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TABLE OF CONTENTS

Page	Title	Author(s)
8	ASSESSMENT OF PHYSICO-CHEMICAL PARAMETERS AND BACTERIOLOGICAL QUALITY OF GROUNDWATER SOURCES IN RESIDENTIAL AREA IN ZANGO COMMUNITIES, SABON GARI LOCAL GOVERNMENT, KADUNA STATE, NIGERIA	Adesakin, T. A, Odewade, L. O, and Odewade, J. O
21	IDENTIFICATION OF HOTSPOTS AND SETTING PRIORITIES FOR CONSERVATION IN RELATION TO PLASTIC POLLUTION AND BIODIVERSITY LOSS	Amarie, E., Agbogidi, O.M. and Onochie, P.
28	CLIMATE CHANGE MITIGATION THROUGH GREEN INFRASTRUCTURE: COMBINING COMMUNITY ENGAGEMENT AND SPATIAL TECHNOLOGY IN URBAN PLANNING	Gidado, Usman Muhammad, Umar, Hamza and Abdullahi, Isa Makarfi
34	IMPACT OF CRUDE OIL EXPLOITATION ON PLANT DIVERSITY STOCK IN WETLAND ECOSYSTEMS IN BAYELSA STATE, NIGERIA	Kotingo, Ebizimo Kelly, Ayodele A. Oyedele, Emmanuel Nwabueze Ogamba, Amuyou, Ushuki Ayankukwa
51	EFFECTS OF MACA ROOT POWDER AS ADDITIVE ON THE WATER QUALITY PARAMETERS OF <i>Clarias gariepinus</i> REARED IN PLASTIC TANKS	ABUBAKAR, D., DAUDA, I., KAWUWA, A., ADAMU, T. A., IBEAGI, M. C. AND YUSUF, Z. A.
56	PHYTOCHEMICAL SCREENING OF MORINGA OLEIFERA LEAVES AND ITS MEDICINAL BENEFITS IN NASARAWA LOCAL GOVERNMENT AREA, KANO STATE, NIGERIA	Abdulrashid, I., Bilyaminu H. Fada M. A. Mukhtar R.B., Abubakar A., and B.R. Wali
62	Carbon Emissions Trading (CET) Practices as Mitigation Strategy to Climate Disorders: Assessing the Construction Industry Response	MercyJane N. Ihekweke Samuel I. Ekwunatun Benjamin E. Idisi
75	Mitigating negative impact of a climate change effect, soil salinization, with salicylic acid application in <i>Arachis hypogaea</i> L. (groundnut) cultivation	Otitoloju Kekere, Sunday Emmanuel Boniface and Oluwaferanmi Motunrayo Ajayi
89	EVALUATION OF THE EFFECTS OF CLIMATE CHANGE ON ECOSYSTEM SERVICES AND COMMUNITY LIVELIHOODS AROUND NGEL NYAKI FOREST RESERVE TARABA, NIGERIA	Babale, A. Galadima, I., Basiri, B. and Abdullahi, M. B
107	VEGETATION: THE WEALTH OF THE NATIONS	Agbogidi O. M., Okonigbo D. B., Obogbayiro, I. O., Chukwuka P. I., Domma, O. P. and Ogbe, O.
115	Evaluation of Vegetative and Phenological Traits of Sixteen Tomato Genotypes	Eugenia Ebene Goodlife, Emylia T. Jaja, Victoria Wilson, Martina T. V. Adeleke
124	ASSESSMENT OF PHYSICO-CHEMICAL PARAMETERS, HEAVY METALS, AND BACTERIOLOGICAL QUALITY OF GROUNDWATER SOURCES FROM RESIDENTIAL AREA IN ZANGO COMMUNITY, NORTHWEST, NIGERIA	Adesakin, T. A, Odewade, L. O, and Odewade, J. O
134	SPATIO-TEMPORAL EFFECTS OF LAND USE AND LAND COVER CHANGE ON CLIMATE VARIABLES IN NIGER DELTA REGION, NIGERIA	Ubaekwe, R.E., Japheth, H. D. and Chima U. D.
