying the estimated AGB by a carbon fraction of 0.47, following standard conversion practice.

The AGB for trees was estimated using equation (4) and for shrubs using equation (5).

$$\text{AGB} = a \times \left(\text{DBH}^2 \times H\right)^b \text{…….. (1)}$$

(Chave *et al.,* 2014; Henry *et al.,* 2009)

Where:

DBH = Diameter at Breast Height (in cm)

H = Tree height (in meters)

$$\text{AGB} = a \times \left(\text{D}^b\right) \quad \text{…….(2)}$$

(Conti *et al.,* 2019)

Where:

D = Shrub diameter (in cm)

Carbon Sequestration was estimated by multiplying the AGB with a constant 0.47 (IPCC, 2006, IPCC, 2019)

$$\text{Carbon} = \text{AGB} \times 0.47 \text{…… (3)}$$

Litter biomass sampling was conducted by laying 0.5 m × 0.5 m quadrats within a 1 m × 1 m subplot. All litter materials within the quadrats were collected and weighed in accordance with the method of Asrat *et al.,* (2022). The sampled materials comprised fine necromass, including dead woody fragments less than 5 cm in diameter or less than 50 cm in length, as well as non-decomposed plant materials, crop residues, unburned leaves and branches, roots, and partially decomposed dark litter collected from randomly selected quadrats (Asrat *et al.,* 2022).

Litter biomass was estimated using:

$$AGB = \frac{W}{A} \text{…… (4) (IPCC, 2006)}$$

where:

W = Total dry weight of litter collected (g)

A = Sampled area (m²)

Belowground biomass estimation and carbon stock analysis

Belowground biomass was estimated indirectly as a fixed proportion of aboveground biomass using the root-to-shoot ratio approach. For both trees and shrubs, belowground biomass (BGB) was calculated by multiplying the estimated aboveground biomass (AGB) by a root-to-shoot ratio ((R)) of 0.26. Thereafter, belowground carbon stock was derived by applying a carbon conversion factor of 0.47 to the estimated BGB.

Belowground Biomass (BGB):

$$BGB = AGB \times R \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

(IPCC, 2006; IPCC, 2019)

Where:

AGB = Aboveground biomass (in kg or tons)

R = Root-to-shoot ratio (0.26).

Carbon Sequestration:

$$Carbon\ (BGB) = BGB \times 0.47 \quad \ldots\ldots\ldots\ldots(6)$$

(IPCC, 2006; IPCC, 2019

Remote sensing method of data collection

Multi-temporal satellite imagery of the study area was acquired from the United States Geological Survey (USGS) EarthExplorer archive using the Landsat 8 Operational Land Imager (OLI) data series. The imagery was selected to support vegetation analysis and the derivation of vegetation indices required for the spatial assessment of land-cover characteristics and ecosystem condition within the study area. Image processing was undertaken at the Zonal Advanced Space Technology Applications Laboratory, National Centre for Remote Sensing, Federal University Kashere, Gombe State, Nigeria.

Following acquisition, the relevant Landsat 8 OLI spectral bands were imported into ArcMap and combined through layer stacking to produce a multispectral composite image suitable for analysis. The Composite Bands tool in ArcMap was used for this purpose. Thereafter, radiometric calibration was performed to convert the original digital number (DN) values to top-of-atmosphere (TOA) reflectance using scene-specific metadata. This standardised reflectance values across scenes..

Atmospheric correction was subsequently carried out using the Dark Object Subtraction (DOS) method to reduce the effects of atmospheric scattering and enhance spectral consistency. These preprocessing procedures were necessary to improve the quality and reliability of the satellite data prior to vegetation-index computation and further spatial analysis.

Spatial data analysis

Computation of Vegetation Indices

Raster Calculator tool was used to compute each vegetation index. Below are the formulas and steps for each index:

Normalized Difference Vegetation Index (NDVI)

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)} \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

(Rouse *et al.,* 1974; Tucker, 1979).

Soil-Adjusted Vegetation Index (SAVI):

$$SAVI = \frac{(NIR-RED)\times(1+L)}{(NIR+RED+L)} \quad \ldots\ldots\ldots\ldots\ldots..(8)$$

(Huete, 1988).

Atmospherically Resistant Vegetation Index (ARVI):

$$ARVI = \frac{\left(NIR-\left(RED-\gamma\times(RED-BLUE)\right)\right)}{\left(NIR+\left(RED-\gamma\times(RED-BLUE)\right)\right)} \ldots\ldots\ldots..(9)$$

(Kaufman and Tanré, 1992).

For each index (NDVI, SAVI, ARVI), the maximum annual composites were computed by selecting the highest value recorded for each pixel over the course of a year. This

helps reduce noise caused by seasonal fluctuations, cloud cover, and phenology.

Data analysis

The summation of the carbon stock in aboveground biomass (AGB), belowground biomass (BGB) and soil carbon content were used to estimate the carbon sequestration potential in the reserve.

Regression analysis was used to examine relationships between vegetation indices and biomass. The relationship between the field data and the vegetation indices was established using a non-linear regression model. The following general equation was used:

1. **Aboveground Biomass (AGB)**:

$$\mathrm{AGB} = a_1 \times \left(\mathrm{NDVI}^{b_1}\right) + a_2 \times \left(\mathrm{SAVI}^{b_2}\right) + a_3 \times \left(\mathrm{ARVI}^{b_3}\right)$$

2. **Belowground Biomass (BGB)**:

$$\mathrm{BGB} = c_1 \times \left(\mathrm{NDVI}^{d_1}\right) + c_2 \times \left(\mathrm{SAVI}^{d_2}\right) + c_3 \times \left(\mathrm{ARVI}^{d_3}\right)$$

In these equations:

a_1, a_2, ..., a_5, **c_1, c_2, ..., c_5** are regression coefficients to be determined through model calibration.

b_1, b_2, ..., b_5, **d_1, d_2, ..., d_5** are exponents that capture the non-linear nature of biomass distribution.

The parameters **a** and **b** were calibrated using a non-linear least squares regression approach based on the African field data (Henry *et al.,* 2009).

***Spatial overlay* analysis**

Spatial overlay analysis was used to determine changes overtime and to evaluate the carbon sequestration potential of the reserve. The vegetation index layers were overlaid with climate data (temperature, precipitation). The analysis involved combining these layers to analyze correlations and influences on biomass and carbon stocks.

Spatial overlay analysis was implemented using raster map algebra. Vegetation index layers and climate surfaces (temperature, precipitation) were co-registered to a common spatial reference and resolution. Values were extracted at field plot coordinates to enable correlation analysis between spectral indices, climatic variables, and field-measured carbon stocks. Additionally, zonal statistics were computed for each study site polygon to summarize mean climate conditions and vegetation index values (Tomlin, 1990).

Model Formulation and Calibration

A suite of 21 candidate models were evaluated including single-index, dual-index, and multi-index nonlinear power-sum formulations. The general form of the multi-index model was:

$$\mathrm{AGB} = a_1(\mathrm{NDVI}^{b_1}) + a_2(\mathrm{SAVI}^{b_2}) + a_3(\mathrm{ARVI}^{b_3})$$

Models were calibrated using gradient-based optimization with field-measured AGB data and validated using 30% hold-out samples.

Model calibration and validation

Model training

A seventy percent (70%) of the field data was used to train the non-linear regression model. The non-linear optimization will minimize the difference between observed and predicted biomass.

Model validation

The model was validated using thirty percent (30%) of field data not used in training. Performance metrics - R^2 (coefficient of determination) and RMSE (root mean square error), will assess model accuracy.

Uncertainty analysis

Uncertainty in the model predictions was evaluated through Monte Carlo Analysis (MCA). MCA was used to assess uncertainty and variability in models by running 500 simulations using randomly generated inputs based on probability distributions (Yanai *et al.,* 2010; Chave *et al.,* 2004).

Akaike Information Criterion (AIC)

Model selection was performed using the Akaike Information Criterion (AIC), which provides a quantitative basis for comparing competing models by balancing model goodness-of-fit against model complexity. For each candidate model, the maximum likelihood was estimated and the number of fitted parameters was identified.

The AIC value was then computed as:

$AIC = 2k - 2\ln(L)$

where k is the number of estimated parameters in the model and L is the maximum likelihood of the model. The model with the lowest AIC value was selected as the most parsimonious model because it was considered to provide the best trade-off between explanatory power and overparameterization (Akaike, 2003; Burnham and Anderson, 2002).

In practice, all competing models were fitted to the same response variable and dataset, after which their AIC values were compared. Differences in AIC values (ΔAIC) were also used to assess the relative support for each model, with smaller values indicating stronger model support. Where necessary, models with $\Delta AIC < 2$ were considered to have substantial empirical support relative to the best model (Burnham and Anderson, 2002).

RESULTS

The results for aboveground biomass (AGB), belowground biomass (BGB), carbon sequestration, and carbon stock accumulation —are presented in Table 1. the total aboveground biomass across all plots was 1,257.09 Mg ha^{-1}, corresponding to an aboveground carbon (AGC) stock of 590.83 Mg ha^{-1} (Table 1). This represents a substantial CO_2 sequestration potential of approximately 2,152.93 Mg ha^{-1}. Belowground biomass totalled was 326.85 Mg ha^{-1}, storing 153.62 Mg ha^{-1} as belowground carbon (BGC), equivalent to an estimated 563.77 Mg ha^{-1} of CO_2 equivalent. The aggregate total biomass (AGB + BGB) was 1,583.94 Mg ha^{-1}. Biomass distribution at the plot level exhibited pronounced heterogeneity (Table 1). Plot KFR 5 emerged as a notable outlier, with exceptionally high values across all parameters (e.g., AGB: 445.43 Mg ha^{-1}; Total Biomass: 561.24 Mg ha^{-1}). In contrast, plots such as KFR 7 and KFR 9 recorded lower biomass and carbon stocks (e.g., KFR 7 Total Biomass: 41.19 Mg ha^{-1}). Mean litter biomass was (18,132.83 ± 961.18).

Vegetation index pattern

Across the five-year study period overall vegetation index values was 0.318 (NDVI), 0.510 (SAVI) and 0.311 (ARVI). Interannual variability was generally modest in the reserve SAVI SD = 0.09; ARVI SD = 0.08), indicating more pronounced year-to-year fluctuations in vegetation/soil-background conditions.

Table 1: Carbon stock parameters for Kanawa Forest Reserve

PLOTS	AGB (Mg ha⁻¹)	AGC	AGCO₂ Equivalent	BGB (Mg ha⁻¹)	BGC	BG CO₂ Equiv	Total Biomass (Mg ha⁻¹)
KFR 1	84.71	39.81	146.12	22.03	10.35	37.99	106.74
KFR 2	44.16	20.75	76.17	11.48	5.40	19.80	55.64
KFR 3	74.43	34.98	128.38	19.35	9.10	33.38	93.78
KFR 4	194.58	91.45	335.63	50.59	23.78	87.26	245.17
KFR 5	445.42	209.35	768.31	115.81	54.43	199.76	561.24
KFR 6	109.23	51.34	188.42	28.40	13.35	48.99	137.63
KFR 7	32.69	15.36	56.39	8.50	3.99	14.66	41.19
KFR 8	72.91	34.27	125.77	18.96	8.91	32.70	91.87
KFR 9	34.78	16.35	59.99	9.04	4.25	15.60	43.82
KFR 10	164.18	77.16	267.75	42.69	20.06	73.63	206.86
Total	**1257.09**	**590.83**	**2152.93**	**326.84**	**153.62**	**563.77**	**1583.94**

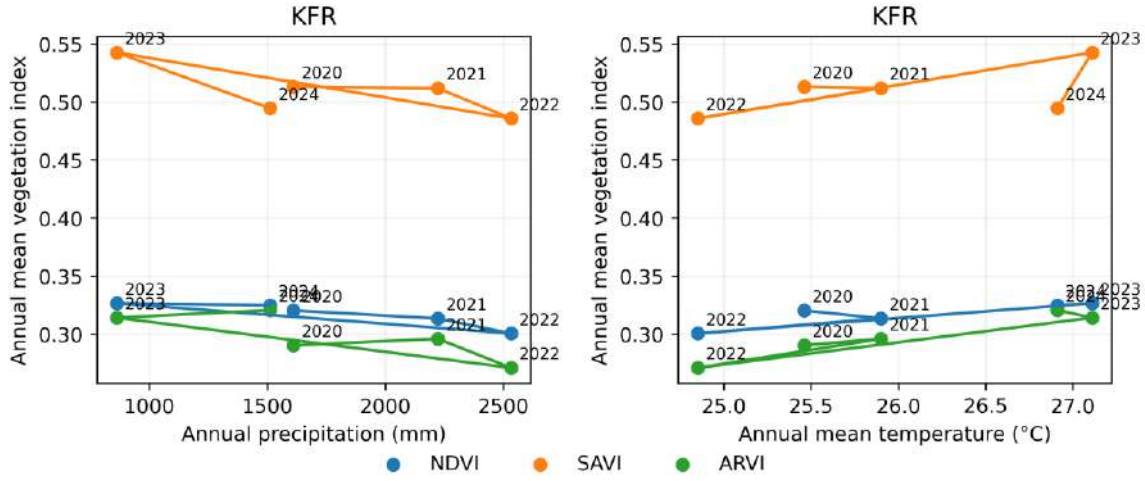


Figure 1. Annual mean vegetation indices (NDVI, SAVI, ARVI) plotted against annual precipitation (left panel) and annual mean temperature (right panel) at Kanawa Forest Reserve (KFR), 2020–2024

Climate-vegetation correlations

Pearson correlations quantified the association between annual mean indices and annual climate (Table 2). In KFR, ARVI was strongly and positively correlated with temperature (r = 0.974, p = 0.005), while NDVI was strongly and negatively correlated with precipitation (r = -0.921, p = 0.026). Other index-climate relationships were directionally consistent with these patterns but were not statistically significant (p>0.05) (e.g., NDVI vs temperature: r = 0.869, p = 0.056).

Table 2. Pearson correlations between annual mean vegetation indices and annual climate

Site	Index	Climate variable	n	r	p	Remarks
KFR	ARVI	Precipitation	5	-0.790	0.111	Not significant
	ARVI	Temperature	5	0.974	0.005	Significant
	NDVI	Precipitation	5	-0.921	0.026	Significant
	NDVI	Temperature	5	0.869	0.056	Not significant
	SAVI	Precipitation	5	-0.770	0.127	Not significant
	SAVI	Temperature	5	0.576	0.310	Not significant

n = number of years, r = correlation coefficient, p = (p-value > 0.05)

Spatial Analysis of Kanawa Forest Reserve (KFR)

Spatial overlay analysis: pixel-wise correlations

Pixel-wise spatial overlay analysis showed positive correlations between raster-predicted above-ground biomass (AGB) and the vegetation indices NDVI, SAVI, and ARVI (Table 3). The strength of the correlation varied by site, year, and index, although the general pattern remained positive throughout. NDVI correlations ranged from r = 0.8316 in 2024 to r = 0.8680 in 2023, while SAVI again closely matched NDVI in all years, with values ranging from r = 0.8316 to r = 0.8680. ARVI correlations ranged from r = 0.8357 in 2021 to r = 0.8687 in 2023. The number of sampled pixels at KFR was smaller and varied slightly across years, from 720 to 725 pixels.

Model Performance and Ranking Across Vegetation Sites

A total of 21 candidate models were evaluated — spanning three response variable configurations: untransformed aboveground biomass (AGB), its logarithmic transformation (Log *AGB*), and its inverse transformation (Inverse *AGB*). Model selection was based on a composite ranking criterion incorporating the Akaike Information Criterion (AIC), adjusted coefficient of determination (Adj. R^2), and root mean square error (RMSE).

Sensitivity of Model Fit to Response Variable Transformation

Model predictive performance exhibited marked sensitivity to the form of the response variable, with transformation type emerging as a primary determinant of goodness-of-fit. Untransformed AGB models yielded the highest heterogeneity in fit statistics (Table 4). Raw AGB models yielded substantially attenuated fit, with maximum Adj. R^2 values of 0.358, indicating that untransformed biomass is poorly approximated by linear spectral predictors at these locations. Logarithmic and inverse variance-stabilising transformations consistently improved model fit. The application of the Inverse*AGB* configuration with ARVI as the sole predictor increased Adj. R^2 from 0.358 (raw AGB) to 0.889 — a gain of 0.531.

Table 3. pixel-wise correlations and spatial autocorrelation

Site	Year	Index	Corr(AGB,VI)	N sample
	2020	NDVI	0.84040113	721
	2020	SAVI	0.840401129	721
KFR	2020	ARVI	0.853954212	721
	2021	NDVI	0.842946949	720
	2021	SAVI	0.842947544	720
	2021	ARVI	0.835667149	720
KFR	2022	NDVI	0.838039026	720
	2022	SAVI	0.838038934	720
	2022	ARVI	0.839425512	720
	2023	NDVI	0.867982134	725
	2023	SAVI	0.867982157	725
	2023	ARVI	0.868713101	725
	2024	NDVI	0.831629477	725
	2024	SAVI	0.831629356	725
	2024	ARVI	0.83746285	725

Model Hierarchy and Predictor Dominance

Evaluation of model rankings across response configurations reveals specific patterns of predictor dominance and index combination efficacy (Table 4). The single-index models — principally SAVI and ARVI — dominated the top-ranked positions for both raw AGB and Log*AGB* configurations, suggesting that spectral collinearity among multi-index combinations confers no additional explanatory advantage at this site.

Monte Carlo–Derived Predictive Uncertainty

Simulation stability was assessed using the coefficient of variation (CV%) derived from Monte Carlo bootstrap iterations, with low CV values indicating robust and reproducible model behaviour across resampled data partitions (Table 5).

Log*AGB* models maintained comparably low instability across all three sites, with CV values ranging from 13.3% to 21.7%. These values indicate that logarithmic transformation not only improves model fit but also substantially enhances the reproducibility of predictions under stochastic resampling, a property of considerable importance for extrapolative applications in carbon stock estimation. The best-ranked model was ARVI under the InverseAGB response form, with an adjusted R^2 of 0.889, an AIC of -174.38, and a CV of 7.21%.

Model Validation

Model validation was conducted for aboveground biomass (AGB) regression models. The model regressed inverse-transformed AGB against ARVI, yielding the equation $1/AGB = 0.000554 - 0.001375 \times ARVI$ (Table 5). Upon back-transformation, predicted values tracked the 1:1 reference line with acceptable correspondence across the central AGB range, though deviations were more pronounced at the upper tail, where the asymptotic amplification inherent to inverse back-transformation produced disproportionately large AGB changes for small ARVI increments. Residuals in inverse space were approximately randomly distributed around zero with no systematic trend or strong heteroscedastic pattern, confirming that the linearising transformation was appropriate and that OLS assumptions were satisfied within the transformed domain (Figure 2).

Multi-year AGB Raster Predictions and Temporal Change at Kanawa Forest Reserve (2020–2024)

Application of the biomass model to multi-year raster datasets yielded spatially explicit above-ground biomass (AGB) predictions for the Forest Reserve (KFR) across the 2020–2024 study period (Figure 3). The raster-derived mean AGB at KFR averaged 6,901.53 kg ha^{-1} across all years, reflecting the relatively dense woody biomass characteristic of a gazetted forest reserve under partial canopy closure. The maximum annual mean AGB recorded at the site was 8,031.32 kg ha^{-1}, while the minimum was 6,104.65 kg ha^{-1}, yielding an interannual range of approximately 1,926.67 kg ha^{-1}.

With respect to interannual variability, the reserve exhibited a standard deviation of mean AGB of 792.77 kg ha^{-1} across years. However, the corresponding coefficient of variation (CV) was 0.1149, indicating that year-to-year fluctuations were modest relative to the site's high biomass mean, and that AGB estimates at KFR were comparatively stable over the study period.

The direction of temporal change reveals that KFR recorded a net decline in raster-scale mean AGB between 2020 and 2024. Mean AGB decreased from 6,093.65 kg ha^{-1} in 2020 to 5,825.60 kg ha^{-1} in 2024, representing a change of −268.05 kg ha^{-1} and a percentage decline of −4.40% over the five-year period. Although KFR holds protected status, the downward trajectory suggests gradual biomass erosion from

anthropogenic pressures — encroachment, selective harvesting, fuelwood extraction — common across Guinea–Sudan reserves. The reserve is projected to decrease to 5,217.91 kg ha^{-1} by 2054, representing a net loss of approximately 7.8% over three decades. Similarly, mean carbon stocks are expected to decline from 2.66 Mg C ha^{1} to 2.45 Mg C ha^{-1}.

Table 4. Model Performance Across Study Sites and Ranking

Site	Response	Model	AIC	Adj_R²	RMSE	AIC_Rank	R²_Rank	Composite_Score	Final_Rank
	AGB	SAVI	216.29	0.3582	8917.1037	1	1	1	1
	AGB	ARVI	216.4	0.3515	8963.4454	2	2	2	2
	AGB	NDVI+SAVI	218.14	0.2774	8850.8828	3	3	3	3
KFR	AGB	SAVI+ARVI	218.29	0.2671	8913.8546	4	4	4	4
	AGB	NDVI+ARVI	218.32	0.2646	8928.7669	5	5	5	5
	AGB	NDVI+SAVI+ARVI	220.07	0.1635	8816.1620	6	6	6	6
	AGB	NDVI	221.8	-0.1129	11742.4281	7	7	7	7
	Inverse_AGB	ARVI	-174.38	0.8895	0.000029	1	1	1	1
	Inverse_AGB	SAVI+ARVI	-172.7	0.8778	0.000029	3	2	2.5	2
	Inverse_AGB	SAVI	-172.78	0.8704	0.000032	2	4	3	3
KFR	Inverse_AGB	NDVI+ARVI	-172.38	0.8737	0.000029	4	3	3.5	4
	Inverse_AGB	NDVI+SAVI	-170.91	0.8538	0.000031	5	6	5.5	5
	Inverse_AGB	NDVI+SAVI+ARVI	-170.77	0.8583	0.000029	6	5	5.5	6
	Inverse_AGB	NDVI	-151.2	-0.1215	0.000093	7	7	7	7
	Log_AGB	SAVI	15.05	0.7319	0.380365	1	1	1	1
	Log_AGB	ARVI	15.08	0.7311	0.380939	2	2	2	2
KFR	Log_AGB	SAVI+ARVI	16.99	0.6952	0.379379	3	3	3	3
	Log_AGB	NDVI+SAVI	17.01	0.6947	0.379709	4	4	4	4
	Log_AGB	NDVI+ARVI	17.08	0.6927	0.380916	5	5	5	5
	Log_AGB	NDVI+SAVI+ARVI	18.98	0.6448	0.379198	6	6	6	6
	Log_AGB	NDVI	29.37	-0.1228	0.778434	7	7	7	7

Table 5. Comparative performance and stability metrics of optimal AGB estimation models across study sites.

Site	Response	Model	Mean_Sim_AGB	SD_Sim_AGB	Lower_95	Upper_95	CV_Percent
	AGB	NDVI	12389.20	4152.60	4289.91	20898.49	33.52
	AGB	SAVI	12582.00	3125.23	6488.93	18828.37	24.84
	AGB	ARVI	12620.39	3217.83	6632.28	18863.53	25.50
KFR	AGB	NDVI+SAVI	12440.00	3389.04	5922.78	18978.79	27.24
	AGB	NDVI+ARVI	12467.72	3267.73	6127.73	18937.98	26.21
	AGB	SAVI+ARVI	12659.94	3389.70	5912.41	18977.21	26.78
	AGB	NDVI+SAVI+ARVI	12435.65	3551.38	5252.55	19387.38	28.56
	Inverse_AGB	NDVI	7363.67	2020.97	4762.50	12165.23	27.45
	Inverse_AGB	SAVI	7019.90	560.87	6071.13	8248.59	7.99
	Inverse_AGB	ARVI	6996.93	504.37	6103.77	8036.01	7.21
	Inverse_AGB	NDVI+SAVI	7011.42	590.38	5972.77	8256.10	8.42
KFR	Inverse_AGB	NDVI+ARVI	7023.51	542.78	6099.39	8178.73	7.73
	Inverse_AGB	SAVI+ARVI	7017.59	546.77	6093.74	8201.78	7.79
	Inverse_AGB	NDVI+SAVI+ARVI	7012.02	578.47	6002.07	8221.78	8.25
	Log_AGB	NDVI	9455.86	2675.65	5115.77	15731.83	28.30
	Log_AGB	SAVI	9100.59	1241.99	6942.68	11782.33	13.65
	Log_AGB	ARVI	9091.40	1222.35	6881.26	11675.29	13.45
	Log_AGB	NDVI+SAVI	9103.01	1309.21	6828.09	11859.49	14.38
	Log_AGB	NDVI+ARVI	9146.45	1325.66	6754.19	12114.63	14.49
	Log_AGB	SAVI+ARVI	9113.70	1315.67	6848.95	12017.09	14.44
	Log_AGB	NDVI+SAVI+ARVI	9139.17	1440.42	6665.82	12253.82	15.76

Table 5: Best-Fit Vegetation Index Models for Estimating Aboveground Biomass (AGB)

Site	Response Variable	Top-Ranked Model	Equation	Adj. R^2	AIC	CV (%)
KFR	Inverse_AGB	ARVI	$AGB = \frac{}{0.000554}$	0.889	−174.38	7.21

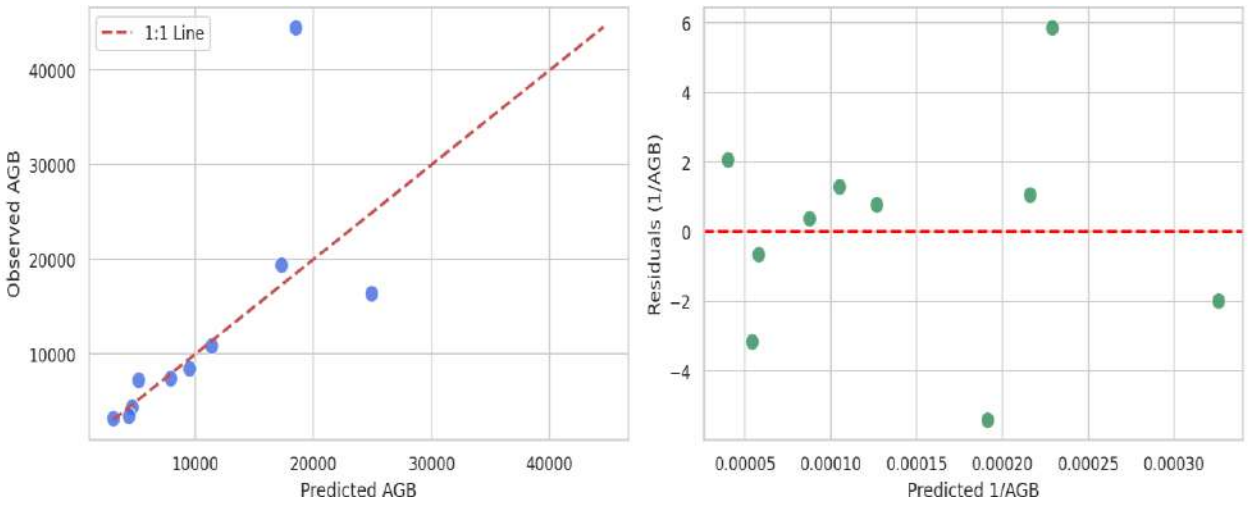


Figure 2. Model diagnostic plots for the best-fit inverse linear regression model at Kanawa Forest Reserve

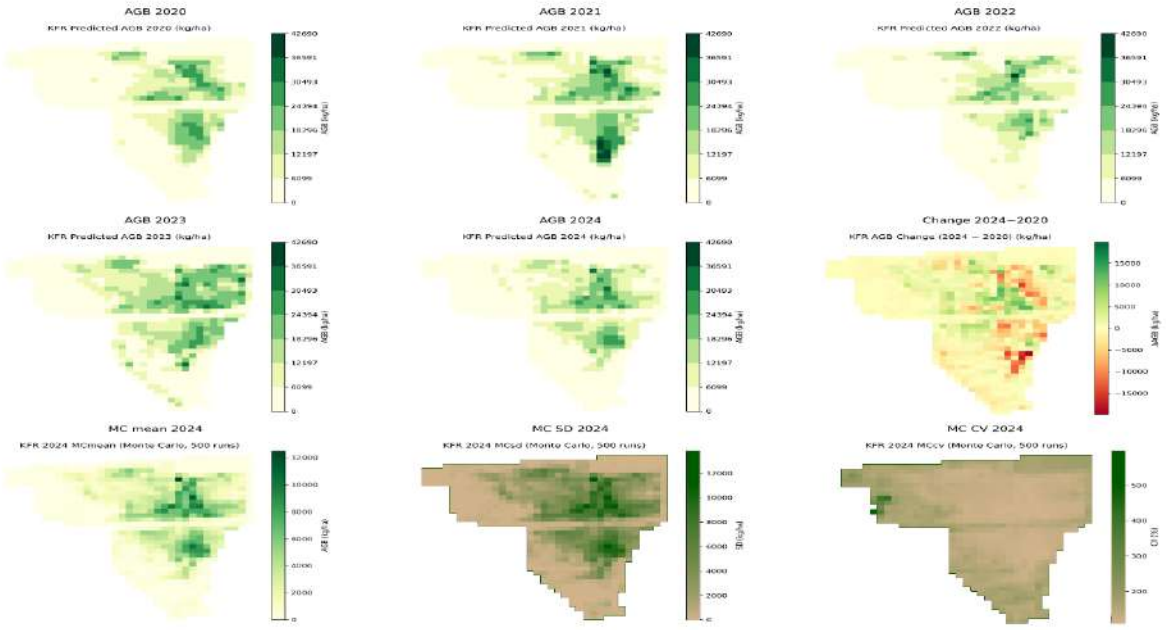


Figure 3. Spatio-temporal dynamics and change detection of vegetation indices at Kanawa Forest Reserve from 2020 to 2024

Discussion

Aboveground Biomass and Carbon Stock: Spatial Heterogeneity and Ecological Drivers

The assessment of aboveground biomass (AGB) in Kanawa Forest Reserve (KFR) reveals a pronounced spatial heterogeneity that fundamentally challenges the assumption of ecological uniformity within gazetted Sudan–Guinea transition forests. Plot-level AGB densities ranged from 32.69 to 445.42 Mg ha^{-1}, reflecting a complex mosaic of vegetation structures driven by

micro-topographic, edaphic, and hydrological gradients. The exceptionally high biomass recorded in riparian plots (e.g., KFR 5) aligns with the established ecological principle that hydrological refugia within savanna matrices sustain structurally complex, multi-layered canopies dominated by large-statured, high-wood-density taxa such as *Afzelia africana* and *Isoberlinia doka* (Mugabowindekwe *et al.,* 2022). These riparian microhabitats act as critical carbon sinks, contributing disproportionately to the aggregate standing stock of the reserve. In contrast, the lower AGB values observed in open, xeric plots are characteristic of the more frequently disturbed tropical thorn forest and tall grass communities typical of the broader dryland habitats, where edaphic constraints and anthropogenic pressures limit canopy closure.

When contextualized regionally, the aggregate plot-level standing stock of KFR exceeds the mean aboveground biomass densities reported for shrub-savanna (45.29 Mg ha^{-1}) and riparian forests (94.58 Mg ha^{-1}) in the Sudan savanna of Benin (Chabi *et al.,* 2016). However, it remains lower than the total biomass estimates for undisturbed tropical rainforest biomes in southwestern Nigeria (Dada *et al.,* 2024). This gap reflects the floristic and structural boundary between the Guinea–Sudan transition zone and the southern rainforest belt. The translation of these plot-level biomass pools into aboveground carbon (AGC) stocks yields substantial sequestration potential, reinforcing the critical role of KFR in regional carbon accounting. Given the escalating global focus on nature-based solutions, the empirically derived carbon baselines for KFR provide indispensable data for Nigeria's Nationally Determined Contributions (NDCs) and the operationalization of the nascent carbon market framework established under the Climate Change Act of 2021. The magnitude of these carbon stocks positions KFR as a high-priority candidate for results-based climate mitigation financing, provided that baseline leakage and additionality can be rigorously verified.

Belowground Biomass Allocation and Root-to-Shoot Dynamics

Belowground biomass (BGB) allocation is a critical, yet frequently under-sampled, component of ecosystem carbon accounting. The application of the IPCC-prescribed root-to-shoot (R:S) ratio of 0.26 yielded a mean BGB of 326.84 Mg ha^{-1} across sampled plots, constituting approximately 20.6% of the total live vegetation carbon stock. While this fixed-ratio approach is methodologically pragmatic and aligns with IPCC 2019 guidelines (Baasansuren *et al.,* 2019) for tropical moist forests, it obscures the nuanced phenotypic plasticity of woody species in water-limited environments. Recent syntheses of root allocation in terrestrial biomes demonstrate that R:S ratios are highly dynamic, scaling inversely with precipitation and soil fertility as plants optimize foraging for limited belowground resources (Mokany *et al.,* 2006; Ma *et al.,* 2021).

In the context of KFR, where mean annual precipitation fluctuates between 658 and 923 mm, a uniform R:S ratio likely introduces a systematic bias into the carbon inventory. Specifically, it likely underestimates BGB in xeric, open-canopy plots where root investment is maximized for drought survival and nutrient acquisition, and overestimates it in mesic riparian zones where aboveground competitive exclusion for light predominates (Ma *et al.,* 2021). The reliance on generalized allometric equations, such as the multi-species model of Henry *et al.* (2009), further compounds this uncertainty, as these models may not fully capture the extreme structural variance of high-biomass riparian plots that exceed standard savanna calibration ranges (Chave *et al.,* 2014). Future carbon

accounting protocols in heterogeneous West African savannas must transition toward species-specific, site-stratified allometric BGB models. Integrating partial or complete root excavation data for dominant woody taxa will significantly reduce uncertainty margins in total ecosystem carbon inventories, a prerequisite for rigorous REDD+ monitoring, reporting, and verification (MRV).

Spatial Estimation of Biomass: Spectral Modelling and the Modifiable Areal Unit Problem

The spatial estimation of biomass using Landsat 8 Operational Land Imager (OLI) derived vegetation indices highlights both the utility and the inherent limitations of moderate-resolution optical remote sensing in heterogeneous savanna landscapes. The pixel-wise spatial overlay analysis demonstrated that the Atmospherically Resistant Vegetation Index (ARVI) and Soil-Adjusted Vegetation Index (SAVI) are highly effective proxies for AGB distribution, significantly outperforming the traditional Normalized Difference Vegetation Index (NDVI). The failure of NDVI as a sole predictor—evidenced by negative adjusted R^2 values in untransformed models—corroborates the well-documented saturation threshold of NDVI in moderate-to-high biomass environments, where the near-infrared reflectance asymptote diminishes sensitivity to structural complexity (Tian *et al.*, 2025). Conversely, ARVI's incorporation of the blue band for atmospheric aerosol correction sharpens the spectral contrast in high-biomass pixels, yielding superior predictive fidelity (Adj. $R^2 = 0.889$ under inverse-transformed AGB). The dominance of single-index models over multi-index formulations reflects the high collinearity of spectral bands in structurally moderate woodlands; adding redundant indices introduces multicollinearity without enhancing explanatory variance under the Akaike Information Criterion (AIC) framework.

A critical finding of this study is the pronounced discrepancy between the field-measured plot-level AGB maxima (up to 445.42 Mg ha^{-1}) and the landscape-averaged raster-derived mean AGB (approximately 6.90 Mg ha^{-1}). This divergence is not an artefact of model failure but a fundamental manifestation of the spectral mixing effect inherent to 30-m Landsat pixels in spatially fragmented ecosystems. The Landsat pixel integrates the spectral signature of dense canopy crowns, sparse shrub understories, and exposed lateritic soils, thereby diluting the per-pixel biomass estimate relative to intensive 1-ha field plots (Amitrano *et al.,* 2023). The soil-background correction embedded in SAVI mitigates, but does not entirely eliminate, this issue in sparse-to-moderate canopy conditions (Huete, 1988). While the inverse-transformation of the response variable successfully stabilized the heteroscedasticity typical of right-skewed biomass distributions, bridging the plot-raster gap will necessitate the integration of very-high-resolution (VHR) multispectral data (e.g., Planet NICFI, Sentinel-2) or airborne LiDAR. These advanced sensors can resolve sub-pixel canopy structural variability, enabling the upscaling of plot-level carbon stocks to landscape levels with the precision required for commercial carbon crediting.

Temporal Dynamics, Climate Correlations, and Forest Degradation

The multi-year raster-based temporal analysis revealed a net decline in mean AGB of 4.40% between 2020 and 2024. While KFR holds a gazetted protected status, this gradual erosion of the forest carbon stock is highly indicative of incremental, plot-scale anthropogenic degradation—such as selective logging, fuelwood extraction, and boundary encroachment—rather than catastrophic deforestation. Recent

continental-scale analyses utilizing L-band vegetation optical depth (L-VOD) have demonstrated that small, persistent canopy disturbances account for the majority of carbon losses in African dry forests and savannas (Feng *et al.,* 2024). The observed trajectory at KFR underscores the inadequacy of passive conservation models in the face of escalating local resource demands and highlights the urgent need for active boundary enforcement and community-integrated livelihood interventions.

The climate-vegetation correlations were counterintuitive but explicable. The strong positive correlation between ARVI and annual mean temperature, coupled with the negative correlation between NDVI and annual precipitation, requires closer scrutiny. In the Sudan–Guinea transition zone, temperature and vegetation greenness are co-seasonal; wet seasons drive both canopy flush and elevated ambient temperatures, producing a spurious positive correlation at the inter-annual scale (Nooni *et al.,* 2024). The negative NDVI-precipitation relationship is likely an optical artefact driven by increased cloud cover and atmospheric scattering during peak monsoon months, which attenuates the Landsat surface reflectance signal. This artefact is compounded by the temporary spectral suppression of waterlogged riparian soils during extreme rainfall events, which depresses the spatial mean NDVI despite elevated biological productivity (Mustapha *et al.,* 2024). These findings emphasize the necessity of applying atmospheric corrections, such as the Dark Object Subtraction used herein, while acknowledging that physical radiative transfer models would further mitigate topographic and adjacency effects in future temporal analyses. Extending the temporal resolution to a 10–20-year time series will be critical to decoupling short-term climatic noise from anthropogenic degradation signals.

Uncertainty Quantification, Methodological Limitations, and Policy Implications

The Monte Carlo bootstrap uncertainty analysis confirmed that the inverse-transformed ARVI model provides robust predictive stability (CV = 7.21%), generating confidence intervals that meet the rigorous transparency requirements of REDD+ carbon crediting (Emick *et al.,* 2023; Li *et al.,* 2022). The variance-stabilizing properties of the inverse transformation proved essential in overcoming the statistical limitations of right-skewed ecological data, demonstrating that well-specified parametric models can achieve accuracy levels comparable to computationally intensive machine learning ensembles in structurally coherent reserves. However, several methodological constraints necessitate cautious interpretation. First, the sample size (n = 10 plots), while sufficient for preliminary stratification, limits the statistical power to capture the full variance of the reserve's micro-topographic gradients and amplifies the leverage of outlier plots on the fitted model parameters. Expanding the field inventory to a spatially balanced network of 30–50 plots is imperative for generalizing the spectral-biomass models across the broader North East region. Second, the exclusion of soil organic carbon (SOC) means the reported carbon stocks represent only the live vegetation pool; comprehensive national greenhouse gas inventories must incorporate SOC dynamics to avoid systemic underestimation of the reserve's total mitigation potential.

The integration of field-based allometry with variance-stabilized spectral modelling establishes a highly scalable, cost-effective MRV architecture for KFR. For the Gombe State Government and federal policymakers, these findings provide an empirically

defensible Forest Reference Emission Level (FREL) baseline. To arrest the documented 4.4% biomass decline, management paradigms must shift from static boundary enforcement to dynamic, community-integrated conservation strategies that address the socio-economic drivers of fuelwood extraction. The methodological framework validated in this study— combining stratified inventory, inverse-transformed ARVI modelling, and Monte Carlo uncertainty quantification— offers a template that could be tested at other Sudan–Guinea savanna reserves, subject to site-specific calibration. This baseline can inform KFR-specific FREL estimates under Nigeria's Climate Change Act; extrapolation to national NDC reporting would require replication across additional reserves.

CONCLUSIONS

This study presents the first spatially explicit, multi-year assessment of aboveground biomass, belowground biomass, and carbon stocks for Kanawa Forest Reserve, a gazetted Sudan–Guinea transitional forest in northeastern Nigeria. Results revealed substantial aggregate carbon stocks — totalling 1,583.94 Mg ha^{-1} in combined live vegetation biomass and 2,716.70 Mg ha^{-1} in total CO_2 equivalents — with pronounced spatial heterogeneity driven by micro-topographic and hydrological gradients. The integration of Landsat 8 OLI-derived vegetation indices with non-linear regression modelling identified the atmospherically corrected ARVI index, applied under an inverse-transformed response variable, as the optimal spatial predictor of AGB, achieving an Adj. R^2 of 0.889 and a Monte Carlo CV of 7.21%. Multi-year raster predictions document a net AGB decline of 4.40% over the 2020–2024 study period, consistent with low-intensity anthropogenic degradation because of its protected status.

REFERENCES

Ajayi, O.O. (2022). Nigeria's Climate Change Act 2021: Implications for carbon markets and national climate governance. *Environmental Policy and Law*, 52(3), 145–158.

Akaike, H. (2003). Information theory and an extension of the maximum likelihood principle. In E.N. Parzen, K. Tanabe, and G. Kitagawa (Eds.), *Selected Papers of Hirotugu Akaike* (pp. 199–213). Springer.

Amitrano, D., Di Martino, G., Iodice, A., Riccio, D., and Ruello, G. (2023). A review of SAR-based biomass estimation for tropical forests. *Remote Sensing*, 15(2), 411.

Asrat, Z., Taddese, H., Ørka, H.O., Gobakken, T., Burud, I., and Næsset, E. (2022). Estimation of forest biomass in Ethiopian highland landscapes using Sentinel-2 and GEDI data. *Remote Sensing*, 14(4), 935.

Baasansuren, J., Bernoux, M., Calvo, E., and Schiettecatte, L.S. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. IPCC.

Bojinski, S., Verstraete, M., Peterson, T.C., Richter, C., Simmons, A., and Zemp, M. (2014). The concept of Essential Climate Variables in support of climate research, applications, and policy. *Bulletin of the American Meteorological Society*, 95(9), 1431–1443.

Bordoloi, R., Das, B., Tripathi, O.P., Sahoo, U.K., Nath, A.J., Deb, S., … and Gupta, A. (2021). Satellite data derived spatiotemporal variation of biomass carbon stocks and their relation with vegetation type in tropical forests of Assam in northeast

India. *Ecological Indicators*, 123, 107341.

Bos, A.B., De Sy, V., Duchelle, A.E., Herold, M., and Martius, C. (2019). Global data and tools for local forest cover loss and REDD+ performance assessment: Gaps, needs and possible approaches. *Environmental Science and Policy*, 92, 357–367.

Bouchene, N., Zeraib, S., Belrhlid, M.A., and Ait Seddik, S.O. (2021). Climate change: Empirical evidence and impacts. *Journal of Environmental Studies and Sciences*, 11, 1–15.

Burnham, K.P., and Anderson, D.R. (2002). *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach* (2nd ed.). Springer.

Chabi, A., Lautenbach, S., Tondoh, J.E., Orekan, V.O.A., Kyei-Baffour, N., and Blaes, X. (2016). The relevance of using in situ carbon stocks and satellite indices to assess aboveground carbon stock of tropical forest ecosystems. *iForest*, 9, 606–615.

Chave, J., Coomes, D.A., Jansen, S., Lewis, S.L., Swenson, N.G., and Zanne, A.E. (2009). Towards a worldwide wood economics spectrum. *Ecology Letters*, 12(4), 351–366.

Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M.S., Delitti, W.B.C., … and Vieilledent, G. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology*, 20(10), 3177–3190.

Conti, G., Enrico, L., Casanoves, F., and Díaz, S. (2019). Shrub biomass estimation in the semiarid Chaco forest: A contribution to the understanding of South American dryland carbon sinks. *Journal of Arid Environments*, 166, 51–60.

Dada, A.O., Aborisade, A.B., Nduka, B., Fajola, A.O., and Alabi, A.A. (2024). Aboveground biomass and carbon stock estimation of tropical rainforest in southwestern Nigeria. *Trees, Forests and People*, 15, 100435.