153	DISTRIBUTION OF POTASSIUM FRACTIONS ON DIFFERENT FOREST PLANTATIONS IN OMO FOREST RESERVE OGUN STATE	Oladoye A.O, Adepoju K.D, Henry C.A, Olubayo O.O and Olajire-Ajayi B
170	DISTRIBUTION OF POTASSIUM FRACTIONS ON DIFFERENT FOREST PLANTATIONS IN OMO FOREST RESERVE OGUN STATE	Oladoye A.O, Adepoju K.D, Henry C.A, Olubayo O.O and Olajire-Ajayi B
182	WETLANDS OF SOUTHWEST NIGERIA: IMPORTANCE, EMERGING CHALLENGES, TRENDS, AND FUTURE DIRECTIONS FOR SUSTAINABLE MANAGEMENT	Sunday O. OLAJESU and Funmilayo Lewiska ONI
191	ECOLOGICAL ASSESSMENT OF WETLAND HABITAT SUPPORTING FRESHWATER TURTLE (<i>Pelusios castaneus</i> Schweigger 1812) IN ILAJE, ONDO STATE, NIGERIA	OGUNJOBI, J. A

- 196 ASSESSMENT OF HEAVY METAL TRANSFER TO VEGETABLES CULTIVATED ALONG THE KUBANNI WETLAND IN ZARIA, NIGERIA Jabir Abdulkadir, Abdullahi Jibrin, Mukhtar Ibrahim and Jabir Haruna Abdulkareem
- 205 PHYSIOLOGICAL EVALUATION OF FRESHWATER TURTLE (*Pelusios castaneus* Schweigger 1812) FOUND IN ILAJE, ONDO STATE, NIGERIA OGUNJOBI, J. A
- 210 FOREST STRUCTURE ANALYSIS OF AKAGUAMA MANGROVE FOREST IN NEMBE, BAYELSA STATE, NIGERIA. Gbosidom, Victor Lebura., Amadi, Noble., Adooh, Legborsi LSK
- 223 ASSESSMENT OF THE IMPACT OF INVASIVE PLANT SPECIES ON ECOSYSTEM STRUCTURE ANDS FUNCTION IN KADUNA STATE, NIGERIA Iliyasu M. Anzaku
- 236 STRENGTHENING WETLAND CONSERVATION IN NIGERIA: CHALLENGES, POLICIES, AND FUTURE DIRECTIONS Oni Funmilayo Lewiska, Ajiboye Babatunde Oluseyi, Oyeleye David Olayinka, Ayoola John Oluwafemi, Opanike Abraham Olanrewaju
- 245 POPULATION ECOLOGY OF PLANTS OF FOOD AND MEDICINAL PRODUCTS IN A COMMUNITY-MANAGED MOIST RAINFOREST IN AKWA IBOM STATE, NIGERIA Ikpaactor, M. M. and Olajide, O.
- 257 DIVERSITY VS. ABUNDANCE: IMPACT OF URBANISATION ON BIRD NUMBERS AND BEHAVIOURS Efenakpo, O. D. Jacob, D. E. and Okagbare, O. H.
- 272 SPATIO-TEMPORAL ANALYSIS OF WETLAND DEGRADATION HOTSPOTS IN RIVERS STATE, NIGERIA UBAEKWE, R.E.; CHIMA, U.D.; MINIMAH, D.H. and NWAIRE, I.B.
- 288 ASSESSMENT OF SPATIAL AND TEMPORAL PHYSICOCHEMICAL PARAMETERS IN THE SELECETED PORTION OF THE HADEJIA-NGURU WETLAND IN JIGAWA-YOBE, NIGERIA. Odewade, L. O., Suleiman, S. I., Odewade, J. O. and Adesakin, T. A.
- 305 WETLAND DEGRADATION THROUGH POOR PLASTIC WASTE MANAGEMENT IN THE YENAGOA URBAN AREA Ojile, Meshach O. and Disi, Francis T.
- 319 SEASONAL ASSESSMENT OF HEAVY METALS IN WATER AND SEDIMENT FROM OSUN RIVER AND SELECTED WELLS IN OSOGBO TOWN AND THEIR IMPACTS ON AQUATIC FAUNA Adeyemo, S. O., Fasasi, K. A. and Surakat, A. O.
- 325 IMPACT OF ANNUAL FLOODING ON AGRICULTURAL ACTIVITIES AND FOOD SECURITY IN WETLAND COMMUNITIES: A CASE STUDY OF OGBOGORO, BAYELSA STATE Sibisaba, Ebilade Bridget., Ojile, Meshach Owho PhD
- 339 MORPHOMETRIC AND MERISTIC CHARACTERISTICS OF *Alestes baremoze* IN RIVER KOMADUGU-YOBE, GASHUA LOCAL GOVERNMENT, YOBE STATE – NIGERIA Abdulkarim, M., Chindo, M. Y., Yusuf, Z. A., Abubakar, A. A., Ahmadu, M., Abdulkareem, Z. and Ali, M. E.
- 345 COMPARATIVE PHYSICOCHEMICAL PROPERTIES OF SURFACE AND GROUND WATER QUALITIES AND ITS PUBLIC HEALTH IMPLICATIONS IN OSOGBO TOWN, OSUN STATE, SOUTHWEST, NIGERIA Adeyemo, S. O., Fasasi, K. A., Mustapha, A. K., Adeleke, M. A. and Surakat, A. O.
- 354 EFFECTS OF MACA ROOT POWDER AS ADDITIVE ON THE WATER QUALITY PARAMETERS OF *Clarias gariepinus* REARED IN PLASTIC TANKS Abubakar, D., Maisheru, J. A. Useni, S. S., Yusuf, Z. A., Dauda, I., Kawuwa, A., Adamu, T. A. and Ibeagi, M. C.
- 359 STRATEGIES FOR ADAPTATION AND MITIGATION OF CLIMATE CHANGE EFFECTS IN NIGERIA: A REVIEW Olatidoye, O.R., Ojo, M.O., Abodunrin, L. A, Ikusebiala, M. E
- 370 *SPHAGNUM* MOSSES (BOG/QUACK MOSSES) FOR BIOREMEDIATION: A REVIEW OF ENVIRONMENTAL POLLUTION CLEANUP STRATEGIES. Onochie, P., Agbogidi, O.M. and Amarie, E.
- 379 ECONOMIC BENEFITS OF SUBSTITUTING FISHMEAL WITH GRADED LEVELS OF BAMBARA GROUNDNUT (*Vigna subterranean*) MEAL IN NILE TILAPIA (*Oreochromis niloticus*) DIET Watafua, H., Waziri, U. M., Kwarams, S. H., Yusuf, Z. A. Kawuwa, A., ⁶Dauda, I. Sanni, K. N. and Lawal, R. O.
- 386 WATER PURIFICATION AND ANTIMICROBIAL EFFICACY OF *MORINGA OLEIFERA* DRIED AND MACERATED SEED Wahab Abideen Akinkunmi, Oyebanji, Iyanuoluwa Ayobami, Nana Aisha Yusuf-Omoloye, Ajigbewu Habib O, Adeyemi, Muibat Folasade, Dare Alabi Peter
- 402 PHYSICOCHEMICAL PARAMETERS OF HADEJIA-NGURU WETLANDS IN NORTHERN NIGERIA Yusuf, Z. A., Abubakar, A. A., Chindo, M. Y., Abdulkarim, M.,

- 410 IN VITRO STUDIES ON NITROGEN FIXATION AND CARBON SEQUESTRATION TRENDS OF *Bradyrhizobium japonicum* Ogah, S. I., Idris, M. A., Abdulkareem, Z., Nayaya, A. J. and Ezra, A. G.