Emick, E., Babcock, C., Hudak, A.T., and Finley, A.O. (2023). Uncertainty quantification of forest biomass estimates using Monte Carlo simulation and Bayesian inference. *Remote Sensing of Environment*, 285, 113404.

FAO and ICRAF. (2019). *Agroforestry and Tenure*. Food and Agriculture Organization of the United Nations.

Feng, Y., Negrón-Juárez, R., and Chambers, J.Q. (2024). Carbon loss from low-intensity disturbances in African dry forests from L-VOD observations. *Nature Geoscience*, 17, 220–228.

Forfora, N., Marin, M., Boateng, A., and Chew, I. (2024). Biomass as a decarbonisation strategy: Availability, composition, and sustainability considerations. *Renewable and Sustainable Energy Reviews*, 191, 114156.

GCOS. (2016). *The Global Observing System for Climate: Implementation Needs* (GCOS-200). World Meteorological Organization.

Henry, M., Picard, N., Trotta, C., Manlay, R.J., Valentini, R., Bernoux, M., and Saint-André, L. (2009). Estimating tree biomass of sub-Saharan African forests: A review of available allometric equations. *Silva Fennica*, 45(3B), 477–569.

Herold, M., Carter, S., Avitabile, V., Espejo, A.B., Jonckheere, I., Lucas, R., … and Román, M. (2019). The role and need for space-based forest biomass-related measurements in environmental management and policy. *Surveys in Geophysics*, 40, 757–778.

Houghton, R.A. (2005). Aboveground forest biomass and the global carbon balance. *Global Change Biology*, 11(6), 945–958.

Huete, A.R. (1988). A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment*, 25(3), 295–309.

Intergovernmental Panel on Climate Change (2023). *Climate change 2023: Synthesis report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (H. Lee and J. Romero, Eds.). IPCC. https://doi.org/10.59327/IPCC/AR6-9789291691647

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. IGES.

IPCC. (2014). *Climate Change 2014: Mitigation of Climate Change*. Cambridge University Press.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. IPCC.

IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Cambridge University Press.

Johnston, C.M.T., Guo, J., and Gillespie, A.J.R. (2021). Aboveground biomass of temperate and boreal forests. In J.B. Martin and A.L. Thompson (Eds.), *Forest Carbon*. SpringerLink.

Kaufman, Y.J., and Tanré, D. (1992). Atmospherically resistant vegetation index (ARVI) for EOS-MODIS. *IEEE Transactions on Geoscience and Remote Sensing*, 30(2), 261–270.

Kralicek, K., Huy, B., Poudel, K.P., Temesgen, H., and Salas, C. (2017). Simultaneous estimation of above- and below-ground biomass in tropical forests of Vietnam. *Forest Ecology and Management*, 390, 137–148.

Kumar, L., and Mutanga, O. (2017). Remote sensing of above-ground biomass. *Remote Sensing*, 9(9), 935.

Li, W., Niu, Z., Shang, R., Qin, Y., Wang, L., and Chen, H. (2022). High-resolution mapping of forest canopy height using machine learning by coupling ICESat-2 LiDAR with Sentinel-1, Sentinel-2 and Landsat-8 data. *International Journal of Applied Earth Observation and Geoinformation*, 92, 102163.

Ma, H., Mo, L., Crowther, T.W., Maynard, D.S., van den Hoogen, J., Stocker, B.D., … and Zohner, C.M. (2021). The global distribution and environmental drivers of aboveground versus belowground plant biomass. *Nature Ecology and Evolution*, 5, 1110–1122.

Manduna, I.T., and Fundira, B. (2022). Empirical evidence of climate change: A global synthesis. *African Journal of Ecology*, 60(1), 22–35.

Mohammed, I., Aminu, S., and Ali, A. (2015). Phytosociological study of Kanawa Forest Reserve, Gombe State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 19(2), 343–348.

Mohd Zaki, N.A., and Abd Latif, Z. (2017). Carbon sinks and tropical forest

biomass estimation: A review on role of remote sensing in aboveground-biomass modelling. *Geocarto International*, 32(7), 701–716.

Mokany, K., Raison, R.J., and Prokushkin, A.S. (2006). Critical analysis of root: shoot ratios in terrestrial biomes. *Global Change Biology*, 12(1), 84–96.

Mugabowindekwe, M., Brandt, M., Chave, J., Reiner, F., Skole, D.L., Kariryaa, A., … and Ciais, P. (2022). Nation-wide mapping of tree-level aboveground carbon stocks in Rwanda. *Nature Climate Change*, 13, 91–97.

Mustapha, A., Aliyu, B.M., Hashim, M., and Ahmad, N. (2024). Optical artefacts and spectral corrections in Landsat time-series analyses over tropical wetlands. *Remote Sensing Letters*, 15(4), 366–375.

Nooni, I.K., Wang, L., Hagan, D.F.T., Ullah, W., Lu, J., Li, J., … and Prempeh, N.A. (2024). Temporal co-seasonality of temperature and vegetation greenness in semi-arid West Africa. *Journal of Geophysical Research: Biogeosciences*, 129, e2023JG007512.

Ravindranath, N.H., and Madelene, O. (2008). *Carbon Inventory Methods: Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Roundwood Production Projects*. Springer.

Reichstein, M., and Carvalhais, N. (2019). Aspects of forest biomass in the Earth system: Its role and major unknowns. *Surveys in Geophysics*, 40, 693–707.

Rouse, J.W., Haas, R.H., Schell, J.A., and Deering, D.W. (1974). Monitoring vegetation systems in the Great Plains with ERTS. *Proceedings of the Third Earth Resources Technology Satellite-1 Symposium*, 1, 309–317.

Rügnitz, M.T., Chacón, M.L., and Porro, R. (2009). *Guía para la Determinación de Carbono en Pequeñas Propiedades Rurales*. ICRAF.

Sharma, C.M., Baduni, N.P., Gairola, S., Ghildiyal, S.K., and Suyal, S. (2022). Biomass and carbon stock estimation along an altitudinal gradient in subtropical forests of Indian Himalaya. *Trees*, 36, 1447–1460.

Sukhbaatar, G., Uyanga, B., and Ishta, D. (2023). Root-to-shoot ratios of Mongolian forest-steppe woody species and their implications for ecosystem carbon accounting. *Forest Ecology and Management*, 529, 120697.

Tali, J.A., Naikoo, M., Khan, A.H., Rashid, I., and Romshoo, S.A. (2022). Structure and floristic diversity of forest ecosystems as habitats for bird species in Kashmir Himalaya. *Ecological Indicators*, 136, 108597.

Temesgen, H., Affleck, D., Poudel, K., Gray, A., and Sessions, J. (2015). A review of the challenges and opportunities in estimating above ground forest biomass using tree-level models. *Scandinavian Journal of Forest Research*, 30(4), 326–335.

Tian, Z., Fan, J., Yu, T., de Leon, N., Kaeppler, S. M., and Zhang, Z. (2025). Mitigating NDVI saturation in imagery of dense and healthy vegetation. *ISPRS Journal of Photogrammetry and Remote Sensing*, *227*, 234-250.

Tomlin, C.D. (1990). *Geographic Information Systems and*

Cartographic Modelling. Prentice Hall.

Tucker, C.J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, 8(2), 127–150.

Williams, M., Richardson, A.D., Reichstein, M., Stoy, P.C., Peylin, P., Verbeeck, H., … and Ciais, P. (2009). Improving land surface models with FLUXNET data. *Biogeosciences*, 6(7), 1341–1359.

Yanai, R.D., Battles, J.J., Richardson, A.D., Blodgett, C.A., Wood, D.M., and Rastetter, E.B. (2010). Estimating uncertainty in ecosystem budget calculations. *Ecosystems*, 13, 239–248.

Yani, S.A., Maswandi, M., Isa, M., and Putra, R.F. (2025). Assessment of aboveground biomass and carbon stock using field inventory and remote sensing integration. *Forests*, 16(2), 231.

Yavasli, D.D. (2012). Carbon stock estimation in forests: Methodological challenges and implications for climate policy. *International Journal of Climate Change Strategies and Management*, 4(3), 302–315.

Zhang, Y., Liang, S., and Yang, L. (2021). A review of regional and global gridded forest biomass datasets. *Remote Sensing*, 11(23), 2744.

EVALUATION OF CARBON ACCUMULATION WITHIN PALM PLANTATION AT JOSEPH SARWUAN TARKA UNIVERSITY (JOSTUM), MAKURDI, BENUE STATE

[1]Thomas OKOH, [2]*Onyinyechi Priscilla OKPARA, [3]Elizabeth UMOREN

Joseph Sarwuan Tarka University, Benue State, Makurdi – Nigeria

ORCID IDs.:[1]0000-0001-5689-5032, [2]0009-0002-2505-1499, [3]0009-0006-7040-7035

* Corresponding Author's Email: okpara.onyinyechi@uam.edu.ng,

ABSTRACT

Carbon sequestration by plantation ecosystems has gained increasing attention as a nature-based solution for mitigating climate change and enhancing carbon credit opportunities. This study estimated the carbon credit potential of *Elaeis guineensis* plantation at Joseph Sarwuan Tarka University, Makurdi (JOSTUM), using an allometric model (AGB = 2.8662 × stem height) to determine above-ground biomass (AGB). Below-ground biomass (BGB) was estimated as 20% of AGB, while AGB was evaluated using diameter at breast height (DBH), basal area, and plant height. Herbaceous vegetation and litter were assessed using 1 m² quadrats, and their biomass was determined as oven-dry weight. The results showed that Plot 3 recorded the highest AGB (1062.96 kg), total sequestered carbon (531.48 kg), and sequestered carbon dioxide equivalent (1950.53 Mg CO_2e), whereas Plot 2 had the lowest values. AGB, total sequestered carbon, CO_2 equivalent, and soil organic carbon varied significantly ($p < 0.01$) among the plots. Soil organic matter exhibited a significant positive correlation with soil organic carbon ($p < 0.01$). Herbaceous biomass averaged approximately 50% dry biomass, with Plot 3 recording the lowest herbaceous biomass (2.20 kg). Plot 3 also had the highest herbaceous CO_2 equivalent (320.96 Mg CO_2e), while Plot 1 recorded the highest litter CO_2 equivalent (87.44 Mg CO_2e). Above-ground biomass showed strong positive correlations with DBH ($R = 0.888$, $p < 0.001$) and plant height ($R = 0.517$, $p < 0.001$), indicating that biomass accumulation increases with tree size and validating the suitability of the allometric model for biomass estimation in the plantation. The findings demonstrate the considerable carbon sequestration capacity of *E. guineensis* plantations and highlight their potential contribution to carbon credit initiatives and climate change mitigation.

Keywords: *Elaeis guineensis*, Carbon Sequestration, Carbon Credits, Above-Ground Biomass, Allometric Model.

INTRODUCTION

The increasing levels of greenhouse gases (GHGs) concentration, especially carbon dioxide (CO_2) in the atmosphere is majorly the reason for climate change in the current global environment [Elum and Momodu, 2017]. The current atmospheric carbon dioxide concentration is estimated to be about 415 ppm [Noaa, 2019], which is 54% above the preindustrial level of 270 ppm [Eggleston *et al.,* 2006]. The drivers of

climate change monitoring have pinpointed the terrestrial ecosystem which comprises of trees and herbs as a viable option for mitigating CO_2 emission through carbon sequestration.

Carbon storage in tropical ecosystems has been disturbed through numerous anthropogenic interferences such as land use and land cover change releasing greenhouse gases (C emission) with a relative value ranging from 10-13% annually. There are some anthropogenic sequestration methods which solely exploit these natural processes, while other methods are artificial practices [Sedjo and Sohngen, 2012].

The terrestrial ecosystems account for a majority of carbon sink owing to photosynthesis and storage of carbon in living and dead organic matters. As a result, numerous benefits such as. improved soil and water quality, restoration of degraded ecosystems, and increased crop yield are gained. Terrestrial carbon sequestration is often termed as a win-win strategy [Lal, 2004]. There are three prime components of terrestrial carbon sequestration which include forests, soils and wetlands. Tropical forest houses an estimate of 200-300 pentagrams of carbon globally and this accounts for about 54% of the biotic Carbon pools [Meijaard *et al.,* 2020; Avitabile *et al.,* 2016].

Oil palm (*Elaeis guineensis*) species are amongst the most important agricultural crops in the tropical ecosystem [Rakesh and al. 2020], due to the importance, several research have been carried out on the carbon sequestration potential in many tropical regions but there is still need for more works [Le Quéré *et al.,* 2016]. Thus, an extensive quantification of carbon pools in the tropics remain understudied. Forest ecosystems may provide a better understanding of the contribution to carbon credit to climate change mitigation. As a result of management and growth, the changes in forest areas and biomass are greatly influenced by the exchange of carbon between the terrestrial ecosystem and the atmosphere. Therefore, estimating the forest carbon stocks is important to assess the magnitude of carbon transfer between the forest ecosystem and the atmosphere.

Many studies have been carried out on carbon sequestration of forest species. Relatively, little research has emphasized the use of palm trees and herbs as a carbon storage sink, and this could be attributed to variation in the method of measuring palm trees and herbs. Herbaceous species are annual, and their carbon sequestration potential is on a short term.

Elaeis guineensis is chosen for this study because it can be found all over and is the most dominant palm species. Palm trees serve agricultural and economic benefits. The trees are one of the main tree species in Makurdi, and it is considered a significant global carbon sequester [Goodman *et al.* 2013].

Their degradation and deforestation can severely increase greenhouse gases

emission and contribute to climate change [Komolafe *et al.,* 2020]. However, the belief that they have lower biodiversity value than upland rainforests has led to relatively less attention from researchers [Singh *et al.,* . 2018]. In the present study the estimation and evaluation of carbon stocks in the palm plantation would provide information on carbon sequestration estimates in the study location and relative contribution to climate change mitigation strategies, and carbon credits that can be inventoried in the national data rank on carbon credit system.

The aim of the research is to estimate the total sequestered carbon stocks of the palm plantation in Joseph Sarwuan Tarka University, Makurdi (JOSTUM). While the specific objectives are to determine above ground biomass (AGB), below ground biomass (BGB), and estimate the total storage carbon (TSC) in the trees, herbs, litters and soil.

MATERIAL AND METHODS

Study Area

This study was conducted at the Palm plantation in Federal University of Agriculture (now called Joseph Sarwuan Tarka University), Makurdi. Located within the Southern Guinea Savanna zone which lies within latitude 7°44′ North and longitude 8°35′ East [Okoh *et al.,* 2019]. It is located at Nyiev district, North-East of Makurdi Local Government Area of Benue State. It is boarded in the Northeast by Guma Local Government Area and by River Benue in the South. The region is characterized by two major seasons, namely, wet and dry season. The wet season usually occurs from April to October, and dry season from November. Rainfall distribution is bimodal within the area occurring in June and September. Mean annual rainfall is between 1000 mm and 1500 mm [Ikyaagba, 2019]. Mean annual temperature is 30 °C, and relative humidity between 60% and 80% wet but decreases in the early months of dry season [JIMOH *et al.,* 2009]. The vegetation of the University is open savannah woodland, characterized predominantly by trees, shrubs and tall grasses. The land is generally fertile and supports extensive arable cropping and rearing of animals.

Plant Species Selection

All the palm trees within three plots in Federal University of Agriculture, Makurdi Palm Plantation were selected. The sample palm plantation was divided into three (3) plots of 50 m×50 m which were randomly selected within the plantation. In the plots, all trees with Diameter Breast Height (DBH) of 1.3 m and plant height were obtained. Also, the herbs present within the sample area were obtained. Herbs were randomly selected at five points per plot using the 1 m × 1 m sized quadrat. The litter found within the sub-quadrat on the soil surface were collected and oven dried [Martins *et al.,* 2022].

Procedure

Biophysical Measurements

Diameter at the breast height (DBH) and plant height, and basal area were taken for

each palm tree. Data generated was used in estimating the total biomass (above and below ground biomass) for each palm. Diameter was measured using a measuring tape while plant height was measured using Haga altimeter. Both the herbs' species and their residues were separately bagged, labelled and taken to the laboratory where they were oven dried at 70 °C to a constant weight, and weighed.

Biomass Determination

Above ground biomass (AGB) was determined using the allometric equation:

AGB = 2.8662 × H stem.

where: AGB is the above ground biomass, 2.8662 is a constant and H stem is the height of the stem (m). Dry AGB was determined as 65% of AGB. Below ground biomass (BGB) was determined as 20% of AGB [OKOH and al. 2019].

Sequestered Carbon and Carbon Dioxide (CO2) Equivalent.

Total sequestered carbon in palm trees was determined as 50% of dry biomass.

Carbon dioxide (CO_2) equivalent was determined as TSC × 3.67 (carbon conversion factor) [Okoh *et al.,* 2019].

Herbaceous Standing Biomass and Carbon Stock

This was determined as dry weight of herbs/quadrat. While Carbon stock was determined as 50% of dry weight of herbs, while CO_2 equivalent was determined as TSC (herbs) × 3.67 [Okoh *et al.,* 2019].

Litter Biomass

Litter biomass was determined from sub quadrats (on the soil surface). Litter collected from each quadrat was oven dried and 50% of dry weight was used as carbon stock in litter [Okoh *et al.,* 2019].

Soil Carbon Stock

Soil samples were determined by Walkley Blacky method. It was computed by multiplication of the concentration total carbon (C) by bulk density and the corresponding depth at which sampling was done. Soil Carbon (Mg/ha) = bulk density (g/cm^3) × Soil depth × % Carbon [Okoh *et al.,* 2019].

Total Carbon Credits

The total carbon credits in the palm plantation were determined as the sum of various carbon compounds.

Total Carbon Credit (TCC) = TSC (palm trees) + TSC (herbs) + TSC (litter) + TSC (soil) [Okoh *et al.,* 2019].

Shannon Diversity Index

Claude Shannon (1948) formula was used to estimate the diversity and distribution of herbs.

$H = \Sigma p_i \times \ln (p_i)$

where: H = Shannon index, Σ = sum, p_i = the proportion of the entire community made up of species, ln = natural log. [Okoh *et al.,* 2019].

Results and discussions

This study estimated the above ground biomass (AGB), below ground biomass (BGB) and Total sequestered carbon (TSC) in *Elaeis guineensis* (plantation) at Joseph

Sarwuan Tarka University, Makurdi. From the results in Table 1, AGB (1062.96) and BGB (212.59) were highest in plot 3. The Total sequestered carbon (53.48) and Sequestered carbon dioxide Equivalent (1950.53) was equally highest in plot 3 of the plantations studied which suggests that higher biomass stores more carbon.

In Figure 1 there was strong Correlation between total AGB (above ground biomass) and DBH (Diameter at the breast height) of *Elaeis guineensis species* evaluated, ($P>0.000$, $R=0.89$, $R^2=0.79$ $Y=0.18+1.26*X$), showing a strong positive relationship. In Figure 2, there was weak Correlation between total AGB and height of *Elaeis guineensis* ($P>0.000$, $R = 0.52$, $R^2=0.27$, $Y =0.03+ 0.04^*X$). The Correlation between total DBH and height correlate weakly in figure 4 ($P = 0.01$, $R = 0.158$, $Y = 0.23 + 9.28\ E - 3^*X$).

Soil organic carbon varies significantly with plots within the plantation as shown in figure 4. Highest value was recorded in plot A2 (1.42 ± 0.14^c) while plot C2 (0.30 ± 0.18^a) had the least value respectively. Soil organic matter evaluates at study sites correlates positively as shown in figure 5. In a comparative evaluation analysis soil organic matter and organic carbon varied significantly ($p<0.01$), indicating that organic carbon increases with increasing organic matter in Figure 6.

Diversity and species distribution study shows that in Plot 1 (Table 2) diversity index were highest (2.39) and *Vernonia cinerea* was the most dominant species (39). Plot 2 (Table 3) had the highest distribution of herbs (26) within the plantation, having a Shannon diversity index of 2.32 with *Vernonia cinerea* as dominant species (93). Plot 3(Table 4) had the least diversity index (2.20) with *Mitracarpus villosusas* as the most frequently distributed species (86) respectively.

In Table 5, Plot 3 had the highest herbaceous biomass (174.91g), TSC (87.46Mg) and SCO_2E (320.96Mg) respectively, while litter biomass was highest in plot 1 (47.65g), TSC (23.83Mg) and SCO_2E (87.44Mg).

Table 1. Above ground biomass, total sequestered carbon stock in *Elaeis guineensis* Plantation at JOSTUM

Plantation	Plot	AGB	BGB	TSC	SCO_2E
Elaeis guineensis	1	1050.00	210.00	525.00	1926.76
	2	804.82	161.00	402.41	1476.85
	3	1062.96	212.59	531.48	1950.53

Key: AGB-Above ground biomass, BGB-Below ground biomass, TSC-Total sequestered carbon, SCO_2E- Sequestered Carbon dioxide equivalent

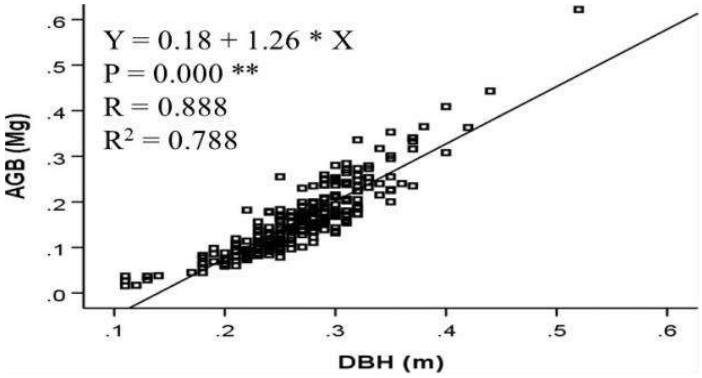


Figure 1: Correlation between total AGB and DBH of *Elaeis guineensis* at study location

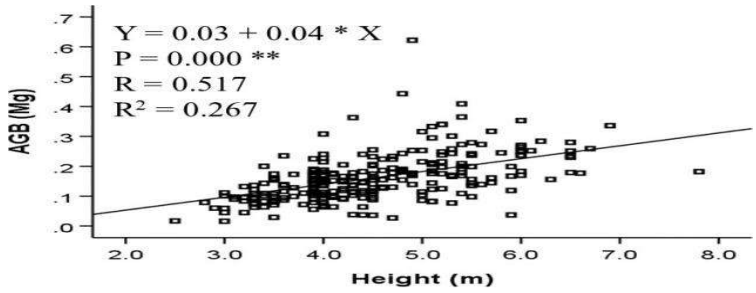


Figure 2. Correlation between total AGB and height of *Elaeis guineensis* at study location

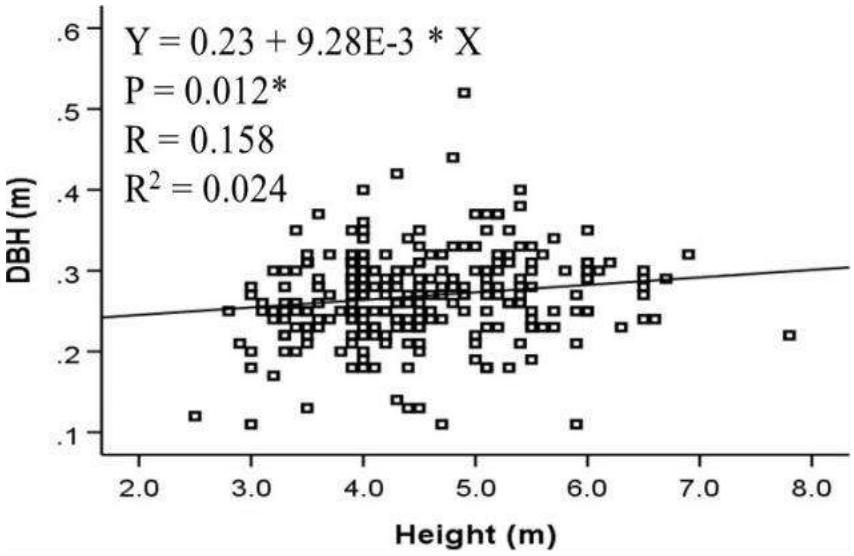


Figure 3. Correlation between total DBH and height of *Elaeis guineensis* at study location

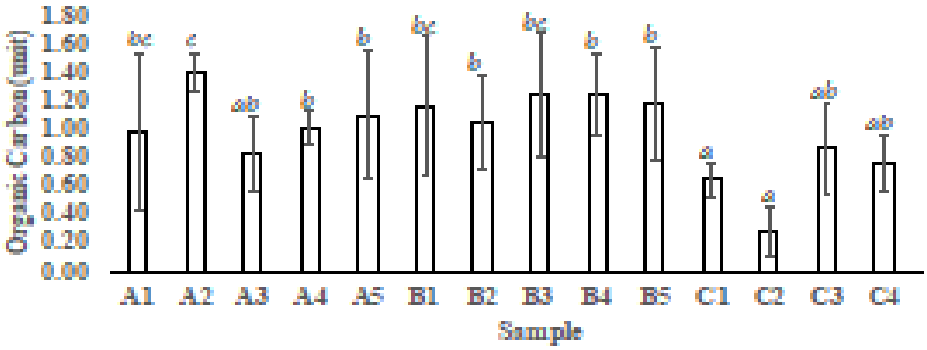


Figure 4: Soil Organic Carbon in the various plots sampled (A, B, C are plots 1, 2, and 3).

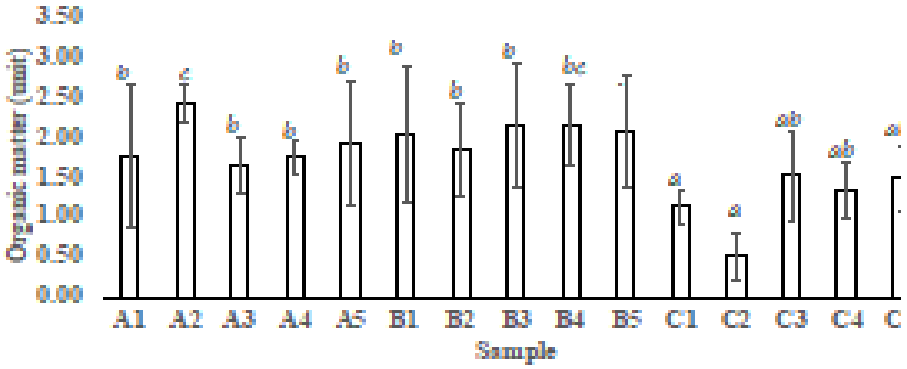


Figure 5: Soil Organic matter in the various plots sampled. (A, B, C represents plots 1, 2, and 3).Pearson corelation

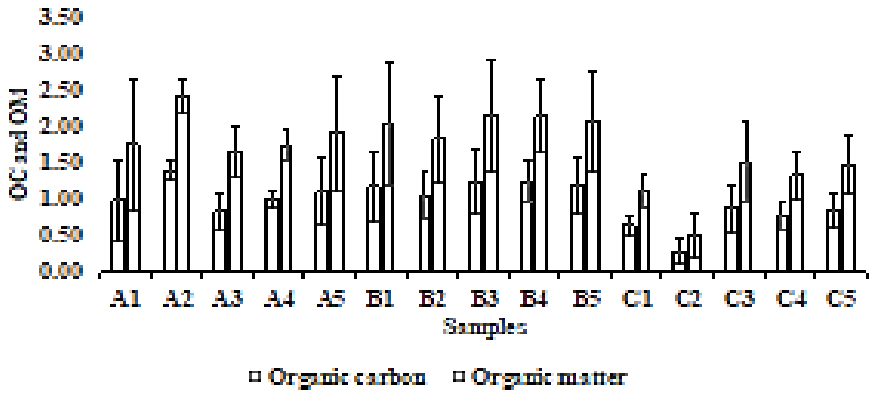


Figure 6: Correlation between soil organic carbon and organic matter in the various plots sampled (A, B, C represents plots 1, 2, and 3).

Table 2. Diversity and distribution of herbs within Plot 1 of *Elaeis guineensis* plantation of JOSTUM

S/N	Species	Count	Shannon Index
1	*Acanthospermum hispidum*	1	-0.024
2	*Biophytum petersianum*	26	-0.247
3	*Corchorus olitorius*	2	-0.041
4	*Desmodium scorpiurus*	5	-0.083
5	*Desmodium tortuosum*	1	-0.024
6	*Euphorbia heterophylla*	1	-0.024
7	*Euphorbia hirta*	1	-0.024
8	*Gomphrena celosioides*	8	-0.117
9	*Kyllinga erecta*	1	-0.024
10	*Laggera aurita*	1	-0.024
11	*Malvastrum coromandelianum*	5	-0.083
12	*Mitracarpus villosus*	23	-0.231
13	*Oldenladia corymbose*	11	-0.146
14	*Pentodon pentandrus*	24	-0.236
15	*Phyllanthus amarus*	18	-0.200
16	*Sida acuta*	1	-0.024
17	*Synedrella nodiflora*	30	-0.266
18	*Tridax procumbens*	31	-0.271
19	*Vernonia cinerea*	39	-0.301
	SUM	229	2.39

Table 3. Diversity and distribution of herbs within Plot 2 of *Elaeis guineensis* plantation at JOSTUM

S/N	Species	Count	Shannon Index
1	*Ageratum convzoides*	2	-0.039
2	*Azolla spinnata*	2	-0.039
3	*Biophytum petersianum*	3	-0.054
4	*Chloris Pilosa*	1	-0.022
5	*Corchorus olitorius*	5	-0.079
6	*Cynadon dactylon*	18	-0.191
7	*Desmodium tortuosum*	1	-0.022
8	*Eclipta alba*	1	-0.022
9	*Elaeis guineensis*	4	-0.067
10	*Elytrophorus spicatus*	2	-0.039
11	*Euphorbia heterophylla*	1	-0.022
12	*Euphorbia hirta*	4	-0.067
13	*Euphorbia hyssopifolia*	2	-0.039
14	*Kyllinga erecta*	3	-0.054
15	*Laggera aurita*	8	-0.111
16	*Mitracarpus villosus*	27	-0.243
17	*Oldenladia corymbose*	26	-0.238
18	*Pennisetum pedicellatum*	1	-0.022
19	*Pentondon pentandrus*	12	-0.147
20	*Phyllanthus amarus*	10	-0.130
21	*Platostoma africanum*	1	-0.022
22	*Setaria barbata*	1	-0.022
23	*Spigelia anthelmia*	10	-0.130
24	*Synedrella nodiflora*	6	-0.091
25	*Tridax procumbens*	2	-0.039
26	*Vernonia cinerea*	93	-0.368
	SUM	246	2.32

Table 4. Diversity and distribution of herbs within Plot 3 of *Elaeis guineensis* plantation of JOSTUM

S/N	Species	Count	Shannon Index
1	*Andropogon gayanus*	1	-0.024
2	*Andropogon tectorum*	1	-0.024
3	*Azolla pinnata*	1	-0.024
4	*Biophytum petersianum*	19	-0.208
5	*Boerhavia erecta*	16	-0.187
6	*Calopogonium mucunoides*	1	-0.024
7	*Commelina bengalensis*	2	-0.042
8	*Desmodium scorpiurus*	7	-0.108
9	*Desmodium tortuosum*	1	-0.024
10	*Euphorbia heterophylla*	4	-0.071
11	*Heterotis rotundifolia*	7	-0.108
12	*Hyparrhenia rufa*	2	-0.042
13	*Laggera aurita*	4	-0.071
14	*Malvastrum coromandelianum*	10	-0.138
15	*Mitracarpus villosus*	86	-0.368
16	*Paspalum scrobisculatum*	1	-0.024
17	*Pentondon pentandrus*	6	-0.096
18	*Phyllanthus amarus*	4	-0.071
19	*Synedrella nodiflora*	6	-0.096
20	*Tephrosia bracteolate*	1	-0.024
21	*Tephrosia linearis*	1	-0.024
22	*Tridax procumbens*	2	-0.042
23	*Vernonia ambigua*	1	-0.024
24	*Vernonia cinerea*	41	-0.310
25	*Vernonia perrottetii*	1	-0.024
	SUM	226	2.20

Table 5. Total sequestered carbon in herbaceous and litter biomass within *Elaeis guineensis* plantation at JOSTUM, October 2021

Plantation	Plot	TSC (Mg)		
		Oven Dry Biomass (g)	(50% Dry Weight)	SCO2E (Mg)
Elaeis guineensis	1	74.91	37.46	137.46
	2	100.49	50.25	184.40
	3	174.91	87.46	320.96
Elaeis guineensis	1	47.65	23.83	87.44
	2	34.70	17.35	63.67
	3	24.88	12.44	45.65

Sequestered carbon dioxide Equivalent (SCO_2E), total sequestered carbon (TSC), soil organic carbon and above ground biomass (AGB) varied among the three plots studied. The reason for this relative variation could be due to the density of trees along with the management practices within the plantation. It can also be due to the occurrence of oil palm trees with diameter breath height (DBH) in plot 3.

Result reviews the carbon sequestration rates in the respective plots in which plot 3 sequestered more carbon stocks than the other plots across the study area which is in agreement with PAUL and al. (2019) who reported that carbon stock is influenced in any particular area by factors such as disturbances, climate, species composition, soil characteristics and age of the forest.

The result of this study is comparable to the findings of OKOH and al. (2019) in which DBH determines more than 95% of the variation in above ground tropical forest carbon stocks, even in highly diverse regions. Thus, the DBH and above ground biomass (AGB) strongly correlates.

The result also shows that AGB contributes to the major perennial biomass stock in the *Elaeis guineensis* plantation which is in agreement with RAKESH and al. (2020) who reports that in palm plantations, 96% of total annual dry matter is stored in the above ground biomass (AGB) as trunks, fronds, and brunches.

The strong positive correlation between AGB and DBH and plant height indicates that AGB increases with increasing DBH and plant height, which validates the suitability of the allometric model employed. Correlation between DBH and plant heights shows a weak positive relationship as opposed by MARKUS and al. (2015) and RIBEIRO and al. (2009), who stated that the combination of plant height and DBH was a better variable to predict the total amount of carbon and total biomass than the use of a single variable. Also, plants with larger width can sequester carbon more from the atmosphere than smaller trees with small width as observed within the study area. The reason for the relatively higher biomass in plot 3 than the other plot could be due to the presence of a higher species density and less livestock and human activities than in plot 1 and 2 as compared to who states that the higher dry matter production recorded may be as a result of it high vegetative yield. Also, the above-mentioned reasons could be as a result of agricultural practice within plot 1 than plot 3, it implies that agricultural activities reduce the growth of herbs and decrease the above ground herbaceous biomass.

CONCLUSIONS

Analysis of the herbaceous standings within the study area in three plots of the oil palm (*Elaeis guineensis*) plantation review that, herbaceous standings have the ability to sequester carbon greatly. Following the average sequestration rate of (642.82 Mg) in the study carried out. The study indicates that these grasses like every other terrestrial sink can serve as a good sequester.

The overall amount and proportion of carbon storage vary depending on soil fertility, climate, and land use type. It also shows clearly that persistence increases in carbon stock with an increase in the age group of oil palm due to increase in biomass of trunks and roots. Also, this finding shows that *Elaeis guineensis* and its herbaceous standings stored a significant quantity of carbon dioxide in their biomass and is therefore useful in mitigating climate change. It has a proposition for a better perceptive and forecast of the accumulation and distribution of organic matter within the study area.

The implications of the findings in this study are that *Elaeis guineensis* and herbaceous standing have great potential as carbon repository hence, suggesting the use of oil palm and its herbaceous standings (grasses) for carbon credit audit and agroforestry practices as these practices will not only serve the primary aim of protecting the soil from degradation, it will aid accountability and minimal impact of climate change and greenhouse emissions following credible research.

REFERENCES

Avitabile V., Herold M., Heuvelink G. B., Lewis S. L., Phillips O. L., Asner G. P., Armston J., Ashton P. S., Banin L., Bayol N., Berry N. J., Boeckx P., De Jong B. H., Devries B., Girardin C. A., Kearsley E., Lindsell J. A., Lopez-Gonzalez G., Lucas R., Malhi Y., Morel A., Mitchard E. T., Nagy L., Qie L., Quinones M. J., Ryan C. M., Ferry S. J., Sunderland T., Laurin G. V., Gatti R. C., Valentini R., Verbeeck H., Wijaya A., Willcock S. 016. An Integrated Pan-Tropical Biomass Map Using Multiple Reference Datasets. *Global Change Biology*. **22**(4): 1406-1420. Https://Doi.Org/10.1111/Gcb.13139

Arubasa, O.O and Odiwe A.I 2016. Carbon Stock In Different Pools Across Different Vegetation Structures In Tropical Rainforest In Ile-Ife, Nigeria. International Journal of Plant and Soil Science, **10**(1):1-10, Https://Doi.Org/10.9734/Ijpss/2016/23719

Eggleston H. S., Buendia L., Miwa K., Ngara T. and Tanabe K. (Eds.). 2006. 2006 Ipcc Guidelines for National Greenhouse Gas Inventories, prepared by the National Greenhouse Gas Inventories Programme; Published: Iges, Hayama, Japan. Https://Www.Ipcc-Nggip.Iges.Or.Jp/Support/Primer_2006gls.Pdf

Issn0016-7061, (Https://Www.Sciencedirect.Com/Science/Article/Pii/S0016706104000266)

Elum Z. A. and Momodu A. S. 2017. Climate Change Mitigation and Renewable Energy For Sustainable Development in Nigeria: A

Discourse Approach. *Renewable And Sustainable Energy Reviews*. **76**: 72-80.

Goodman R. C., Phillips O. L., Del Castillo Torres D., Freitas L., Cortese S. T., Monteagudo A. and Baker T. R. 2013. Amazon Palm Biomass and Allometry. *Forest Ecology and Management.* **310**: 994-1004. Https://Doi.Org/10.1016/J.Foreco.2013.09.045

Henry O. T., Isreal B. Y., Mensah B., Thomas A., Abdul A. K., Awudu A., Caleb M. and Pearl K. 2014. Soil Carbon: Relating The Walkley-Black Wet Oxidation Method to Loss on Ignition and Clay Content. *International Journal of Scientific Research In Knowledge.* **2**(5): 249-256. Https://Doi.Org/10.12983/Ijsrk-2014-P0249-0256

Ikyaagba E. T., Amonum J.I., and Okwuche S. 2019. Tree Species Composition and Diversity of Ipinu-Igede Sacred Forest in Oju Local Government Area Of Benue State, Nigeria. *Journal Of Agriculture and Ecology Research International*. **18**(3):1-10. Https://Doi.Org/10.9734/Jaeri/2019/V18i330059

Jimoh S.O., Debisi, L.A.A., Ikyaagba (2009). Biodiversity And Ethno-Botanical Potential Of Plant Species of University of Agriculture, Makurdi Wildlife Park and Ikwe Games Reserve, Benue State Nigeria. *International Journal of Biological and Chemical Sciences*. **3**(6): 1375-1385. Http://Ajol.Info/Index.Php/Ijbcs

John Martin J. J., Yarra R., Wei L., Cao H. 2022. Oil Palm Breeding In The Modern Era: Challenges And Opportunities. *Plants*. **11**(11):1395. Https://Doi.Org/10.3390/Plants11111395

Komolafe E. T., Chukwuka K. S., Maxwell C. Obiakara M. C. and Osonubi O. 2020. Carbon Stock And Sequestration Potential Of Ibodi Monkey Forest In Atakumosa, Osun State, Nigeria. *Trees, Forests And People*. **2:** 100031. Https://Doi.Org/10.1016/J.Tfp.2020.100031

Lal R. 2004. Soil Carbon Sequestration to Mitigate Climate Change. *Geoderma.* **123**(1-2): 1-22. Https://Doi.Org/10.1016/J.Geoderma.2004.01.032

Le Quéré C., Andrew R. M., Canadell J. G., Sitch S., Korsbakken J. I., Peters G. P., Manning A. C., Boden T. A., Tans P. P., Houghton R. A., Keeling R. F., Alin S., Andrews O. D., Anthoni P., Barbero L., Bopp L., Chevallier F., Chini L. P., Ciais P., Currie K., Delire C., Doney S. C., Friedlingstein P., Gkritzalis T., Harris, I., Hauck J., Haverd V., Hoppema M., Klein Goldewijk K.,

Jain A. K., Kato E., Körtzinger A., Landschützer P., Lefèvre N., Lenton A., Lienert S., Lombardozzi D., Melton J. R., Metzl N., Millero F., Monteiro P. M. S., Munro D. R., Nabel J. E. M. S., Nakaoka S., O'brien K., Olsen A., Omar A. M., Ono T., Pierrot D., Poulter B., Rödenbeck C., Salisbury J., Schuster U., Schwinger J., Séférian R., Skjelvan I., Stocker B. D., Sutton A. J., Takahashi T., Tian H., Tilbrook B., Van Der Laan-Luijkx I. T., Van Der Werf G. R., Viovy N., Walker A. P., Wiltshire A. J. and Zaehle S.: Global Carbon Budget 2016. *Earth System Science Data*. **8**: 605–649. Https://Doi.Org/10.5194/Essd-8-605-2016, 2016.

Gastauer M., Leyh W., and Meira-Neto J. 2015. Tree Diversity and Dynamics of The Forest of Seu Nico, Vicosa, Minas Gerais, Brazil. *Biodiversity Data Journal.* 3: E5425. Https://Doi.Org/10.3897/Bdj.3.E5425

Meijaard E, Brooks T. M, Carlson K. M., Slade E. M., Garcia-Ulloa J., Gaveau D. L. A., Lee J. S. H., Santika T., Juffe-Bignoli D., Struebig M. J., Wich S. A., Ancrenaz M., Koh L. P., Zamira N., Abrams J. F., Prins H. H. T., Sendashonga C. N., Murdiyarso D., Furumo P. R., Macfarlane N., Hoffmann R., Persio M., Descals A., Szantoi Z., Sheil D. 2020. The Environmental Impacts Of Palm Oil In Context. *Nature Plants.* **6**(12): 1418-1426. Https://Doi.Org/10.1038/S41477-020-00813-W

Noaa. National Oceanic and Atmospheric Administration. (2019, June 4). *Carbon Dioxide Levels In Atmosphere Hit Record High In May*. Accessed June 2020. Https://Www.Noaa.Gov/News/Carbon-Dioxide-Levels-In-Atmosphere-Hit-Record-High-In-May

Okoh T., Edu E. A. and Ebigwai J. K. 2019. Sequestered Carbon Stocks in Eight Selected Woody Species of The Guinea Savanna Ecosystem in Makurdi, Benue State, Nigeria. *International Journal of Biology and Biological Sciences.* **5**(1): 1-8.

Paul A. M., Iheukwumere C. C., Aguoru C. U., Okoh T. and Alfred U. J. 2019. Carbon Sequestration Potentials of Woody Plant Species in Makurdi Zoological Garden Benue State Nigeria. *Asian Journal of Resources in Agriculture and Forestry.* **3**(2): 1-12. Https://Doi.Org/10.9734/Ajraf/2019/V3i230034

Rakesh S. S., Davamani V., Sara Parwin Banu K., Maragatham S., Lakshmanan A., Parameswari E. and Velmurugan M. 2020.

Assessing The Potential of *Elaeis Guineensis* Plantations for Carbon Sequestration and Fresh Fruit Bunch Yield in Coimbatore, Tamil Nadu. *Current Journal of Applied Science and Technology.* **39**(6): 80-90. Https://Doi.Org/10.9734/Cjast/2020/V39i630562

Ribeiro M.C, Metzger J.P., Martensen A.C., Ponzoni F.J., Hirota M.M 2009. The Brazilian Atlantic Forest Distributed? Implications For Conservation. Biological Conservation. **142**(6):1141-1153. Https://Doi.Org/10.1016/J.Biocon. 200Sedjo R. and Sohngen B. 2012. Carbon Sequestration In Forests And Soils. *Annual Review of Resource Economics*. **4**: 127-144. Https://Doi.Org/10.1146/Annurev-Resource-083110-115941

Singh S. L., Sahoo U. K., Kenye A. and Gogoi A. 2018. Assessment Of Growth, Carbon Stock and Sequestration Potential of Oil Palm Plantations in Mizoram, Northeast India. *Journal Of Environmental Protection*. **9**(9): 912-931.

Https://Doi.Org/10.4236/Jep.2018.99057

THE IMPACT OF PALYNOMORPHS ON THE HEALTH AND WELL-BEING OF STUDENTS AT JOSEPH SARWUAN TARKA UNIVERSITY, MAKURDI, NIGERIA

Onyinyechi Priscilla Okpara*, Thomas Okoh, Ilebode-Sam Margret, Uma Suur Dorinda

Joseph Sarwuan Tarka University, Benue State, Makurdi, Nigeria

* Corresponding author's Details: okpara.onyinyechi@uam.edu.ng, ORCID: 0009-0002-2505-1499

ABSTRACT

Airborne pollen grains and fungal spores (palynomorphs) are important biological components of the atmosphere that influence air quality and are recognized as major triggers of allergic and respiratory diseases in humans. This study investigated the diversity of airborne palynomorphs and their potential impact on the health and well-being of students at Joseph Sarwuan Tarka University, Makurdi, Nigeria. A mixed-methods approach was employed involving 100 undergraduate students selected from five lecture venues. Airborne palynomorphs were sampled over four weeks using improvised pollen traps installed at the study sites, while dust samples collected from the same locations were analyzed for pollen content. Structured questionnaires were also administered to assess the prevalence of respiratory symptoms and their perceived effects on students' health and well-being. The results revealed that pollen grains belonging to the Asteraceae were the most abundant, exhibiting considerable variation in size, shape, ornamentation, and aperture characteristics. This was followed by members of the Poaceae and Malvaceae. In addition, a diverse assemblage of fungal and fern spores was identified and characterized based on their morphological features. The prevalence of respiratory ailments among respondents ranged from 50% to 65% across the lecture venues. The Student Lecture Theatre recorded the highest prevalence (65%), whereas Aper Aku Lecture Theatre and the Convocation Square recorded the lowest prevalence (50%). The findings suggest a positive association between the abundance of airborne palynomorphs and the occurrence of respiratory conditions among students. The study highlights the need for continuous aerobiological monitoring, the establishment of a palynomorph database, and interdisciplinary research to improve environmental health surveillance and allergen management. It also recommends improved ventilation, enhanced sanitation, reduced overcrowding, and targeted health awareness programmes to minimize exposure to airborne allergens and reduce the incidence of respiratory diseases within university learning environments.

Keywords: Aerobiology; Palynomorphs; Airborne pollen; Respiratory health; Environmental monitoring.

INTRODUCTION

Palynomorphs are microscopic organic entities that include pollen grains, fungal

spores, algae, and other microfossils. These particles have gained considerable attention for their importance in both environmental assessment and public health. Typically present in the air, they have been extensively examined for their association with respiratory illnesses and allergic reactions (ElKelish, Tešija Kuna, Khaitov, Davies, and Smolinska, 2020). Their significance goes beyond environmental relevance, as they play a key role in contributing to the burden of airborne allergens, particularly in tropical and subtropical climates with rich vegetation and marked seasonal changes. Airborne palynomorphs have been identified as contributors to several allergic conditions such as asthma, conjunctivitis, and allergic rhinitis ailments frequently experienced by adolescents and young adults (D'Amato, Cecchi, D'Amato, and Annesi-Maesano, Amato, 2015). Higher institutions of learning that accommodate a dense population of young individuals within shared spaces are particularly susceptible to the effects of these allergens, especially when exposure is prolonged or seasonal. This concern is especially pertinent in Nigeria where weather patterns, urban development, and diverse plant life combine to produce inconsistent yet elevated levels of airborne organic particles (Agwu and Osibe, 2012).

Makurdi, the capital of Benue State, lies in Nigeria's guinea savanna region and is characterized by alternating rainy and dry seasons. The area's ecological setting supports a broad spectrum of plants, grasses, and fungi, all of which contribute significantly to the variety of palynomorphs in the atmosphere. Joseph Sarwuan Tarka University, Makurdi (JOSTUM), located within this environment, is likely to be subjected to substantial palynomorph exposure, particularly during peak seasons for flowering and dryness, when dispersal rates are highest (Odoh, Agwu, and Ibe, 2017).Although the health risks posed by palynomorphs are well-documented globally, localized research assessing their impact on university students in Nigeria remains limited, especially at JOSTUM. Students in such environments may be at greater risk due to frequent outdoor activities, communal living arrangements, and often restricted access to advanced healthcare. Furthermore, incidents of illness and reduced academic productivity caused by allergies or respiratory symptoms are seldom systematically recorded or associated with environmental triggers (Ugwoke e*t al.*, 2018).

Recent literature highlights the urgent need for regional monitoring of airborne biological particles in campuses and public areas (Weyh e*t al.*, 2021). In the absence of specific data on the types, abundance, and seasonal fluctuations of palynomorphs, formulating appropriate public health responses becomes challenging. Gaining insights into the local palynological profile and linking it to reported health complaints among students is vital for crafting effective health and environmental management strategies. Health and well-being among students encompass more

than just the absence of disease; it includes mental, emotional, and social wellness. Chronic allergic conditions and respiratory issues can lead to psychological stress, sleep problems, and decreased classroom engagement, all of which collectively impair students' quality of life and academic success (Kim, Lee, and Park, 2022). Identifying environmental contributors to these conditions is therefore essential for enhancing student wellness and educational outcomes.

To effectively address this issue, it is necessary to conduct a thorough study that identifies the prevalent palynomorphs within the university's surroundings, examines their distribution patterns across seasons, and assesses their correlation with both medically diagnosed and self-reported health conditions in the student population. The research should also consider the students' level of awareness about allergenic sources and the methods they employ to manage related symptoms. Knowledge gained from such a study can inform policy changes in areas like campus landscaping and health education programs. The core issue this study seeks to tackle is the absence of concrete, localized data on the health effects of palynomorph exposure among students at Joseph Sarwuan Tarka University, Makurdi. In the absence of such data, institutional health policies may fail to adequately protect the student body from preventable environmental health risks. It is, therefore, crucial to assess the scale and nature of this exposure to enable the development of informed, responsive strategies.

Awareness has been increasing about the harmful effects of environmental allergens on human health, especially among young people in higher education settings. Palynomorphs tiny airborne organic particles like pollen, fungal spores, and algae have been identified as major contributors to allergic reactions and respiratory ailments. This concern is particularly relevant in places like Makurdi, where the climate, vegetation, and seasonal patterns encourage the widespread release of these particles into the air. However, at institutions such as Joseph Sarwuan Tarka University, Makurdi (JOSTUM), there has been little to no in-depth research to evaluate the level of student exposure to these particles or their potential effects on health and academic performance. Although there are increasing unreliable and clinical observations of allergies, asthma, and related respiratory issues among students in Nigeria, the link between these symptoms and palynomorph exposure remains unclear due to a lack of documented research. In the absence of concrete data on the occurrence and fluctuations of palynomorphs within the university environment, health challenges related to allergen exposure are often handled in an uncoordinated and reactive manner. Consequently, many students may continue to suffer from avoidable health problems, which can cause school absences, reduced academic focus, sleep disturbances, and overall diminished well-

being. The lack of site-specific data on the types, concentration, and seasonal dynamics of palynomorphs, as well as their connection to student health and well-being, reveals a critical gap in research. Furthermore, students generally have limited awareness about the environmental sources of their health conditions, and institutional measures to mitigate these effects are minimal or non-existent. This knowledge gap hinders the creation of focused solutions, including early warning systems for allergens, improved vegetation management, and health education initiatives. As such, there is a pressing need to explore the palynological conditions within JOSTUM to guide informed interventions that safeguard student health and well-being.

The aim of the study is to investigate the impact of palynomorphs on student health and well-being at JOSTUM, the study was guided by the following specific objectives:

Objectives of the Study

1. Identify and classify the dominant types of airborne palynomorphs present within the environment of Joseph Sarwuan Tarka University, Makurdi.
2. Examine the concentration of palynomorphs present within the environment of Joseph Sarwuan Tarka University, Makurdi.
3. Assess students' awareness of palynomorph-related health risks and existing coping mechanisms used within the university community.

Research Questions

The following research questions were formulated to guide the study.

1. What are the dominant types of airborne palynomorphs present within the environment of Joseph Sarwuan Tarka University, Makurdi?
2. What is the concentration of palynomorphs present within the environment of Joseph Sarwuan Tarka University, Makurdi?
3. Create study awareness on health risks of palynormorphs within the university community?

This study is significant because it seeks to bridge a critical knowledge gap in the understanding of how palynomorphs affect the health and well-being of students in the university. By investigating the types and seasonal patterns of palynomorphs in JOSTUM, this research would contribute empirical evidence necessary for informed health and environmental decision-making within the institution. It has potential to inform and improve disease prevention strategies targeting respiratory and allergic conditions. Allergies and asthma, often triggered by airborne particles like pollen and fungal spores, are common among young adults and can lead to chronic health issues if not addressed. This research could support the university's medical clinic and public health authorities in diagnosing and

managing allergen-related conditions, reducing the burden on healthcare services, and improving early detection and treatment protocols.

It is important because students' physical well-being directly impacts their cognitive functioning, attendance, participation, and overall academic performance. Chronic respiratory discomfort or allergic symptoms can disrupt sleep, reduce concentration, and lead to missed lectures and poor academic engagement. By identifying environmental factors that compromise student health, the research would highlight areas of intervention that can enhance student productivity and foster a more conducive learning environment.

It would contribute to the broader field of environmental science by providing data on the palynological composition of Nigeria. This would also add to the body of scientific knowledge about tropical and subtropical ecosystems and can support future comparative or longitudinal studies across different ecological zones.

The geographical scope of this study is limited to the natural and environmental conditions of the university. This study is specifically focused on investigating the types, concentrations, and seasonal variations of airborne palynomorphs such as pollen grains, fungal spores, and algae within Joseph Sarwuan Tarka University, Makurdi (JOSTUM). The research will involve palynological sampling and analysis in various parts of the university campus during different climatic seasons to determine patterns of distribution and potential periods of heightened exposure. The study will also assess the health implications of palynomorph exposure by analysing student-reported cases of allergic and respiratory conditions.

Operational Definition of Terms

Palynomorphs: are microscopic, airborne organic particles such as pollen grains, fungal spores, algal cells, and other plant microfossils that are present in the university's (JOSTUM) atmosphere.

Airborne Allergens: are palynomorphs suspended in the air that can trigger allergic responses such as sneezing, itching, nasal congestion, or asthma in sensitive individuals.

Respiratory Conditions: refers to student-reported or clinically diagnosed health issues affecting the respiratory system, including asthma, allergic rhinitis, sinusitis, and other pollen-induced respiratory discomforts.

Seasonal Variation: describes the changes in quantity and type of airborne palynomorphs across different climatic periods (dry and rainy seasons) within the study area.

Health and Well-being: refers to both the physical health (absence of illness or respiratory symptoms) and general wellness (mental, emotional, and academic functionality) of students as influenced by exposure to environmental allergens.

Student Awareness: describes the level of knowledge and understanding that students

have regarding palynomorphs, their sources, health impacts, and possible preventive measures.

Coping Mechanisms: are the strategies or actions employed by students to reduce or manage the negative health effects of exposure to airborne palynomorphs, including medical, behavioural, and environmental interventions.

JOSTUM Environment: refers specifically to the physical and ecological surroundings of Joseph Sarwuan Tarka University, Makurdi including its buildings, vegetation, and open spaces where students reside, study, and socialize.

MATERIALS AND METHODS

Research Design

This research employed a mixed-methods research design, combining experimental and survey approaches. This design is applicable because it allows the researcher to collect and analyse quantitative data such as air quality counts and types of airborne palynomorphs (pollen and spores), and health survey responses related to respiratory and allergic conditions among students. Exploring qualitative insights with affected students to gain an understanding of how exposure impacts their health and general well-being. Quantitative data will help establish correlations between palynomorph presence and surveyed health issues, while the qualitative component captures experiences and perceptions of students.

Area of Study

The area of study for this research was at Joseph Sarwuan Tarka University, Makurdi, Benue State, Nigeria, a region known for its tropical climate, with distinct wet and dry seasons, containing diverse vegetation, all of which contribute to the presence and seasonal variation of airborne palynomorphs such as pollen grains and fungal spores. The university campus, which encompasses academic buildings, student hostels, open green spaces, and agricultural fields, provides a unique ecological setting that facilitates the dispersion of palynomorphs, especially during the flowering season and harvest periods. Makurdi environment is also influenced by the surrounding farmlands and natural vegetations which can increase the concentration of palynomorphs in the atmosphere, probably impacting air quality and posing health risks to the student population, particularly those with pre-existing respiratory conditions like asthma or allergic rhinitis. Given that students spend significant time on campus both indoors and outdoors, they are likely to experience varying levels of exposure to these microscopic particles, which may affect their health and academic performance. The university setting thus offers a controlled yet dynamic environment for studying the relationship between environmental allergens and human health, making it an ideal location for assessing the impact of palynomorphs on student well-being and contributing valuable insights to both academic research

and institutional health management strategies.

Population of the Study

The population of this study comprised 100 undergraduate students of the Joseph Sarwuan Tarka University, Makurdi cut across various colleges and departments who reside within or frequently utilize the university campus (Agwa, 2022). This diverse population is appropriate for assessing the impact of palynomorphs on the health and well-being of the students. Many students live/study within the university premises, making them consistently exposed to the local environmental conditions including potential airborne allergens like pollen and fungal spores, especially during specific seasons.

Sample and Sampling Techniques

A sample size of 100 students was drawn using Taro Yamane's formula for sample size determination from the population of 20,234 undergraduate students at Joseph Sarwuan Tarka University, Makurdi for the study.

Data Collection

Data for this study were collected via three approaches. First, experimental data was effectively collected using improvised pollen traps based on the Modified Tauber Sampler in line with the methodology developed by Agwu (1992). These traps were strategically deployed in selected locations within Joseph Sarwuan Tarka University, Makurdi. The constructed traps were prepared with a 5 cm aperture lid. The lids were lined with fine metal wire mesh to prevent the entry of debris while allowing the capture of airborne pollen and

spores. Five key sampling sites identified for the installation of these traps include: Aper Aku Auditorium, CASE Auditorium, Veterinary Auditorium, Convocation Square, and Science Lecture Theatre (SLT). Each trap was mounted securely at an approximate height of 12 meters above ground level with structural support to prevent displacement by wind. To preserve and fix the collected palynomorphs, a mixture of 50 ml glycerol, 10 ml formaldehyde, and 5 ml phenol was added to each trap. Sampling was conducted over a period of four consecutive weeks. The contents of the traps were collected and replaced on the last day of each week. After collection, the samples were taken to the laboratory for examination. Secondly, dust samples were collected from the sampling locations above and placed into labelled, airtight containers. These containers were then transported to the laboratory and stored in a cool, dry environment to preserve the quality of the samples. Lastly, data concerning health and the well-being status of the students was collected using a structured questionnaire to obtain a report on the kind of health-related issues associated with the students in the university.

Data was analysed using laboratory procedures and quantitative evaluation to determine the abundance of palynomorphs in relation to student health and well-being.

Palynomorph samples were collected on a weekly basis following a standard preparation process, adapted from Faegri and Iversen (1989) to ensure accurate identification and quantification. Each collected sample was first centrifuged and washed with distilled water. The washed residues were then transferred into pre-labelled 10 ml graduated centrifuge tubes according to their week of collection. A second centrifugation was conducted at 2,500 rpm, after which the supernatant was decanted into freshly labelled test tubes. To enhance the visibility of pollen and spores, samples were subjected to acetolysis. This involves treating the samples with an acetolysis mixture made by combining one part concentrated sulfuric acid (H_2SO_4) with nine parts acetic anhydride. 3ml of concentrated H_2SO_4 was be added to 27 ml of acetic anhydride, and the mixture was pipetted into the test tubes containing the samples. The test tubes were then be heated in a water bath at 70°C for 5 minutes, with occasional stirring using glass rods. Following heating, the samples were cooled, transferred into another set of labelled test tubes, and centrifuged again at 2,500 rpm for 5 minutes. This step was repeated with distilled water until all traces of the acetolysis mixture were removed. The resulting residues were stored in labelled bottles based on their respective collection locations and weeks. Microscopic analysis involving pipetting three drops of the prepared residue onto a 22×22 and 22×23 mm labelled glass slide containing glycerine jelly was used to ensure even distribution. A 1mm cover slip was applied to avoid trapping air bubbles, and nail polish was used to seal the cover slip. Slides were examined using a light microscope at 40x magnification to identify and quantify palynomorphs.

Acetolysis

Each of the dust sample collected were taken to the lab for acetolysis method. This begins with adding 10ml of 10% of Potassium Hydroxide (KOH) and heat in water bath at 70°C for 5 minutes. Centrifuge and decant and Rinse with distilled water. Add 15 ml of concentrated Hydrochloric Acid. Allow the boiling to stop, centrifuge and decant. Rinse with distilled water repeatedly to remove the acid traces. The function is to remove carbonates and calcareous materials. Add 10 ml of 40% Hydrofluoric Acid. Allow to stand for 24 hr, centrifuge, decant, and rinse thoroughly with distilled water. The Function was to dissolve siliceous materials. Afterward, the samples will be passed through a fine mesh sieve (10–50 µm) to separate and concentrate the palynomorphs. Next, the residue was treated with a mixture of glacial acetic and concentrated sulfuric acid to remove any remaining cellulose and improve the visibility of pollen grains. The resulting solution was centrifuged and repeatedly rinsed with distilled water to remove all chemical residues. Finally, the cleaned material will be placed on microscope slides using glycerine jelly and stained with safranin samples were then examined under a light microscope (at 400x to 1000x

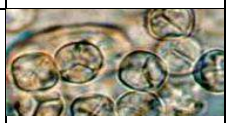
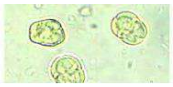
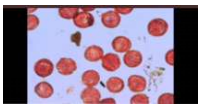
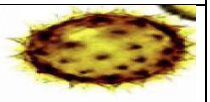
magnification) to identify and count pollen, spores, and other palynomorphs present in the dust. The percentage abundance of each species was calculated. Then, a correlational analysis of pollen concentrations was statistically compared with surveys of allergic and respiratory health complaints reported by students to establish any correlations between palynomorph presence and student health and well-being in the university.

RESULTS

Table 1 presents the comparative morphological analysis of pollen grains from the dust samples collected at Joseph Sarwan Tarkaa University which reveals considerable variation in terms of size, shape, ornamentation, aperture type, and Colouration across different plant families. Pollen size ranges from very small grains such as those in the Pinaceae (10–19 μm) to very large ones, like those in the Malvaceae family (130–155 μm). Shapes also vary significantly, with most families displaying spherical or sub-spheroidal forms, while others such as Pinaceae and Poaceae, exhibit irregular or slightly oval grains. Ornamentation patterns differ greatly, with some pollens like those of the Poaceae family having thin, smooth walls (psilate), while others, such as Asteraceae and Malvaceae, display echinate or spiny surfaces. Aperture types range from monoporate (single pore) in many Poaceae and Asteraceae members to tricolporate in Fabaceae, Asteraceae, and Malvaceae, while some, like Cyperaceae, exhibit multiple pores. The colour of pollen grains varies from green, cream, and yellowish brown to dark grey and orange-brown, indicating differences in pigmentation that could relate to their ecological or physiological adaptations.

The findings show that pollen grains from the Asteraceae family were the most dominant in terms of diversity, displaying a wide range of sizes, shapes, ornamentation, and aperture types, followed by Poaceae and Malvaceae. This variation reflects the diverse plant composition in the study area and highlights the ecological significance of pollen morphology in environmental and palynological studies.

Table 1 Comparative, morphological characteristics of pollen identified from the dust sample at Joseph Sarwan Tarkaa University.

S/N	Family	Pollen Size	Pollen Shape	Ornamentation	Aperture	Colour of Pollen	Micro-photograph of Observed Pollens and spores
1	Cyperaceae (Sedge)	18–22 µm	Oval	Nill	multiple Pores	green	
2	Fabaceae (Leguminosae)	Medium (20–32 µm)	Spherical	Thick (tectate-columellate)	Tricolporate (3-aperturate)	Cream	
4	Chlorophyceae (Green Algae)	180 µm	Spherical	Echinate	Colporate	Yellowish Brown	
5	Pinaceae (Corters)	10–19 µm	Irregular	Thick (Scabratereticulate)	Monolete (One narrow/pore)	Brown	
6	Asteraceae (Sunflower)	Small	Spherical	Echinate	Monoporate (One pore)	Brownish	
7	Asteraceae (Sunflower)	Medium	Spheroidal	Thick (Echinate)	Colporate	Brownish	
8	Poaceae (Grass)	20–40 µm	Spheroidal	Psilate	Monoporate	Light yellow	
9	Poaceae (Grass)	15–40 µm	Slightly Oval	Thin Smooth (Slightly granular)	Monoporate (single pore)	Yellowish brown	
10	Malvaceae (Hibiscus)	Large (130–155 µm)	Sub spheroidal	Echinate	Pantoporate	Dark Grey	
11	Poaceae (Grass)	20–40 µm	Oval	Psilate (Thin Smooth)	Tricolporate (3colpi with Pore)	Yellowish Brown	

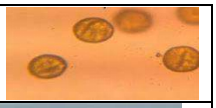
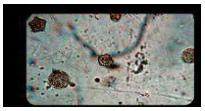
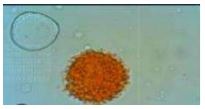
12	Asteraceae (Sunflower)	20–50 µm	Spherical	Thick wall (Psilate)	Monoporate (one pore)	Yellowish Brown	
13	Nymphaeaceae (Angiosperm)	60–70 µm	Spherical	Thick wall (apsilate)	Monoporate	Yellowish Brown	
14	Asteraceae (Sunflower)	30–35 µm	Sub-circular	Thick wall (Spiny)	Multiple pores	Dark Brown	
15	Asteraceae (Sunflower)	Small	Spherical	Spring (Echinate)	Tricolporate	Dark Brown / Yellowish Brown	
16	Malvaceae (Hibiscus)	Large	Slightly Oval	Thick (Chinate)	Tricolporate	Dark-stained pulple	
17	Asteraceae (Sunflower)	20–50 µm	Spherical	Thick sculptured, spiny	Tricolporate (3 narrow/pores with colp)	Orange-Brown	

Table 2 presents the morphological characterization of spores identified from the indoor trap sampler at Joseph Sarwan Tarkaa University, which revealed a wide diversity in terms of shape, size, wall structure, and Colouration across different sampling locations. Spore sizes varied considerably, ranging from as small as 3–8 µm in Saccharemyas (fungi spores) to as large as 220–223 µm in Dicellarsporites minutus (fern spores). Shapes were equally diverse, including oval, spherical, globular, triangular, kidney-shaped, and irregular forms, indicating contributions from multiple spore-producing taxa. Wall structures ranged from thin and smooth, as seen in Cyptococus spores, to thick or sculptured walls as found in Lycopsida and Uromyces spores, suggesting differences in structural adaptations and dispersal mechanisms. Colouration also varied widely, with spores exhibiting yellowish-brown, golden, creamy, light brown, yellowish black, and dark pigmentation, possibly reflecting differences in spore chemistry or maturity levels.

The distribution pattern shows that spores were collected from various strategic locations, including the Aper Aku Auditorium, Veterinary Auditorium, Case Auditorium, SLT complex, and Convocation Square. Notably, some spore's genus such as *Blastocystis* were found in clustered chains, while others, like *Laevigtos porites*, occurred as single spores, indicating different reproductive or dispersal strategies among the species.

The findings demonstrate a rich diversity of fungal and fern spores within the university environment, with varying morphological adaptations. This diversity may have implications for aerobiology, environmental monitoring, and allergen studies within indoor environments.

Table 2 Morphological characteristics of spores identified from the indoor trap sampler at Joseph Sarwan Tarkaa University

Sample ID	Family/group	Shape	Size (µm)	No. of spores	Wall structure	Colour	Location	Locality
A1	Blastocystis sp. / mech spots	Irregular	30 - 40	Clustered in chains		Dark	Ujam Village, Makurdi	Middle of Aper Aku Auditorium
A2	Cryptococcus / Fungi spores	Oval	40	Clustered	Thin and smooth	Yellowish-brown	Ujam Village, Makurdi	Back of Aper Aku Auditorium
V1	Dicellarsporites minutus/fern spores	Oval	220-223	Bicellate	Thick	Dark	Ujam Village, Makurdi	Middle of Aper Aku Auditorium
V2	Atriyriaceae/Fern Spine	Kidney shape	20-325	10 spores	Smooth - slightly sculptured	Light brown	Ujam Village, Makurdi	Back of Veterinary Auditorium
C1	Uromyces/fungal spores	Spherical, ellipsoidal	17- 5	3 Pores	Thick	Yellowish-brown	Ujam Village, Makurdi	Middle of case Auditorium
C2	Sceleroderodermataceae/fern spore	Ovlid	18 - 20	7 Spores	Thick	Golden	Ujam Village, Makurdi	Back of case Auditorium
SLT1	Lycopsida / Fern spore	Sub-circular – triangular	Nill	8 spores	Sculptured	Yellowish black	Ujam Village, Makurdi	Middle of SLT
SLT2	Entylma Ficariae/fungi spore	Globular	14 µm	10 spores	Thick	Light brown	Ujam Village, Makurdi	Back of SLT

Table 3 presents the distribution of participants according to lecture venue and age. Out of the 100 respondents, 43 were below 25 years of age, while 57 fell within the 25–30 years age group, showing that the majority of the participants were slightly older.

Across the different lecture venues, Aper Aku had 20 participants, with 5 below 25 years and 15 between 25–30 years, indicating older participants in this venue. The SLT venue also had 20 respondents, with 8 younger and 12 older, showing a fairly balanced spread, though with a slight dominance of those in the older category. In the Vet. Auditorium, 15 respondents were below 25 years, while only 5 were aged 25–30, making it the only venue where younger participants clearly outnumbered the older ones. CASE recorded 7 younger and 13 older participants, maintaining the general trend of older dominance. At the Convocation Square, the distribution was similar to SLT, with 8 younger and 12 older respondents. The age distribution showed more concentration in the 25–30 years category, except for the Vet. Auditorium where younger participants dominated.

Table 3 Lecture Venue and Age Distribution of Participants (N=100)

S/N	Lecture Venue (s)	Age		Total
		Below 25yrs a	25-30yrs	(%)
1	Aper Aku	5	15	20
2	SLT	8	12	20
3	Vet. Auditorium	15	5	20
4	CASE	7	13	20
5	Convocation square	8	12	20
	Total	43	57	100

Table 4 shows the prevalence of respiratory diseases among participants across different lecture venues. Out of the 100 participants examined, 57 were infected while 40 were not, and 3 cases of infection were specifically associated with classroom usage

At Aper Aku, 20 participants were examined, with 10 infected and 10 not infected, resulting in a prevalence rate of 50 percent and no cases linked to classroom usage. In SLT, 20 were also examined, 13 were infected, 6 not infected, and 1 case was linked to classroom usage, giving the highest prevalence rate of 65 percent. In the Vet. Auditorium, 12 out of 20 were infected while 8 were not, yielding a prevalence of 60 percent with no classroom-associated infections. CASE had 12 infected, 7 not infected, and 1 classroom-related case, also with a prevalence of 60 percent. At the Convocation Square, 10 were infected, 9 were not, and 1 case was linked to classroom usage, with an overall prevalence rate of 50 percent. This gives a total prevalence rate of 57 percent among the participants with respiratory disease.

The bar chart illustrates the prevalence of respiratory infections among participants across different lecture venues, along with the proportion of infections associated with classroom usage. The blue bars represent the overall prevalence of infection in each venue, while the red bars represent infections linked specifically to classroom usage. At Aper Aku, the prevalence of infection was 50 percent, with no cases attributed to classroom usage. In SLT, the infection rate was highest at 65 percent, and about 7.7 percent of infections were linked to classroom usage. The Vet. Auditorium showed a prevalence of 60 percent, but with no infections tied directly to classroom use. CASE also recorded a prevalence of 60 percent, with about 8.3 percent of infections linked to classroom usage. At the Convocation Square, infection prevalence stood at 50 percent, and 10 percent of cases were associated with classroom usage.

The chart shows that prevalence rates were relatively high across all venues, ranging from 50 to 65 percent. SLT recorded the highest prevalence, suggesting it may present the greatest risk of transmission. This suggests the importance of improved ventilation, hygiene, and preventive measures in lecture venues to minimize infection risks.

Table 4 Participants with Respiratory Disease

S/N	Lecture Venue	Number Examined	Number Infected	Number Not Infected (%)	Infection Associated with Classroom Usage (%)	Prevalence (%)
1	Aper Aku	20	10	10	0	50
2	SLT	20	13	6	1	65
3	Vet. Auditorium	20	12	8	0	60
4	CASE	20	12	7	1	60
5	Convocation square	20	10	9	1	50
	Total	100	57	40	3	57

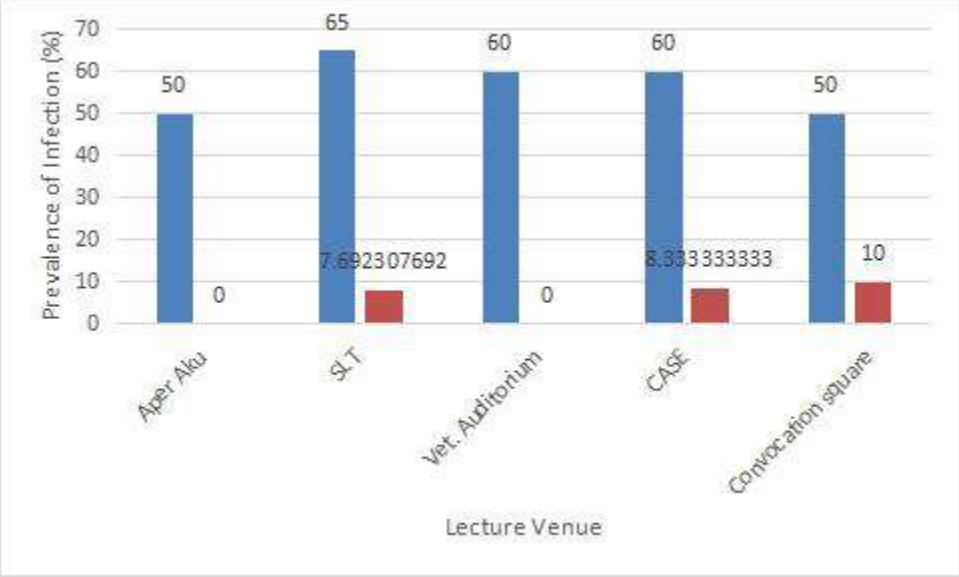


Figure 1: Prevalence of respiratory diseases among students and infections associated with poor hygienic classrooms

DISCUSSION

The results revealed that respiratory disease prevalence among participants across different lecture venues at Joseph Sarwan Tarkaa University was relatively high, with an overall rate of 57 percent. The bar chart shows that prevalence rates ranged from 50 to 65 percent, with SLT recording the highest prevalence (65%), followed by CASE and the Vet. Auditorium (60% each), while Aper Aku and Convocation Square both recorded 50 percent. Infections associated with classroom usage were few, totalling 3 cases, indicating that while the general prevalence was high, only a small proportion of cases were directly linked to classroom conditions. Nevertheless, SLT, with the highest infection rate, may present a greater risk of transmission, highlighting the need for improved ventilation, hygiene, and preventive measures in lecture venues to minimize infection risks.

The current findings from Joseph Sarwan Tarkaa University align with previous studies that have documented the ecological

and health implications of palynomorph diversity in university environments across Nigeria. The observed variation in pollen size, shape, aperture type, and ornamentation mirrors the results of Tyohemba *et al.* (2023), who identified Poaceae and Asteraceae as dominant pollen families during the dry season in Makurdi. Their findings correlated the abundance of these pollen types with increased cases of respiratory ailments, suggesting that the dominance of Asteraceae and Poaceae in the present study may similarly contribute to heightened health risks for students during peak seasons.

The detection of diverse fungal and fern spores in indoor environments at Joseph Sarwan Tarkaa University also resonates with the observations of Olorunfemi and Adeyemi (2023), who reported that poorly ventilated indoor spaces in university settings tend to trap significant amounts of airborne palynomorphs. This accumulation increases students' exposure and often coincides with symptoms such as fatigue, respiratory irritation, and reduced academic performance. The present study's findings on spore diversity, particularly the presence of *Blastocystis sp.* and *Dicellarsporites minutus* in clustered and bicellate forms, further support the argument that indoor environments can act as reservoirs for allergenic particles, consistent with previous studies conducted in similar ecological zones.

The seasonal influence on palynomorph concentration reported by Okeke *et al.* (2021) and Musa and Adekunle (2022) also provides context for interpreting the current findings. Their studies revealed that during the dry and Harmattan seasons, pollen and spore counts significantly increase, leading to spikes in allergy-related health cases among students. The dominance of allergenic pollen families such as Asteraceae and Poaceae in the present study reinforces these earlier findings, suggesting a direct link between ecological factors, airborne palynomorph loads, and student health outcomes.

Intervention studies by Chukwu and Obi (2022) and Okezie *et al.* (2022) demonstrated that vegetation management and improved indoor air quality measures, such as air filtration units, significantly reduce palynomorph exposure and associated allergic reactions. These findings highlight the importance of implementing similar strategies at Joseph Sarwan Tarkaa University, where the high diversity of pollen and spore species documented in this study indicates a substantial potential for allergenic impacts on students and staff. A total prevalence rate of 57 percent among the participants with respiratory disease underscores the need for urgent interventions. Moreover, Akpan and James (2023) emphasized the value of awareness campaigns in reducing health risks associated with airborne palynomorphs. Their observation that informed students adopted preventive behaviors aligns with the present study's implication that proactive interventions, including education on seasonal patterns of palynomorph dispersion, could help mitigate adverse health effects.

CONCLUSION

The study reveals a strong connection between the diversity and morphological characteristics of palynomorphs and the high prevalence of respiratory diseases among students. The comparative morphological analysis of pollen grains from dust samples shows considerable variation in size, shape, ornamentation, aperture type, and Colouration across different plant families, with Asteraceae, Poaceae, and Malvaceae being the most dominant. These families, known for their allergenic properties, contribute significantly to airborne

particulate loads within the university environment. The presence of diverse fungal and fern spores, such as *Blastocystis sp.*, *Cryptococcus*, and *Dicellarsporites minutus*, further indicates poor indoor air quality and the likelihood of sustained allergen exposure in lecture venues. The recorded 57 percent prevalence of respiratory infections among participants, with SLT showing the highest rate of 65 percent, underscores the health risks associated with palynomorph accumulation in poorly ventilated and unhygienic learning environments. These findings emphasize that ecological and environmental factors particularly airborne pollen and spore diversity play a critical role in influencing student health outcomes. The study concluded that the prevalence of respiratory disease was high among students, implying high impact of palynomorphs on the health of participants.

Recommendations

Based on the findings of the study, the following recommendations should be considered:

1. Pollen and spore database should be established within the University, which can serve as a reference for environmental monitoring, biodiversity assessment, and potential allergen studies to better understand seasonal variations and their implications for public health.
2. Research on aerobiological surveillance to monitor spore diversity and concentration levels are recommended, especially those related to the assessment of potential health risks, guiding allergen management strategies, and supporting environmental quality control measures should be supported.
3. Immediate preventive measures should be implemented by the university across all lecture venues, with particular attention to SLT where the risk is highest. Improving ventilation, enforcing regular sanitation, reducing overcrowding, and sensitizing students on personal hygiene and health practices will help reduce the spread of respiratory diseases.

REFERENCES

Adekanmbi, O.H., Ogundipe, O.T. (2019). Airborne pollen and spore studies in southwestern Nigeria: Implications for allergy sufferers. *Aerobiologia*, 35(2), 251-264. https://doi.org/10.1007/s10453-019-09585-7

Adeleye, Y.A., Ogunwale, R.F., Bamidele, O.J. (2020). Airborne fungal spores and their health implications in university hostels in Southwest Nigeria. *Environmental Health Perspectives*, 128(9), 097004. https://doi.org/10.1289/EHP6723

Adhikari, A., Reponen, T., Grinshpun, S.A. (2020). Airborne fungal spores and allergen concentrations in indoor and outdoor environments. *Environmental Research*, 183, 109136. https://doi.org/10.1016/j.envres.2019.109136

Agwa, T.R. (2022). Students' attitudes towards entrepreneurship education in Josseph Sarwuan Tarka University, Makurdi-Nigeria. *International Journal of Management, Social Sciences, Peace and Conflict Studies (IJMSSPCS)*, 5(3), 175-185. https://www.ijmsspcs.com/in

dex.php/IJMSSPCS/article/view/409/441

Agwu, C.O., Osibe, E.E. (2012). Airborne pollen grains in Nsukka, Nigeria. *Grana*, 31(1), 91- 98. https://doi.org/10.1080/00173130600555797

Akinbami, O.J., Ogunleye, A.O., Olatunde, A.T. (2022). Fungal spores in the air: seasonal distribution and health implications in southwestern Nigeria. *African Journal of Environmental Health*, 18(3), 210–219.

Akpan, S. and James, A. (2023). Environmental allergy awareness and health outcomes among university students in Nigeria. *Journal of Public Health in Africa*, 12(1), 34–42.

Ayanbode, A., Bello, K., Musa, L. (2022). Airborne palynomorphs and respiratory health: An assessment across Nigerian campuses. *Nigerian Journal of Environmental Sciences*, 14(3), 211–225.

Beggs, P.J., Katelaris, C.H., Davies, J.M. (2022). Environmental allergens: Pollen and fungi. *Journal of Allergy and Clinical Immunology: In Practice*, 10(1), 14–25. https://doi.org/10.1016/j.jaip.2021.08.038

Bisht, R., Singh, A., Joshi, P. (2021). Environmental impacts of pollen and fungal spores: A review on their role in allergic diseases. *Ecotoxicology and Environmental Safety*, 214, 112116. https://doi.org/10.1016/j.ecoenv.2021.112116

Bousquet, J., Anto, J.M., Bachert, C. (2021). Allergic rhinitis. Nature Reviews. *Disease Primers*, 7(1), 1–21. https://hdl.handle.net/10520/ejc-nm_specf_v21_n7_a8

Chukwu, I., Obi, T. (2022). Campus landscaping and allergy management: A case study in southeastern Nigeria. *Environmental Health Reports*, 7(2), 98–105.

D'Amato, G., Cecchi, L., Annesi-Maesano, I. (2021). Climate change and respiratory diseases. *European Respiratory Review*, 30(160), 200205. https://doi.org/10.1183/16000617.0205-2020

D'Amato, G., Cecchi, L., D'Amato, M., Annesi-Maesano, I. (2015). Climate change and respiratory diseases. *European Respiratory Review*, 23(132), 161–169.

Ekong, V., Bello, J. (2021). Psychological effects of environmental allergens among Nigerian undergraduates. *Nigerian Journal of Mental Health*, 9(4), 112–123.

ElKelish, A., Tešija Kuna, A., Khaitov, M., Davies, J.M., Smolinska, S. (2020). Pollen allergens and climate change: Implications for future health. *Current Allergy and Asthma Reports*, 20(4), 1-10.

Faegri K, Iversen J (1989). *Textbook of pollen analysis*. 4th ed. ,revised by Faegri K, Kaland PE and Krzywinski K. Wiley,Chicheste

Ibrahim, A.Y., Mba, C.U. (2021). Impact of vegetative zones on airborne pollen concentrations in Nigerian tertiary institutions. *Journal of*

Environmental Studies, 45(2), 133–141.

Kim, H.J., Lee, J.H., Park, Y.H. (2022). The impact of seasonal allergic rhinitis on quality of life and mental health among college students. *International Journal of Environmental Research and Public Health*, 19(6), 3425.

Levetin, E., Horner, W.E., Scott, J.A. (2019). Fungal Allergens. In D. A. Goldblum and A. W. Burks (Eds.), Middleton's Allergy: Principles and Practice (9th ed.). Elsevier.

Liu, Y., Zhang, L., Zhao, W. (2022). Advances in palynology: Classification, applications, and future directions. *Review of Palaeobotany and Palynology*, 300, 104627. https://doi.org/10.1016/j.revpalbo.2021.104627

Loftus, P.A., Wise, S.K., Hopkins, C. (2020). The impact of environmental allergens on cognition and quality of life. *Current Allergy and Asthma Reports*, 20(10), 56.

Musa, M., Adekunle, A. (2022). Comparative allergy incidence among university students in North Central Nigeria. *Nigerian Medical Review*, 18(2), 67–75.

Odoh, B.I., Agwu, C.O.C., Ibe, A. (2017). Pollen rain and allergic respiratory symptoms in Enugu metropolis. *Palynology*, 41(1), 50–58.

Okeke, N., Eze, U., Anya, C. (2021). Seasonal pollen trends and health impacts in Benue State. *Journal of Tropical Environmental Health*, 5(1), 49–60.

Okezie, H., Lawal, S., and Umar, D. (2022). Improving indoor air quality through air filtration in academic settings. *Journal of Nigerian Air Quality*, 6(3), 132–140.

Okonkwo, E.C., Obasi, N.P., Alabi, R.A. (2020). Influence of bush burning on airborne pollen and human health in Middle Belt Nigeria. *Nigerian Journal of Environmental Pollution and Health*, 9(1), 45–52.

Okoye, N.C., Eze, E.A., Chukwura, E.I. (2023). Seasonal variation of airborne pollen in Makurdi and its health effects. *Nigerian Journal of Environmental Sciences*, 41(2), 75-83.

Oladokun, A.L., Akinyele, B.J., Ogunyemi, F.M. (2023). Assessment of airborne fungal spores in Nigerian university environments: A case study of student hostels. *African Journal of Environmental Science and Technology*, 17(1), 45–53.

https://doi.org/10.5897/AJEST2022.3178

Olorunfemi, A., Adeyemi, B. (2023). Indoor pollen exposure and academic performance in southwestern Nigerian universities. *Journal of Indoor Environmental Quality*, 8(2), 76- 89.

Ongoma, V., Chen, H., Orindi, V. (2021). Climate variability and allergenic pollen in tropical Africa. *Aerobiologia,* 37, 165–177.

Onyema, M.O., Eze, C.A., Yusuf, A. (2023). Meteorological influence on aeroallergen dynamics in a Nigerian University setting. *West African Journal of Public Health*, 5(1), 87–95.

Puc, M., Kasprzyk, I., Uruska, A. (2023). Long-term pollen monitoring as a tool to evaluate urban ecological changes. Science of the Total Environment, 864.

Reinmuth-Selzle, K., Kampf, C.J., Lang-Yona, N. (2017). Air pollution and climate change effects on allergens and allergy. *Trends in Immunology*, 38(1), 54–62. https://doi.org/10.1016/j.it.2016.10.001

Sharma, N., Tripathi, A. (2022). Palynology in environmental science: Applications and advances. *Environmental Research*, 214.

Traverse, A. (2007). *Paleopalynology* (2nd ed.). Springer.

Tyohemba, E., Dondo, A., Agbo, M. (2023). Aerobiological survey of Makurdi and implications for public health. *Benue Journal of Science and Technology*, 10(1), 58–72.

Udeh, R., Ibrahim, Y. (2020). Vegetation proximity and allergic reactions among university students in Makurdi. *Savannah Health Journal*, 4(1), 20–35.

Udo, J.E., Ekong, U.B. (2021). Climatic determinants of airborne pollen variation in humid tropics. *Journal of Climatology and Environmental Science*, 39(1), 67–75.

Ugwoke, S.C., Nwankwo, C.N., Eneh, C.O. (2018). Environmental health risks in higher education institutions in Nigeria. *Nigerian Journal of Environmental Sciences and Technology*, 2(2), 109-117.DOI: 10.36263/nijest

Weyhe, D., Koffi, M., Zinsstag, J. (2021). The role of airborne biological particles in urban health: A One Health perspective. *One Health*, 12,.

.