- 420 IMPACT OF CLIMATE CHANGE ON WETLAND FOREST PATHOGENS AND BIOGEOCHEMICAL CYCLES: IMPLICATIONS FOR PLANT HEALTH, ECOSYSTEM RESILIENCE, AND SOCIOECONOMIC SUSTAINABILITY. Olatunji, Mercy N., Ntakwa, Favour O., Ngumah, Chima C., Ugwu, Tochukwu N., Kemka, Ugochi N., Okwara, Kelechi and Olatunji, Olatunde W.
- 421 EVALUATION OF MANGROVE SPECIES - *Nypa fruticans* WURMB FRUIT ASH AS BIO-FERTILIZER Azeez, A. A., Mudashiru, B. A., Azeez, A. T.
- 422 EFFECTS OF SOIL PHYSICO-CHEMICAL PROPERTIES ON SURVIVAL AND EARLY SEEDLING GROWTH OF A MANGROVE SPECIES (*Syzygium guineense* var. *littoral* Keay) IN THE NURSERY Ejims, Cynthia Ifeoma and Okonwu, Kalu
- 423 COMMUNITY BASED WETLAND CONSERVATION: A CASE STUDY OF JOINKRAMA COMMUNITY OF AHOADA WEST LOCAL GOVERNMENT AREA OF RIVERS STATE, NIGERIA. Omokhua, G. E., Fredrick, C. and Monday, A. W
- 424 EVALUATING SEED BANK COMPOSITION AND DIVERSITY IN SELECTED SPENT OIL WASTE DUMPSITE IN OBIO/AKPOR LOCAL GOVERNMENT AREA AKOLOKWU Faith, Obusor and MMOM ThankGod Chikwere
- 425 COMPARATIVE PHYSICO-CHEMICAL PROPERTIES OF SURFACE AND GROUND WATER QUALITY AND ITS PUBLIC HEALTH IMPLICATION IN OSOGBO TOWN, OSUN STATE, SOUTHWEST, NIGERIA Amadi, N., Konyeme, T.E., Okubor, P.C., and Gbosidom, V.L.
- 426 EFFECT OF ARTIFICIAL CHEMICAL INDUCED-RIPENING OF FRUITS IN BAYELSA STATE, NIGERIA Adeyemo, S. O., Fasasi, K. A. and Surakat, O. A.
- 427 SUSTAINING LIVELIHOODS AMID WETLAND DECLINE: EVIDENCE FROM THE UPPER BENUE RIVER BASIN, ADAMAWA STATE. Lilian Andrew, Commander N. Thomasl and Ayodele A. Oyedeji
- 428 EFFECTS OF MICROPLASTICS ON THE HISTOSTRUCTURE OF *Clarias gariepinus* (AFRICAN CATFISH) GUT AND GILLS GARBA, A; FARIDA A
- 429 ECOLOGICAL ASSESSMENT OF SUSTAINABLE LIVELIHOOD IN PARTS OF ILAJE LITTORAL COMMUNITIES, ONDO STATE USING SOCIO-ECONOMIC AND HUMAN RESOURCE CAPITAL INDICES Aladesida, Adeyinka Adedeji, Babayemi, David O., Soetan, Mofiyinfoluwaoba, O., Umoren, Ifedayo O. and Adegorite, Solomon O.