GROWTH AND YIELD PERFORMANCE OF MAIZE (*Zea mays L.*) PLANT USING COW BLOOD MEAL AND GOAT WASTES AS BIOFERTILIZERS

Ani N.J., Olasan, J.O and Emoyi B.O.
Plant Science and Biotechnology Unit, Department of Botany, Joseph Sarwuan Tarka University Makurdi, Nigeria.
*****Corresponding Author's Email: ndidiamakajani@gmail.com

ABSTRACT

Declining soil fertility remains one of the major constraints to maize production in sub-Saharan Africa, necessitating the adoption of sustainable nutrient management practices that enhance crop productivity while reducing dependence on inorganic fertilizers. This study evaluated the response of different varieties of *Zea mays* to cow blood meal, goat waste, and NPK fertilizer. The experiment was conducted using a Completely Randomized Block Design (CRBD) with five replications per treatment. Organic amendments (cow blood meal and goat waste) were applied at 0.8 kg per experimental unit, while NPK fertilizer was applied at 0.2 kg per unit, giving a total of 225 experimental units. Growth and yield parameters were assessed throughout the experimental period. Data were subjected to analysis of variance (ANOVA), and treatment means were separated using Duncan's Multiple Range Test (DMRT) and the Least Significant Difference (LSD) test at the 5% level of significance ($p < 0.05$). The results showed that the flour maize variety treated with cow blood meal produced the highest growth and yield performance, recording plant height (177.0 cm), number of leaves (13.53), number of cobs per plant (2.00), cob length (19.28 cm), cob weight (0.298 kg), and number of kernels per cob (484.2). The same variety treated with goat waste ranked second, with plant height of 156.29 cm, stem diameter of 6.00 cm, leaf length of 85.40 cm, number of tassels (21.34), number of leaves (13.29), number of cobs per plant (1.589), and number of kernels per cob (307.3). Overall, the flour maize variety exhibited superior performance under organic nutrient amendments compared with the other varieties evaluated. The study demonstrates that cow blood meal and goat waste are effective organic nutrient sources capable of improving maize growth and yield and can serve as sustainable alternatives or complements to inorganic fertilizers. Their adoption, particularly for the flour maize variety, could enhance maize productivity while promoting environmentally sustainable soil fertility management.

Keywords: *Zea mays*; Cow blood meal; Goat waste; Organic fertilizer; Maize yield.

INTRODUCTION

Zea mays L. is a highly significant cereal crop that ranks third in the world after rice and wheat, and its output is constantly increasing (Kandil, 2013). Maize is processed into different products such as starch, corn syrup, sweeteners, oil, beverages, glue, alcohol and fuel ethanol which are important for industrial purposes as well as animal feed according to Ranum *et al.* (2014). More importantly, maize has become a model crop for molecular studies which has led to successful breeding and wider adaptation in Africa (Vivek *et al.*, 2010). Maize is an important crop with significant contribution to global economy especially in the developed world where it is considered as industrial material (Ranum *et al.*, 2014). Maize has become a major cereal in the last few years in the bio-fuel industry (Ranum *et al.*, 2014). Due to moderate cost of production and high dependent on maize as source of food in developing countries, and where micronutrient deficiencies are common public health issues, maize is also

becoming an ideal crop for food bio-fortification such as enhancement of pro-vitamin A (Ranum *et al.*, 2014; Espinoza and Ross, 2010). There are six major types of maize are dent corn, flint corn, pod corn, popcorn, flour corn and sweet corn and they are characterized according to their kernel types (Linda *et al.*, 2013).

Maize is a valuable food crop that widely consumed because of its nutritional values, there need to identify the best fertilizer suitable for its production. Therefore, this study was designed to evaluate the growth and yield performance analysis of maize (*zea mays l.*) plant using two potential biofertilizers (cow blood meal and goat wastes).

MATERIALS AND METHODS

Study Area

The study was carried in Botanical Garden of Joseph Sarwuan Tarka University, the site study is back of Block B. Makurdi as the headquarters of Benue state is located at latitude 7^0 40' N to 7^0 50' N of the Equator and Longitude 8^0 20' E – 8^0 40' E of the Greenwich Meridian

Collection of Plant Materials

Samples were collected from five different species of maize (*Zea mays*) namely Flour corn (*Zea mays* Var. amylacea), sweet corn (*Zea mays* Var. rugosa), waxy corn (*Zea mays* Var. ceratina), popcorn (*Zea mays* Var. everta), pod corn (*Zea mays* Var. tunicata). These species of maize were obtained from Benue State Agricultural and Rural Development (BNARDA), the Third National Fadama Agricultural development project located along Old Otukpo road, Makurdi. The maize seeds were identified and authenticated by a taxonomist in Plant Science and Biotechnology Department.

Collection of Manure

The three different fertilizers that were applied are; Blood meal of cow, Goat wastes and NPK 20:10:10, The organic fertilizer cow blood meal was gotten from abattoir slaughtering house and goat wastes collected from cattle market located in North Bank Makurdi. Th NPK 20:10:10 fertilizer was purchased from North Bank market Makurdi. The blood meal of cow was and the goat waste were properly dried and crushed before application in order to allow easy absorption by the plants.

Experimental Design

The experiment was set up in randomized completely block design (RCBD). The researched plot measured 15×20m was divided into (3) three equal blocks of equal sizes. These blocks include A, B and C with a distance of 0.7m between ridges and the spacing of 1.02m between each plants having 15plants in each row (ridge) in the first block, second block, and third block respectively, having a total number of 75 plants per block, and a sum total of 225 plants in all the three block experimental design. Five varieties of maize with three treatments (Blood cow meal, goat waste and N.P.K 20:10 :10) replicated five times.

Planting

Four (4) seeds of the five varieties of maize (*Zea mays*) which include: Flour corn (*Zea mays* Var. amylacea), sweet corn (*Zea mays* Var. rugosa), waxy corn (*Zea mays* Var. ceratina), popcorn (*Zea mays* Var. everta), pod corn (*Zea mays* Var. tunicata), were sown at 3cm depth manually in each pot (small polythene bag, perforated under) and were thinned to two per pot after seedling establishment. The polythene bag contains 10kg of loam soil and was irrigated daily. Treatments were applied after 14 days (2 weeks) of planting. The measurement level of treatment used for the both organic fertilizer is 0.8kg and 0.2kg for the inorganic fertilizer. Growth parameter data were

collected such as plant growth, leaf length, leaf width, number of leaves .

Data Analysis

Data collected were analyzed using appropriate Descriptive and Inferential Statistics such as Analysis of Variance ANOVA. Mean separation was done using Ducan Multiple Test DMRT and LSD of 95% confidence limit ($p<0.05$).

RESULTS AND DISCUSSION

The descriptive statistics of maize character evaluated in the field is presented in Table 1. Pod corn variety treated with N.PK fertilizer gave the tallest plants than other plants possibly because more concentrated nutrients or minerals were made readily available and easily absorbable by the receiving plants leading to faster growth and development. It is also similar to the findings of Fagimi and Odebode (2007) who reported increased plant height and number of leaves of pepper resulting from application of higher rate of N.P.K fertilizer. Goat wastes application in waxy corn variety increased leaf breadth higher than other treatments combination investigated possibly because that rate was most suitable or appropriate for increasing carbon content, water holding capacity, aggregation of soil and decrease of bulk density, all of which interplay to increase leaf breadth and total chlorophyll content of maize. This is consistent with the findings of Amujoyegbe *et al.* (2007) who reported that increased application rate of goat wastes enhanced leaf breadth, total chlorophyll content, carbon content, water holding capacity, and decrease bulk density of soil which culminate and interplay to promote yield. Application of goat wastes in flour corn was superior to other treatments combination applied with respect to producing higher number of leaves of maize. This could be attributed to the fact that 0.8kg of goat wastes was compatible with the requirements and growing characteristics of the crop, drainage and slope of the land. This is in consonance with the findings of DIPA (2006), which recommended that manure be applied at rates that are compatible with the nutrient requirements and growing characteristics of the crops for growth and yield enhancement. The number of cob of maize obtained from flour corn plants that received N.P.K treatment was higher than the number of cobs obtained from other treatments combination possibly because more nutrients were released which mineralized rapidly for plant uptake and utilization. It could also be attributed to reduction in mosaic diseases or other soil-borne diseases which depress yield or to increased microbial activities which favour yield increases as reported by (Enujeke *et al.*, 2013). Sweet corn variety treated with goat wastes manure were superior in cob weight compare to other treatments combination, was not only compatible with the crop requirement in the agro-ecological area but favoured the release of such plant nutrients as water soluble and exchangeable potassium and magnesium which enhance crop yield. This is consistent with the findings of Ibeawuchi *et al.* (2007) which reported that higher rates of manual increased the water-soluble and exchangeable potassium and magnesium which enhances grain yield and dry matter of maize.

The table of means for plant height is presented in Table 2, it reveals that plant height in cow blood meal gave the highest yield in flour corn variety; the consistent taller plant produced in flour corn variety indicates its better performance, which is a desirable trait for increasing grain yield in maize. This agrees with report of Ojo *et al.* (2009) which stated that cow blood meal produced the highest mean height and leaf production in the experiment involving the

use of both organic and inorganic fertilizer on the grow of *Entandrophragma angolense* seedlings.

The table of means for length, number of tassels, number of leaves, number of cob per plant, cob length, cob weight and number of kernel per cob is presented in Table 3,4,5,6,7,8, and 9 respectivefully. The current study shows that the influences of fertilizer type on the number of leaves counted and number of tassels were significantly higher for fertilizer type cow blood meal and goat wastes applied at the rate of 0.8kg, this shows that the application of organic manure in maize can play a critical role in increasing plant photosynthesis by increasing the number of leaves. It aligns with the result of King *et al.* (2020), who recorded that organic material contains a massive group of plant nutrients which are vital to plant buildup by containing different elements beneficial to plants that contribute to forming amino acids involved in creating proteins and regulating osmotic pressure. It also agrees with the findings of Singh (2012), who reported variation in number of leaves observing that the maximum number of leaves per plant was recorded from the application of 125% RDF + FYM @5t/ha at 30, 45 and 60 days after sowing. Flour corn variety treated with cow blood meal gave the highest values followed by sweet corn variety treated with goat wastes. Similar results showing increase in yield attribute with the increase in nutrient application have also been observed by Gupta and Sharma (2003). The improvement in number of leaves might be due to the increase metabolic activity, stimulation of root growth ultimately increasing the uptake of Nitrogen. The increased applications of cow blood meal and goat wastes may have optimized the conditions for the growth of the crop which led to luxuriant yield performance of the plant with respect to number of cobs produced, cob length, cob weight, number of kernels produced per plant.

The effect of variety on the Growth and Yield Performance of the maize plant is presented in Table 11. It reveals that flour corn performed better in plant height, number of tassel and kernel width more than the other varieties, suggesting that this variety is the best of the five varieties. The effect of treatment on the growth and yield of the maize plant is presented in Table 12. It reveals that cow blood meal performed better in plant height, number of leaves, number of cob per plant, cob length, cob weight, whole/cob weight, number of kernel, and kernel weight, suggesting cow blood meal is the best treatment for the production of maize. This agrees with the findings of Singh (2012) on the effect of fertilizer on the growth and yield of maize which reported better response of maize varieties to varied organic and inorganic fertilizer type. This result aligns also with the findings of (Gao *et al.*, 2020), who revealed that using organic matter is one of the alternative methods to boost vegetative growth and increase the productivity of maize and other crops. According to Iqbal *et al.* (2014), organic matter may directly or indirectly impact crop growth and production by improving the physical properties of the soil, which contributes to improving the root environment, leading to increased plant growth and development

Table 1: Descriptive Statistics of Maize Varieties at Different Treatment Showing Growth and Yield Performance

Characters	Minimum	Maximum	Mean	Treatment combination with Maximum value
Plant Height(cm)	55	192.0	147.8	Pod corn + N.P.K
Plant diameter (cm)	2	10	4.953	Flour corn+ CBM
Leaf length(cm)	25	100	66.60	Flour corn + Goat waste
Leaf breadth (cm)	3	12	7.773	Waxy corn + Goat waste
No of tassels per plant	4	30	15.58	Flour corn+ Goat wastes
No of leaves per plant	4	16	11.14	Flour corn + Goat waste
No of cob plant	1	3	1.718	Flour corn+ N.P.K
Cob length (cm)	11	24	17.00	Flour corn+ N.P.K
Cob weight (kg)	0.1	0.4	0.2097	Sweet corn + Goat waste
Whole cob weight(kg)	0.1	0.45	0.2738	Sweet corn + CBM
No of kernel cob	144	467	385.0	Pod corn + N.P.K
Average kernel width	1.5	2.5	2.351	Waxy corn + Goat waste

Table 2: Table of Means for Plant Height (cm)

VARIETY	COW BLOOD MEAL	GOAT WASTES	N.P.K.
Flour corn	177.0	156.29	151.58
Sweet corn	167.84	144.90	143.53
Waxy corn	144.34	151.63	124.83
Pop corn	158.33	110.82	138.51
Pod corn	154.36	134.90	158.27
Grand Mean	160.42	139.71	143.34

F (Treatment) = 178.50, P=P<0.001 (highly significant difference exist)
F (variety) = 90.20, P = P<0.001 (highly significant difference exist)

Table 3: Means of Leaf Length (cm)

VARIETY	COW BLOOD MEAL	GOAT WASTES	N.P.K
Flour corn	79.6	85.4	64.9
Sweet corn	75.0	70.2	69.0
Waxy corn	59.3	57.9	71.5
Pop corn	66.0	53.5	67.9
Pod corn	50.3	63.9	64.6
Grand Mean	66.1	66.2	67.6

F (Treatment) = 0.18, P=P>0.840(non-significant difference exist)
F (variety) =7.62, P = P<0.001 (highly significant difference exist)

Table 4: Means of Number of Tassels per plant

F (Treatment) = 0.63, P=P>0.537 (non-significant difference exist)
F (variety) =11.82, P = P<0.001 (highly significant difference exist)

Table 5: Means of Number of Leaves per Plant

VARIETY	COW BLOOD MEAL	GOAT WASTES	N.P.K
Flour corn	13.53	13.29	10.59
Sweet corn	13.26	10.70	9.71
Waxy corn	11.29	12.47	9.71
Pop corn	10.88	7.94	10.82
Pod corn	9.88	12.71	10.36
Grand Mean	11.77	11.42	10..24

F (Treatment) = 12.42, P=P<0.001 (highly-significant difference exist)
F (variety) =9.49, P = P<0.001 (highly significant difference exist)

Table 6: Means of Number of Cob per Plant

VARIETY	COW BLOOD MEAL	GOAT WASTES	N.P.K
Flour corn	2.000	1.589	1.178
Sweet corn	1.822	1.589	1.589
Waxy corn	2.000	1.356	2.122
Pop corn	1.644	1.589	1.767
Pod corn	2.233	1.822	1.467
Grand Mean	1.940	1.589	1.467

F (variety) =1.65, P = P>0.190 (non- significant difference exist)
F (Treatment) = 8.45, P=P<0.001 (highly-significant difference exist)

Table 7: Means of Cob Length (cm)

VARIETY	COW BLOOD MEAL	GOAT WASTES	N.P.K
Flour corn	19.88	14.59	17.12
Sweet corn	19.53	15.59	17.81
Waxy corn	18.01	15.59	15.89
Pop corn	19.12	15.23	17.01
Pod corn	17.64	14.89	17.51
Grand Mean	18.84	15.10	17.07

F (Treatment) = 42.97, P=P<0.001 (highly-significant difference exist)
F (variety) =1.77, P = P>0.163 (non- significant difference exist)

Table 8: Means of Cob Weight (kg)

VARIETY	COW BLOOD MEAL	GOAT WASTES	N.P.K
Flour corn	0.2981	0.1561	0.1500
Sweet corn	0.2361	0.1767	0.1929
Waxy corn	0.2122	0.1589	0.2341
Pop corn	0.2748	0.1494	0.1944

Pod corn	0.2748	0.2117	0.2233
Grand Mean	0.2593	0.1706	0.1992

F (Treatment) = 24.19, P=P<0.001 (highly-significant difference exist)
F (variety) =1.65, P = P>0.189 (non-significant difference exist)

Table 9: Means of Number of Kernels per Cob

VARIETY	COW BLOOD MEAL	GOAT WASTES	N.P.K.
Flour corn	484.2	307.3	389.1
Sweet corn	466.5	364.1	371.7
Waxy corn	408.4	347.5	399.9
Pop corn	439.2	321.1	337.6
Pod corn	467.6	289.5	381.8
Grand Mean	453.2	325.9	376.0

F (Treatment) = 42.47, P=P<0.001 (highly-significant difference exist)
F (variety) =1.11, P = P>0.374 (non-significant difference exist)

Table 10: The Analysis of Variance Showing the Effect of Organic (Cow blood meal and Goat wastes) and Inorganic (N.P.K) Fertilizer on the Growth and Yield Performance of *Zea may*

SOV.	Df	PLANT HEIGHT	PLANT DIAMETER	LEAVE LENGTH	LEAVE BREADTH	NO. OF TASSELS	NO. OF LEAVES	NO. OF COBS PER PLANT	COB LENGTH	COB WEIGHT	WHOLE/ COB WEIGHT	NO. OF KERNEL	KERNEL WIDTH
REP.	2	0.43	0.079	5.59	0.004	0.072	0.227	0.134	0.778	0.000	0.000	1290	0.004
ACCESSION	4	926.51**	0.447^{ns}	458.90**	5.228**	30.542**	7.658**	0.109^{ns}	2.152^{ns}	0.002^{ns}	0.001^{ns}	1605^{ns}	0.381**
Treatment	2	1833.52**	0.008^{ns}	10.59^{ns}	0.123^{ns}	0.641^{ns}	9.647**	0.560**	52.314**	0.031**	0.028**	61657**	0.718**
A*T	8	509.63**	2.433**	224.40**	1.656**	19.237**	7.369**	0.244**	1.353^{ns}	0.003*	0.004^{ns}	2738^{ns}	0.276**
Error	28	10.27	0.223	60.22	0.416	2.585	0.777	0.006	1.218	0.001	0.002	1452	0.004
TOTAL	44												

Table 11: The Main Effect of Variety on the Growth and Yield Performance of the Five Different *Zea mays* Variety Applied with Organic and Inorganic Fertilizer

Accessions	PLANT HEIGHT	PLANT DIAMETER	LEAVE LENGTH	LEAVE BREADTH	NO. OF TASSELS	NO. OF LEAVES	NO. OF COB PER PLANT	COB LENGTH	COB WEIGHT	WHOLE/ COB WEIGHT	NO. OF KERNEL	KERNEL WIDTH
V1	161.69^{a}	5.078^{ab}	76.6^{ab}	8.056^{ab}	18.49^{a}	12.47^{a}	1.589^{ab}	17.20^{ab}	0.201^{ab}	0.2893^{ab}	393.6^{ab}	2.089^{a}
V2	152.09^{b}	4.863^{a}	71.4^{a}	8.019^{ab}	15.42^{b}	11.22^{ab}	1.667^{ab}	17.64^{a}	0.202^{a}	0.2627^{ab}	400.8^{ab}	2.500^{ab}
V3	140.27^{c}	5.278^{b}	62.9^{ab}	8.474^{a}	16.94^{c}	11.16^{b}	1.826^{ab}	16.38^{ab}	0.201^{ab}	0.266^{ab}	385.3^{ab}	2.500^{b}
V4	135.89^{d}	4.826^{ab}	62.5^{ab}	6.474^{b}	13.92^{ab}	9.88^{c}	1.667^{ab}	17.12^{ab}	0.206^{b}	0.280^{ab}	366.6^{ab}	2.167^{c}
V5	149.17^{e}	4.722^{ab}	59.6^{b}	7.841^{ab}	14.61^{d}	10.98^{d}	1.841^{a}	16.68^{ab}	0.237^{c}	0.271^{ab}	379.7^{ab}	2.500^{d}
Mean	147.87	4.953	66.6	7.773	15.88	11.14	1.718	17.00	0.209	0.274	385.0	2.351
LSD $_{(0.05)}$	3.095	0.456	17.49	0.623	1.553	0.851	0.249	1.066	0.035	0.041	36.79	0.0628

Keys: V1=Flour corn; V2= Sweet corn; V3= Waxy corn; V4= Popcorn; V5= Pod corn.

Table 12: The Main Effect of Fertilizer Type on Growth and Yield Performance of Zea mays

TREATEMENT	Plant Height	Plant Diameter	Leaf Length	Leaf Breadth	No of tassels per plant	No of leaves	No of cob per plant	Cob length	Cob weight/ plant	Whole Cob weight/ plant	No of kernel per cob	Kernel width
COW BLOOD MEAL	160.42[a]	4.956[a]	66.1[a]	7.813[a]	15.64[a]	11.77[a]	1.940[a]	18.84[a]	0.259[a]	0.321[a]	453.2[a]	2.500[a]
GOAT WATES	139.71[b]	4.976[a]	66.2[a]	7.836[a]	15.74[a]	11.42[a]	1.589[b]	15.10[b]	0.170[b]	0.235[ab]	325.9[b]	2.100[a]
NPK	143.34[c]	4.929[a]	67.6[a]	7.669[a]	16.26[a]	10.24[b]	1.624[b]	17.07[c]	0.199[b]	0.264[b]	376.0[c]	2.453[b]
$LSD_{0.05}$	2.397	0.353	5.80	0.4827	1.203	0.659	0.193	0.825	0.026	0.032	28.50	0.049

CONCLUSION

The study clearly indicates positive response of maize to cow blood meal treatment at application rate of 0.8kg compared to goat wastes and N.P.K. Flour corn variety that received cow blood meal was superior in most parameters assessed. Based on the findings of the study, thus it is concluded that variety flour corn + cow blood meal could be adopted by farmers enhance growth and yield of maize. This information is relevant to researchers that will want to carry out more work on the plant and also to farmers as it provides the best variety and the best fertilizer type.

REFERENCES

Amujoyegbe, B.A., Opabode, J.T and Olayinka. (2007). Effect of Organic and Inorganic Fertilizer on Yield and Chlorophyll Content of Maize *(Zea mays L.)* and Sorghum *(Sorghum bicolour L* Moench). *Fertilizer and Manure Journal,* 6 (16):1869 – 1873.

DIPA. (2006). Handbook of Agriculture: Facts and Figures for Farmers, Students and all Interested in Farming. Directorate of Information and Publications of Agriculture. *Indian Council of Agricultural Research,* New Delhi, 53: 435 -437.

Enujeke E.C. (2013). Nutrient Content (% dry matter) of Maize as Affected by Different Levels of Fertilizers in Asaba area of Delta State. *Sustainable Agriculture Research,* 2(3):76-85 Canadian Center of Science and Education, Canada.

Espinoza L. and Ross J. (2010). Corn Production hand book Little Rock, Arkansas Cooperative Extension Service *America Journal of Science,* 67: (112-114).

Fagimi, A.A. and Odebode, C.A. (2007). Effect of Poultry Manure on Pepper Veinal Mottle Virus (PVMV), Yield and Agronomic Parameters of Pepper (*Capsicum annum*) in Nigeria. *East Africa Journal of Science,* 1(2): 104-111.

Gao C, El-Sawah AM, Ali DFI, Alhaj Hamoud Y, Shaghaleh H, Sheteiwy MS (2020). The integration of bio and organic fertilizers improve plant growth, grain yield, quality and metabolism of hybrid maize (Zea mays L.). Agronomy 10(3): 1-25.

Gupta, V., Sharma, G.L., Sonakiya, V.K. and Tiwari, G. (2003). Impact of Different Levels of FYM and Sulphur on Morphological Indices and Productivity of Soybean Genotypes. *JNKVV Research Journal of science*, 37(2):76 – 78.

Ibeawuchi, I.I., Opara, F.A, Tom, C.T and Obiefuna, J.C. (2007). Graded Replacement of Inorganic with Organic Manure for Sustainable Maize Production in Owerri Imo

State, Nigeria. *Life Science Journal,* 4 (2):82-87.

Iqbal S, Khan HZ, Zamir MSI, Marral MWR, Javeed HMR (2014). The effects of nitrogen fertilization strategies on the productivity of maize (Zea mays L.) hybrids. ZemdirbysteAgric. 101(3): 249-256.

Kandil EEE (2013). Response of some maize hybrids (Zea mays L.) to different levels of nitrogenous fertilization. *Journal of Applied Science Res*earch 9(3): 1902-1908.

King AE, Ali GA, Gillespie AW, Wagner-Riddle C (2020). Soil organic matter as catalyst of crop resource capture. *Front. Environ. Sci*. 8(1): 50-56

Linda, and Campbell Franklin (2013). Corn, in Andrew F. Smith (edition.), The Oxford Encyclopedia of Food and Drink in America. *Oxford University Press,* 12*:* 551–558.

Ojo, D. O. (2009). Variation of Morphological Characters in Maize. *Africa Agriculture Journals,* 34: 27-29.

Ranum P., Peña-Rosas J. P. and Garcia-Casal M. N. (2014). Global Maize Production, Utilization, and Consumption. *Annuals of the New York Academy of Sciences,* 1312(1): 105-112.

Singh, A. (2012). Effect of Organic and Inorganic Fertilizers on Yield of maize. Editor: V. Mere and A. K. Singh. Publisher: *Lambert Academic Publishing*, ISBN: 978-3-659-47283.

Vivek B. S., Odongo O., Njuguna J., Imanywoha J., Bigirwa G., Diallo A. and Pixley K. (2010). Diallel. Analysis of Grain Yield and Resistance to Seven Diseases of 12 African Maize (*Zea mays* L.) Inbred Lines *Euphytica*. *Journal of Applied Science,* 172(3):329-340.

CLIMATE INDUCED FLOODS IMPACT ON INFRASTRUCTURE, STAPLE FOOD SUPPLY AND PRICES IN YENAGOA, BAYELSA STATE, NIGER DELTA

Charles Oyibo[1], Authority Benson[2], Kemebigha Ine-ebi[3], Ekpotenmene Tamaraumiemene[4]
[1]Department of Environmental Management, Niger Delta University, Amassoma, Wilberforce Island, Bayelesa State, Nigeria.
[2]Department of Environmental Management, Niger Delta University, Amassoma, Wilberforce Island, Bayelesa State,
[3]Bayelsa State Ministry of Environment
[4]Department of Geography and Environmental Management, Niger Delta University, Amassoma, Wilberforce Island, Bayelesa State, Nig
Corresponding Author's Email: charles.oyibo@ndu.edu.ng

ABSTRACT

Flooding remains one of the most destructive climate-related hazards in Nigeria, with grave implications for food security. This research investigates the effects of floods on support infrastructure, availability, prices, and quality of essential staple food items such as yam, garri, plantain, fufu, and palm oil. The study focuses on traders in the local markets of Swali, Kpansia, and Igbo-gene within the Yenagoa metropolis. Using a mixed-method and a purposive sampling survey to select a sample of 60 respondents across three major markets, data collection utilizes questionnaire, and the findings are presented in frequencies, percentages and plates illustrating significant shifts in staple food dynamics post-flood. Findings reveal significant disruptions in supply chains, price inflation, and quality deterioration of key staples and severe damage to transport networks. Specifically, results highlight disruptions to road infrastructure in Bayelsa State and reveal that among the staple foods examined, Plantain faced the most significant impact, with reduced availability and increased prices attributed to the flood. Regarding Plantain availability 50% of the traders strongly agreed that the food significantly decreased plantain availability, 41.7% agreed, and 8.3% held a different view. In terms of plantain pricing, 50% of the traders strongly agreed, and another agreed that the floods had a noteworthy effect on the price of plantain in Yenagoa. This adverse effect on plantain availability could be attributed to transportation routes or other relevant factors. It was recommended that traders should develop strategic sourcing alternatives and foster collaboration to mitigate sudden price fluctuations. Also, government intervention in transportation, storage infrastructure, financial aid, and information dissemination can effectively assist traders in managing price fluctuations during crises. The study underscores the urgent need for resilience strategies to safeguard food systems and road infrastructure in flood-prone regions.

Keywords: Climate Change**,** Floods, Infrastructure, Staple foods and food security.

INTRODUCTION

Climate change has intensified extreme weather events, including heavy rainfall leading to recurrent flooding and rising sea levels in Nigeria. Flooding has long been recognized as one of the most devastating climate-related hazards worldwide. In Nigeria, recurrent floods have disrupted livelihoods, destroyed infrastructure, and threatened food security. The 2022 flood

disaster was particularly severe and unprecedented, affecting 30 out of 36 states and displacing millions (Okojie and Odifa, 2022). In the Niger Delta, flooding is not only a natural hazard but also a socio-economic crisis. The inundation of farmlands and disruption of supply chains directly affect food security, especially for staple items. Bayelsa State, and especially its capital Yenagoa, emerged as one of the worst-hit regions, with seven of its eight local government areas submerged, over 700,000 people displaced (Busari, 2022). Beyond food insecurity, the floods severely damaged road infrastructure, cutting off access to markets and worsening supply chain disruptions. This article explores how the floods impacted road network, the availability, pricing, and quality of staple food items in Yenagoa markets.

Aim: is to determine the impact of the 2022 floods on support infrastructure and food security in Yenagoa, Bayelsa State, Nigeria. The objective was to determine the impact of the 2022 floods on road infrastructure, availability and variations in the prices of the following purposively selected indigenous staple food items - yam, garri (processed cassava flakes), plantain fufu (processed cassava meal), and palm oil.

Although climate-related hazardous events have always existed, climate change has potential to increase their severity and the likelihood of creating food security challenges. According to ICPC (2014), extreme precipitation events will become more intense and frequent in many regions; flooding and global mean sea level will continue to rise owing to global heating, driven primarily by anthropogenic greenhouse gas emissions. Flooding has been a major natural disaster affecting over 2.8 billion people and touching many households in several ways (Olanrewaju, 2019)

Nigeria witnessed three prominent flood incidents in 2012, 2018 and 2022 (Umar *et al.*, 2022), but the 2022 flood marked a grim milestone in Nigeria's history as it wreaked havoc across the nation, affecting about 30 out of the 36 states, resulting in numerous deaths, extensive property damage, destruction of health facilities, and agricultural losses (Okojie and Odifa, 2022).

Amongst all, Bayelsa state appeared to be one of the worst affected, as about seven out of eight local government areas in the state were submerged in water, 300 communities and villages were totally or partially submerged in water, 700,000 people displaced or affected (Busari, 2022). The two major entry points by road were impassible as water washed off most parts of the road.

MATERIALS AND METHODS

The study adopted a mixed survey design, combining qualitative and quantitative approaches. The study area comprises of six market namely Swali, Igbo-gene, Tombia, Kpansia, Opolo and Agudama and all flood impacted entry points into the studyarea. The Taro Yamane formula was used to determine the sample size (n = N/1+ne2: where n = sample size, N = Population size, 1 = Constant and E = Error limit or margin of error or level of significance (Accepted error set at 5% i.e. 0.05) = 3) of three (3) used in turn to sub-divided study area into Up, Mid and Downstream sectors to ensure effective sampling spread. Furthermore, the corresponding market in each stream was purposively selected.

To that end, one market out of the total of six in the study area was selected in each sub-section namely Igbogene (Upstream), Kpansia (Midstream) and Swali (Downstream) markets respectively. Consequently, Twenty (20) copies of a structured questionnaire were purposively adopted and administered randomly on staple food vendors in each of the markets. Also,

one-on-one interview was conducted on respondents to strengthen views expressed, and followed by observations made in real time. Additional physical assessments were carried out on flood height at points considered relevant to the study while observations were made on road conditions and accessibility during the flood period.

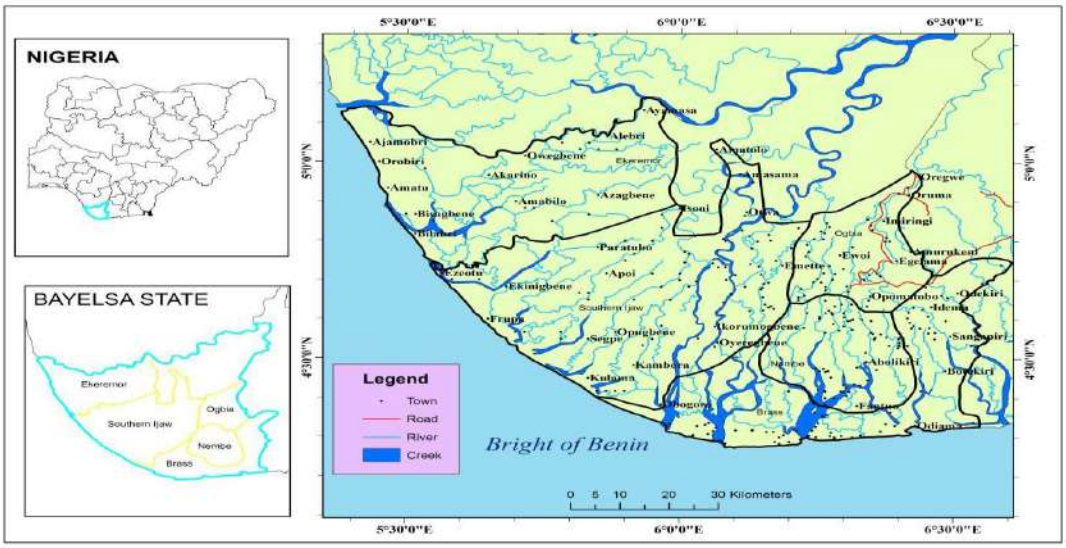


Figure 1: A digital expression of Study Area.

RES ULTS AND DISCUSSION

The Bayelsa Flood Index for the 2022 flood incident is presented in Table 1 on local government bases and the results as captured by the Bayelsa State Emergency Management Agency (BYS-EMA) are quite revealing. Incidentally, about 210,099 of the 227,816 persons affected were displaced, while 61 suffered injuries of various kinds, 24 were reported to have lost their lives amongst others fates. This data is corroborated in the report of Okojie and Odifa, (2022) whos stated that the flood wreaked havoc across the nation, affecting more than 30 out of the 36 states, resulting in numerous deaths, extensive property damage, destruction of health facilities, and agricultural losses

Table 1: Showing Data of the 2022 floods (BYSEMA, 2022)

BAYELSA STATE 2022 FLOOD DATA

Flood Impact on Road Network

Evidence of flood impact through physical assessments and implications for food security is illustrated in Tables 2 and3 and Plates 1and2 respectively. Results indicate that at both entry (Umeh) and exit (Ikeh) points (or vice versa) of the impacted areas, flood heights were higher than the road elevations by 1.06m and 0.16m respectively. These observations are suggestive of the fact that roads were submerged and washed off at those points constituting serious restrictions to access, transportation of goods and service rendition within the study area. Similarly, Busari, (2022), had reported that the two major entry points into the state by road from Delta and Rivers states were impassible as water had washed off most parts of the road, preventing agricultural produce and other essential goods and services from accessing the state, thereby creating economic crises in terms of increase in prices of goods and services.

Availability of Staples

Data on the availability of staple food items is contained in Table 4. Results from respondents' inputs show that flooding reduced the availability of plantain (by about 92%) and fufu (by about 58%) more than other staples. Furthermore, Vendors reported severe supply chain disruptions, reflecting the vulnerability of perishable crops to flood induced damage. Accordingly, Nigeria's farmers' association have reported that the 2022 flood incident destroyed around 90 per cent of farms in major crop-producing states, leading to a significant crop production shortfall (Okojie and Odifa, 2022).

Table 2: Showing flood impact on road infrastructure in study area (Field study, 2023)

PHYSICAL ASSESSMENT OF THE 2022 FLOODS ON ROAD INFRASTRUCTURE IN BYS.

LOCATION/STATE	GROUND ELEVATION (m)	ROAD ELEVATION (m)	FLOOD MARK (m)	REMARK
AMASSOMA RD. BAYELSA	10.0	12.5	12.3	Flood mark was higher than ground by **2.3m** and less than road by **0.2m**
UMEH DELTA	10.0	11.0	12.06	Flood mark was higher than ground and road elevations by **2.06 & 1.06m**
IKEH RIVERS	10.0	11.79	11.95	It was higher by **1.95 & 0.16m**

Table 3: Road Infrastructure Impacts

Road Segment	Status During Flood	Effect on Food Supply
East-West Road (western entry point at Uweh)	Washed off in multiple sections	Severely restricted access to Yenagoa markets
Eastern exit point at Ikeh/Ahoada	Submerged	Traders unable to transport goods
Ogbia–Yenagoa Links	Partially damaged	Increased transport costs
Amassoma - Yenagoa Link	Cut off	Alternative sourcing of food items became necessary

Umeh and Ikeh Sections of the East -West Road Eroded by 2022 Flood (Author's field work)

Plates 1 and 2: Evidence of road infrastructure damages at entry (Umeh) and exit (Ikeh) points (Field Study, 2023)

Observation: Road damage compounded food insecurity by limiting access to markets and inflating transport costs.

Table 4: Availability of Food Items

Food Item	Strongly Disagree (%)	Disagree (%)	Agree (%)	Strongly Agree (%)	Remark
Yam	25.0	66.7	8.3	–	–
Garri	16.7	33.3	41.7	8.3	–
Plantain	–	8.3	41.7	50.0	Least available
Fufu	–	41.7	41.7	16.7	Next to Plantain
Palm Oil	8.3	33.3	58.3	–	–

Source; Field Study (2023)

Observation: Plantain and fufu were least available during the floods in that order.

Prices of Staples

An interpretation of data in Table 5 on respondents' input, has revealed that Plantain recorded the sharpest cumulative price increase at 100%, followed by yam at 78%. Garri and palm oil experienced moderate inflation, while fufu price fluctuated depending on sourcing. These findings highlight how floods exacerbate food inflation in already fragile economies. In corroboration, data from the National Bureau of Statistics (2022) indicated that the average prices of all staple foods across major cities

in the country increased by over 100 per cent, causing food inflation to hit 24.13 per cent in November. Also, the shortfall of about 90 per cent of farms in major crop-producing states leading to a significant crop production shortfall caused a rapid soar in food prices, with inflation hitting 21.47 per cent in November, a 17-year high (Okojie and Odifa, 2022).

Table 5: Price Increases of Staple Food Items

Food Item	Disagree (%)	Agree (%)	Strongly Agree (%)	Remark
Yam	25.0	66.7	8.3	Second most expensive
Garri	33.3	41.7	–	–
Plantain	–	50.0	50.0	Most expensive
Fufu	58.3	33.3	–	–
Palm Oil	66.7	25.0	–	–

Source; Field Study, (2023)

Observation: Plantain price rose most sharply, and followed by Yam.

Quality of Staple Food Items

Information on the quality of staple food items is illustrated in table 6 and Appendices. Results indicate that Garri and Palm oil quality deteriorated the most due to immature harvests, contamination, and poor storage conditions during the floods; with vendors citing contamination and poor storage conditions as enabling factors during the floods. Yam and plantain quality remained relatively stable but were less available. This observation is corroborated in the report of Zewdie 2014 (as cited in Ekpotenmene, 2023), who indicated that flooding can have detrimental effects on plant tissue damaging it and promoting the development of diseases affecting crop quality.

Table 6: Floods Impact on Quality of Staple Food Items

Noticeable impact on the quality of Palm oil sold in my market	Frequency	Per cent (%)	Valid Per cent (%)	Cumulative Per cent (%)
Strongly Disagree				
Disagree	1	1.7	8.3	8.3
Agree	6	10.0	50.0	58.3
Strongly Agree	5	8.3	41.7	100.0
Total	12	20.0	100.0	
2022 flood had a noticeable impact on the quality of Garri sold in my market				
Strongly Disagree				
Disagree	2	3.3	16.7	16.7
Agree	7	11.7	58.3	75.0
Strongly Agree	3	5.0	25.0	100.0
Total	12	20.0	100.0	

Outsourcing of Staples

Hallegatte *et al.* (2020), reported that Smallholder rural farmers who rely on their farms for income and food, are hit hardest by flood incidents; facing income losses, increased poverty and high food prices which constrain households' access to affordable food, leading to a cycle of limited purchasing power and reduced productivity capacity. Data on the outsourcing of Staple Food Items is contained in Table 7 and Appendices. Results show that Fufu and garri were the most outsourced items, as traders sought alternative supply routes. This reliance on external markets further inflated prices and strained logistics. Again, it has been reported that flooding also disrupts physical access between communities, cutting off transportation routes and isolating rural areas, hindering the movement of food products and inputs (Ede *et al.*, 2019). Supply chain disruptions, increased prices, and the destruction of farm produce further exacerbate food scarcity and restrict food accessibility leaving citizens with no option than to seek alternative sourcing outlets.

.Table 7: Data on Out-Sourcing of Food Items

I had to source food item from different locations due to flood-related disruptions	**Valid(%) Yam**	**Valid (%) Garri**	**Valid (%) Plantain**	**Valid (%) Fufu**	**Valid (%) Palm Oil**	**Remark**
Strongly Disagree	33.3		16.7	8.3	16.7	
Disagree	50.0	33.3	50.0	25.0	33.3	
Agree	16.7	50.0	25.0	41.7	41.7	

CONCLUSION AND RECOMMENDATIONS

The study has revealed that the 2022 floods had a huge impact on roads through submergence and infrastructural collapses within the study area and decreased the availability of plantain and fufu more than any other staple food item. Again, it significantly increased the prices of plantain and

yam respectively in the markets surveyed and inferentially so, in the entire study area. Also, the flood incident had a noticeable impact on the quality of garri and palm oil relatively; whereas fufu and garri remained the most outsourced staple food items within the period under review.

It is evident that the 2022 floods significantly disrupted food systems and infrastructure in Yenagoa which was another copious evidence adducible for the hardship suffered by inhabitants of the study area. Furthermore, it reduced the availability, inflated prices and deteriorated the quality of staple foods; and damaged aspects of the access roads collectively worsened food insecurity. These impacts highlight the intersection of climate change, poverty, and infrastructure vulnerability in the Niger Delta and no doubt, have grave implications for food security in the study area.

Recommendations

Drawing from the lines of convergence of the results, discussions and conclusions, it is hereby recommended as follows: that on

i. **Strategic sourcing:** Traders should diversify supply chains and collaborate to mitigate disruptions.
ii. **Government intervention:** Investment in transport, storage, and financial aid is critical.
iii. **Private sector role:** Partnerships in logistics and information dissemination can cushion future shocks.
iv. **Climate adaptation:** Long-term flood management strategies, including improved drainage and resilient road construction, are essential.

REFERENCES

ACAPS Briefing Note - Nigeria: Country-wide flooding (21 October 2022) – Nigeria https://reliefweb.int/report/nigeria/acaps-briefing-note-nigeria-countrywide-flooding-21-october-2022

Ajumobi, V. E., Womboh, S. E., and Sebhaziba, B. (2022). Impacts of the 2022 flooding on residents of Yenagoa, Bayelsa, State, Nigeria. *Greener Journal of Environmental Management and Public Safety.* 11(1), 1-6.

Azubuike, E. S., Godwin, B. L., andObuzor, M. E. (2020). Flood and traditional coping strategy in Ahoada East (2012-2020), Rivers State. *African Journal of Social Sciences and Humanities Research* 6(2), 68-80. Doi: 10.52589/AJSSHRC0ERVUO2.