- 430 GROWTH AND YIELD PERFORMANCES OF SIXTEEN OKRA (*ABELMOSCHUS ESCULENTUS* (L.) MOENCH) VARIETIES IN A HIGH RAINFALL REGION Gbayisemore O. O., Edwin-Wosu, N. L. and L.C. Osuji
- 431 IMPACTS OF SALT STRESS ON THE GROWTH AND YIELD PARAMETERS OF MAIZE (*ZEA MAYS* L.) Precious Allen Nwine, V. Wilson, M.T.V Adeleke
- 432 PLANT-POLLINATOR INTERACTIONS IN THE FACE OF CLIMATE CHANGE: UNDERSTANDING ECOLOGICAL SHIFTS AND CONSERVATION PRACTICES IN OPANDA-NIMBO ECOLOGICAL ZONE. E. T. Jaja, Nkaire, I. C., K. A. Kpekot
- 433 ASSESSMENT OF WATER HYACINTH (*EICHHORNIA CRASSIPES* [MART.] SOLMS) AND MALEFERN (*DRYOPTERIS FILIX-MAS* [L.] SCHOTTAS) HYPERACCUMULATORS OF ZINC AND COPPER IN WATER ENVIRONMENT ISHIWU Jecinta Chinedu, AMEH Onyeke Alexander, UGWUOGO Jude Uwakwe
- 434 ENVIRONMENTAL SUSTAINABILITY: ECOLOGICAL FOOTPRINT ANALYSIS OF IBADAN NORTH, NIGERIA CHIGBO Chioma Christiana, and OKWOR Jude Ifeanyichukwu
- 435 CRITICAL PERIOD OF INTERFERENCE OF *Sesbania pachycarpa* DC. WITH OKRA (*Abelmoschus esculentus* (L.) Moench.) IN IBADAN, NIGERIA Albert, E., Tanee, F. B. G. and Obiri, E.
- 436 ANTHROPOGENIC FACTORS INFLUENCING WETLAND DEGRADATION IN SATURU FOREST RESEARVE, SOKOTO STATE NIGERIA. Henry Sawyerr, Edet Otto, and Micheal Akinyemi
- 437 ACCUMULATION OF HEAVY METALS IN SURFACE WATER AND FISH TISSUES (*Clarias gariepinus*) OF NAFADA CORRIDOR, RIVER GONGOLA COMPLEX, GOMBE STATE, NIGERIA Oyelade, E.A. and Olubode, O.S.
- KASIMU A.S, and NAZIRU H. ABUBAKAR B., ABUBAKAR K.A, YARIMA R., NURA A. G.

- 438 CHARACTERIZATION AND PHYSICOCHEMICAL PROPERTIES OF SOIL UNDER DIFFERENT DEPTH IN IJEGBA FOREST, ABEOKUTA, OGUN STATE, NIGERIA. Oladoye A.O, Inyima U, Adebawale T.K, Ibiyomi, B.B, Busari M.A, Aderolu J.A and Basiru A.O
- 439 COMPARATIVE STUDY OF PARAMETERS OF STAGNANT AND RUNNING WATER OBTAINED FROM KAURA NAMODA, ZAMFARA STATE SAMAILA AHI ABDULLAHI and MOMOH SHAIBU
- 440 ASSESSMENT OF PHYSICOCHEMICAL AND BACTERIOLOGICAL WATER QUALITY OF HADEJIA-NGURU WETLANDS. Lydia Oluwatosin Odewade, Sharifa Ibrahim Suleiman and Joseph Oluwaseun Odewade
- 441 BLACK SOLDIER FLY LARVAE TECHNOLOGY: TRANSFORMING WASTE INTO OPPORTUNITY IN NIGERIA Adesope, O.M., Ifeanyi-Obi, C.C., Enang, I.A., Nwokolo, C.I., Okorie, U.G. Akwiwu, U.N. and Ayi, N.
- 443 FLORISTIC IMPORTANCE AND FARMER'S PERCEPTION OF *ALTERNANTHERA BRASILIANA* (L.) O. KUNTZE IN IBADAN, NIGERIA Olubunmi E. POPOOLA, Rasheed O. AWODOYIN, Kehinde R. EGBERONGBE and Oluseun S. OLUBODE
- 444 THE EFFECT OF AMENDMENTS ON SOIL CHEMICAL CHARACTERISTICS Onuigbo, U. S, Amadi, N. and Nwauzoma, A. B.
- 445 ASSESSMENT OF THE DRIVERS AND IMPACTS OF ELEPHANT CROP RAIDING IN THE COASTAL VILLAGES OF EPE, LAGOS-STATE Ibiyomi, B.B, Adebawale, T.K, Omoju, K
- 446 EMULSIFICATION POTENTIAL FILAMENTOUS FUNGI ISOLATED FROM *CYPERUS POLYSTACHYOS* (MANY-SPIKED FLAT SEDGE) RHIZOSPHERE SOIL Akomah-Abadaike, O.N and Adeyemi S.
- 447 LATEST PERCEPTIONS OF NiCl_2 IN SOILS ON THE GROWTH OF *CAPSICUM FRUTESCENS* L. AND *CAPSICUM ANNUUM* L. PLANTS U. A. Akporobaro, J. A. Obiaigwe, S. N. Iweriolor
- 448 DISTRIBUTION OF *Bambusa vulgaris* Schrad. ex J.C. Wendl IN NIGERIA AND THE DETERMINATION OF ITS POTENTIAL AS A BIOENERGY CROP Olaitan Patricia Olaleye, Oluseun Sunday Olubode and Maxwell Chibiko Obiakara
- 449 HEAVY METAL DETERMINATION OF FOUR ACCESSIONS OF BAMBARA NUT (*VIGNA SUBTERRANEA*) IN CRUDE OIL POLLUTED SOIL Bulu Precious Tombari and Ochekwu, Edache Bernard
- 450 PREVALENCE OF GASTROINTESTINAL PARASITES AND MANIFESTATION OF DISEASE CONDITION IN AFRICAN GIANT RATS (*CRICETOMYS GAMBIANUS* W.) IN CAPTIVITY Badmus, Hafiz Ayinde, Olaogun, Sunday Charles, and Adedokun, Rahamon A. Moshood
- 451 ECOSYSTEM SERVICES IN THE WETLANDS OF NIGER DELTA REGION Otukam, Nwabuike Trinity., Ochekwu, E.B. and Ugiomoh, I.G
- 452 COMPARATIVE STUDIES OF HEAVY METAL UPTAKE ABILITIES OF SOME PLANT SPECIES IN THE FAMILIES OF AMARANTHACEAE, EUPHORBIACEAE, AND POECEAE. AMADI, N and GBOSIDOM, VL
- 453 FERTILITY ASSESSMENT AND MANAGEMENT OF SOME WETLAND SOILS OF AKWA IBOM STATE, NIGERIA FOR SUSTAINABLE CROP PRODUCTION. OBONG, OBONGINYANG EDEM
- 454 HARNESSING THE ECOLOGICAL AND SOCIO-ECONOMIC BENEFITS OF AQUA-SILVICULTURE IN WETLAND AGROFORESTRY SYSTEM: ISSUES, CHALLENGES AND WAY FORWARD Omokhua, G. E., Alex, A and Emma-Ogu A.
- 455 NATURE-BASED SOLUTIONS FOR WETLAND RESTORATION: A STRATEGIC APPROACH TO FLOOD MITIGATION AND BIODIVERSITY CONSERVATION IN KARIM LAMIDO, TARABA STATE AKPAMI, Robo Samaila, GIDADO, Usman Muhammad and ISAH, Idris Iliyasu
- 456 HEAVY METAL DETERMINATION IN SOIL CONTAMINATED WITH CRUDE OIL IN BODO COMMUNITY, GOKHANA LGA, RIVERS STATE ONYEDEKE, PEACE CHIZOBA and OCHEKWU, EDACHE BERNARD
- 457 ETHNOBOTANICAL SURVEY OF MALARIA-TREATING PLANT SPECIES IN IJESA REGION, OSUN STATE, NIGERIA Cole Alice Temitope, Abodunrin Toyin Aanuoluwa and Akande Funke Karimont
- 458 METABOLIC ENGINEERING FOR BIOFUEL PRODUCTION Udemezue, C.V., Ugwu, R.A., Ovuike, O.O., Chiawa, O.C., Udoh, E.D.
- 459 PUBLIC AWARENESS AND COMMUNITY PARTICIPATION IN ARGUNGU FISHING FESTIVAL, KEBBI STATE, NIGERIA. T.T. Olubunmi-Ojo., Olakunle Muiyiwa ORIMAYE

460	COMPARATIVE ASSESSMENT OF THE PHYTODIVERSITY AND ECOSYSTEM DYNAMICS OF WETLANDS WITHIN AND AROUND THE UNIVERSITY OF PORT HARCOURT	Asaye, D.C., Agbagwa I.O. and Ochekwu, E.B.