Busari, B. (2022). Flooding: Bayelsa' worst hit, 1.3m affected. SEMA. Vanguard. https://www.vanguardngr.com/2022/11/flooding-bayelsa-worst-hit-1-3m-affected-sema/

Center for Research on the Epidemiology of Disasters (CRED) (2020). EM-DAT database. Available from: https://public.emdat.be

Chinedu, N. (2022). Year of killings, deaths, floods, pains, and politics. Vanguard. https://www.vanguardngr.com/2022/12/2022-year-of-killings-deaths-floods-pains-politics/

Dipeolu, A. A., andIbem, E. O. (2020). Green infrastructure quality and

environmental sustainability in residential neighbourhoods in Lagos, Nigeria.
International Journal of Urban Sustainable Development .https://doi.org/10.1080/19463138.2020.171950 0
Durodola, O. (2019) The Impact of Climate Change Induced Extreme Events on Agriculture and Food Security: A Review on Nigeria. *Agricultural Sciences*, **10**, 487-498. doi 10.4236/as.2019.104038.
Echendu, A. (2020). The Impact of flooding on Nigeria's sustainable development goals (SDGs). *Ecosystem Health and Sustainability,* 6 (1), 171-179.
Ekpotenmene Tamaraumiemene (2023). A Project Report on The Impact of the 2022 Floods on Selected Staple Food Items in Yenagoa, Bayelsa State, Nig. Department of Environmental Management, Niger Delta University, Amassoma, Wilberforce Island, Bayelesa State, Nig
Firdaus, R. B., Gunaratne, M. S., Rahmat, S. R. and Kamsi, N. S. (2019). Does climate change only affect food availability? What else matters? Cogent Food and Agriculture, 5(1), 1707607, DOI: 10.1080/23311932.2019.1707607
Hallegatte S., Vogt-Schilb, A., andRozenberg,J. (2020). From poverty to disaster and back: a review of the literature. *Econ. Disaster Clim. Change.* 4(1):223–247.
Hwalla, Nahla, Sibelle El Labban, and Rachel A Bahn. 2016. Nutrition security is an integral component of food security. Frontiers in Life Science 9: 167–72.
Idoko, Ikani Daniel. 2016. An Impact Assessment of Flooding on Food Security among Rural Farmers in Dagiri Community, of Gwagwalada Area Council, Abuja, Nigeria. Agricultural Development
Komolafe, A.A., Adegboyega, S.A., and Akinluyi, F.O., 2015, A review of flood risk analysis in Nigeria. American Journal of Environmental Sciences 11(3), 157–166. doi: 10.3844/ ajessp.2015.157.166
Kreidenweis, U., Humpenoder, F., Stevanovic, M., Bodirsky, B. L., Kriegler, E., Lotze-Campen, H. and Popp, B. L. (2016). Afforestation to mitigate climate change: impact on food prices under consideration of albedo effects. *Environmental Research Letters.*
Nemine, Erekpokeme Lucia. 2015. Flood Disasters in Nigeria: Farmers and Governments' Mitigation Efforts. Journal of Biology, Agriculture and Healthcare 5: 150–54.
Nigeria - Floods (NiMet, media) (ECHO Daily Flash of 12 July 2022). Available from: https://reliefweb.int/report/nigeria/nigeria-floods-nimet-media-echo-daily-flash-12-july-202
Norgu B. G. (2015). Educational research: Basic issues and methodology. Nsukka, University Trust Publishers.
Ochuba, O.I. and Cookey, I.F. (2020). Food prices and the challenge of food security in Bayelsa State, Nigeria. Asian Journal of Economics, Business and Accounting, 16 (4), 17-27.
Office of the Queensland Chief Scientist. What is a flood? Available from: https://www.chiefscientist.qld.gov.au/publications/understanding-floods/what-is-a-flood.
Ogbuabor JE, Anthony-Orji OI, Ogbonna OE, Orji A (2019) Regional integration and growth: new empirical evidence from WAEMU. Prog Dev

Stud. https://doi.org/10.1177/1464993418822883Okaka, 2018

Okojie, J. andOdifa, D. (2022). 2022: Events that disrupted Nigeria's food security. Business day. https://businessday.ng/agriculture/article/2022-events-that-disrupted-nigerias-food-security/

Olaitari, I.D. (2020). Impact of flood and the need for preventive and mitigating measures in Bayelsa State, Nigeria. International Journal of Academic Research in Education and Review, 8 (7), 160-180.

Olanrewaju, C.C., Chitakira, M., Olanrewaju, O.A. and Louw, E., (2019). Impacts of flood disasters in Nigeria: A critical evaluation of health implications and management. Jamba Journal of Disaster Risk Studies, 11(1), 1-12

Oyebola, O. Oyediran, Jackson Efitre, Augustine EyiwunmiFalaye, Taiwo M. Dada, and Funmilayo C. Idowu. 2018. Agriculture in the Face of Climate-Mediated Flooding in Tropical Africa: Technical Innovations of Fish Farmers in Southwestern Nigeria. In Handbook of Climate Change Resilience. Edited by Walter Leal Filho. Cham: Springer.

PreventionWeb (National Disaster Framework: Understanding The Framework). Available from: https://www.preventionweb.net/files/21708_nigherianationaldisastermanagementf.pdf

Reddy, Vangimalla, Mura Jyostna Devi, and Venkatachalam Anbumozhi. 2019. Ensuring Food and Nutritional Security in the Face of Disasters and Climate Change: What is the Adaptive Solution? In Towards a Resilient ASEAN Volume 1: Disasters, Climate Change, and Food Security: Supporting ASEAN Resilience. Jakarta: ERIA.

Smith, K. (1996). Environmental hazards: Assessing risk and reducing disaster. London: Routledge.

Talbot, C. J., Bennett, E. M., Cassell, K., Hanes, D. M, Minor, E. C., Paerl, H., Raymond, A. P., Vargas, R., Vidon, P. G., Wollheim, W. andXenopoulos, M. A. (2018). The impact of flooding on aquatic ecosystem services. Biochemistry. 141, 439-461.

Umar, N., and Gray, A. (2022). Flooding in Nigeria: a review of its occurrence and impacts and approaches to modelling flood data. International Journal of Environmental Studies, 1-22.

United Nations (2016). Sustainable development goal report

United Nations Office for the Coordination of Humanitarian Affairs (2021). West and Central Africa: Floods DREF operation no. MDR 61006, Feb. 25 2021. www.refworld.org/publisher,Ocha,Handbook.

Week, D.A andWizor, C.H. (2020). Effects of flood on food security, Livelihood and socioeconomic characteristics in the flood-prone areas of the core Niger Delta, Nigeria. Asian Journal of Geographical Research, 3 (1), 1-17.

Wikipedia (2023). 2022 Nigeria floods. https://en.wikipedia.org/wiki/2022_Nigeria_floods.

Wizor, C. H., and Week, D. A. (2014). Impact of the 2012 Nigeria flood on emergent cities of Nigeria: The case of Yenagoa, Bayelsa State. Civil and Environmental Research, 6(5), 31-40

World Economic Forum. (2022). Nigeria's worst floods in a decade have displaced over a million people. Retrieved from:

https://www.weforum.org/agenda/2022/10/nigeria-flood-rain-climate
Zewdie, A. (2014). Impacts of climate change on food security: A literature review in Sub Saharan African. Earth Sci Clim Change. 5(8): 225. Doi: 10.4172/2157-7617.1000225

UNORTHODOX FISHING PRACTICES AND THE BANE OF ICHTHYOFAUNAL DIVERSITY: THE ENIONG RIVER EXAMPLE

Isemin, Nsidibe Linus[1], Azua, Terese, and Ekanem, Idorenyen Emmanuel[2]
[1]Department of Zoology, Federal University of Agriculture, Makurdi, Benue State, Nigeria.
[2]Department of Fisheries and Aquatic Environmental Management, University of Uyo, Uyo, Akwa Ibom State, Nigeria.
Corresponding Author's Email: nsimin1@yahoo.com.

ABSTRACT

The Eniong River, Southeastern Nigeria is a freshwater ecosystem which serves as an important fishing ground for artisanal fishers, sand dredging, inland water transportation, as well as source of domestic water supply to the resident communities. Ichthyofaunal survey of the river was carried out between April, 2018 – March, 2020 at the upper and lower courses of the river; Ekweme and Ukpa Okon represented the upper river, while Ito and Itu represented the lower river. Traditional fishing practice included throw nets and traps, while unorthodox practices included the use of chemical and explosive, particularly at the upper course of the river. Species richness was calculated according to Margalef; Shannon's Index of general diversity (H') according to Shannon and Weaver; equitability according to Pielou, and Jaccard similarity index according to Jaccard. A total of 178 fish (14 families and 25 species) were sampled, with Cichlidae (5 species) as the dominant taxa. The ichthyofauna indicated superior spatial variations for in the lower river compared to the upper river. Two species, *Clarias macromystax* (Clariidae**)** and *Malapterurus electricus* (Malapteruridae) were only present in the upper Eniong river but not in the lower river; 9 species *Ctenopoma kingsleyae, Ctenopoma nebulosum*, *Pollimyrus adspersus, Hemichromis fasciatus, Coptodon zillii*, *Pelmatolapia mariae*, *Schilbe uranoscopus*, and *Protopterus annectens* were only present in the lower river but not in the upper river, while the remaining 14 species were found in both upper and lower streams. Diversity indices revealed that the upper stream has fish Shannon diversity of 2.088, while lower stream recorded fish Shannon diversity of 2.707; Margalef's richness showed 2.733 for upper stream and 4.788 for lower stream. The depauperate ichthyofaunal diversity in the upper Eniong river highlights the negative impacts of unorthodox fishing practice in the river. In addition to the unwholesome fishing practice, the size class of fish (8.30-33.80 cm) in this study which is considered juvenile implies that the stream serves as nursery

ground, hence an indication of overfishing. The exploitation of fingerlings and juvenile fishes should be discouraged, while the use of unorthodox fishing method should be banned to ensure safety and integrity of Eniong River.

Keywords: Eniong River, Unorthodox Fishing, Ichthyofaunal Diversity, Freshwater Fauna, Species Composition

INTRODUCTION

Fish communities respond noticeably and predictably to many kinds of anthropogenic disturbances, including eutrophication, acidification, chemical pollution, flow regulation, physical habitat alteration, fragmentation and introduced species and overfishing (Li *et al.*, 2010).

Rating the ichthyofaunal assemblage of any river anchors on collection, sorting, identification and separation of the available species into different taxa in order to x-ray the ecological significance of the species and to expose the economic performance of a particular fishery. Thus, species diversity and composition of a fishery either vertical or horizontal are major ecological indicators of fish habitat preference and the expression of ecological viability of any habitat. The success of ichthyofaunal assemblage of any aquatic community therefore depends significantly on the numerical abundance, all-year-around availability and the profitability of the commercial species in the ecosystem. Generally, biodiversity has become prominent in recent years owing to world-wide high rate of extinction of some species of animals including fish (Adekoya and Olunuga, 1999; Nolan and Callahan, 2006; Baran *et at*., 2007; Lawson and Olusanya, 2010; Danba *et al.*, 2021).

Unorthodox fishing practices, which often result in overfishing can change ichthyofaunal composition and abundance, and this has an important implication on the fisheries (Peter *et al.*, 2015). Therefore, an estimation of the species composition is critical to the study of a stock's dynamics and in the management of species (Danba *et al.*, 2021). Diversity indices of stocks are usually applied in the stock multi-species assessment, ecosystem studies and in studies of economically and environmentally important fish species (Danba *et al.*, 2021) and is often necessary to the absolute size of the stock (Ahmad *et al.*, 2014). According to Nolan and Callaban (2005) species richness, evenness and diversity are all used in the study of biology and can be used to compare different populations. The diversity of fishes mainly depends upon the physicochemical characteristics, the abiotic components, and types of ecosystems (Baran *et al.*, 2007; Abiodun and John, 2017; Birk *et al.*, 2020). Fisheries resources in Nigeria are currently experiencing downturn due to overfishing and unsustainable management of inland waters.

Increased competition for the dwindling stock of fish Nigeria, particularly in the Niger Delta has pushed fishers into using prohibited fishing gears, such as dynamite, cyanide poison and explosives, to secure their livelihoods (Asua and Nwangwu, 2025). According the authors, unsustainable fishing activity affects the marine ecosystem and threatens the provision of current and potential ecosystem services. It is important to note that these ecosystem services co-depend on the environment, which means the distortion in one sector can affect the entire ecosystem flow.

The effects of fishing with explosives (blast-fishing) and sodium cyanide and of anchor damage on live coral were investigated on a heavily exploited fringing reef were also reported in Boli-nao, Philippines from 1987 to 1990 (McManus *et al.*, 1997). A simple

balance-sheet model revealed that approximately 1.4%/yr of the hermatypic coral cover may have been lost to blasting, 0.4%/yr to cyanide, and 0.03%/yr to coral-grabbing anchors, the potential coral recovery rate reduced by about one third from 3.8%/yr in the absence of disturbances to 2.4%/yr (McManus *et al.*, 1997). According to the authors, blast-fishing in particular may reduce resilience to natural perturbations, leading to assemblages of small, sparse corals and reduced patchiness.

In most cases, concoctions are prepared from using the bark or roots of a number of local plants are and poured into the water. Upon discharge to the water, this poison elicits abnormal behaviour in fish, which sometimes manifest in the form of fish floating belly-up on the surface, making them vulnerable to cash. Sadly, poisons are not selective, non-target organisms are also killed in the process, thus, raising a serious ecological concern. According to Ochiewo (2004) small fish, which are not desired, are much more vulnerable to the effects of poisons than the target fish.

This work intends to produce a checklist of ichthyofauna of Eniong River with a view to determining the temporal and spatial variations in the aquatic biota of Eniong River.
The work also intends to decipher how the observable unorthodox fishing practices influence the composition, abundance and distribution of fish in the river.

MATERIALS AND METHODS

Description of Study Area and Sampling Stations

The Eniong River, Nigeria, lies between latitudes 5°11′ to 5°28′N and longitude 7°51′ to 8°00′E (Fig.1). The river is controlled by diverse geologic formations, from Asu River formation such as the anticlinorium in Abakiliki to the recent alluvium at the south. The Asu River group controls most areas of the Eniong river with its intensely fractured outcrops at Ubaru. The Asu River which is considered Albian by age is further categorised into 3 geologic formations with over 200 m bluish-grey to olive-brown shales and sandy shales, calcareous sandstones, fine-grained micaceous sandstones, and limestones (Offordile, 2002). Structurally, the study area is characterised by controlled ridges, denudational hills such a 150 meter-Obotme conical hill, saddle and col at Obot Ito Ikpo, steep-sided valleys, expanded wetlands, alluvium, and alluvial plains which forms soil covers of silty clay, sandy, and heavy weathered loam (Udosen *et al.*, 2016).

Eniong river is within the tropics with temperature varying between 26 to 32º C. This temperature fluctuation is fairly uniform except in the dry season months when the temperature
is higher than it is during the long-wet period (eight Months-March to October) typical of a rainforest region. Humidity is high (84%) due to close proximity to the Cross River estuary while the average annual rainfall in the basin is 2200 mm with maximum contribution from southwest trade winds (Udosen *et al.*, 2016).
This study was conducted at four sampling locations along the Eniong River viz; river channels at Ekweme (Station 1), Ukpa Okon at the upper course of the river, while Ito and Itu represented the lower course of the river (Figure 1)

).

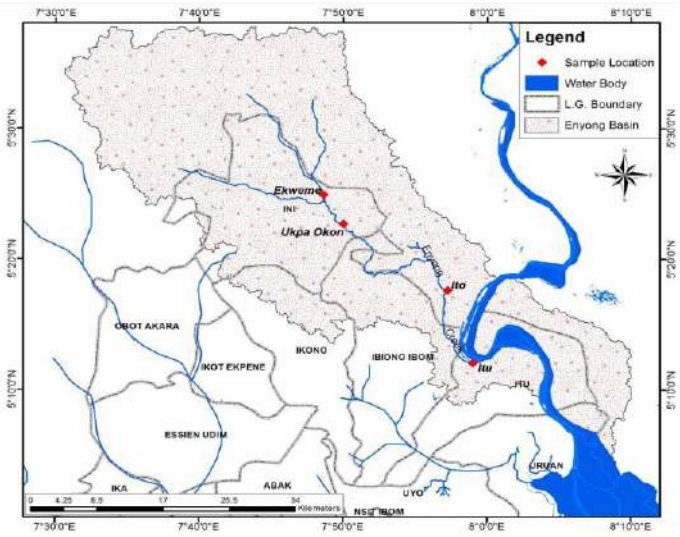


Figure 1: Map of Eniong River, Nigeria showing four sampling stations (in red). Source: UNIUYO GIS Lab

Ichthyofaunal Composition

The study was carried out for a period of 24 months. Monthly samples were collected from the sampling stations between the hours of 8.00 am- 12.00 noon of the day during the 2nd week of every month. Fishing was done with the aid of the local fishers each sampling day using throw nets, hook lines, and traps. Beyond the conventional fishing practices, some fishers particularly at the upper river course were also seen using unorthodox fishing methods such as chemicals and explosives which I tried to discourage. The fish samples were fixed right in the field with 10% formalin before being taken to the laboratory for identification and classification to the species level.

Fishes were identified using standard identification keys such as Wheeler (1994); Nigeria freshwater fishes (Olaosebikan and Raji, 1998); Ecological notes, diet and utilization (Idodo-Umeh, 2003); Taxonomy, fin fishes of the Andoni Rivers in Niger Delta (Sikoki and Francis, 2007); Album of marine/brackish water ornamental and food fishes of the Niger Delta of Nigeria (Ibim and Francis, 2012). The total length (TL, cm) and total weight (W, g) of the fish samples were also measured using measuring meter and weighing balance (Cent-0-Gram™ 300 series) respectively.

Data Collection

At the end of the 24 months field work and laboratory analyses, data were collated for ichthyofaunal communities.

Data Analysis

Community Indices

The following ecological index values were obtained through quantitative analysis: species richness, calculated according to Margalef (1958); Shannon's Index of general diversity (H') (Shannon and Weaver, 1949; and equitability according to Pielou (1975).

Jaccard Similarity Index

This association coefficient shows the proportion of agreements to be found in the presence or absence of organisms among the study stations or sites. The Jaccard Index is mostly used because of its simplicity and suitability for presence – absence data, and its exclusion of negative matches. In other words, only the mutual presence of taxa, not mutual absence contributes to similarity between collections (Jaccard, 2012).

Jaccard Index (C_j) = j/a + b – j

Equation 3.6

Where;

j = the number of species found at both of two stations being compared (example station 1 and 2)

a = the number of species found at station 1

Figure 1: Field survey
Source: Researcher's Field Work (2020).

Fig. 3: Collection of ichthyofauna
Source: Researcher's Field Work (2020).

RESULTS

The composition and abundance of fish species encountered in Eniong River are presented in Tables 1-3. A total of 178 individuals of fish species belonging to 14 families and 25 species were sampled in both the lower and upper Eniong River, with 56 individuals (30.68%) sampled in upper stream and 122 individuals (69.32%) sampled in lower stream. Cichlidae recorded the highest

number of taxa (5) and the families embraced one or more species which differ in number and weight from each other. The morphometric characteristics of the collected species revealed differences in length and body weight as indicated in (Figure 4.)

Fish were generally more abundant in lower stream (122) than their counterparts' upper stream (56). The largest fish found in the study area was *Protopterus annectens* (25.5-33.8, mean: 29.65 cm TL) while the smallest fish encountered was *Hemichromis fasciatus* (8.2-10.9, mean 10.23 cm TL), and 11.24-24.65, mean: 18.22 g TW. The length ranged majorly between10.0 cm-20.0 cm. However, it is important to note that the fish sizes recorded in this study may not be a true reflection of the fishery, as fishers only made available these sizes for research purposes.

In terms of numerical abundance by family, Clariidae was the most abundant family and comprised four (4) species which accounted for 29.54% by number and 33.87% by weight. Cichlidae comprised five (5) species and accounted for 27.28% by number and 17.71% by weight. Mormyridae comprised three (3) species and accounted for 6.25% by number and 4.14% by weight. Schilbeidae comprised two (2) species and accounted for 1.70% by number and 1.04% by weight. Other families were represented by one species each (Figure 4.51).

Table 1: Taxonomy, occurrence, numerical abundance and size structure of fish in in upper Eniong River

Family/ Species	No.	Total Length (cm)		Mean	Total Weight (g)		Mean
		Min	Max		Min	Max	
HEPSETIDAE							
Hepsetus akawo Decru, Vreven*and*Snoeks	1	12.0			23.0		
ALESTIIDAE							
Brycinus nurse (Ruppell)	1	26.0			207.06		
ARAPAIMIDAE							
Heterotis niloticus (Cuvier)	1	-			-		
ANABANTIDAE							
Ctenopoma kingsleyae (Günther)	0	-			-		
Ctenopoma nebulosum (NorrisandTeugels)	0	-			-		
MORMYRIDAE							
Marcusenius senegalensis (Steindachner)	1	19.2			61.84		
Marcusenius mento (Boulenger)	1	18.6			63.05		
Pollimyrus adspersus (Günther)	0	-			-		
CICHLIDAE							
Hemichromis fasciatus (Peters)	0	-			-		
Coptodon guineensis (Günther)	1	12.1			52.8		
Coptodon zillii (Gervais)	0	-			-		
Oreochromis niloticus (Linne)	4	12.3	17.2	14.56	41.42	115.0	72.58
Pelmatolapia mariae (Boulenger)	0	-			-		
CHANNIDAE							
Parachanna obscura (*Günther)*	1	25.2			149.7		
CLAROTEIDAE							
Chrysichthys nigrodigitatus	9	13.2	19.8	17.44	19.26	73.29	43.18

(Lacépède)							
CLARIIDAE							
Clarias gariepinus (Burchell)	2	16.3	24.0	20.15	49.0	125.0	87.0
Clarias agboyiensis (Sydenham)	6	18.3	29.4	21.35	51.8	110.0	70.86
Clarias buthupogon (Sauvage)	0	-			-	87.05	58.05
Clarias macromystax (Günther)	21	14.5	22.0	18.71	24.03	87.05	58.05
MOCHOKIDAE							
Synodontis obesus Boulenger	2	12.2	15.9	14.05	22.65	41.09	31.87
MALAPTERURIDAE							
Malapterurus electricus (Gmelin)	3	20.7	21.0	20.8	190.0	208.56	196.5
SCHILBEIDAE							
Schilbe mystus (Linnaeus)	1	15.4			43.08		
Schilbe uranoscopus Ruppell	0	-			-		
CITHARINIDAE							
Citharinus citharus (Geoffroy Saint-Hilaire)	1	23.5			165.3		
PROTOPTERIDAE							
Protopterus annectens (Owen)	0	-			-		
Total	56						
% Composition	30.68						

Source: Researcher's Field Data (2020).

Table 2: Taxonomy, occurrence, numerical abundance and size structure of fish in in lower Eniong River

Family/ Species	No.	Total Length (cm)		Mean	Total Weight (g)		Mean
		Min	Max		Min	Max	
HEPSETIDAE							
Hepsetus akawo	7	16.4	21.7	18.88	25.1	67.15	45.82
ALESTIIDAE							
Brycinus nurse	3	11.5	17.5	13.83	20.27	77.37	41.76
ARAPAIMIDAE							
Heterotis niloticus	5	20.4	25.5	22.26	69.02	137.09	104.4
ANABANTIDAE							
Ctenopoma kingsleyae	4	9.7	11.8	10.48	14.03	38.42	25.35
Ctenopoma nebulosum	1	12.4			22.0		
MORMYRIDAE							
Marcusenius senegalensis	1	15.5			37.44		
Marcusenius mento	3	14.0	15.3	14.6	22.68	29.81	25.52
Pollimyrus adspersus	3	10.5	11.7	11.07	14.92	15.41	15.11
CICHLIDAE							
Hemichromis fasciatus	8	8.4	10.9	10.3	11.0	24.65	18.4
Coptodon guineensis	3	8.5	10.7	9.73	21.01	115.8	53.59

Coptodon zillii	3	8.3	11.6	10.0	11.02	34.0	22.09
Oreochromis niloticus	27	9.0	16.0	12.56	4.17	88.07	34.84
Pelmatolapia mariae	2	10.3	11.2	10.75	26.0	36.04	31.02
CHANNIDAE							
Parachanna obscura	9	10.3	11.3	10.5	26.0	26.04	26.02
CLAROTEIDAE							
C. nigrodigitatus	13	11.2	18.7	15.93	30.67	81.07	46.82
CLARIIDAE							
Clarias gariepinus	2	15.2	16.3	15.75	36.06	39.08	37.52
Clarias agboyiensis	5	15.1	23.0	19.18	30.35	82.04	56.43
Clarias buthupogon	16	13.6	31.3	18.98	19.26	118.0	55.13
Clarias macromystax	0	-			-		
MOCHOKIDAE							
Synodontis obesus	1	13.2			36.08		
MALAPTERURIDAE							
Malapterurus electricus	0	-			-		
SCHILBEIDAE							
Schilbe mystus	2	16.3	16.9	16.2	30.0	36.82	37.41
Schilbe uranoscopus	1	12.0			16.81		
CITHARINIDAE							
Citharinus citharus	1	10.3			19.84		
PROTOPTERIDAE							
Protopterus annectens	2	25.5	33-8	29.65	61.8	159.9	110.9
Total	122						
% Composition	69.32						

Source: Researcher's Field Data (2020).

Table 3: Taxonomy, occurrence, numerical abundance and size structure of fish in in upper and lower Eniong River (pooled)

Family/ Species	**No.**	**Total Length Min max**		**Mean**	**Total Weight Min Max**		**Mean**
HEPSETIDAE							
Hepsetus akawo	8	12.0	21.7	18.025	23.0	67.15	42.96
ALESTIIDAE							
Brycinus nurse	4	11.5	26.0	16.88	20.27	207.06	83.08

ARAPAIMIDAE							
Heterotis niloticus	6	20.4	25.5	22.26	69.02	137.09	104.37
ANABANTIDAE							
Ctenopoma kingsleyae	4	9.7	11.8	10.48	14.03	38.42	25.36
Ctenopoma nebulosum	1	12.4			22		
MORMYRIDAE							
Pollimyrus asperses	3	10.5	11.7	11.067	14.92	15.41	15.11
Marcusenius senegalensis	2	15.5	19.2	17.35	37.44	61.84	49.64
Marcusenius mento	4	14.0	18.6	15.6	22.68	63.05	34.905
CICHLIDAE							
Hemichromis fasciatus	8	8.4	10.9	10.3	11.0	24.65	18.4
Oreochromis niloticus	31	9.0	17.3	12.61	4.17	115.0	37.5
Coptodon guineensis	4	8.5	12.1	10.325	20.01	115.8	53.39
Coptodon zillii	3	8.3	11.6	10.0	11.02	34.0	22.09
Pelmatolapia mariae	2	10.3	11.2	10.75	26.0	36.04	31.02
CHANNIDAE							
Parachanna obscura	10	16.3	25.2	11.97	26.02	149.7	38.39
CLAROTEIDAE							
Chrysichthys nigrodigitatus	22	11.2	19.8	15.8	19.28	81.02	44.35
CLARIIDAE							
Clarias gariepinus	4	15.2	24.0	17.41	31.55	125.0	54.86
Clarias agboyiensis	11	15.1	29.4	20.36	30.35	110.0	64.3
Clarias buthupogon	16	13.6	31.3	18.98	19.26	118.0	55.13
Clarias macromystax	21	14.5	22.0	18.71	24.03	87.05	58.05
MOCHOKIDAE							
Synodontis obesus	3	12.2	15.9	13.76	22.65	41.09	33.27
MALAPTERURIDAE							
Malapterurus electricus	3	20.7	21.0	20.8	190.0	208.56	196.49
SCHILBEIDAE							
Schilbe mystus	3	15.4	16.3	15.85	36.82	43.08	39.95
Schilbe uranoscopus	1	12			16.81		
CITHARINIDAE							

Citharinus citharus	2	10.3	23.5	16.9	19.84	165.3	92.57
PROTOPTERIDAE *Protopterus annectens*	2	25.5	33.8	29.65	61.8	159.92	110.7
Total	178						

Source: Researcher's Field Data (2020).

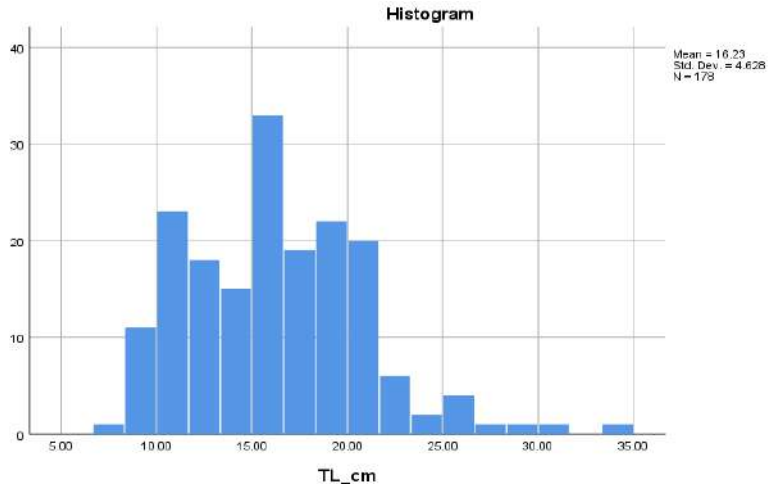


Fig. 4: Length distribution of fish species in Eniong River
Source: Researcher's Field Data (2020).

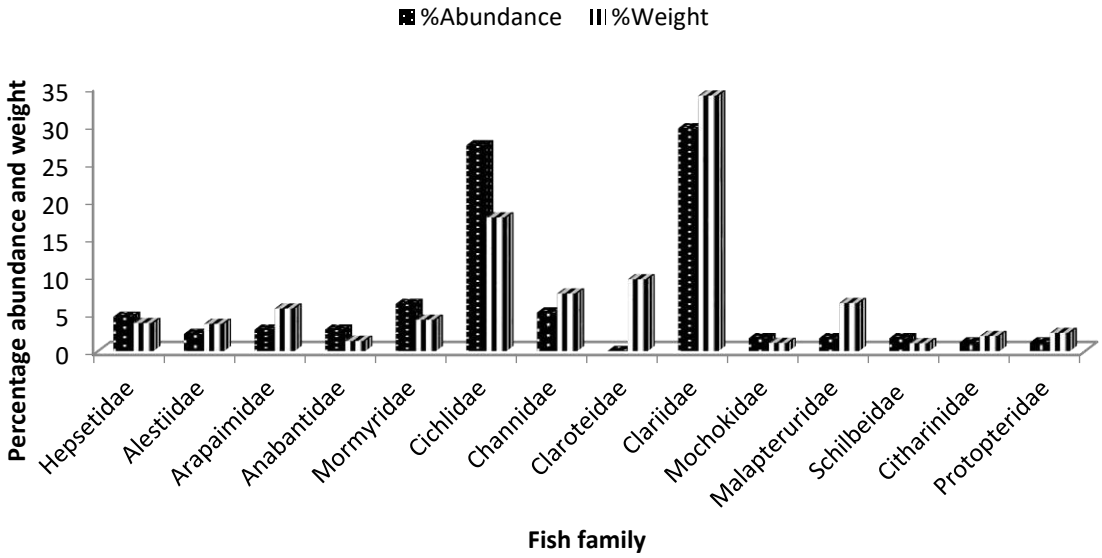


Figure 5: Percentage abundance by number and weight of fish families in Eniong River
Source: Researcher's Field Data (2020)

Community Indices The results of the fish species diversity

(Shannon-H) and richness (Margalef) in Table 4.39 revealed that the upper stream has fish Shannon diversity of 2.088, while lower stream recorded fish Shannon diversity of 2.707. Richness (Margalef) showed 2.733 for upper stream and 4.788 for lower stream. Dominance showed 0.0752 for upper stream and 0.0922 for lower stream, while Evenness revealed 0.5765 for upper stream ad 0.6276 for lower stream.

Jaccard Similarity Index

Jaccard Index ranges from zero (for complete dissimilarity) to one (for complete similarity) and the higher the joint occurrence (Cj) or the index, the higher the similarity. The result of Jaccard Index Similarity of the number of species found between the upper stream and lower stream revealed the value of 0.461. The Jaccard Index Similarity is less than the critical value of 0.50 or 50%, thus, the two stations are not similar in terms of species occurrence.

Table 5: Species diversity in Eniong River

	Upper Stream	Lower Stream	Total
Individual	56	122	178
Dominance (D)	0.0752	0.0922	0.08206
Simpson I.D	0.8099	0.9022	0.9179
Shannon –H	2.088	2.707	2.829
Richness (margalef)	2.733	4.788	4.825

Source: Researcher's Field Data (2020).

DISCUSSION

A total of 178 individuals of fish species belonging to 14 families and 25 species were sampled in both the lower and upper Eniong River, with 56 (30.68%) sampled in upper stream and 122 (69.32%) sampled in lower stream. Cichlidae recorded the highest number of taxa (5) and the families embraced one or more species which differ in number and weight from each other. The morphometric characteristics of the collected species revealed differences in length and body weight thus, signifying potential culturable species. The result produced similar values to those presented by Allison and Okadi (2009) who recorded 25 species from 14 families from the Lower Nun River, Niger Delta area of Nigeria. The result of this study is higher than the report of Onuoha *et al.* (2010) who recorded 25 species belonging to 7 families in 14 genera from Ntak Inyang stream and Ikpa River, Akwa Ibom State, Nigeria. This result is also higher than the values; 103, 111 and 96 individuals recorded by Lawson and Olusanya (2010) in Igbesa, Itele and Iba tributaries of River Ore in Southwestern Nigeria. The result of this study is also higher than 11 species belonging to 6 families recorded by Ibemenuga *et al.* (2018) in Oguta Lake, Imo State, Nigeria.

However, the total number of individuals, families and species recorded in this study is smaller than the results of several researchers at different aquatic ecosystems. For instance, 52 fish species belonging to 17 families were reported by Odo *et al.* (2009) in Anambra River Basin; 30 species were reported by Oti (2001) in Ehoma Lake; 31 species were recorded by King (1997) in Okwangwo Division in lower Cross River. The species richness from this study was equally lower than 54 species reported by Mdaihli *et al.* (2003) in Takamada Forest Reserve, upper Cross River (Cameroon); 896 fish samples, belonging to 15 families, 24 genera and 32 species recorded by Avoaja (2011) from Umudike Water Reservoir; 11 orders, 34 families, 59 genera and 136 species recorded by Ekpo *et al.* (2012) in Ikpa River, Akwa Ibom State; 25 fish species, 15 genera, 21

families and 6 orders of freshwater species recorded by Adaka *et al.* (2014) from Oguta Lake, Southeastern Nigeria.

Although the individuals, families, genera and species recorded by these authors at different localities are higher than the findings of this study, however, the observed synchronization and dissimilitude in numerical abundance of individuals, species, genera and families in different localities may be attributed to various dynamics such as sampling location, fishing methods, fish survival strategies, breeding seasons, river zonation, season of the year, channel depth, bottom types (hydrographic heterogeneity), rainfall pattern and volume of discharge in various habitats.

Occurrence, Numerical abundance and Size Structure of Fish in Eniong River

Although the result of this study shows that *Oreochromis niloticus* (17.61%), *Chrysichthys nigrodigitatus* (11.95%) and *Clarias macromystax* (11.92%) were the most abundant and significant species recorded in Eniong river during this study, *Heterotis niloticus* is among the most important fishes that sustain the freshwater fishery of the Eniong River. *H. niloticus* usually comes in large sizes which perhaps informed why fishers only included juvenile in the samples. However, the dominance of *Oreochromis niloticus* (Cichlidae) is similar to the report of Okogwu and Ugumba (2010) on the abundance and diversity of the finned and shell fish of Mid-Cross River, Southeastern Nigeria and similar to the findings of Moses (1979) and Mdaihli *et al.* (2003) in the lower and upper Cross River respectively.

The families Clariidae (29.54%), Cichlidae (27.28%) and Mormyridae (6.25%) dominated the catch of the Eniong fishery. This contradicts the report of Obi *et al.* (2009) that the dominant species in the Anambra Basin belonged to the Characidae (19.5%) and Mochokidae (11.8%) families and equally deviated from the report of Ayanwale *et al. (*2013) who reported the families Clariidae and Alestiidae as the least abundant families consisting of less than 1% of the catch of Tagwai Lake, Minna, Nigeria.

Cichlidae was the fish taxa of high biodiversity significance and richness contributing six (6) species (27.28% by number and 17.71% by weight). The diversity of Cichlidae reported in this study is similar to the report of Ekpo and Udo (2013) in the Lower Cross River Floodplain, Nigeria, but deviated from the results of Onuoha *et al.* (2010) of fish species in Ntak Inyang stream, Ikpa River, Akwa Ibom State. The fish diversity ranges from typical fresh water fishes such as *Clarias gariepinus* to brackish species such as *Chrysichthys negrodigitatus.* The most abundant group of fish was the Clariids with *Clarias macromystax* as the dominant species of the population. The result of this study agrees with Adadu *et al.* (2019) who recorded clariids as the dominant species in River Okpokwu, Benue State, Nigeria.

Community Indices of Ichthyofaunal Communities of Eniong River

The results of the fish species diversity (Shannon-H) and richness (Margalef) revealed that the upper stream has fish Shannon diversity of 2.088, while lower stream recorded fish Shannon diversity of 2.707. Richness (Margalef) showed 2.733 for upper stream and 4.788 for lower stream. This result may not be unconnected to the unorthodox fishing practices such as the use of chemical and explosive at the upper course of the river as at the time this study was conducted.

Jaccard Index Similarity of the number of species found between the upper stream and lower stream revealed the value of 0.461. The Jaccard Index Similarity is less than the critical value of 0.50 or 50%, thus, the two

stations are not similar in terms of species occurrence.

CONCLUSION

Although, Eniong River fishery is a very important source of income to the local fishers, sadly, this fishery is under threat as recent evidence showed that fishers particularly in the upper stream employ unorthodox fishing methods such as the use of ichythyocide and explosives such as dynamite for fishing. The use of these chemicals, which include gammalin-20 and narcotic extracts can endanger the rare species and affect the mono-specific families. The depauperate ichthyofaunal diversity in the upper Eniong river as compared to the lower river highlights the negative impacts of unorthodox fishing practice in the river. It is therefore imperative that every key actor in the fishery sector, including the government, particularly the lawmakers formulate policies with strict enforcement to protect our aquatic systems from the many dangers of these noxious practices.

REFERENCES

Abiodun, J. A. and John, P. (2017). Biodiversity and Abundance of Fish and Some Processing Methods in Lower Niger River Idah, Kogi State. Nigeria. *Nigerian Journal of Fisheries and Aquaculture, 5(2)*: 20-25.

Adadu, M. O., Garba, A. A. and Mshelia, J. P. (2019). Diversity and Abundance of Fish species in River Okpokwu, Benue state, Nigeria. *International Journal of Fisheries and Aquatic Studies, 7(6)*: 55-60.

Adaka, G. S., Udoh, J. P. and Onyeukwu, D. C. (2014). Freshwater Fish Diversity of a Tropical Rainforest River in Southeast Nigeria. *Advances in Life Science and Technology, 24*:16-23.

Ahmad, M., Shagari, F. U. and Sani, A. N. (2014). Fish Biodiversity and Fishing Methods of some Water Bodies in Katsina State of Nigeria. *International Journal of Fisheries and Aquaculture studies, 1(6)*: 218-221.

Allison, M.E. and Okadi, D. (2009). Species distribution and abundance in the lower Nun River, Niger Delta, Nigeria. *Journal of Fisheries International, 4: 13-18.*

Asua, S. A. and Nwangwu, C. (2025). Marine insecurity, Environmental degradation and the development of Nigeria's blue economy. *Journal of Asian and African Studies, 6*1(4): 3281-3297.

Avoaja, D. A. (2011). Fish Species Composition in a Tropical Lentic Freshwater Ecosystem, Umudike, Umuahia, Abia State, Nigeria. *Animal Reservoir International, 8(2)*:1405-1410.

Ayanwale, A. V., Shokunbi, M. T., Olayemi, J. K., Chukwuemeka, V. I., Falusi, F. M. and Erhabor, O. F. (2013). A Study of the Fish Fauna of Tagwai Lake Minna, Nigeria in Relation to Gear Selectivity. *Pakistan Journal of Biological Sciences, 16*:731-734.

Baran, E., Jantunen, T. and Chong, C. K. (2007). *Values of inland fisheries in the Mekong River Basin.* World Fish Center, Phnom Penh, Cambodia. p.76.

Birk, S., Chapman, D., Carvalho, L., Spears, B. M., Andersen, H. E., Argillier, C., Auer, S., Baattrup-Pedersen, A., Banin, L., Beklioğlu, M., Bondar-Kunze, E., Borja, A., Branco, P., Bucak, T., Buijse, A. D., Cardoso, A. C., Couture, R.-M., Cremona, F., de Zwart, D., Hering, D. (2020).

Impacts of Multiple Stressors on Freshwater Biota across Spatial Scales and Ecosystems. *Nature Ecology and Evolution, 4*: 1060–1068.

Danba, E., Afaru, J., Abubakar, K., Zira, J. D., Kefas, M. and Barau, B.W. (2021). Fish Biodiversity and Abundance in River Taraba, Taraba State, Nigeria. *Ethiopian Journal of Environmental Studies and Management, 13*: 535-544.

Ekpo, I, E., Udo, M. T. and Usip, P. L. (2012). Seasonality and size variation of Fish Species in Nwaniba, Ikpa River, Southeast Nigeria. *Elixir Aquaculture, 51*:11043-11050.

Ekpo, I. and Udoh, J. (2013). Age and Growth of *Chrysichthys auratus* in the Lower Cross River, Southeast Nigeria. *International Journal of Ecosystem, 3(4)*:64-71.

Ibemenuga, K. N., Uche, N. A., Nwosu, M. C. and Arazu, V. N. (2018). Assessing the current Fish Diversity and Abundance of a Tropical Rainforest Lentic Freshwater Ecosystem, South - Eastern Nigeria. *International Journal of Current Research, 10(01)*:63777-63781.

Ibim, A. T. and Francis, A. (2012). Album of Marine and Brackish Water Ornamental and Food Fishes of the Niger Delta of Nigeria. Published by University of Port Harcourt Press, p.42.

Idodo-Umeh, G. (2003). Freshwater Fishes of Nigeria (Taxonomy, Ecological Notes, Diet and Utilization, p.233.

Jaccard, P. (1912). "The Distribution of the Flora in the Alpine Zone.1". *New Phytologist, 11*(2): 37–50

King, R. P. L. (1997). The waters and fishes of Okwangwo Division, Cross River National Park, Nigeria. Research Project No. 1. Cross River National Park, Okwangwo Division. Museum for the Republic of Cameroon. WWF Report No. 3206/A8: 1

Lawson E. O. and Olusanya O. M. (2010). Fish Diversity in Three Tributaries of River Ore, South West, Nigeria. *World Journal of Fish and Marine Sciences, 2 (6)*: 524-531.

Li, W. Q., Li, X. Q., Leng, X. J., Fu, G. H., Luo, Y. X. (2010). Preliminary study on Flesh Quality Evaluation of *Siniperca chuatsi* (Basilewsky). *Indian Journal* of *Food Science* and *Technology*, *31 (9):*114-117.

Margalef, R. (1958). Temporal succession and spatial heterogeneity in phytoplankton. In Buzzati-Traverso, A. A. (Ed.). *Perspectives in marine biology.* Berkeley: University of California, p. 323-349.

McManus, J. W. (2012). "Tropical Marine Fisheries and the Future of Coral Reefs: A Brief Review with an Emphasis on Southeast Asia." *Coral Reefs*, 16.5 (2007): 121-27.

Mdaihli, M., du Feu, T. and Ayeni, J. S. O. (2003). Fisheries in the Southern Border Zone of Takamanda Forest Reserve, Cameroon. In: Takamanda: *The Biodiversity of an African Rainforest. SI/MAB Series, 8*:141-154.

Moses, B. S. (1983). Introduction to Tropical Fisheries, Studies in the Biology of Africa, Ibadan University press, Nigeria, p.117.

Nolan, K.A. and Callahan, J.E. (2006). Beachcomber Biology: the Shannon-Weiner species Diversity index. *Tested Studies for Laboratory Teaching, 27*: 334-338.

Obi, G. E., Didigwu, N. C. and Eyo, J. E. (2009). The Fish Fauna ofAnambra River Basin, Nigeria: species Abundance and Morphometry. *Revista de Biología Tropical, 57(1-2)*:177-186.

Ochiewo, J. (2004). Changing fisheries practice and their socioeconomic implications in South Coast Kenya. *Ocean and Coastal Management*, *47*:389-408.

Odo, G. E., Nwani, C. D. and Eyo, J. E. (2009). The fish fauna of Anambra River Basin, Mogeroa: Species Abundance and Morphometry. *Revista de Biologia Tropical, 57(1-2)*:177-186.

Offodile, M. E. (2002). Groundwater study and development in Nigeria. Mecon Services Ltd, Jos, Nigeria, p.303-332.

Okogwu, O. I. and Ugwumba, O. A. (2006). The Zooplankton and Environmental Characteristics of Ologe Lagoon, Southwest, Nigeria. *Zoologist, 3*: 86-92.

Olaosebikan, B. D. and Raji, A. (1998): Field guide to Nigerian Freshwater Fishes. Published by Federal College of Freshwater Fisheries Technology, New Bussa, Nigeria. Decency Printers Ltd, Ilorin, Nigeria, p.106.

Onuoha, G. C., Ekpo, I. E., Chude, L. A. and Isangedighi, I. A. (2010). Composite Preliminary Ichthyofaunal Survey of Ntak Inyang Stream, Ikpa River, Nigeria. *Nigerian Journal of Agriculture, Food and Environment. 6(1 and 2)*:82-89.

Oti, E. E. (2001). Some recent observations on the Fish Fauna of Ehoma Floodplain in Afikpo, Ebonyi State South-Eastern Nigeria. *NAAS Proceedings*, 271-281.

Peter, K. J., Kwaji, B. P. and Sogbesan, O. A. (2015). Artisanal Fisher's Use of Sustainable Fishing Practices in Nigeria; a Review. *Journal of Agricultural Science, 3(1)*: 140-148.

Pielou, E. C. (1975). *Ecological diversity*. New York: John Wiley and Sons, p.165.

Shannon, C. E. and Weaver, W. (1949). *The mathematical theory of communication*. Illinois: Urbana; University of Illinois Press, p.117.

Sikoki, F. D. and Francis, A. (2007). An atlas of fin fishes of the Andoni River in Niger Delta,Nigeria. Molysfem Unites Services, PorthaCourt. p. 64.

Udosen, C., Esshiett, A. A. and Etok, A. S. (2016). The Physicochemical Hydrology of a Humid Tropical River System in South Eastern, Nigeria. *International Journal of Research in Geography (IJRG), 2(2)*:22-35.

Wheeler, A. (1994) Field key to the shore fishes of the British Isles. *Field Studies, 8*:481- 521.

DORMANCY BREAKING OF *Tithonia diversifolia* , *Chromolaena odorata* and *Euphorbia heterophylla* SEEDS USING HOT WATER TREATMENTS

Dare O. AYOOLA*[1] and Rasheed O. AWODOYIN[2,3]
[1]Federal Polytechnic, Ado-Ekiti, Ekiti State, Nigeria.
[2]Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria.
[3]Federal University of Agriculture and Technology, Okeho, Oyo State, Nigeria.
*Corresponding Author's: Email: dareayoola78@yahoo.com

ABSTRACT

Dormancy is one of adaptive mechanisms used by weed to survive unfavourable conditions and helps to sustain the population of weed species in the agroecosystems. This study was carried out to investigate the effect of hot water treatment on breaking of seed dormancy of selected weed species. Seeds of some common weeds, *Tithonia diversifolia-(Td*), *Chromolaena odorata-(Co*), and *Euphorbia heterophylla-(Eh*), were subjected to hot water treatments at 30–70°C for 0–60 seconds to break their dormancy. The study was arranged in a factorial combination and laid out in a Completely Randomised Design (CRD) with three replications. Data were recorded on Germination Percentage (GP) and analysed using analysis of variance; means were separated using Duncan Multiple Range Test at 5% probability level. The GP of *Td*, *Co* and *Eh* increased with temperature level and duration. The interaction between the temperature level and duration had significant effect on the GP of *Td* (37.66±0.26), *Co* (31.33±011) and *Eh* (34.04±1.12), respectively peaking at 50°C for 50 seconds at 20 Days after sowing. The study showed that hot water treatment at 50°C for 50 seconds duration break the seed dormancy of the three weed species.

KEYWORDS: Dormancy, Temperature, Duration, *Tithonia diversifolia*, *Chromolaena odorata, Euphorbia heterophylla*

INTRODUCTION

Weed is one of the biggest obstacles facing agricultural production in the world because of the losses it causes in the productivity and quality of crops. Yield reduction by weeds raging between 50-99% depend on the crop species (Saudy and Mubarak, 20115), weed species and duration of interaction between crop and weeds. According to Jabran *et al*. (2015) report, 34% of yield losses are caused by weeds compared to 18% and 16% by disease and insects, respectively. Similar findings were reported by Kumar *et al.* (2022), that 34% yield loss in major crops were caused by weed around the world. However, weeds exercise their competitive ability through many mechanisms including seed dormancy. According to Bewley *et al*. (2012), seed dormancy in plant is one of the adaptive mechanisms to survive an unfavourable environment. The dormancy level of the weed seed bank has direct interaction with predominating ecological condition which determine the degree and timing of weed emergence (Batlla and Benech-Arnold, 2010). Weed seeds can remain in the soil for many years and germinate after a favourable condition such as temperature and duration or timing needed to break the dormancy have been satisfied.

However, understanding the duration and temperature level to break the dormancy of weeds for optimal weed seeds germination has a practicable role in choosing the appropriate tillage practices for a sustainable weed control strategy.

Therefore, objective of this study is to find the best duration and temperature level to break the dormancy of *Tithonia diversifolia,*

Euphorbia heterophylla and *Chromolaena odorata* seeds using hot water at varying temperatures and durations.

MATEIALS AND METHODS

The study was carried out in the Department of Crop Protection and Environmental Biology (CPEB), University of Ibadan (UI), Ibadan, Nigeria. Pre-germination treatment experiment was conducted with aim of removing possible mechanical hindrance possessed by the weed seeds using hot water treatment. Fifty (50) seeds of *Tithonia diversifolia, Euphorbia heterophylla* and *Chromolaena odorata* per treatment were wrapped in muslin cloth and immersed in a pre-heated hot water for 10, 20, 30, 40, 50 and 60 seconds at 30ºC, 50ºC and 70ºC in a beaker. The seed used for the control were not immersed in hot water. The study was arranged in a factorial combination and laid out in a Complete randomised Design with three replications. A thermometer was used to monitor the temperatures. At a particular temperature and duration of immersion, the wrapped seeds were removed and placed under running water in the laboratory for 5 min. to cool down the seeds (Das, 2011). The seeds were placed in the Petri dishes lined with Whatman No. 1 filter papers moistened with distilled water.

The set up was observed for twenty consecutive days for the emergence of radicle which indicates germination. The percentage germination was calculated as;

$$\text{Germination (\%)} = \frac{\text{Total number of seed(s)that germinated}}{\text{Total number of seeds in Petri dishes}} \text{ x } 100$$

RESULTS

Seeds of the weed species (*Tithonia diversifolia, Euphorbia heterophylla* and *Chromolaena odorata*) immersed in hot water treatment at varying temperatures (30℃, 50℃ and 70℃) for 50 and 60 seconds germinated on the 8th day and reached the peak of their germination on the 20th day **(**Table 1). At 8 DAS, the highest GP of 6.02 ± 1.12 was observed in 50℃ for 50 seconds, which was significantly higher (P≤0.05) than GP in 70℃ for 60 seconds (2.66 ± 1.41). It was, however, significantly different (P≤0.05) from the remaining treatments (Table 1). At 10 DAS, the lowest GP (5.33±0.07) was observed in 50℃ for 60 seconds and the highest GP of 10.33±1.12 in 50℃ for 50 seconds, which was significantly higher (P≤0.05) than the GP observed in the remaining treatments **(**Table 1). At 12 DAS, 50℃ for 50 seconds had the highest GP of 16.01±0.26 which was significantly higher (P≤0.05) than GP observed in other remaining treatments **(**Table 1). At 14 DAS, similar trend was observed, 50℃ for 50 seconds had the highest GP of 20.01±0.21 and the lowest GP (12.00±0.04) was observed in 50℃ for 60 seconds. However, 50℃ for 50 seconds, was not significantly (P≤0.05) different from 70℃ for 50 seconds (Table 1). At 16 DAS, 50℃ for 50 seconds was significantly higher (P≤0.05) than the GP of the other treatments. At 18 DAS, the lowest GP (16.38±0.10) was observed in 70℃ for 60 seconds, while 50℃ for 50 seconds had the highest GP of 31.33±0.06, which was significantly higher (P≤0.05) than the other treatments. At 20 DAS, the highest GP of 37.66±0.26 was obtained in 50℃ for 50 seconds, and 70℃ for 60 seconds had the lowest GP (18.02±0.04). However, the seed treated at 50℃ for 50 seconds was significantly (P≤0.05) different from other treatments (Table 1).

The GP of *Chromolaena odorata* followed similar trend with *T. diversifolia* and germination commenced at 8th day in treatment 50℃ for 30 seconds. At 8 DAS, 50℃ for 50 seconds had the highest GP (5.02±0.21) and the lowest GP of 1.33±0.04

was observed in the 70℃ for 60 seconds (Table 2). However, 50℃ for 50 seconds was not significantly (P≤0.05) different from 70℃ for 50 seconds. At 10 DAS, the lowest GP (3.00±1.04) was observed in 70℃ for 40 seconds while 50℃ for 50 seconds had the highest germination. However, the germination of seeds treated in 50℃ for 50 seconds was not significantly different from seeds treated in 50℃ for 70 seconds (Table 2). At 12 DAS, the highest GP of 14.02±0.11 was observed in the seeds treated in 50℃ for 50 seconds, while the seeds treated in 50℃ for 30seconds had the lowest GP (6.66±0.03). At 14 DAS, the highest GP of 17.66±0.31 was observed in the seed treated in 50℃ for 50 seconds while 70℃ at 60 seconds had the lowest GP (8.66±0.24). However, the GP observed in 50℃ for 50 seconds was significantly (P≤0.05) higher than the GP of other treatments (Table 2). At 16 DAS, 70℃ for 60 seconds had the lowest GP (11.03±0.26) and the highest GP of 23.33±0.04 was observed in 50℃ for 50 seconds (Table 2). However, the GP of 50℃ at 50 seconds was significantly higher (P≤0.05) than the other treatments (Table 2).

At 18 DAS, the seeds treated in 50℃ for 50 seconds had the highest GP of 26.33±0.23 while 70℃ for 60 seconds had the lowest GP (14.33±1.03). However, the GP of 50℃ for 50 seconds was not significantly different (P≤0.05) from 70℃ for 50 seconds (Table 2). At 20 DAS, a similar GP trend in 18 DAS was observed, 50℃ for 50 seconds had the highest GP of 31.33±0.11 while the lowest GP (16.03±0.05) was observed in 70℃ for 60 seconds. While, there was no significant difference between 50℃ at 50 seconds and 70℃ at 50 seconds, however, significantly higher(P≤0.05) than other treatments (Table 2).

The GP of *E. heterophylla* increased from day 8 up to day 20. At 8 DAS, the seed treated in 50℃ for 50 seconds had the highest GP of 5.01±0.05 while those treated in 70℃ for 40 seconds had the lowest GP (2.66±0.23) (Table 3). However, the GP of 50℃ for 50 seconds was not significantly (P≤0.05) different from70℃ for 50 seconds. At 10 DAS, 30℃ for 40 seconds had the lowest GP (5.20±0.05) while highest GP (8.66±0.25) was observed in 50℃ for 50seconds. However, the GP value of 50℃ for 50 seconds was not significantly different (P≤0.05) from 70℃ for 50 seconds (Table 3). At 12 DAS, 50℃ for 50 seconds was significantly (P≤0.05) higher than other treatments. However, GP of seeds treated with 30℃ for 50 seconds, was significantly (P≤0.05) lower than all other treatments. At 14 DAS, the trend is similar to 12 DAS, 50℃ for 50 seconds was significantly higher than all other treatments. However, 70℃ for 60 seconds had the lowest GP (10.66±0.06). At 16 DAS, 50℃ for 50 seconds had the highest GP value of 24.02±0.05 and the lowest GP value (13.66±0.21) was observed in70℃ for 60 seconds (Table 3). However, the GP value of 50℃ for 50 seconds was significantly different from GP values of the other treatments (Table 3). At 18 DAS, 70℃ for 60 seconds had the lowest GP value (15.33±0.14) and the highest GP value of 27.33±0.23 was observed in 50 seconds, 50℃ for 50 seconds (Table 3). At 20 DAS, 50℃ for 50 seconds had the highest GP value of 34.04±1.12 and the lowest GP value of 16.03±0.05 was observed in70℃ for 60 seconds, However, the GP observed in 50℃ for 50 seconds was significantly higher (P≤0.05) than the GP of the other treatments (Table 3)

Table 1: Germination of *Tithonia diversifolia*/Seeds Subjected to Hot Water Treatment.

	Days After Sowing						
Treatment	8	10	12	14	16	18	20
30°C/50 sec	$3.31^{ab}\pm0.12$	$6.00^{a}\pm0.31$	$11.33^{ab}\pm0.33$	$13.33^{a}\pm0.76$	$16.33^{a}\pm1.05$	$19.33^{b}\pm0.27$	$24.66^{c}\pm0.23$
50°C/50 sec	$6.02^{c}\pm1.12$	$10.33^{c}\pm1.12$	$16.01^{d}\pm0.26$	$20.01^{c}\pm0.21$	$27.66^{d}\pm1.03$	$31.33^{e}\pm0.06$	$37.66^{f}\pm0.26$
70°C/50 sec	$4.33^{b}\pm0.54$	$8.33^{b}\pm0.03$	$14.33^{cd}\pm0.25$	$18.00^{bc}\pm0.11$	$25.01^{c}\pm0.11$	$28.01^{d}\pm0.03$	$34.33^{e}\pm0.04$
30°C/60 sec	$4.23^{b}\pm1.23$	$7.33^{b}\pm0.04$	$13.33^{bc}\pm0.03$	$16.66^{b}\pm0.25$	$23.66^{c}\pm0.05$	$26.03^{c}\pm0.12$	$31.33^{d}\pm0.14$
50°C/60 sec	$3.30^{ab}\pm0.52$	$5.33^{a}\pm0.07$	$10.66^{a}\pm0.58$	$12.00^{a}\pm0.04$	$15.66^{b}\pm0.03$	$18.33^{b}\pm0.04$	$20.66^{b}\pm0.16$
70°C/60 sec	$2.66^{a}\pm1.41$	$5.66^{a}\pm0.41$	$11.33^{ab}\pm0.03$	$13.66^{a}\pm0.14$	$14.66^{a}\pm0.12$	$16.33^{a}\pm0.10$	$18.02^{a}\pm0.04$

Values shown are mean ± S.E (n = 6). Means were separated by Duncan New Multiple Range Test.
Means in the same column with the same letter are not significantly different ($p\leq0.05$).,
DAS= Days After Sowing, Sec = Seconds

Table 2: Germination of *Chromolaena odorata* Seeds Subjected to Hot Water Treatment.

	Days After Sowing						
Treatment	8	10	12	14	16	18	20
30°C/50 sec	$2.33^{bc}\pm0.13$	$4.33^{cd}\pm0.05$	$6.66^{c}\pm0.03$	$10.02^{c}\pm0.22$	$14.03^{c}\pm1.02$	$16.33^{b}\pm1.11$	$19.03^{c}\pm0.01$
50°C/50 sec	$5.02^{a}\pm0.21$	$8.66^{a}\pm0.13$	$14.02^{a}\pm0.11$	$17.66^{ab}\pm0.31$	$23.33^{b}\pm0.04$	$26.33^{a}\pm0.23$	$31.33^{a}\pm0.11$
70°C/50 sec	$4.33^{a}\pm0.07$	$7.66^{ab}\pm0.04$	$13.12^{ab}\pm0.23$	$16.33^{a}\pm0.03$	$21.66^{a}\pm0.23$	$25.03^{a}\pm0.52$	$30.66^{a}\pm0.23$
30°C/60 sec	$4.03^{a}\pm0.23$	$6.66^{b}\pm0.14$	$12.03^{b}\pm1.02$	$15.03^{b}\pm0.05$	$20.66^{b}\pm0.03$	$24.03^{a}\pm0.04$	$27.05^{b}\pm1.02$
50°C/60 sec	$2.66^{b}\pm0.07$	$5.33^{c}\pm0.11$	$7.33^{c}\pm0.42$	$9.66^{cd}\pm0.13$	$12.03^{d}\pm0.11$	$15.31^{c}\pm0.06$	$19.03^{cd}\pm0.03$
70°C/60 sec	$1.66^{bc}\pm0.23$	$3.33^{d}\pm1.02$	$7.03^{c}\pm0.05$	$8.66^{cd}\pm0.24$	$11.03^{d}\pm0.26$	$14.33^{d}\pm1.03$	$16.03^{e}\pm0.05$

Values shown are mean ± S.E (n = 7). Means were separated by Duncan New Multiple Range Test. Means in the same column with the same letter are not significantly different ($p\leq0.05$)., DAS= Days After Sowing, Sec = Seconds

Table 3: Germination of *Euphorbia heterophylla* Seeds Subjected to Hot Water Treatment

	Days After Sowing						
Treatment	**8**	**10**	**12**	**14**	**16**	**18**	**20**
30°C/50 sec	$2.66^{cd}\pm1.03$	$5.20^{de}\pm0.05$	$9.66^{b}\pm0.24$	$12.66^{b}\pm0.04$	$15.66^{c}\pm0.11$	$18.66^{b}\pm0.06$	$24.04^{c}\pm0.32$
50°C/50 sec	$5.01^{a}\pm0.05$	$8.66^{a}\pm0.25$	$14.01^{a}\pm0.02$	$17.33^{a}\pm0.10$	$24.02^{a}\pm0.07$	$27.33^{a}\pm0.23$	$34.04^{a}\pm1.12$
70°C/50 sec	$3.66^{bc}\pm0.07$	$7.66^{ab}\pm0.03$	$13.00^{a}\pm0.12$	$17.33^{a}\pm0.05$	$22.03^{b}\pm0.01$	$26.33^{a}\pm0.17$	$30.33^{b}\pm0.24$
30°C/60 sec	$4.21^{ab}\pm1.03$	$7.21^{bc}\pm0.04$	$12.01^{a}\pm0.26$	$15.33^{a}\pm0.13$	$21.33^{b}\pm0.05$	$24.66^{a}\pm0.32$	$29.03^{b}\pm0.23$
50°C/60 sec	$3.33^{bc}\pm0.11$	$5.33^{de}\pm0.34$	$9.66^{b}\pm0.02$	$12.03^{bc}\pm0.21$	$15.66^{c}\pm0.11$	$18.04^{b}\pm0.03$	$20.33^{d}\pm1.13$
70°C/60 sec	$2.66^{cd}\pm0.23$	$5.66^{cd}\pm0.23$	$7.66^{bc}\pm0.04$	$10.66^{bc}\pm0.06$	$13.66^{d}\pm0.21$	$15.33^{d}\pm0.14$	$19.53^{d}\pm0.24$

Values shown are mean ± S.E (n = 6). Means were separated by Duncan New Multiple Range Test.
Means in the same column with the same letter are not significantly different ($p\leq0.05$)., DAS= Days After Sowing, Sec = Seconds

DISCUSSION

Tithonia diversifolia, Euphorbia heterophylla and *Chromolaena odorata* seeds displayed dormancy potentials. This corroborates the findings of Baskin and Baskin (2014) who reported that annual

weeds with small-seeded generally produce more dormant seeds than long-lived and big seed weeds. Similarly, Lu *et al*. (2020) reported that seeds of some weeds in the Asteraceae family to which *Tithonia diversifolia* and *Chromolaena odorata* belong have stronger and thicker pericarp that prevent germination. Also, Tanimola and Awodoyin (2020) reported that Fabaceae family exhibits dormancy of seeds as result of hard seed coat. According to Baskin and Baskin (2014), seed dormancy controls germination through various physical and or physiological means imposed by the seed coat or within the embryo.

A clear understanding of the mechanisms involved in removing seed dormancy is important for effective plant propagation and successful management of weeds. Dormancy of seed is a method or means of preventing germination during unfavourable environmental conditions. Gama-Arachchigie *et al*. (2013b) opined that the water gap in the seeds is majorly being controlled by temperature for most weed species with physical dormancy and allow enough water availability once the water gap is fragmented. They require temperature for the dormancy breakage in response to the plant growth regulators (gibberellins). Results from dormancy breaking in this study showed that the seeds of *Tithonia diversifolia, Euphorbia heterophylla* and *Chromolaena odorata* were not different when immersed in distilled water for various number of hours. Dormancy and seed germination in *T. diversifolia, E. heterophylla* and *C. odorata* was mainly influenced by the temperature and time duration. Steeping in hot water at temperature regime of 50ºC, 60ºC and 70ºC for duration of 50 seconds enhanced germination percentage better than all other treatments. This corroborates the findings of McDonnell *et al*. (2012) who reported that seeds immersed in both 70ºC and 80ºC hot water germinated earlier and was best temperature for dormancy breaking in *Illiamna remota*. Additionally, prolonged time and higher temperature were correlated with germination rate. The two factors interacted with each other to influence dormancy breaking and germination characteristics of the weed seeds. This corroborates the findings of Temel *et al*. (2023) who reported a higher germination rate of goat wheat plant at increased temperature and lower emergence time

CONCLUSION

The study reveals that the seed dormancy of *Tithonia diversifolia, Euphorbia heterophylla* and *Chromolaena odorata* are better broken in 50ºC for 50 seconds duration of hot water treatments. These findings contribute to our understanding of germination biology of *Tithonia diversifolia, Euphorbia heterophylla* and *Chromolaena odorata*, which provides information for research work on the management of the three weed species in the agroecosystem.

REFERENCES

Baskin, C. C and Baskin, J. M. 2014. Seeds: Ecology, Biogeography and Evolution of dormancy and germination. 2nd edition. Elsevier, Academic Press, San Diego, CA.

Batlla, D. and Bench-Arnold, R. L. 2010. Predicting changes in dormancy level in natural seed soil banks. *Plant Molecular Biology*, 73:3-13.

Das, T. K. 2011. *Weed Science, Basics and Application*, 910

Gama-Arachchige, N. S., Bakin, J. M., Geneve, R. L and Baskin, C. 2013. Identification and characterisation of ten new water gaps in seeds and fruits with physical dormancy and classification of water-gap

complexes. *Annals of Botany*, 112(1):69-84.

Jabran, K., Mahajan, G. Sardana, V. and Chauhan, B. S. 2015. Allelopathy for weed control in agricultural systems. *Journal of Crop Production*, 72: 57-65.

Kumar, D., Vivek and Kumar, S. 2022. Effect of herbicides and nutrient management practices on weeds, nutrient depletion and yield of wheat (*Triticum aestivum* L.). *International Journal of Chemical Studies*, 8(5): 1217-1221.

Lu, J., Dong, W., Tn, D., Bakin, C. C. and Baskin, J. M. 2020. Dormancy and germination of the trimorphic achenes of a cold desert annual: spreading the risk over time. AOB Plants,12:56.

McDonnell A., Grant, M. and Coons, J. M. 2012. Effects of hot water on breaking seed dormancy of the endangered Kankakee mallow (*Illiamna remota* Greene). Faculty Research and Creative Activity, 192.

Saudy, H. S. and Mubarak, M. M. 2015. Mitigating the detrimental impacts of nitrogen deficit and fenoxaprop-pethyl herbicide on wheat using silicon. *Common Soil Science Plant Analysis*, 46:913-923.

Tanimola, O. O. and Awodoyin, R. O. 2020. Germination of *Mimosa diplotricha* C. Wright and its critical period of interference with maize (*Zea mays*) in Ibadan, Nigeria. *African Journal of Agriculture, Technology and Environment*, Volume 9(1):62-72.

Temel, S., Keskin, B. and Cakmakci, S. 2023. Effect of different dormancy-breaking methods on the seed germination and vigour of *Atraphaxis spinosa*. *Zemdirbste-Agriculture*, 110(1):39-46.

DISTRIBUTION AND ABUNDANCE OT TOOTHACHE PLANT (*Acmella brachyglossa* CASS.) IN OYO STATE, NIGERIA

Ogunjobi, A. J.[1], Adeniji, A. O.[2]*., Awodoyin, R. O.[1,2] And Olubode, O. S.[1]
[1]Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria.
[2]Federal University of Agriculture and Technology, Okeho, Oyo State, Nigeria.
*Corresponding Author's Email: adeniji.ayobami@yahoo.com

ABSTRACT

Floristic study was carried out to assess the distribution and abundance of *Acmella brachyglossa* Cass. in three farm communities, Iwere-Ile (Iwajowa), Okeho (Kajola) and Moniya (Akinyele) in Oyo State, Nigeria. A random sampling technique was employed to enumerate the weed species. Twenty 0.5 m x 0.5 m quadrats were laid in a 100 m^2 cultivated and fallow land in each community. The floral identification, Relative Importance Values (RIV), species diversity, Evennes and Jaccard index of similarities followed standard procedures. Fifty two plant species distributed within 22 families were identified in the three farm communities. *Acmella brachyglossa* had the highest RIV (Okeho, 24.04, Iwere-Ile, 35.48, and Moniya-Ibadan, 37.87). The lowest RIV was obtained for *Boerhavia erecta* Linn. (0.52) in Iwere-Ile, *Mariscus alternifolius* Vahl. (0.5) in Okeho, and *Paulinia pinata* Linn. (0.52) in Moniya-Ibadan. Species diversity was high in Okeho (Shannon Weiner Index, 2.06). The eveness was low in the three communities (Iwere-Ile, 0.4, Okeho, 0.19, and Moniya-Ibadan, 0.21) and there was no dominance of a particular species. The Jaccard similarity index indicated the species in Moniya-Ibadan to be similar to Okeho farm community. The phytosociology and percentage flora for the three communities indicated *A. brachyglossa* as having between 21-50% cover in both cultivated and fallow land.

Key words: *A.brachyglossa*, RIV, Shannon Weiner Index, Eveness, Phytosociology.

INTRODUCTION

The genus *Acmella*. comprises 30 species and 9 additional infraspecific taxa that are mainly distributed in tropical and subtropical regions around the world (Jansen 1985; Chung *et al*., 2008). Many *Acmella* species have become naturalised and invasive, including *A. oleracea, A. ciliata, A. paniculata, A. uliginosa* and *A. brachyglossa* (Chung *et al*., 2008). *Acmella brachyglossa* Cass., is a weed that thrives in central America, Northern and South America and West Indies, Thailand and Taiwan (Jansen, 1985). In China, the plant is used to treat throat and gum diseases in addition to being consumed as a vegetable (Chung et al., 2008). The flower is considered an aphrodisiac (Ramsewak *et al*., 2003). Given its weedy nature in other parts of the world, *A. brachyglossa* has spread and thrived in Oyo State, Nigeria. It was most likely introduced to Nigeria by nomadic cattle through their dungs and has since become a severe weed of field crops, commonly found along roadsides where the conditions are favourable for its growth.

Invasive plant species have harmful impacts on biodiversity and ecosystem. They exhibit broad environmental tolerance, quick growth rates, and extensive dispersal mechanisms (Birthisel *et al*., 2021; Shephard *et al*., 2022), allowing them to outcompete indigenous species and homogenise flora in habitats (Shuvar *et al*., 2021). These species reduce the diversity and richness of native species in a region (Dornelas *et al*., 2014; Rivas-Torres *et al*., 2018). Furthermore, invasive plants are generally unwanted since they are difficult to manage and can take over vast regions. According to Tom and Richard (2013), managing an infestation of invasive plants can be extremely expensive and environmentally harmful.

Acmella brachyglossa is one of Nigeria's most overlooked agricultural concerns. A

timely report on alien species naturalisation is critical for efficiently managing and controlling potential invasive species (Yang *et al*., 2005). A. brachyglossa is found in both the forest and savanna ecological zones of Oyo State, on farmlands, fallow ground, roadsides, marshes, and near streams and rivers. It has become a plant out of place, not purposefully sown, whose negative features exceed its positive points (Lingenfelter and Hartwig, 2002). The farmers in Oyo state had identified the weed as being ubiquitous and problematic. This is because of the weed's invasive nature, the effort and time required to eradicate it, and the reduction in crop output. The study examined the floral components of three farm communities in Oyo state in relation to *A. brachyglossa*, its distribution, and abundance in the invaded ecosystem.

MATERIALS AND METHODS

Study sites

Three farming communities were selected for the field enumeration of populations of *Acmella brachyglossa* and other weeds. The arable farm settlements of Iwere-Ile, Iwajowa Local Government Area (Latitude 08º 00.235N´Longitude 03º 05.582´E, 188 m above sea level (asl) and 111.39 km northwest of Ibadan), Okeho, Kajola Local Government Area (Latitude 08º 02.595´N; Longitude 03º 22.733´E, 376 asl and 92.45 km northwest of Ibadan) and Moniya, Akinyele Local Government Area (Latitude 07º 31.862´N; Longitude 03º 55.810´E, 223 m asl and 16.15 km north of Ibadan), Oyo state were selected based on prevalence of *Acmella brachyglossa* in the farmlands.

In each of these sites, two plots, 10 m × 10 m, in cultivated and fallowland were marked out for density estimation of *Acmella brachyglossa* in relation to other plant species at the blooming (flowering) stage of the plant (November).

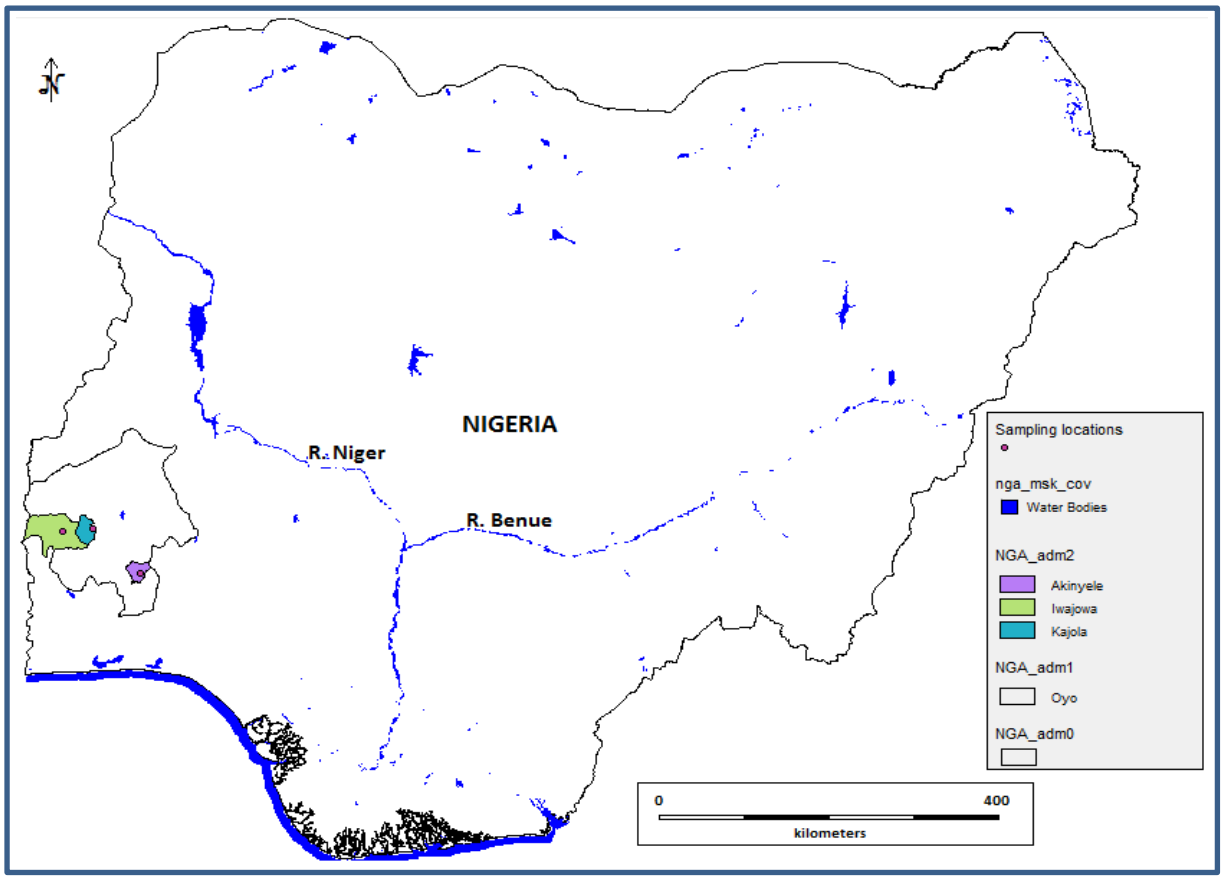


Figure 1. Map of Nigeria showing the three survey sites in Oyo State.

Sampling procedure

The floristic components of the farm settlements were sampled when the vegetation was at its peak of maturity in November 2013 using random sampling technique. A 10 m x 10 m piece of land in cropped and fallowland infested by *Acmella. brachyglossa* was marked out for sampling in each site. A series of random numbers (1 to 10) was drawn by means of a table of random numbers in a pair of ordinates *x* and *y*. Grid lines, 1 meter apart, perpendicular to the baseline or boundary was marked out. With the pairs of numbers obtained from the random number table, a 0.5 m x 0.5 m quadrat was laid on each of the coordinates on the grid lines to have 10 sampling unit in each of the cropped and fallowland. The plant species composition occupying each stand was identified following Akobundu and Agyakwa (1987) and recorded. The number of stands explored was twenty per farm settlements and sixty for the three farm settlements in a season. The plant species that cannot be identified were taken to the University of Ibadan, Ibadan herbarium for proper identification.

The Relative Frequency (RF), Absolute Density (AD), Relative Density (RD) and Relative Importance Value (RIV) of the floral species were calculated according to Awodoyin and Olubode (2009) as follows:

Sampling procedure

The floristic components of the farm settlements were sampled using random sampling technique. A 10 m x 10 m piece of land in cropped and fallowland infested by *Acmella. brachyglossa* was marked out for sampling in each site. A series of random numbers (1 to 10) was drawn by means of a table of random numbers in a pair of ordinates *x* and *y*. Grid lines, 1 meter apart, perpendicular to the baseline or boundary was marked out. With the pairs of numbers obtained from the random number table, a 0.5 m x 0.5 m quadrat was laid on each of the coordinates on the grid lines to have 10 sampling unit in each of the cropped and fallowland. The plant species composition occupying each stand was identified following Akobundu and Agyakwa (1987) and recorded. The number of stands explored was twenty per farm settlements and sixty for the three farm settlements in a season. The plant species that cannot be identified were taken to the University of Ibadan, Ibadan herbarium for proper identification.

The Relative Frequency (RF), Absolute Density (AD), Relative Density (RD) and Relative Importance Value (RIV) of the floral species were calculated according to Awodoyin and Olubode (2009) as follows:

$$RF = \frac{Frequency\ of\ a\ species}{Frequency\ of\ all\ species} \times 100\ \%$$

$$AD = Total\ number\ of\ individuals\ of\ a\ species\ in\ a\ stated\ area$$

$$RD = \frac{Total\ number\ of\ individuals\ of\ a\ species\ in\ all\ the\ quadrats}{Total\ number\ of\ individuals\ of\ all\ the\ species\ in\ all\ the\ quadrats} \times 100$$

$$RIV = \frac{Relative\ Density + Relative\ frequency}{2}$$

A two dimensional quadrat ordination was obtained from the Detrended Correspondence Analysis (DECORANA/DCA) to compare the similarities and or differences that occurs in the three farm settlement. The quadrat laid was classified further using the TWINSPAN (Hill, 1977).

The species diversity of each farm settlement was computed using Shannon-Weiner index (Kent and Coker, 1996) as

$$\text{Equitability index } (H') = \sum pi\ (ln\ pi)\ where\ pi = ni/N$$

where pi = the proportion of individual or the abundance of the ith species expressed as a proportion of total cover,

ni = Number of individuals in the ith species, N = Total number of individuals in the sample, ln = log base n (Naperian log 2.303 x $\log_{10}$)

Eveness index (J) = $\frac{H'}{ln\ S}$ Where S = Total number of species in the community.

Jaccard index of community similarity
Jaccard index determines community similarity, and it is based on the presence/absence relationship between the number of species in each community and the number of common species (Spellerberg, 2005). The Jaccard index of community similarity (SCj) was calculated as;
SCj = $(w/A + B - w)\ x\ 100\%$
where; w is the number of common species to farm A, B or C;
A is the number of species in community A, B is the number of species in community B and C is the number of species in community C. The values range from zero percent (no similarity) to 100% (maximum similarity) (Spellerberg, 2005, Awodoyin *et al*., 2013).

RESULTS

The soil collected from the three farming communities was sandy loam in both cultivated and fallow land with slight acidity. The total nitrogen, potassium, Cation exchange capcity (CEC) and axchangeable acidity were higher in the cultivated land than in fallow land, but the available phosphorus in the fallow was higher in the fallow than cultivated land ((Table 1).

In the study, Poaceae family had the highest number of species and was followed by the Asteraceae family across the three farm communities surveyed (Iwere-ile, Okeho, Moniya-Ibadan and Okeho). Fifty two (52) weed species distributed in 20 families were encountered in the farm communities. Seven weed species, *Acmella brachyglossa*, *Ageratum conyzoides*, *Chromolaena odorata*, *Tridax procumbens*, *Commelina benghalensis*, *Mimosa pudica*, and *Ludwigia abyssynica* were present across the three farm communities (Table 2).

In Iwere – Ile, seventeen (17) weed species were found in the cultivated land and sixteen (16) in the fallow land farm coummunities. Fifteen (15) and sixteen (16) weed species were encountered in the cultivated and fallow land of Moniya-Ibadan farm communities respectively. In Okeho, eleven (11) weed species were found in the cultivated land and twenty four (24) in the fallow land fallow communities. *Acmella brachyglossa* had the highest Relative Importance Value (RIV) in the fallow land of Moniya-Ibadan across the three farm communities (Table 3.)

The taxa was highest in the fallow in Okeho while the Shannon Weiner was highest in the cultivated land of Moniya-Ibadan farm community. The eveness values across the three communities were less than 0.50. The fallow land in Moniya-Ibadan only had a dominance value greater than 0.50 (Table 4).

In the Detrended Correspondence Analysis (DCA) of the floristic composition in the three farm communities, the axis of definition for the study sites were axis 1 and 2 with contribution of 74.1% and 39.2% respectively. Individual quadrats corresponds to different points on the scattergrams. The quadrat ordination for the cultivated land in Okeho and Moniya-Ibadan farm communities showed higher degree of closeness while the cultivated and fallow land of Iwere - Ile farm community were more closely associated (Figure 1).

Sixty quadrats (stands) were fed into TWINSPAN software and yielded twenty-two (22) divisively classified phytosociological groupings at the sixth level of association. The sixty quadrats were divided into phytogroups of 40 and 20 quadrats. Further classification yielded four groups of 2 negative and 2 positive differentials of 10 and 30, and 10 and 10 respectively. At the third level for groups of 7, 18, 12, 8 and 8 produced 2 dichotomies 18(8, 10) and 12 (3, 9). The next lower level

had phytogroups of 7 which did not divide further. The fifth phytogroups had subgroups of 9, 6, 6 and which divides further into the sixth and last phytoclass which comprises 22 subgroups of 3, 4, 3, 1, 3, 6, 3, 3, 2, 3, 5, 1, 3, 2, 2, 4, 2, 2, 3, 2, 1, 2 pairs of negative and positive preferentials for the rainforest transition and the savannah grassland agroecosystem (Figure 2).

The two-way output (TWINSPAN) depicted *A. brachyglossa* as non-preferential species whose stand cut across the ecological zones of the farm studied. *Acmella brachyglossa* further occupied a unique position by clearly demarcating the other species into positive and negative preferentials (Table x). The common species were *Acmella brachyglossa*, located in 58 quadrats, *Tridax procumbens,* 32 quadrats and *Ageratum conyzoides,* 25 quadrats. *Acalypha ciliata* and *Centrosema pubescens* were the rarest species located in 1 quadrat each. The species association in the three agroecosystem shows *Acmella brachyglossa, Tridax procumbens* and *Eragrostis tenella* as having between 21-50 percent (%) cover (Table 4.9), while *Ageratum conyzoides*, *Mariscus alternifolius*, *Mariscus flaberliformis*, *Ludwigia abyssinica* and *Mimosa pudica* had between 2-20%.

Jaccard's index of similarities showed that the plant species in both cultivated and fallow land in Moniya-Ibadan were similar to the cultivated land in Okeho with 35% level of similarities (Table 5). Thus, the plant species in the cultivated land of Moniya-Ibadan and Okeho farm communities with 35% index of similarity were more similar than the Iwere-Ile farm community.

Table 1. The physico-chemical properties of the soil from the selected study sites

	Farm community							
	Iwere-Ile		Moniya-Ibadan		Okeho		M . C	M .F.
Properties	C	F	C	F	C	F	C	F
pH (H_2O)	6.40	6.83	6.90	6.92	6.80	6.85	6.70±0.15	6.87±0.03
Total Organic Carbon (g/kg)	15.91	17.01	16.65	15.89	15.17	15.81	15.91±0.43	16.24±0.39
Total Nitrogen (g/kg)	1.48	1.49	1.56	1.38	1.41	1.43	1.48±0.04	1.43±0.03
Available Phosphorus (mg/kg)	14.27	14.32	4.77	4.91	5.52	5.51	8.19±3.05	8.25±3.05
Potassium (c/mol)	0.49	0.42	0.20	0.28	0.66	0.64	0.55±0.10	0.45±0.10
Cation exchange capacity (CEC)	8.62	8.46	4.35	4.41	6.25	5.95	7.83±0.79	6.27±1.18
Exchangeable acidity	0.20	0.18	0.20	0.19	0.20	0.20	0.20±0.00	0.19±0.01
Clay (g/kg)	148.00	147.20	128.00	128.00	168.00	157.50	154.67±6.67	144.23±8.65
Silt (g/kg)	114.00	113.80	94.00	95.20	134.00	141.00	120.67±6.67	116.67±13.31
Sand (g/kg)	738.00	738.90	778.00	775.80	698.00	701.50	724.67±13.35	738.73±21.47
Soil texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	-	-

C=Cultivated land, F=Fallow, M.C.= Mean±standard error of cultivated land, M.F.= Mean±standard error of fallow land

Table 2. Families and species of herbaceous plants enumerated in Iwere-ile, Okeho and Moniya farm communities in November, 2013

S/N	Family	Species
1	Amaranthaceae (2)	*Alternanthera sessilis* (Linn.) DC.
		Amaranthus cruentus (Linn.)
2	Asteraceae (7)	*Acmella bracchyglossa* (Cass.)
		Ageratum conyzoides (Linn.)
		Chromolaena odorata R.M. King and Robinson
		Sclerocarpus africanus Jack. Murr.
		Synedrella nodiflora Gaertn.
		Tithonia diversifolia (Helms.) A. Gray.
		Tridax procumbens (Linn.)
3	Bignoniaceae (1)	*Newbouldia laevis* P. Beau. Seaman ex Burm
4	Commelinaceae (2)	*Commelina benghalensis* (Linn.)
		Commelina erecta J.K. Morton
5	Cyperaceae (1)	*Cyperus haspan* (Linn.)
6	Discoreaceae (2)	*Discorea alata* (Linn.)
		Discorea rotundata (Linn.)
7	Euphorbiaceae (5)	*Acalypha ciliata* Fork.
		Euphorbia heterophylla (Linn.)
		Euphorbia hirta (Linn.)
		Manihot esculenta Crantz.
		Phyllanthus amarus Schum and Thonn.
8	Fabaceae (1)	*Vigna unguiculata* Walp.
9	Graminae (2)	*Zea mays* (Linn.)
		Sorghum guineensis
10	Laminaceae (1)	*Lapotea aestuans* (Linn.) Chew.
11	Loganaceae (1)	*Spigelia anthelmia* (Linn.)
12	Malvaceae (4)	*Mariscus alternifolius* Vahl.
		Mariscus flaberliformis Kunth.
		Melanthera scandens (Kunth and Thonn.) Robert
		Sida acuta Burm f.
13	Mimosoidae (1)	*Mimosa pudica* (Linn.)
14	Nyctaginaceae (2)	*Boerhavia diffusa* (Linn.)
		Boerhavia erecta (Linn.)
15	Onagraceae (2)	*Ludwigia abyssynica* A. Rich.