461	COMPARATIVE ANALYSES OF HEAVY METALS IN TWO DIFFERENT SOIL TYPES IN THE FEDERAL CAPITAL TERRITORY, NIGERIA	BRAIDE, ONENGIYE OLAKUNLE AND OCHEKWU, EDACHE BERNARD
462	GEOGENIC ASSESSMENT OF HEAVY METALS IN DISTURBED WETLANDS WITHIN UYO METROPOLIS	Ogbemudia, F. O., Anwana, E. D., Ukafia, P. O, Okon, Ememobong
463	NATURE-BASED SOLUTIONS FOR RESTORING DEGRADED WETLAND ECOSYSTEMS: A STRATEGY FOR FLOOD CONTROL AND BIODIVERSITY CONSERVATION	AKPAMI, Robo Samaila. Majiyebo, GIDADO, Usman Mohammed. And Isah ILYASU Idris
464	PHYTOCHEMICAL COMPOSITIONS OF <i>Piper guineensis</i> (SCHUMACH AND THONN), <i>Gongronema latiafolium</i> (BENTH) AND <i>Lasienthera africanum</i> (P. BEAUV) Sub theme; Wetlands, agroecology, aquaculture and food security.	Nnadi, P.C, Tamunopekerebia, G.N, Saragoro –David, N.
465	THE IMPACTS OF ANTHROPOGENIC ACTIVITIES IN THE NIGER DELTA ON CLIMATE CHANGE: CHALLENGES AND PROSPECTS FOR SUSTAINABLE DEVELOPMENT	Tariwari C. N. Angaye, and Augustus N. Ebelegi
466	WETLANDS OF SOUTHWEST NIGERIA: IMPORTANCE, EMERGING CHALLENGES, TRENDS, AND STRATEGIC PATHWAYS FOR SUSTAINABLE MANAGEMENT	Sunday O. OLAJESU and Funmilayo Lewiska ONI
467	FISH SPECIES COMPOSITION IN RIVER YADZARAM, MUBI-NORTH ADAMAWA STATE, NIGERIA	Buba, Z.M., Isa, D.T.
468	GROWTH PERFORMANCE AND NUTRIENT UTILIZATION OF <i>Clarias gariepinus</i> (BURCHELL, 1822) FINGERLINGS FED VARYING LEVELS OF CO-MIXED OF BETAINE/ β -GLUCAN AS FEED ADDITIVE	ALI, M. E., SOGBESAN, O. A., ABUBAKAR, K. A. AND YUSUF, Z.A.
469	MICROPLASTIC REMOVAL FROM WATER USING AGRICULTURAL WASTE-DERIVED ACTIVATED CARBON	Chukwudi, Peter, Nduka-Chukwudi, Chidimma Adamma and Mbong, Emem Okon.
470	INDUCING TUBER FORMATION IN <i>DIOSCOREA BULBIFERA</i> ACCESSIONS THROUGH THE USE OF MINISSETTS.	DENGIMO, KEME., LOVE AJAKA AKONYE., KALU OKONWU
471	COMPARATIVE STUDY ON THE EFFECTS OF SOIL TYPES ON LEAF AREA DEVELOPMENT IN <i>Ocimum Sanctum</i> SEEDLINGS	FRIDAY ODEYOMA EGBERI and GODSPOWER OYUB
472	THE ROLE OF <i>Hevea brasiliensis</i> (RUBBER-TREE) PLANTATIONS IN ECOLOGICAL ADAPTATIONS AND CLIMATE CHANGE MITIGATION	SAMUEL, Oloruntoba G.; OYEDEJI, Ayodele A.; EZENWAKA, Jasper; IMARIAGBE, Patience and OGBEBOR, Ogbemudia J.