		Ludwigia decuren Walt. Syn
16	Papilionoide (3)	*Callopogonium mucunoides* Desv.
		Centrosema pubescens (DC.) Benth.
		Desmodium scopiurus (Sw.) Desv.
17	Poaceae (8)	*Brachiaria lata* (Schumach) C.E. Hubard
		Eragrotis tenella (Linn.) P. Beauv. ex Roem and Schult.
		Imperata cylindrica (Linn.) Raeushel G.E.
		Oplismenus burmani (Retz) P. Beauv.
		Paspalum scorbilatum (Linn.)
		Panicum maximum Jacq.
		Pennisetum purperium (Linn.)
		Setaria barbata (Lam.) Kunth.
18	Rubiaceae (5)	*Mitracarpus villosus* (SW.) DC
		Oldelandia herbraceae (Linn.)) Roxb.
		Pentodon petandras (ShumandThonn) Vatke
		Spermacoce octodon (Heppere) Lebrum and Stock
		Spermacoce verticillata (Linn.)
19	Sapindaceae (1)	*Paulinia pinata* (Linn.)
20	Solanaceae (1)	*Ipomooea batatas*

Table 3: Floristic composition and RIV (%) of weed species in Iwere-Ile, Moniya-Ibadan and Okeho farm communities in 2013

	Relative Importance Values					
	Iwere-Ile		**Moniya-Ibadan**		**Okeho**	
Weed Species	**C**	**F**	**C**	**F**	**C**	**F**
Acalypha ciliata	0.87	-	-	-	-	-
Acmella brachyglossa	**33.92**	**37.75**	**20.64**	**43.41**	**30.98**	**20.46**
Ageratum conyzoides	6.25	18.86	15.79	-	-	1.55
Alternanthera sessils	1.28	-	-	-	-	-
Amaranthus cruentus	-	-	-	-	-	1.38
Boerhavia diffusa	-	1.27	-	-	-	-
Boerhavia erecta	-	-	-	-	-	3.21
Brachiaria lata	-	-	-	1.18	-	-
Callopogonium mucunoides	-	-	2.34	8.07	2.86	2.33
Centrosema pubescens	-	-	-	0.97	-	-
Chromolaena odorata	1.18	-	-	2.05	14.34	-
Commelina benghalensis	-	2.53	-	1.08	-	4.28
Commelina erecta	-	-	1.17	-	-	0.78
Cyperus haspan	-	3.44	-	-	-	-
Desmodium scopiurus	-	1.27	-	-	1.43	0.78
Discorea alata	-	-	2.34	-	-	1.55
Discorea rotundata	-	-	-	-	1.43	-
Eragrotis tenella	-	-	-	-	-	20.31
Euphorbia heterophylla	-	-	-	-	-	11.54
Euphorbia hirta	-	-	1.17	2.47	4.49	4.18
Imperata cylindrica	-	-	-	-	-	6.67
Ipomooea batatas	-	-	-	-	-	0.78
Lapotea aestuans	0.97	-	-	-	-	-
Ludwigia abyssynica	15.97	1.27	-	0.97	-	0.78

Ludwigia decuren	0.97	-	-	-	-	-
Manihot esculenta	-	-	3.51	2.15	5.71	-
Mariscus alternifolius	-	-	6.27	6.67	1.43	-
Mariscus flaberliformis	10.87	3.31	-	-	-	-
Melanthera scandens	1.85	-	-	-	-	-
Mimosa pudica	7.33	15.47	2.34	-	-	0.78
Mitracarpus villosus	15.73	7.96	-	-	-	-
Newbouldia laevis	-	-	1.17	-	-	-
Oldelandia herbraceae	-	6.76	-	-	-	-
Oplismenus burmani	-	-	5.29	-	-	-
Paspalum scorbilatum	-	-	-	-	-	0.98
Panicum maximum	-	-	1.17	2.91	-	-
Paulinia pinata	-	-	-	-	1.17	-
Pennisetum purperium	-	0.97	-	2.05	-	-
Pentodon petandras	-	3.00	-	-	-	-
Phyllanthus amarus	3.02	-	-	-	4.31	3.71
Sclerocarpus africanus	-	1.27	-	-	-	-
Setaria barbata	-	-	1.17	3.12	-	-
Sida acuta	-	1.27	-	-	-	-
Sorghum guineensis	-	-	-	-	-	0.78
Spermacoce octodon	1.08	-	-	-	-	3.51
Spermacoce verticillata	3.54	-	-	-	-	2.43
Spigelia anthelmia	-	-	-	3.34	-	-
Synedrella nodiflora	-	-	1.17	2.58	-	1.78
Tithonia diversifolia	-	-	-	-	-	0.78
Tridax procumbens	0.97	-	17.57	9.04	14.53	4.69
Vigna unguiculata	-	1.27	-	-	-	-
Zea mays	8.92	-	-	-	-	-

C=Cultivated land, F=Fallow

Table 4: Diversity indices of the herbaceous plant species on the three farm communities surveyed in 2013

	Farm Community					
	Iwere-Ile		**Moniya – Ibadan**		**Okeho**	
Indices	**C**	**F**	**C**	**F**	**C**	**F**
Taxa	17.00	14.00	17.00	17.00	10.00	24.00
Dominance_D	0.32	0.32	0.17	0.52	0.43	0.23
Shannon_H	1.63	1.58	2.04	1.27	1.28	1.94
Eveness_e ^H/S	0.30	0.30	0.45	0.21	0.36	0.29

C = Cultivated land
F = Fallow
Shannon_H >2.00 = High species diversity
Dominance_D >0.50 = Dominance of a particular species
Evenness_e^H/S >0.50 = Even distribution of species

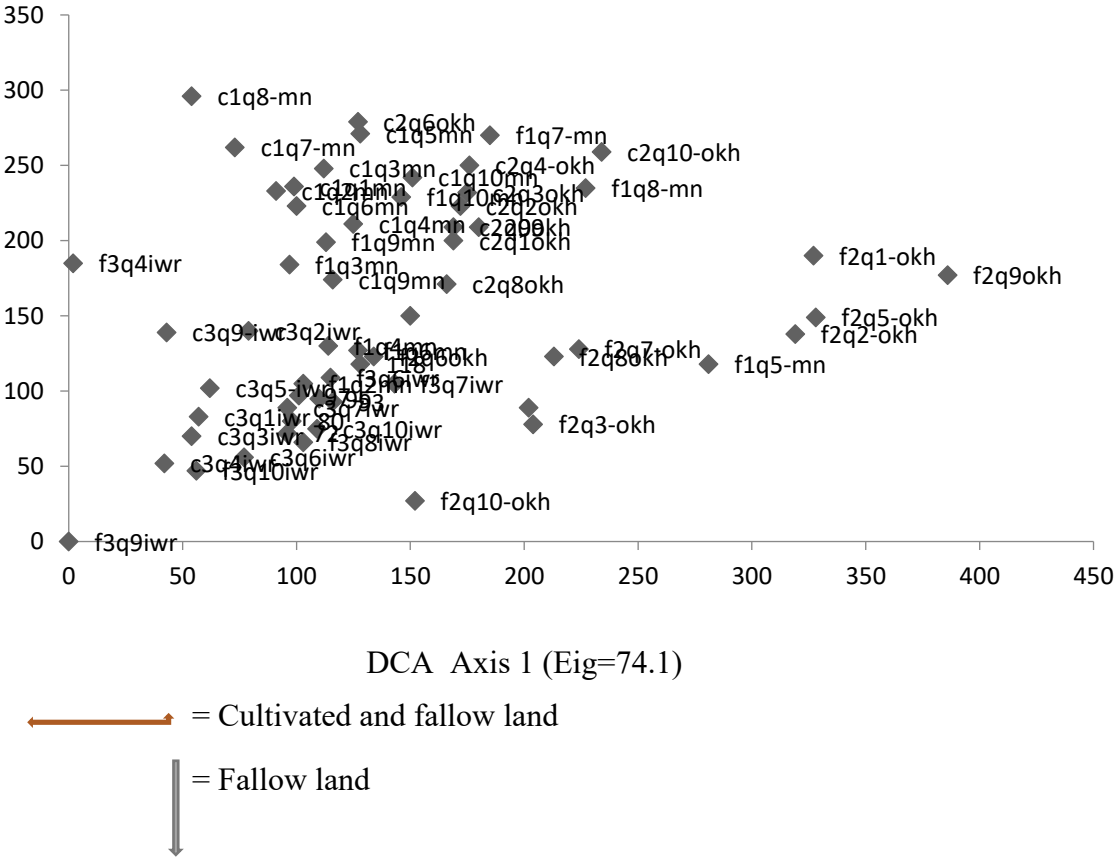


Figure 1: Quadrat ordination (Detrended Correspondence Analysis) of three farm community in Oyo State, Nigeria with reference to *A. brachyglossa* and associated plant species.

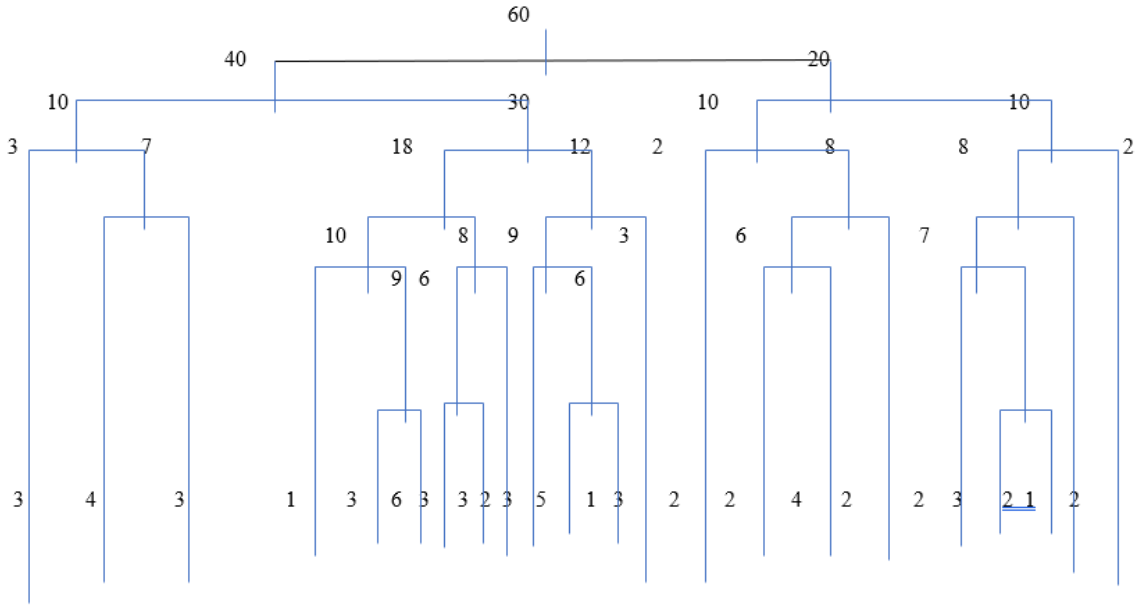


Figure 2: Phytosociological classification of herbaceous flora in Iwere-Ile, Moniya and Okeho farm communities in 2013

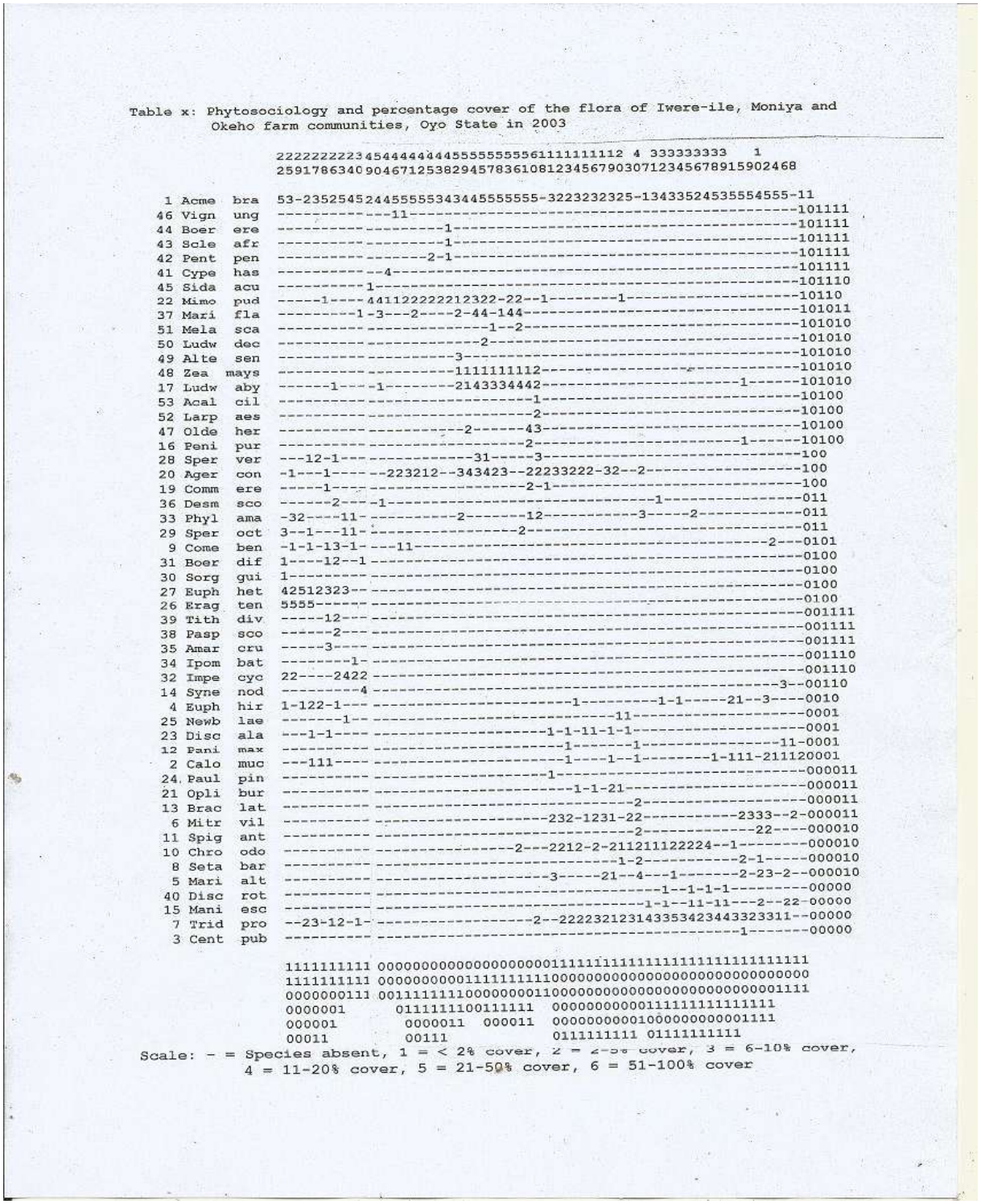


Table x: Phytosociology and percentage cover of the flora of Iwere-ile, Moniya and Okeho farm communities, Oyo State in 2003

			22222222234544444445555555556111111112 4 333333333 1
			25917863409046712538294578361081234567903071234567891590246 8
1	Acme	bra	53-2352545244555553434455555555-3223232325-13433524535554555-11
46	Vign	ung	----------11---------- 101111
44	Boer	ere	----------1---------- 101111
43	Scle	afr	----------1---------- 101111
42	Pent	pen	----------2-1---------- 101111
41	Cype	has	----------4---------- 101111
45	Sida	acu	----------1---------- 101110
22	Mimo	pud	-----1----441122222212322-22--1--------1---------- 10110
37	Mari	fla	---------1-3---2----2-44-144---------- 101011
51	Mela	sca	----------1--2---------- 101010
50	Ludw	dec	----------2---------- 101010
49	Alte	sen	----------3---------- 101010
48	Zea	mays	----------1111111112---------- 101010
17	Ludw	aby	------1----1--------2143334442----------1------ 101010
53	Acal	cil	----------1---------- 10100
52	Larp	aes	----------2---------- 10100
47	Olde	her	----------2------43---------- 10100
16	Peni	pur	----------2----------1------ 10100
28	Sper	ver	---12-1----31-----3---------- 100
20	Ager	con	-1---1-----223212--343423--22233222-32--2---------- 100
19	Comm	ere	-----1----2-1---------- 100
36	Desm	sco	------2----1----------1---------- 011
33	Phyl	ama	-32----11----2-------12-----3-----2---------- 011
29	Sper	oct	3--1---11----2---------- 011
9	Come	ben	-1-1-13-1---11----------2--- 0101
31	Boer	dif	1----12--1---------- 0100
30	Sorg	gui	1---------- 0100
27	Euph	het	42512323---------- 0100
26	Erag	ten	5555---------- 0100
39	Tith	div	-----12---------- 001111
38	Pasp	sco	------2---------- 001111
35	Amar	cru	-----3---------- 001111
34	Ipom	bat	--------1---------- 001110
32	Impe	cyc	22----2422---------- 001110
14	Syne	nod	---------4----------3-- 00110
4	Euph	hir	1-122-1---1---------1-1-----21--3----0010
25	Newb	lae	-------1--11---------- 0001
23	Disc	ala	---1-1----1-1-11-1-1---------- 0001
12	Pani	max	----------1-------1----------11-0001
2	Calo	muc	---111----1----1--1--------1-111-211120001
24	Paul	pin	----------1---------- 000011
21	Opli	bur	----------1-1-21---------- 000011
13	Brac	lat	----------2---------- 000011
6	Mitr	vil	----------232-1231-22----------2333--2-000011
11	Spig	ant	----------2----------22----000010
10	Chro	odo	----------2---2212-2-211211122224--1--------000010
8	Seta	bar	----------1-2----------2-1-----000010
5	Mari	alt	----------3-----21--4---1-------2-23-2--000010
40	Disc	rot	----------1--1-1-1---------00000
15	Mani	esc	----------1-1--11-11---2--22-00000
7	Trid	pro	--23-12-1----------2--22223212314335342344332331--00000
3	Cent	pub	----------1-------00000
			1111111111 00000000000000000000111111111111111111111111111111
			1111111111 00000000001111111111000000000000000000000000000000
			0000000111 00111111110000000011000000000000000000000000001111
			0000001 0111111100111111 00000000000111111111111111
			000001 0000011 000011 00000000001000000000001111
			00011 00111 0111111111 01111111111

Scale: - = Species absent, 1 = < 2% cover, 2 = 2-5% cover, 3 = 6-10% cover, 4 = 11-20% cover, 5 = 21-50% cover, 6 = 51-100% cover

Jaccard index = SCj= (w/A+B-w) x 100. A= Moniya-Ibadan cultivated land, B = Okeho cultivated land.

SCj = (7/17+10-7) x 100 = 35%

Table 5: Number of common plant species and percent similarities in both cultivated and fallow land of Iwere-Ile, Moniya-Ibadan and Okeho farm communities

	IWC	IWF	MIC	MIF	OKC	OKF
IWC	-	-	-	-	-	-
IWF	4 (14.81)	-	-	-	-	-
MIC	4 (13.03)	3 (10.71)	-	-	-	-
MIF	4 (13.03)	4 (14.81)	9 (36.00)	-	-	-
OKC	4 (17.39)	2 (9.09)	7 (35.00)	7 (35.00)	-	-
OKF	8 (25.00)	7 (21.21)	7 (21.21)	7 (21.21)	6 (22.22)	-

IWC = Iwere-Ile cultivated land
IWF = Iwere-Ile fallow land
MNI = Moniya-Ibadan cultivated land
MNF = Moniya-Ibadan fallow land
OKC = Okeho cultivated land
OKF = Okeho fallow land
*Figures in parenthensis are percent similarities

DISCUSSION

The Poaceae and Asteraceae families were the most common across the three study sites. This complements the report of Olayinka *et al*. (2020), who found that Fabaceae, Euphorbiaceae, Asteraceae, and Poaceae were the most common weed families in the monocropping plantations of the University of Ilorin in Nigeria. Similarly, in a survey of weed species in four selected tree crop and forest tree plantations in Ibadan, Nigeria, the most common families were Asteraceae, Fabaceae, and Poaceae (Adeniji *et al*., 2026). According to Majeed *et al*. (2022), plants in the Poaceae family flourish in any temperature or habitat and are the most successful Angiosperms, accounting for approximately 20 percent of the world's land. The Asteraceae family is one of the largest flowering plant groups, with around 1600 genera and 25,000 species world wide (Rolnik and Olas, 2021).

Acmella brachyglossa, *Ageratum conyzoides*, *Chromolaena odorata*, *Tridax procumbens*, *Commelina benghalensis*, *Mimosa pudica*, and *Ludwigia abyssynica* were found in the three faming communities enumerated and surveyed. These weed species can be considered to be invasive because they are not native to the areas and have a wide range of environmental tolerance. Invasive plant species are plants that are not native to a region where they area introduced (Uzomachukwu *et al*., 2024) and have characteristics such as rapid growth rates, large dispersal capabilities and broad environmental tolerance (Birthisel *et al*., 2021; Shephard *et al*., 2022). According to the Global Invasive Species Database (2021), *Ageratum conyzoides*, *Chromolaena odorata*, *Tridax procumbens*, *Commelina benghalensis* and *Mimosa pudica* are among the top invasive plant species.

The RIV of *A. brachyglossa* was highest in the fallow of Moniya-Ibadan farm settlement due to its location in a tropical forest savanna transition ecosystem. The high moisture availability of tropical forest ensures dense canopy cover which enables the plant to tap environmental growth factors such as light, air, space to its advantage. The high density of *A.*

brachyglossa in Moniya-Ibadan farm settlement above the other two farm settlements sampled is a known characteristics of tropical forest. The density of *A. brachyglossa* in Iwere-ile, (a savanna grassland ecosystem) could be attributable to the farm surveyed which is a riverine swampy farmland. Olubode *et al*. 2011, working on three close wetlands in Ibadan, Nigeria, reported high variation in species composition and density. Awodoyin *et al*. (2013) also observed that the generally high species richness in Cocoa plantations in Ekiti and Oyo may be attributable to their locations in the lowland rainforest ecosystem with complex land scape and habitat heterogenity. In Okeho (grassland savanna ecosystem) the lowest RIV for *A. brachyglossa* was observed in the fallow. The low moisture content in the savanna grassland coupled with competition and or struggle for growth factors by other species could be attributed to this phenomenon. High moisture content in the forest/wetland ecosystem enables *A. brachyglossa* to grow faster and suppress other plant species in the locality.

Across the three farm settlements the individual plant species were not evenly distributed. One or a few species have most individuals in the community, i.e. low dominance, this study is in agreement with Giliba *et al*. (2011) whose index of dominance was smaller compared to other studies in Miombo woodlands. The cultivated land in Moniya-Ibadan had the most diverse species with Shannon Weiner of greater than 2.0. Anthropogenic activities in most of the farms resulting from constant soil disturbance could be responsible for the result obtained in this study. WWF-SARPO, 2001 reported that species diversity and composition have been shaped by human beings, and is believed that no part of it remained absent of human influence.

The quadrat ordination for Moniya and Okeho showed higher degree of closeness probably due to the cassava crop under which the enumeration was done in the two location. It could be inferred that similar plant species were associtaed with the cassava plant in the two location. The soil type (sandy loam) in both location were also similar and the plots had been constantly under cassava monocrop cultivation for long. The fallow land in Okeho differed sharply from those of Iwere-ile however, the quadrat ordination for Iwere-ile (being swampy, sandy loam) was under maize monocrop cultivation in both dry and rainy season. Most of the enumerated flora species in this location had hydromorphic habitat characteristics, the plants thus having a robust rooting systems that can serve as barrier to flooding, retain nutrients, reduce erosion and vigorous plant growth. The maize plant gown there allows deep penetration of light which enables other plant species to exploit environmental resources.

The stand similairties between Moniya-Ibadan and Okeho farm communities could be as a result of the climatic and edaphic factors. Kent and Coker (1996) stated that, clearly the most common reason why two species regularly appear together is because they prefer the same environmental conditions and plant species strategies, competition and interaction also need to be taken into account. The high diversity of plant species (52) in these farm community is an indication of good health for soil biota as it preserves the high organic content of the soil and promote activities of insect pollinators. *Acmella brachyglossa* alone occupied 32.43% of the stands enumerated while the other members of the Asteraceae family covered 54.60%. They (Asteraceae) are

one of the largest flowering plant groups, comprising of more than 1600 genera and 25,000 species world wide (Rolnik and Olas, 2021).

CONCLUSION

Acmella brachyglossa is a weed found in both the rainforest and the savanna ecological zones of Oyo State, Nigeria. Inspite of reported medicinal benefits, the ecological input of *Acmella brachyglossa* in biodiversity change is significant. It is a rapidly growing field agricultural weed that, if not controlled, has the potential to dominate the ecosystem. Early detection of *A. brachyglossa* or any other invasive weed species, as well as quick management, will limit their spread and suppression of endemic indigenous weed species.

REFERENCES

Adeniji, A. O., Awodoyin, R. O., and Akintunde, A. A. 2026. Survey of Invasive Species among the Weed Flora in Selected Tree Crop and Forest Tree Plantations in Ibadan, Nigeria. *Asian Journal of Environment and Ecology*, *25*(2), 145-152.

Akobundu I.O. and Agyakwa C.W. 1998. *A Handbook of West African Weeds*. IITA, Ibadan, Nigeria. 521pp.

Awodoyin, R.O. and Olubode O.S. 2009. On-field assessment of critical period of weed interference in okra (*Abelmoschus esculentus* (L.) Moench) field in Ibadan, a rainforest-savanna transition eco-zone of Nigeria. *Asian Journal of Food and Agro-Industry*. 2009, Special issue S288-S296.

Awodoyin, R.O., Akinyemi, L.Y., Bolanle, O.O and Antiabong, I.C. 2013. Spatial distribution and abundance of *Solanecio biafrae* (Olive and Heirne) C. Jeffrey and structure of weed communities in some Cocoa plots in Ekiti, Oyo and Cross-River States, Nigeria. *Ife Journal of Science* 15(3): 661-667

Birthisel, S. K., Clements, R. S., and Gallandt, E. R. (2021). Review: How will climate change impact the 'many little hammers' of ecological weed management? Weed Research, 61(5), 327–341. https://doi.org/10.1111/wre.12497

Chung, Kuo-Fang, Kono Yoshiko, Wang, Chiu-Mei, and Peng-Ching-I. 2008. Notes on *Acmella*. *Botanical Studies* 49 : 73-82.

Dornelas, M., Gotelli, N. J., McGill, B., Shimadzu, H., Moyes, F., Sievers, C., and Magurran, A. E. (2014). Assemblage time series reveal biodiversity change but not systematic loss. Science, 344(6181), 296–299. https://doi.org/10.1126/science.1248484

Global Invasive Species Database (2021) Species profile *Crassostrea gigas*. Available at: http://www.iucngisd.org/gisd/species.php?sc=797 (accessed 16 June 2021).

Giliba, A.R., Boon, E.K., Kayombo, C.J., Musamba, E.B., Kashindye, A.M., and Shayo, P.F., 2011. Species Composition, Richness and Biodiversity in Miomo Woodland of Bereka Forest Reserve,

Tanzania. *J.Biodiversity* 2(1):1-7.

Hill, T.A. 1977. The biology of weeds. The Institute of Biology's studies in Biology No 79, Edward Arnold. 64pp

Jansen, R.K. 1985. The Systematics of *Acmella* (Asteraceae-Heliantheae). *Systematic Botany*; Monograph 8: 1-115.

Kent, M. and Coker, P.1996. *Vegetation Description and Analysis.* A practical Approach. John Wiley and Sons, NY, pp167-169.

Lingenfelter, D. D., and Hartwig, N. L. 2002. *Introduction to weeds and herbicides*. Pennsylvania State University.

Majeed, M., Tariq, A., Haq, S. M., Waheed, M., Anwar, M. M., Li, Q., Aslam, M., Abbasi, S., Mousa, B. G., and Jamil, A. 2022. A detailed ecological exploration of the distribution patterns of wild Poaceae from the Jhelum District (Punjab), Pakistan. Sustainability, 14(7), 3786. https://doi.org/10.3390/su14073786

Olayinka, U. B., Adeyemi, S. B., Abdulkareem, K. A., Olahan, G. S., Lateef, A. A., Garuba, T., and AbdulRahaman, A. A. 2020. Comparative biodiversity assessment of weed species in monocropping plantations of University of Ilorin, Nigeria. West African Journal of Applied Ecology, 28(2), 86–105. https://doi.org/10.4314/wajae.v28i2.202701

Olubode, O.S., Awodoyin, R.O., and Ogunyemi, S. 2011. Floral diversity in the Wetlands of Apete river, Eleyele lake and Oba dam in Ibadan, Nigeria: Its implicatio for biodiversity erosion. *West African Journal of Applied Ecology* 18: 109-119.

Ramsewak, R.S., A.J. Erickson and M.G. Nair 2003. Bioactive N-Isobutylamides from the flower buds of Spilanthes acmella. *Phytochemistry*, 51: 729-732.

Rivas-Torres, G., Flory, S. L., and Loiselle, B. (2018). Plant community composition and structural characteristics of an invaded forest in the Galápagos. Biodiversity and Conservation, 27, 329–344.

Rolnik, A., and Olas, B. (2021). The plants of the Asteraceae family as agents in the protection of human health. International Journal of Molecular Sciences, 22(6), 3009.

Shephard, N. T., Narine, L., Peng, Y., and Maggard, A. (2022). Climate smart forestry in the Southern United States. Forests, 13(9), 1460. https://doi.org/10.3390/f13091460

Shuvar, I., Korpita, H., Shuvar, A., Shuvar, B. and Kropyvnytskyi, R. (2021). Invasive plant species and the consequences of its prevalence in biodiversity. BIO Web of Conferences, 31. https://doi.org/10.1051/bioconf/202131000 24

Spelleberg, I.F. 2005. Monitoring Ecological Change, Cambridge University Press, New York. 2nd edition 334pp.

Tom, C. and Richard, J.A 2013 Penysylvania Department of Conservation and Natural Resources.www.dcnr.state.pa.us/forestry/plants/Invasive

plants/Index.htm. accessed 24-03-2013.

Uzomachukwu, U. E., Kehinde, I. O., Mahama, M., and Hamzat, M. O. (2024). Prevalence of invasive plant species, its effects on biodiversity conservation, challenges and opportunities for management in Africa: A review. Biological and Environmental Sciences Journal for the Tropics, 21(1), 51–80.

WWF-SAPRO. 2001. *Conserving the Miombo Eco-region*. Reconnaissance Summary. WWF-Southern Africa Regional Programm Office, Harare, Zimbabwe

Yang, Q.H., W.H.Ye, X. Deng, H.L. Cao, Y. Zhang, and K.Y. Xu. 2005. Seed germination eco-phsiology of *Mikania microtha* H.B.K. Bot. Bull. Acad. Sin 46: 293-299.

DURATION OF SOLARISATION AS IT AFFECTS WEED BIOMASS AND WEED SPECIES SPECTRUM IN IBADAN

Nasiru Ibrahim[1]*, Rasheed O. Awodoyin[1,2] and Temilade A. Adegbite[1]

[1]Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Nigeria.

[2]Department of Plant and Environmental Biology, Federal University of Agriculture and Technology, Okeho, Nigeria.

*Corresponding Author's Email: ibrahimnasiru900@gmail.com

ABSTRACT

Weed interference remains a major constraint to sustainable okra production, while dependence on manual weeding and herbicides presents economic and environmental challenges. This study, in a pot experiment, evaluated the effect of different durations of soil solarisation on weed species spectrum and weed suppression in Ibadan, Nigeria. The experiment was arranged in a completely randomised design comprising six treatments which are four solarisation durations (2, 4, 6 and 8 weeks) and two control treatments (dry, uncovered, unsolarised; moist, covered, unsolarised), with four replicates. Solarised soil treatments were covered using transparent polythene sheets before arranging the pots in the open field where the received direct insolation. Four pots were randomly selected and withdrawn into the shade at each test duration when the soil temperatures were also monitored. Also, the Control pots were kept away under shade from the commencement of the study. All the pots were moved out to the open field with the polythene removed at eight weeks and the weed seeds germination monitored. The weed species composition and weed biomass were subsequently assessed. Solarisation increased soil temperature, with mean values ranging from 49.96 to 52.09°C across sampling depths, creating conditions unfavourable for weed seeds survival, thus achieving weed suppression. Weed biomass declined progressively with increasing solarisation duration, from 54.03 ± 10.28 g in the dry uncovered control to 8.68 ± 2.22 g after 8 weeks of solarisation. A total of 23 weed species were identified during the study, with *Boerhavia erecta*, *Sesbania bispinosa* and *Cyperus esculentus* among the most prevalent. Increasing solarisation duration reduced weed occurrence and altered weed species composition, although a few heat-tolerant species persisted after prolonged solarisation. The findings demonstrated that soil solarisation is an effective non-chemical approach for suppressing weeds and modifying weed species composition. Therefore, solarisation for at least six weeks is recommended as a component of integrated weed management in Ibadan, Nigeria.

Keywords: Integrated weed management; soil solarisation; weed biomass; weed species composition.

INTRODUCTION

Global agriculture continues to face increasing pressure to meet rising food demands amidst environmental constraints such as land degradation, climate variability and resource scarcity. With limited opportunities for sustainable expansion of cultivated land, improving productivity on existing farmland through sustainable management practices has become a global priority (Food and Agriculture Organization, 2023). Climate change has further intensified production challenges by increasing the frequency and severity of abiotic stresses, including soil degradation, temperature extremes and moisture deficits, alongside biotic stresses such as weed infestation, pest outbreaks and diseases (Bezner Kerr *et al*., 2022). These challenges underscore the need for environmentally sustainable agronomic

practices that enhance crop productivity while conserving ecosystem health.

Weeds are among the most important biotic constraints to agricultural production because they compete with crops for light, water, nutrients and space, thereby reducing crop growth and yield (Chauhan, 2020). Globally, weed interference accounts for substantial crop losses, with the magnitude of damage varying according to weed density, species composition and environmental conditions (Oerke, 2006). Weed communities differ in species composition, commonly referred to as the weed species spectrum, and these differences influence the effectiveness of management strategies because weed species vary in their growth habits, competitive ability and response to control measures. Consequently, understanding weed species composition is fundamental to developing effective and sustainable weed management programmes.

Conventional weed control methods, including manual weeding, mechanical cultivation and herbicide application, have contributed significantly to crop production but are constrained by several limitations. Manual and mechanical methods are labour-intensive, time-consuming and increasingly expensive, particularly for smallholder farmers (Ekeleme *et al*., 2019). Similarly, continuous reliance on herbicides has resulted in the evolution of herbicide-resistant weed populations and raised concerns regarding environmental contamination and human health (Heap, 2022). These limitations have stimulated interest in integrated weed management approaches that combine multiple environmentally friendly techniques to achieve sustainable weed suppression while reducing dependence on chemical herbicides.

Among the non-chemical approaches used in integrated weed management, soil solarisation has emerged as an effective technique for suppressing weeds and soil-borne pests. Soil solarisation involves covering moist soil with transparent polyethylene sheets to trap solar radiation and increase soil temperature to levels capable of reducing weed seed viability and seedling emergence (Stapleton *et al*., 2019). Besides suppressing of weeds, solarisation may improve soil conditions by influencing microbial activity and reducing populations of certain soil-borne pathogens (Lessmann and Rudolph, 2026). However, the effectiveness of soil solarisation depends largely on treatment duration, as longer exposure periods generally result in greater heat accumulation and improved weed suppression (Imoloame *et al*., 2021). Environmental conditions, soil characteristics and the composition of local weed flora may also influence treatment effectiveness, making it necessary to determine appropriate solarisation durations under specific agro-ecological conditions.

Although numerous studies have demonstrated the effectiveness of soil solarisation for weed suppression, information remains limited regarding the optimum duration required to modify weed species composition under the humid tropical conditions of Ibadan, Nigeria. Variations in climate, soil properties and weed flora may influence the response of weed communities to solarisation, making findings from other agro-ecological zones difficult to generalise. Generating location-specific information on the influence of solarisation duration on weed biomass and weed species spectrum is therefore essential for improving sustainable weed management in okra production. This study was therefore conducted to evaluate the effect of different durations of soil solarisation on weed species spectrum and weed biomass accumulation in Ibadan, Nigeria.

MATERIALS AND METHODS

The experiment was conducted in the crop garden of the Department of Crop Protection and Environmental Biology, University of Ibadan, Nigeria, between 30 December, 2025 and 2 June, 2026. The study site is located within the rainforest–savanna transition zone at approximately 7°26′56.8″ N and 3°53′44.6″ E, with an altitude of about 194 m

above sea level. Topsoil (0–15 cm depth) was collected from the experimental field of the Department for the study.

The experiment was arranged in a Completely Randomised Design (CRD) comprising six treatments with four replicates. The treatments consisted of four durations of soil solarisation (2, 4, 6 and 8 weeks), a dry uncovered control (no water, no cover of polythene and no solarisation) and a moist covered control (watered and covered with transparent polyethylene but not solarised).

The collected soil was thoroughly mixed, air-dried and sieved to remove debris before being transferred into experimental pots. Prior to solarisation, the soil was adequately moistened to facilitate heat transfer within the soil profile. Pots designated for solarisation were covered with transparent polyethylene sheets (0.06 µm thickness) and exposed to natural sunlight for the respective treatment durations. At the end of each solarisation duration, four pots were randomly selected and withdrawn into the shade where the control pots were kept. At the end of all solarisation duration (eight weeks) the polyethylene sheets were removed and all the pots were moved back to the open field, watered adequately and monitored for weed species spectrum and weed biomass. Soil temperature was measured using a soil thermometer at depths of 2, 4 and 6 cm throughout the solarisation period to evaluate soil heat accumulation. Weed species were identified using standard weed identification guides. Species composition was determined by recording the presence (+) or absence (–) of each species under the different solarisation and control treatments, while species frequency was calculated and expressed as a percentage of the total weed species recorded during the study. Weed biomass was determined at the end of the experiment by carefully uprooting all weeds from each pot. The samples were cleaned, air-dried and subsequently oven-dried at 70°C until a constant weight was obtained. Weed biomass was expressed as grams per pot (g pot^{-1}). Data on soil temperature and weed biomass were subjected to analysis of variance (ANOVA) appropriate for a Completely Randomised Design. Where treatment effects were significant, treatment means were separated using Duncan Multiple Range Test (DMRT) at 5% level of probability.

RESULTS

Soil Temperature

Table 1 presents the mean soil temperature recorded at different soil depths under the various solarisation treatments. Soil temperature was monitored throughout the solarisation period to determine the effect of solarisation on soil heat accumulation.

Table 1: Mean Soil Temperature (°C) at Different Soil Depths under Varying duration of Solarisation in Ibadan

Treatment	2 cm	4 cm	6 cm
Solarised pots	52.09 ± 1.74	51.00 ± 1.75	49.96 ± 1.77
Control 1 (Dry uncovered)	58.58 ± 2.51	48.68 ± 2.60	47.44 ± 2.71
Control 2 (Moist covered)	29.39 ± 2.51	28.73 ± 2.64	27.98 ± 2.68

WS = Weeks of Solarisation; Control 1 (No water, no polythene and exposed to sun); Control 2 (Water, polythene and not exposed to sun)

The results show that soil solarisation substantially increased soil temperature across the soil profile. Mean temperatures in the solarised treatments ranged from 49.96 to 52.09°C at depths of 2–6 cm, indicating effective heat accumulation within the soil. The dry uncovered control recorded the highest temperature (58.58°C) at 2 cm depth, while the moist covered control consistently maintained the lowest temperatures. The elevated temperatures achieved through solarisation are likely to have reduced

the germination ability of seeds in the soil seed bank and survival of seedlings that manged to form, thereby contributing to weed suppression.

Weed Species Frequency and Percentage Occurrence

The results show that twenty-three weed species belonging to different plant families were identified during the study (Table 2). *Boerhavia erecta* and *Sesbania bispinosa* were the most frequent species, each accounting for 10.0% of the total weed flora. *Cyperus esculentus* and *Echinochloa obtusiflora* followed with 8.3% each, while *Desmodium tortuosum*, *Leptochloa caerulescens* and *Tithonia diversifolia* each contributed 6.7%. Most of the remaining species occurred at relatively low frequencies (1.7–5.0%), indicating that only a few species were dominant within the experimental area.

Weed Biomass

Table 3 shows the effect of different durations of soil solarisation on weed biomass. The results show that weed biomass decreased progressively with increasing duration of soil solarisation. The dry uncovered control produced the highest weed biomass (54.03 ± 10.28 g pot^{-1}), whereas the 8-week solarisation treatment recorded the lowest biomass (8.68 ± 2.22 g pot^{-1}). Weed biomass declined consistently from the 2-week to the 8-week solarisation treatments, indicating that prolonged soil solarisation enhanced weed suppression. The significant reduction observed after six and eight weeks demonstrates the effectiveness of extended solarisation in reducing weed growth.

Table 2: Frequency and Percentage Occurrence of Weed Species Recorded during the Study

Weed species	Frequency	Percentage (%)
Alternanthera bettzickiana	2	3.3
Alternanthera ficoidea	1	1.7
Alternanthera sessilis	3	5.0
Boerhavia erecta	6	10.0
Brachiaria deflexa	2	3.3
Brachiaria lata	1	1.7
Cyperus esculentus	5	8.3
Weed species	**Frequency**	**Percentage (%)**
Desmodium scorpiurus	2	3.3
Desmodium tortuosum	4	6.7
Digitaria ciliaris	1	1.7
Digitaria horizontalis	1	1.7
Echinochloa obtusiflora	5	8.3
Echinochloa stagnina	1	1.7
Euphorbia hyssopifolia	2	3.3
Leptochloa caerulescens	4	6.7
Leucaena leucocephala	1	1.7
Mimosa diplotricha	2	3.3
Mimosa pudica	1	1.7
Physalis angulate	3	5.0
Pteridium aquilinum	1	1.7
Pupalia lappacea	2	3.3
Sesbania bispinosa	6	10.0

Tithonia diversifolia	4	6.7
Total	**60**	**100**

Table 3. Effect of Soil Solarisation Duration on Weed Biomass (g pot^{-1}) in Ibadan

Treatment	Weed biomass (g pot^{-1})
Control 1 (Dry uncovered)	54.03 ± 10.28^{a}
Control 2 (Moist covered)	38.17 ± 2.24^{ab}
2 weeks solarization	45.85 ± 7.45^{abc}
4 weeks solarization	23.50 ± 4.74^{bd}
6 weeks solarization	14.03 ± 1.84^{de}
8 weeks solarization	8.68 ± 2.22^{def}

Values are Mean ± SE. Means followed by the same superscript letter are not significantly different at $\mathbf{P} \leq 0.05$ according to the Least Significant Difference (LSD) test.

Weed Species Composition

Table 4 shows the distribution of weed species under the different solarisation treatments using presence (+) and absence (−) records. The results show that composition of weed species varied across the different solarisation treatments. Several weed species present in the control treatments and shorter solarisation durations were absent after prolonged solarisation. However, *Boerhavia erecta*, *Alternanthera sessilis* and *Desmodium tortuosum* persisted under some long-duration treatments. Overall, long solarisation durations not only reduced weed biomass but also altered the weed species diversity.

Table 4. Weed Species Composition under Different Soil Solarisation Durations

Weed species	Control 1	Control 2	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Alternanthera bettzickiana	–	+	–	+	–	–
Alternanthera ficoidea	–	–	+	–	–	–
Alternanthera sessilis	+	+	–	–	–	+
Boerhavia erecta	+	+	–	+	–	+
Brachiaria deflexa	–	–	+	+	–	–
Brachiaria lata	–	–	+	–	–	–
Cyperus esculentus	+	+	+	+	–	–
Desmodium scorpiurus	+	+	–	–	–	–
Desmodium tortuosum	–	+	–	–	+	–
Digitaria ciliaris	–	+	–	–	–	–
Digitaria horizontalis	–	–	–	–	+	–
Echinochloa obtusiflora	+	–	+	+	+	–
Echinochloa stagnina	–	–	–	–	+	–

Euphorbia hyssopifolia	+	–	–	–	–	–
Leptochloa caerulescens	+	+	+	–	–	–
Leucaena leucocephala	–	–	–	+	–	–
Mimosa diplotricha	+	–	–	+	–	–
Mimosa pudica	+	–	–	–	–	–
Physalis angulata	–	–	–	+	+	–
Pteridium aquilinum	–	–	–	+	–	–
Pupalia lappacea	+	–	+	–	–	–
Sesbania bispinosa	–	+	+	–	+	–
Tithonia diversifolia	+	+	+	–	–	–

Key: (+) = Present; (–) = Absent.

Discussion

The elevated soil temperatures recorded in the solarised treatments demonstrate the effectiveness of transparent polyethylene in trapping solar radiation and increasing heat accumulation within the soil profile. Soil temperatures between 49.96 and 52.09°C are sufficiently high to reduce the viability of many weed seeds and inhibit seed germination. The comparatively lower temperatures observed in the moist covered control indicate that covering the soil alone, without effective solarisation, is insufficient to achieve the thermal conditions required for substantial weed suppression. These findings agree with Stapleton *et al*. (2019), who reported that soil solarisation increases soil temperature to levels capable of reducing weed seed viability, and with Lessmann and Rudolph (2026), who observed that elevated soil temperatures are primarily responsible for the suppression of weeds and other soil-borne organisms during solarisation.

The weed flora recorded during the study reflected the diversity of species commonly associated with cultivated fields in the humid tropics. The predominance of *Boerhavia erecta*, *Sesbania bispinosa*, *Cyperus esculentus* and *Echinochloa obtusiflora* suggests that these species are well adapted to the prevailing environmental conditions of the study area. Differences in species frequency may be attributed to variations in seed production, dormancy characteristics, dispersal mechanisms and adaptation to local soil conditions. Similar observations have been reported by Chauhan (2020), who noted that weed communities in agricultural systems are largely influenced by environmental conditions and management practices.

The progressive reduction in weed biomass with increasing duration of soil solarisation demonstrates the effectiveness of prolonged heat exposure in suppressing weed growth. The substantial decline in weed biomass after six and eight weeks of solarisation indicates that extended treatment durations provided sufficient thermal exposure to reduce weed emergence and subsequent biomass accumulation. High soil temperatures generated during solarisation are known to destroy weed seeds directly or weaken their viability, resulting in reduced germination and lower weed establishment. This finding is consistent with Imoloame *et al*. (2021), who reported that longer solarisation periods enhance weed suppression through greater heat accumulation, and with Stapleton *et al*. (2019), who identified soil solarisation as an effective non-chemical weed

management strategy capable of substantially reducing weed populations.

Changes in weed species composition across the treatments further demonstrated that soil solarisation influenced not only the quantity of weed seeds but also the composition of the weed community. The absence of several weed species following prolonged solarisation suggests that many species were susceptible to elevated soil temperatures, whereas the persistence of *Boerhavia erecta*, *Alternanthera sessilis* and *Desmodium tortuosum* indicates that some species possess greater tolerance or survival mechanisms that enable them to withstand heat stress. Such differences in species response are expected because weed species vary in seed characteristics, dormancy behaviour and thermal tolerance. Similar shifts in weed flora following soil solarisation have been reported by Lessmann and Rudolph (2026), who observed that prolonged soil heating selectively suppresses susceptible species while allowing relatively heat-tolerant species to persist.

Conclusion

Soil solarisation effectively increased soil temperature, reduced weed biomass and altered weed species composition. Prolonged solarisation, particularly for 6–8 weeks, provided the greatest level of weed suppression by reducing both weed occurrence and biomass. The findings demonstrate that soil solarisation is a promising non-chemical weed management strategy and should be considered as a component of integrated weed management for sustainable crop production under the moist agro-ecological conditions of Ibadan.

REFERENCES

Bezner Kerr, R., Hasegawa, T., Lasco, R., *et al*. (2022). Food, fibre, and other ecosystem products. In *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Chauhan, B. S. (2020). Grand challenges in weed management. *Frontiers in Agronomy, 1*, 3. https://doi.org/10.3389/fagro.2019.00003

Ekeleme, F., Atser, G., Dixon, A., Hauser, S., Chikoye, D., Olorunmaiye, P. M., Sokoya, G., Alfred, J., Okwusi, M. C., Korieocha, D. S., Olojede, A. O., Ayankanmi, T., and Lagoke, S. T. O. (2019). Assessment of weeds of cassava and farmers' management practices in Nigeria. *Tropicultura, 37*(2), 1–19.

Food and Agriculture Organization. (2023). *The state of food and agriculture 2023: Revealing the true cost of food to transform agrifood systems*. FAO.

Heap, I. (2022). The international survey of herbicide resistant weeds. Retrieved from http://www.weedscience.org

Imoloame, E., Ayanda, I. and Yusuf, O. (2021). Integrated weed management practices and sustainable food production among farmers in Kwara State, Nigeria. *Open Agriculture*, *6*(1), 124-134. https://doi.org/10.1515/opag-2021-0221

Iyagba, A. G., Onuegbu, B. A., and Ibe, A. E. (2012). Growth and Yield Response of Okra (Abelmoschus Esculentus (L.) Moench) Varieties to Weed Interference in South-Eastern Nigeria. (2012). *Global Journal of Science Frontier Research*, *12*(D7), 23-31. https://journalofscience.org/index.php/GJSFR/article/view/525

Lessmann, P. L. and Rudolph, R. E. (2026). Soil Solarization Efficacy for Pathogens, Nematodes, Weeds, and Arthropod Pests in Vegetable Production Systems: A Review. *Journal of the American Society for Horticultural Science*, *151*(3), 188–201. https://doi.org/10.21273/JASHS05590-26

Oerke, E. C. (2006). Crop losses to pests. *The Journal of Agricultural Science, 144*(1), 31–43.

Pajo, N. D., Nujore, K. A., and Rejoice, J. (2025). Field evaluation of okra (*Abelmoschus esculentus* [L.] Moench) genotypes for yield and yield component characters in Jalingo, Taraba State. *South Asian Research Journal of Agriculture and Fisheries, 7*(4) 57-60. https://doi.org/10.36346/sarjaf.2025.v07i04.003

Stapleton, J. J., Wilen, C. A., and Molinar, R. H. (2019). *Soil solarization for gardens and landscapes* (Pest Notes Publication 74145). University of California Statewide Integrated Pest Management Program.

SPECIES-SPECIFIC PHYTOREMEDIATION INDICES FOR MULTI-METAL SOIL CONTAMINATION: RESTORATION EFFICACY AND THE PERSISTENCE OF LEAD

Kever, D.G[1], Aguoru C.U[2], Olasan, J.O[2] and Dibal, H.I. [3]
[1]Environmental Sustainability Department, Joseph Saawuan Tarka University Makurdi, Nigeria
[2]Botany Department, Joseph Saawuan Tarka University Makurdi, Nigeria.
Biology Department University of Maiduguri, Maiduguri, Borno State, Nigeria.
Correspondence E-mail: keversenator@gmail.com

ABSTRACT

Heavy metal contamination of soils by cadmium (Cd), lead (Pb), and mercury (Hg) threatens soil health and public safety, particularly where conventional remediation options are limited. This study evaluated the phytoremediation potential of Jatropha curcas, wild sugarcane (*Saccharum spontaneum*), and sunflower (*Helianthus annuus*) grown in metal-spiked soils, with and without cow-dung amendment, to determine their comparative effectiveness in restoring soil physicochemical quality. Control soil was characterized against WHO limits. Across contaminated treatments, root and stem metal concentrations, biomass, and uptake indices were quantified under augmented and non-augmented conditions, with treatment means compared using ANOVA and T-tests ($P < 0.05$). Cow-dung amendment significantly increased biomass and uptake indices in most treatments ($P < 0.05$). Metal concentrations were significantly higher in non-augmented than augmented treatments by week 10 for Cd, Pb, and Hg ($P < 0.05$), whereas week 5 differences were largely non-significant except for mercury, which diverged early, indicating that amendment effects accrue progressively rather than immediately. Only *J. curcas* restored key soil properties, including cation exchange capacity, moisture, nitrogen, phosphorus, and electrical conductivity, to values statistically comparable with the control ($P > 0.05$). Neither wild sugarcane nor sunflower achieved comparable restoration, and no species restored Pb-contaminated soil. These findings show phytoremediation efficacy is species-specific, metal-dependent, and time-sensitive. *J. curcas* emerges as the most promising candidate for organic-waste-assisted phytoremediation, while lead's persistence and delayed amendment onset indicate that longer exposure and integrated strategies are needed for multi-metal-impacted soils.

Keywords: phytoremediation; heavy metal contamination; cadmium; lead; mercury; cow-dung amendment; *Jatropha curcas*; species-specific restoration

INTRODUCTION

Heavy metal contamination of soil is an escalating environmental concern with serious implications for soil productivity, ecosystem stability, food safety, and public health. Cadmium (Cd), lead (Pb), and mercury (Hg) are among the most problematic contaminants because they are toxic at low concentrations, persistent in the environment, and capable of entering food chains through plant uptake and soil to crop transfer, thereby posing measurable risks to human health (Sharma *et al*., 2023). In agricultural and peri-urban environments, such contamination often results from industrial emissions, waste disposal, mining-related activities, and the repeated application of polluted amendments, leaving soils functionally degraded and difficult to manage using conventional

physicochemical techniques (Wang *et al.,* 2024). Pb is especially challenging because of its strong affinity for soil particles and its resistance to immobilization even under active remediation, as shown in amendment trials where Cd bioavailability declined more substantially than Pb under identical treatment conditions (Rahim *et al*., 2024). In Nigeria, heavy metal pollution has also been reported around dumpsites and industrial areas, including the Gosa dumpsite in Abuja, where contamination indices indicated significant soil pollution and the potential usefulness of selected plant species for remediation (Adewale *et al*., 2024).

Phytoremediation has emerged as a promising, low-cost, and environmentally compatible approach for managing metal-contaminated soils because it is non-invasive and more suitable for restoring degraded land than many conventional methods (Sharma *et al*., 2023). Its effectiveness, however, depends strongly on plant species, metal type, soil conditions, and amendment use. Therefore, phytoremediation performance should be evaluated using species-specific indices such as bioconcentration factor, translocation factor, and uptake efficiency rather than biomass alone (Niu *et al.,* 2023). Studies have shown that plants differ markedly in their ability to accumulate and redistribute metals; for example, sunflower (*Helianthus annuus*) has been reported to accumulate multiple metals, including Pb and Hg, while other species are more effective at stabilizing metals in the root zone than translocating them to shoots (Dente *et al.,* 2024; Niu *et al.,* 2023). Nigerian studies also support the use of phytoremediation indices in screening plant species, with transfer factor, bioaccumulation factor, and contamination factor proving useful in identifying plants with remediation potential in multi-metal soils (Ojo *et al*., 2016).

A major gap in the literature is that many phytoremediation studies assess only metal accumulation without determining whether soil has been restored to a condition comparable to uncontaminated soil. This is important because effective remediation should improve not only contaminant removal but also soil physicochemical quality, including cation exchange capacity, nutrient availability, moisture retention, and electrical conductivity, which may respond independently of metal immobilization outcomes (Rahim *et al*., 2024). The challenge is greater in multi-metal contaminated soils, where interactions among metals may alter uptake, mobility, and plant response, particularly when dissolved organic matter from amendments influences the release and speciation of co-occurring metals (Luo *et al*., 2024). This issue is highly relevant in Nigeria, where contaminated sites often contain mixed pollutants rather than single-metal systems, and field assessments have shown that Pb and Cd remain significant environmental constraints, with remediation performance varying across plant species and site conditions (Chukwuka *et al.,* 2025). As a result, apparent phytoextraction success may not necessarily translate into complete soil recovery.

Organic amendments may provide a practical solution by enhancing plant growth, improving soil fertility, and modifying metal bioavailability (Kever *et al*., 2024). Cow dung, in particular, has been reported to support biomass production and improve phytoextraction outcomes, including in acidified formulations designed to increase metal availability for uptake by fast-growing species (Ashraf *et al*., 2022), and to influence bioaccumulation differently depending on the crop and metal involved (Wang *et al*., 2024). However, its effect on restoration efficacy across different plant species remains insufficiently characterized. This is especially relevant for *Jatropha curcas*, wild sugarcane (*Saccharum spontaneum*), and sunflower (*Helianthus annuus*), which have each shown varying potential for metal uptake and soil stabilization under different

conditions, including Cd and Pb removal by *J. curcas* (El-Mahrouk *et al.,* 2021), soil-quality improvement under organic amendment in sugarcane systems (Chen *et al*., 2025), and multi-metal accumulation by sunflower (Dente *et al*., 2024; Niu *et al*., 2023). Comparative evaluation of these species under amended and unamended systems is therefore necessary to identify plants that can both accumulate metals and restore soil quality.

In response to this problem, the present study assesses the species-specific phytoremediation indices of *Jatropha curcas*, wild sugarcane, and sunflower in Cd-, Pb-, and Hg-contaminated soils, with and without cow-dung amendment. The study integrates metal uptake, biomass response, and soil restoration parameters to determine which species offers the most effective remediation performance. By focusing on restoration outcomes alongside phytoremediation indices, this work provides a more comprehensive basis for selecting plant–amendment combinations for multi-metal soil contamination and highlights the persistent challenge of lead contamination in practical remediation systems.

MATERIALS AND METHODS

The pot experiment was conducted at the nursery facility of Joseph Sarwuan Tarka University, Makurdi, Nigeria, located within the Guinea Savannah ecological zone. Surface soil (0–15 cm) was collected from an uncontaminated site, air-dried, sieved through a 2 mm mesh, and homogenized prior to use. Each experimental pot contained 5 kg of prepared soil. The study followed a completely randomized design (CRD), which is appropriate for controlled pot experiments because it minimizes bias and supports valid comparison among treatment means (Smith *et al*., 2020).

The experiment was arranged as a 4 × 2 factorial design consisting of four metal treatments (control, Cd, Pb, and Pb-spiked soil) and two amendment levels (with and without cow dung), with three replicates per treatment. Analytical-grade salts, including $Pb(NO_3)_2$, $CdCl_2 \cdot 2.5H_2O$, and Hg_2Cl_2, were used to prepare 1000 mg L^{-1} stock solutions for the metal treatments. The choice of these metals was informed by their recognized ecological and toxicological relevance in contaminated soils, particularly their adverse effects on soil and growth function (Zulfiqar *et al*., 2019; Wuana and Okieimen, 2011; Kever *et al*., 2024). Soil spiking was carried out to obtain a final concentration of 10 mg kg^{-1} for each metal. Cow dung (0.4 kg per pot) was incorporated into the amended treatments and allowed to decompose for four weeks before planting, following the principle that organic amendments can modify metal availability and support plant remediation systems (Jordao *et al*., 2006; Paliza *et al*., 2019). Unamended, unspiked pots served as controls.

Three plant species were evaluated: *Jatropha curcas, Saccharum spontaneum*, and *Helianthus annuus*. Plant materials were authenticated by a botanist using the Flora of West Africa. Whole plants and soil samples were collected at 5 and 10 weeks after planting (WAP). Plant samples were separated into roots and shoots, washed thoroughly, oven-dried at 70°C, ground, and passed through a 2 mm sieve. Soil and plant subsamples were digested using a nitric-perchloric acid mixture (HNO_3:$HClO_4$, 2:1 v/v) on a hotplate until clear solutions were obtained, in line with established analytical procedures for heavy metal determination (AOAC, 1990). The digests were filtered and diluted to 50 mL with deionized water before analysis. Cadmium, lead, and Mercury concentrations were determined using Atomic Absorption Spectrophotometer (AAS) with an ICE 3000 Series instrument (Thermo Scientific) using the method as described by (Wuana and Okieimen, 2011). Data analysis was conducted using Minitab 17.0. Two-way analysis of variance (ANOVA) was used to test the effects of metal treatment, cow dung amendment, and

their interaction on growth and uptake parameters. Mean separation was performed using Tukey's HSD at $p < 0.05$, and t-tests were applied to compare amended and non-amended treatments where necessary. Results are presented as mean ± standard error in tables and figures.

RESULTS AND DISCUSSION

Table 1 provides the baseline preliminary data of the physicochemical properties of uncontaminated soil samples prior to experimental set up. All physical and chemical properties were within the standard regulatory range for normal soil with minor exceptions. The soil was slightly alkaline (pH =7.92±0.01). Electrical conductivity (EC) was 0.29±0.00 um.hos/cm while Cation Exchange Capacity (CEC) level was 4.6±0.00 meg/100g. Organic matter, organic carbon and moisture contents were measured as 4.61%, 2.68% and 6.32% respectively. The texture was largely sandy. It had the following particle distribution: sand (88.2%), silt (7.1%) and clay (4.7%). The soil was poor in Nitrogen (0.23%) and Potassium (1.01 mol kg-1) but rich in Phosphorus (23.80 ppm). Heavy metal concentration was negligible (<0.01ppm) for Lead (Pb), Cadmium (Cd) while mercury (Hg) was not detected (0.000ppm). The reported physicochemical properties served as the control results for subsequent experiments.

Table 2 presents the results obtained from treated experimental pots identified to have improved in physicochemical properties when compared with the baseline data of uncontaminated soil. No potted experimental unit was identified to improve the pH, organic carbon, organic matter and potassium contents of the various heavy metal contaminated soil. None of the test plants had positive impacts on the physicochemical properties of Lead (Pb) contaminated soil as they failed to return any of the parameters to normal baseline values. Only Jatropha plant impacted positively on some physicochemical parameters of heavy metal contaminated soils with the exception of Pb contaminants. In Cadmium (Cd) contaminated soil, Jatropha plant augmented with cowdung improved the soil moisture content to normal baseline value (6.33%). In Mercury (Hg) contaminated soil, Jatropha plant returned soil Nitrogen (0.23%) and Phosphorus (23.56ppm) to normal values while augmented Jatropha also improved the soil EC to normal (0.29 um.hos/cm) baseline value.

Table 3 summarizes Cd, Pb, and Hg concentrations in stem, root, and soil of Jatropha, wild sugarcane, and sunflower under augmented and non-augmented conditions at weeks 5 and 10, with corresponding biomass and uptake indices.

Metal concentrations rose sharply from week 5 to 10 across all species, with roots consistently accumulating more than stems (Table 3). Uptake indices were low at week 5 (Fig. 1–3) but increased substantially by week 10, except for Hg in Jatropha, which peaked at week 5 (62.28) before declining. Augmented wild sugarcane showed the highest overall uptake at week 10 for Cd (188.39), Pb (197.03), and Hg (132.37), outperforming non-augmented sugarcane, Jatropha, and sunflower (Fig. 4). Soil metal levels differed significantly between treatments in most cases at week 10 ($P<0.05$). Sunflower showed the weakest uptake and biomass gains, indicating limited phytoremediation potential compared to wild sugarcane. In all the experiments that involved heavy metal-plant interactions, heavy metal concentration in the root organ was at the peak with a progressive increase from week 5 to week10

Table 1: Baseline Physicochemical Properties and Heavy Metals of Non-Contaminated Soil

Soil properties	Parameters	WHO Baseline value	Baseline values	Unit of Measurement
Physical	pH		7.92±0.01	
	Soil Moisture		6.32±0.02	%
	OM		4.61±0.01	%
	OC		2.68±0.01	%
	EC		0.29±0.00	µmhos/cm
	CEC		4.6±0.00	meq/100g
	Sandy		88.2±0.04	%
	Clay		4.70±0.02	%
	Silt		7.10±0.00	%
Macro-elements	Nitrogen (N)		0.216±0.00	%
	Phosphorus (P)		23.80±0.05	ppm
	Potassium (K)		1.011±0.00	mol kg-1
Heavy metals (Soil)	Lead (Pb)	85	0.003±0.00	ppm
	Cadmium (Cd)	0.8	0.001±0.00	ppm
	Mercury (Hg)	-	ND	ppm
Heavy metals (Plants)	Lead (Pb)	2	ND	ppm
	Cadmium (Cd)	0.02	ND	ppm
	Mercury (Hg)	-	ND	ppm

Key: ND = Not detected

Table 2: Physicochemical Properties and Congruent Treatments

Physicochemical parameters	Control value	Congruent treatments (same as control- P>0.05)	Experimental value
Ph	7.92	No similarity with control	NA
Organic carbon (%)	2.68	No similarity with control	NA
Organic matter (%)	4.61	No similarity with control	NA
Potassium (molkg-1)	1.01	No similarity with control	NA
Cation Exchange Capacity (CEC) (Meq/100g)	4.60	No similarity with control	NA
Soil moisture (%)	6.32	J-Cd-cowd (Jatropha in Cadmium pot augmented with cow dung	6.33
Nitrogen (%)	0.22	J-Hg (Jatropha in Mercury pot)	0.23
Phosphorus (ppm)	23.80	J-Hg (Jatropha in Mercury pot)	23.56
Electrical conductivity (EC) (um.hos/cm	0.29	J-Hg-cowd (Jatropha in Mercury pot augmented with cow dung)	0.29

Only Jatropha (never wild sugarcane or sunflower) restored any parameter to baseline, and none of the three species restored Lead-contaminated soil on any parameter.

Table 3: Mean (± SE) Heavy Metal Concentrations, Biomass, and Uptake Indices of *Jatropha curcas*, Wild Sugarcane (*Saccharum spontaneum*), and Sunflower (*Helianthus annuus*) under Augmented and Non-Augmented Soil

Metal	Plant	Treatment	Week	Stem (ppm)	Root (ppm)	Soil (ppm)	Biomass (g)	Uptake Index
Cd	Jatropha	Aug	5	0.00 ± 0.00[a]	0.29 ± 0.01[a]	0.29 ± 0.01[b]	28.40	8.24
		Aug	10	1.35 ± 0.02[a]	2.20 ± 0.01[a]	4.31 ± 0.01[b]	6.75	23.96
		Non	5	0.00 ± 0.00[a]	0.27 ± 0.00[b]	0.30 ± 0.00[a]	28.40	7.67
		Non	10	1.10 ± 0.01[b]	1.98 ± 0.01[b]	4.52 ± 0.01[a]	6.61	20.36
Cd	Wild sugarcane	Aug	5	0.01 ± 0.00[a]	0.09 ± 0.00[a]	0.01 ± 0.01[b]	19.20	1.92
		Aug	10	1.54 ± 0.01[a]	2.47 ± 0.01[a]	3.87 ± 0.01[b]	46.98	188.39
		Non	5	0.01 ± 0.00[a]	0.00 ± 0.00[b]	0.04 ± 0.01[a]	22.90	0.23
		Non	10	1.35 ± 0.01[b]	2.21 ± 0.01[b]	3.93 ± 0.00[a]	37.49	133.46
Cd	Sunflower	Aug	5	0.00 ± 0.00[a]	0.05 ± 0.00[b]	0.05 ± 0.00[a]	20.00	1.00
		Aug	10	1.12 ± 0.01[a]	2.20 ± 0.01[a]	4.22 ± 0.00[b]	0.83	2.76
		Non	5	0.00 ± 0.00[a]	0.07 ± 0.00[a]	0.05 ± 0.00[a]	0.33	0.02
		Non	10	1.00 ± 0.01[b]	2.12 ± 0.01[b]	4.42 ± 0.01[a]	0.75	2.34
Pb	Jatropha	Aug	5	0.00 ± 0.00[a]	0.05 ± 0.03[b]	0.36 ± 0.06[a]	6.60	0.33
		Aug	10	1.01 ± 0.01[a]	2.18 ± 0.02[a]	0.00 ± 0.00[a]	4.54	14.48
		Non	5	0.00 ± 0.00[a]	0.16 ± 0.03[a]	0.16 ± 0.03[b]	40.50	6.48
		Non	10	0.82 ± 0.00[b]	1.79 ± 0.02[b]	0.00 ± 0.00[a]	12.27	32.02
Pb	Wild sugarcane	Aug	5	0.00 ± 0.00[a]	1.09 ± 0.03[b]	0.83 ± 0.06[b]	37.40	40.77
		Aug	10	1.13 ± 0.01[a]	2.94 ± 0.04[a]	3.12 ± 0.01[b]	48.41	197.03
		Non	5	0.00 ± 0.00[a]	4.69 ± 0.00[a]	4.22 ± 0.06[a]	21.70	101.77
		Non	10	1.06 ± 0.00[b]	2.76 ± 0.01[b]	3.66 ± 0.01[a]	33.51	128.01
Pb	Sunflower	Aug	5	0.02 ± 0.00[a]	0.76 ± 0.01[b]	6.72 ± 0.03[b]	2.00	1.56
		Aug	10	0.76 ± 0.01[a]	2.22 ± 0.02[a]	3.87 ± 0.00[b]	1.56	4.65

		Non	5	0.01 ± 0.00[b]	1.17 ± 0.03[a]	6.86 ± 0.05[a]	5.20	6.14
		Non	10	0.57 ± 0.01[b]	2.14 ± 0.01[b]	4.10 ± 0.01[a]	0.77	2.07
Hg	Jatropha	Aug	5	0.00 ± 0.00[a]	2.09 ± 0.01[a]	5.54 ± 0.02[b]	29.80	62.28
		Aug	10	0.54 ± 0.02[a]	1.66 ± 0.01[a]	6.16 ± 0.03[b]	8.36	18.39
		Non	5	0.00 ± 0.00[a]	1.88 ± 0.01[b]	5.87 ± 0.01[a]	26.80	50.38
		Non	10	0.45 ± 0.01[b]	1.33 ± 0.00[b]	6.54 ± 0.01[a]	12.07	21.48
Hg	Wild sugarcane	Aug	5	0.00 ± 0.00[a]	2.22 ± 0.00[a]	4.84 ± 0.01[b]	10.00	22.20
		Aug	10	0.70 ± 0.01[a]	1.95 ± 0.02[a]	5.12 ± 0.01[b]	49.95	132.37
		Non	5	0.00 ± 0.00[a]	2.13 ± 0.01[b]	5.10 ± 0.02[a]	13.40	28.54
		Non	10	0.54 ± 0.01[b]	1.52 ± 0.01[b]	5.23 ± 0.01[a]	43.58	89.77
Hg	Sunflower	Aug	5	0.00 ± 0.00[a]	1.68 ± 0.01[a]	6.19 ± 0.02[b]	2.00	3.36
		Aug	10	0.59 ± 0.01[a]	2.77 ± 0.67[a]	6.44 ± 0.00[b]	1.04	3.49
		Non	5	0.00 ± 0.00[a]	1.54 ± 0.06[b]	6.33 ± 0.02[a]	0.70	1.08
		Non	10	0.52 ± 0.01[b]	1.60 ± 0.33[b]	6.56 ± 0.01[a]	0.69	1.46

Values are presented as mean ± SE (n = 3). Within each heavy metal, plant species, and response variable (column), means followed by different superscript letters (a, b) differ significantly at $P < 0.05$, whereas means sharing the same superscript are not significantly different

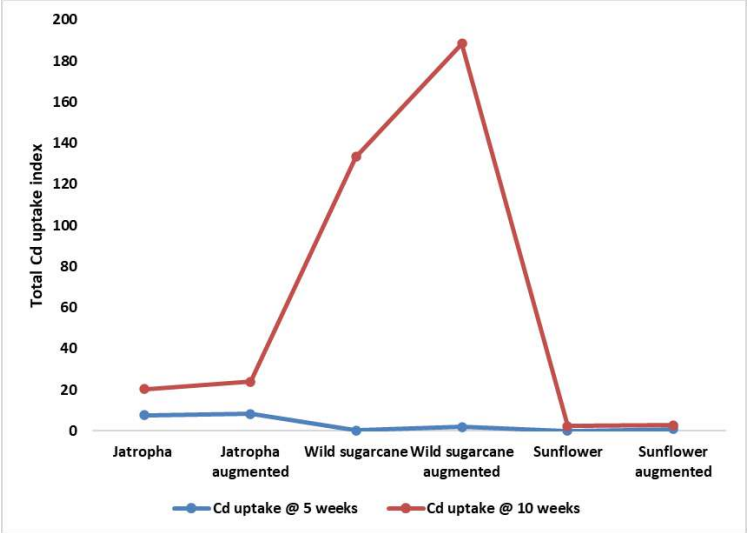


Figure 1: Comparison of Cadmium Uptake by the Three Test Plants

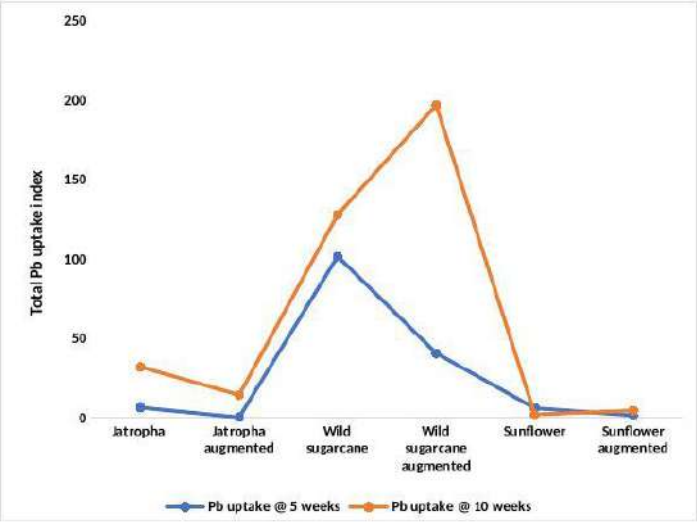


Figure 2: Comparison of Lead Uptake by the Three Test Plants

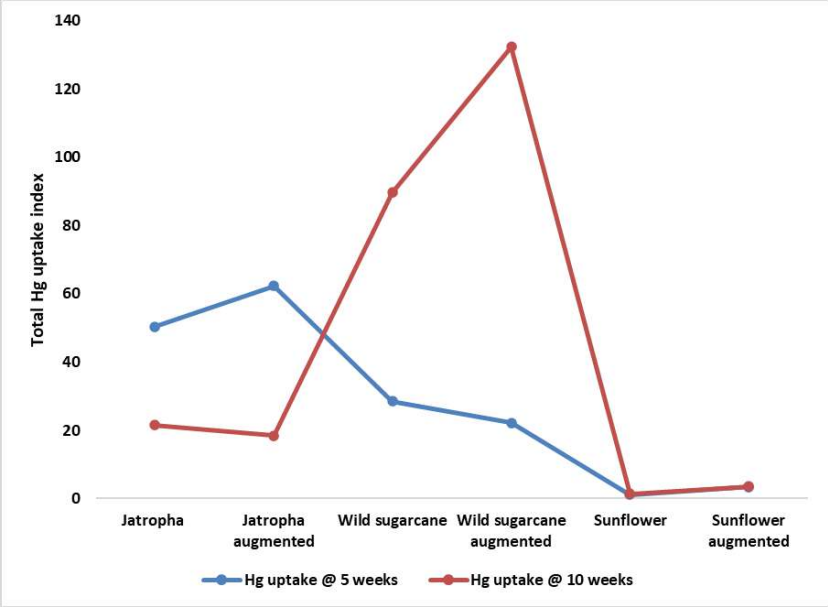


Figure 3: Comparison of Mercury Uptake by the Three Test Plants

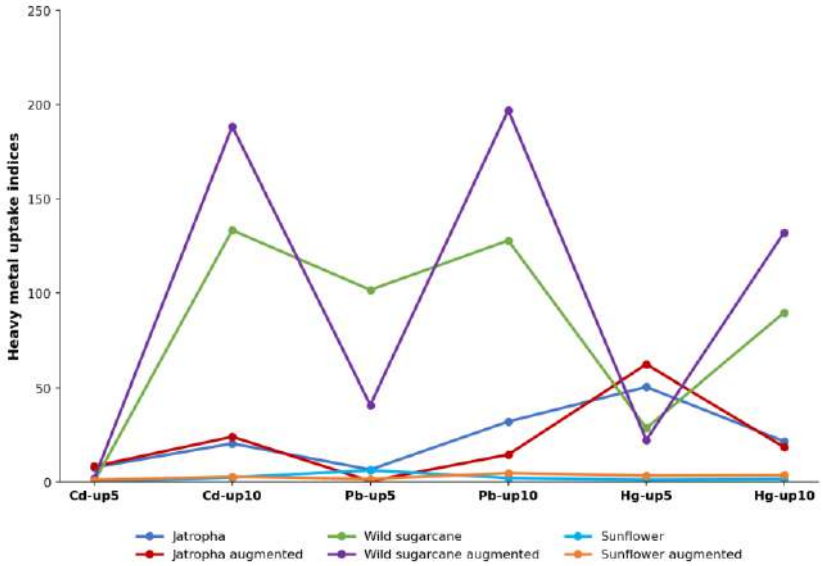


Figure 4: Comparison of Cadmium, Lead and Mercury Uptake Across the Three Plants (Chromium excluded)

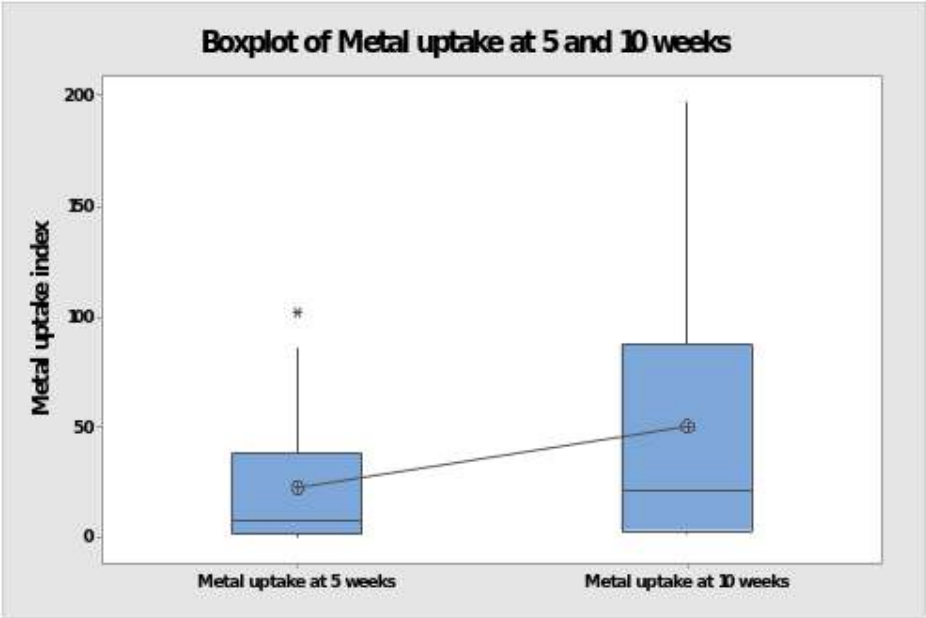


Figure 5: Heavy-Metal Uptake at Week 5 vs. Week 10

DISCUSSION

The present study demonstrates that successful phytoremediation cannot be evaluated solely on the basis of metal uptake. Instead, remediation effectiveness should be assessed using both contaminant removal and restoration of soil functionality. This distinction represents a significant advancement in phytoremediation research because many previous studies have focused primarily on bioaccumulation and translocation indices without determining whether treated soils recover physicochemical characteristics comparable to uncontaminated soils (Sharma *et al.,* 2023; Rahim *et al*., 2024). By integrating species-specific uptake indices with soil restoration parameters, the present study provides a more

comprehensive framework for evaluating phytoremediation performance and addresses an important knowledge gap in multi-metal remediation systems.

The baseline characterization confirmed that the experimental soil provided an appropriate uncontaminated reference for evaluating remediation performance. Heavy metal concentrations were negligible before contamination, while soil physicochemical properties were within acceptable ranges, allowing subsequent changes to be attributed to plant-mediated remediation rather than pre-existing soil conditions. Similar baseline conditions have been recommended as essential for evaluating restoration success in phytoremediation studies (Wuana and Okieimen, 2011; Adewale *et al.,* 2024).

One of the most important findings of this study was the contrasting remediation strategies exhibited by the three plant species. *Saccharum spontaneum* consistently produced the highest biomass and uptake indices for Cd, Pb and Hg under both augmented and non-augmented conditions, confirming its exceptional phytoextraction potential. Its extensive fibrous root system and vigorous biomass production likely increased contact with contaminated soil, thereby enhancing metal acquisition and accumulation. This observation supports previous reports that high-biomass grasses often outperform other species in phytoextraction because total biomass contributes substantially to overall metal update (Chen *et al.,* 2025). However, despite its superior extraction efficiency, wild sugarcane failed to restore any measured soil physicochemical property to baseline values. This demonstrates that efficient contaminant removal does not necessarily translate into restoration of soil function and ecosystem quality.

In contrast, *Jatropha curcas* emerged as the most effective species for restoring soil functionality. Although its uptake indices were considerably lower than those of wild sugarcane, it was the only species capable of restoring selected physicochemical properties including soil moisture, nitrogen, phosphorus and electrical conductivity to values comparable with uncontaminated soil under specific contamination scenarios. These findings suggest that Jatropha contributes to remediation not only through metal accumulation but also through improvement of rhizosphere processes and soil nutrient dynamics. Similar remediation potential has previously been reported for Jatropha in Cd- and Pb-contaminated soils (El-Mahrouk *et al.,* 2021), although the present study extends those findings by demonstrating its superior capacity for restoring soil quality under multi-metal contamination. This distinction has important ecological implications because restoration of soil functionality ultimately determines the long-term sustainability of contaminated land.

Cow dung amendment significantly enhanced phytoremediation performance by increasing tissue metal concentrations while reducing residual soil metal concentrations across nearly all treatments. Organic amendments are known to improve soil fertility, stimulate plant growth and modify heavy-metal bioavailability through interactions with dissolved organic matter (Luo *et al.,* 2024). The present findings support this mechanism, particularly in wild sugarcane where amendment substantially increased biomass and uptake indices. However, Jatropha exhibited relatively reduced biomass under Pb- and Hg-amended conditions despite increased tissue metal accumulation. This suggests that amendment-induced changes in metal speciation or nutrient interactions may influence species differently, emphasizing that amendment effectiveness is plant-specific rather than universal (Wang *et al*., 2024).

A particularly important outcome of this investigation was the persistence of lead contamination. Despite measurable Pb accumulation in plant tissues, none of the

evaluated species restored any physicochemical property of Pb-contaminated soil to baseline conditions. This finding reinforces previous reports describing lead as one of the most recalcitrant heavy metals because of its strong adsorption to soil colloids, low mobility and limited phyto availability (Zulfiqar *et al.,* 2019; Rahim *et al.,* 2024). Consequently, although phytoextraction reduced Pb concentrations, complete ecological restoration was not achieved within a single growing season. This finding is consistent with lead's documented resistance to soil immobilization and its strong retention within the rooting zone (Zulfiqar *et al.*, 2019), and indicates that single-species, single-season phytoremediation is unlikely to be sufficient for lead-impacted soils of the kind reported at Nigerian dumpsites and industrial sites (Adewale *et al.*, 2024; Chukwuka *et al.*, 2025). This finding has practical significance for remediation programmes because it suggests that Pb-contaminated sites may require integrated management approaches involving repeated cropping cycles, sequential phytoremediation, organic amendments and complementary physicochemical remediation technologies.

The findings further demonstrate that phytoremediation species should be selected according to remediation objectives rather than uptake capacity alone. Where rapid extraction of heavy metals is required, Saccharum spontaneum represents the most suitable candidate because of its consistently superior biomass production and uptake indices. Conversely, where restoration of soil health and agricultural productivity is the principal objective, Jatropha curcas offers greater ecological value because it simultaneously improves soil physicochemical properties while reducing contaminant loads. This species-specific distinction provides a practical decision-making framework for environmental managers and land restoration programmes.

Overall, this study advances current understanding of phytoremediation by demonstrating that metal uptake and soil restoration represent complementary but fundamentally different measures of remediation success. Reliance on uptake indices alone may substantially overestimate ecological recovery, particularly in multi-metal contaminated soils where improvements in soil function do not necessarily accompany contaminant removal. The integration of soil-quality benchmarking with conventional phytoremediation indices therefore provides a more robust and ecologically meaningful framework for evaluating remediation outcomes (Sharma *et al.,* 2023).

CONCLUSION AND RECOMMENDATION

This study demonstrates that phytoremediation success should not be evaluated solely by heavy metal uptake but also by the extent to which contaminated soils regain their functional properties. By integrating species-specific uptake indices with soil physicochemical restoration, this study provides a more comprehensive framework for assessing phytoremediation performance in multi-metal-contaminated soils than conventional approaches based exclusively on bioaccumulation. Among the three species evaluated, *Saccharum spontaneum* exhibited the greatest phytoextraction capacity, recording the highest biomass and uptake indices for Cd, Pb and Hg, particularly under cow dung amendment yet restored no soil physicochemical parameter to baseline, while *Jatropha curcas*, despite comparatively modest uptake, was the only species to restore cation exchange capacity, moisture, nitrogen, phosphorus, and electrical conductivity to control-equivalent levels. This distinction matters for how remediation success is defined and measured in future studies and field applications. Uptake indices alone are an insufficient basis for selecting remediation

species, and soil-quality benchmarking against uncontaminated baselines should be treated as a standard, not optional, outcome measure.

The persistence of lead deserves particular emphasis. No species, under any amendment condition, restored any measured soil parameter in lead-contaminated soil, despite lead uptake into plant tissue. Overall, the findings demonstrate that plant selection should be guided by remediation objectives rather than metal uptake alone. While *Saccharum spontaneum* is recommended where rapid phytoextraction is the primary goal, *Jatropha curcas*, particularly when combined with cow dung amendment, offers greater promise for restoring soil quality in degraded agricultural lands. Future research should investigate longer remediation periods, multi-season cropping systems, microbial interactions and integrated amendment strategies to improve restoration efficiency, particularly for persistent Pb contaminated soils. Such approaches will contribute to developing more resilient and sustainable phytoremediation strategies for contaminated agricultural landscapes.

REFERENCES

Adewale, O.O., Adebayo, A.A., and Olaniyi, O.A. (2024). Assessment of heavy metal contamination and phytoremediation potential of plant species at Gosa dumpsite, Abuja, Nigeria. *Nigerian Journal of Environmental Sciences*, 18(2), 112-125.

AOAC (1990). Official Methods of Analysis. Association of Official Analytical Chemists. (11th edn.). Washington D.C. Retrived on 02-7-2026 from the web:https://law.resource.org/pub/us/cfr/ibr/002/aoac.methods.1.1990.pdf

Ashraf, S., Ahmad, S.R., Ali, Q., Ashraf, S., Majid, M., and Zahir, Z.A. (2022). Acidified Cow Dung- Assisted Phytoextraction of Heavy Metals by Ryegrass from Contaminated Soil as an Eco- Efficient Technique. *Sustainability,* 14(23), 15879. https://doi.org/10.3390/su142315879

Chen, J., Liu, X., and Wang, Y. (2025). Soil quality improvement under organic amendment in sugarcane cropping systems. *Soil and Tillage Research*, 245, 106288.

Chukwuka, K.S., Ogunyemi, O.O., and Adebayo, A.A. (2025). Heavy metal contamination patterns and phytoremediation performance in Nigerian industrial sites. *Environmental Monitoring and Assessment*, 197(3), 245-260.

Dente, S.M., Costa, A.C., and Pereira, B.F. (2024). Multi-metal accumulation potential of sunflower (*Helianthus annuus*) in contaminated soils. *International Journal of Phytoremediation*, 26(1), 45-58.

El-Mahrouk, E.M., Ahmed, M.A., and Hassan, F.A. (2021). Phytoremediation potential of *Jatropha curcas* for cadmium and lead removal from contaminated soils. *Journal of Hazardous Materials*, 415, 125678.

Jordao, C.P., Nascentes, C.C., and Cecon, P.R. (2006). Effect of organic amendments on heavy metal bioavailability in soils. *Environmental Chemistry Letters*, 4(3), 165-170.

Kever, D.G., Oluma, H.O.A., Aguoru, C.U., Eneji, I.S. and Olasan, J.O (2024), Eco-physiological Responses of *Saccharum spontaneum* to Chromium (Cr), Cadmium (Cd), Lead (Pb), and Mercury (Hg) in Augmented Phytoremediation Paradigm. *FUAM journal of pure and* applied science, 4 (1), 7 – 17. https://fuamjpas.org.ng/

Luo, J., Zhang, H., and Li, X. (2024). Dissolved organic matter influences metal speciation and uptake in phytoremediation systems. *Environmental Pollution*, 342, 123098.

Niu, X., Wang, L., and Zhang, Y. (2023). Species-specific phytoremediation indices

for evaluating heavy metal uptake efficiency. *Science of the Total Environment*, 859, 160234.

Ojo, O.A., Adebayo, A.A., and Olaniyi, O.A. (2016). Phytoremediation indices for screening plant species in multi-metal contaminated soils in Nigeria. *African Journal of Environmental Science and Technology*, 10(4), 112-124.

Paliza, F., Smith, J.A., and Johnson, P.R. (2019). Organic amendments and their role in phytoremediation systems. *Agronomy Journal*, 111(4), 1789-1801.

Rahim, M., Khan, A., and Ahmed, S. (2024). Amendment trials comparing cadmium and lead bioavailability in contaminated soils. *Environmental Geochemistry and Health*, 46(2), 56-72.

Sharma, P., Singh, R., and Kumar, A. (2023). Heavy metal contamination and phytoremediation strategies: A comprehensive review. *Critical Reviews in Environmental Science and Technology*, 53(8), 1234-1256.

Smith, J.A., Johnson, P.R., and Williams, K.M. (2020). Experimental design considerations for phytoremediation pot studies. *Plant and Soil*, 456(1), 1-18.

Wang, H., Chen, Y., and Zhang, L. (2024). Heavy metal contamination in agricultural and peri-urban environments: Sources and management strategies. *Journal of Environmental Quality*, 53(1), 89- 104.

Wuana, R.A., and Okieimen, F.E. (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. *International Scholarly Research Notices*, 2011, 1-20.

Zulfiqar, U., Farooq, M., and Hussain, S. (2019). Lead toxicity in plants: A review of mechanisms and remediation strategies. *Environmental Science and Pollution Research*, 26(15), 14863-14878.