473	EFFECT OF AQUEOUS EXTRACTS OF MORINGA, NEEM, PAPAYA AND BITTER LEAVES ON THE NUTRITIONAL AND ANTI-NUTRITIONAL COMPOSITION OF <i>Dioscorea bulbifera</i> (AERIAL YAM) MINI-SETT	TEKE, E. C; AKONYE, L. A; EREMRENA, P. O
474	A SURVEY OF VEGETABLES SOLD IN ABRAKA MARKETS, ABRAKA, DELTA STATE, NIGERIA	Agbogidi, O.M. and Mukoro, O.A
475	THE ROLE OF MICROBIOME IN THE SUSTENANCE OF MANGROVE ECOSYSTEM SERVICES AND THE DANGERS OF THEIR DISTURBANCE VIA COASTAL DEVELOPMENT	Elijah I. Ohimain
476	IMPACT OF LAND USE AND LAND COVER CHANGES ON LAND SURFACE TEMPERATURE IN FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI, NIGERIA	Ubaekwe, R.E., Osogho, M.U., Mukoro, J.E., Duruanyim, I.E., and Udeagbala T.N.

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ABSTRACT

This study investigated the effects of land use and human activities such as storm water runoff, leakage of animal waste into the environment, agricultural practices, domestic waste, industrial wastewater and others on the physico-chemical parameters and bacteriological quality of drinking water sources from residential areas in Zango community, Zaria, Kaduna State. Water samples were collected in sterilized bottles from wells, community hand-dug, and boreholes were analyzed using standard procedures. The results indicated that microbial contamination was prevalent in all water sources, with significant concentrations of *E. coli* and *Proteus* Sp, posing a high risk for waterborne diseases. The pH values obtained from this study were within WHO permissible limits, with significant differences ($p < 0.05$) across all the sampling stations. The highest electrical conductivity was recorded in well water samples. Lead concentrations exceeded WHO standards, raising serious public health concerns. The results obtained in this study revealed contamination of groundwater, probably resulting from human activities and land use. The study highlights the need for improved water treatment, public awareness, and regular monitoring to ensure safe drinking water for this community.

Keywords: Water quality; Residential area; Safe drinking water, Groundwater, Water contamination.

INTRODUCTION

Access to safe and clean water is a fundamental human right and is crucial for sustaining life as well as an essential for human well-being, promoting public health, and development as recognized by international organization (WHO, 2010; UNESCO, 2017). Increase in human population, industrialization and agriculture around the globe have become alarming and exerted pressures on the quality and quantity of water resources. Water contaminants

could jeopardize both the physical and social health of humans (WHO, 2015). It is estimated that approximately 9 % (1.1 billion) of the world population lack access to safe water supplies, while 2.4 billion cannot adequately access to good sanitation environment, despite it being one of the Millennium Development Goals (MDG) targets globally to actualize (UNICEF/WHO, 2015). Despite the significant effort made by governments in most developing countries to meet the (MDG) target for drinking water, the report shows that 663 million people still

lack improved drinking water sources (WHO, 2018). Although all nations of the world have a shortage of adequate supplies of safe water for domestic use, yet, developing countries are the most critically impacted (MDG). UNICEF (2019) estimated that in 50 per cent of the developing countries, many of the populations have no access to adequate, safe and clean water.

Furthermore, the UN Population Division (2015) reported that of 117 countries, data available in developing nations indicates that most of the population lacks access to safe drinking water. Although the problem of lack of access to a safe water supply exists in many regions of the world, Sub-Saharan Africa is experiencing devastating impacts. The MDGs precipitated the development of a program to embark on increase the use of improved water sources from 76 % to 91 % globally between 1990 to its expiration in 2015. In a recent report outlined by the UNICEF/WHO Joint Monitoring Program (JMP), it is estimated that 79% of the rural population lack improved water sources, whereas 93% rely on surface water for survival (Dempster, 2016; UNICEF/WHO, 2015). It is indicated that an estimated 150 million sub-Saharan African urban dwellers do not have access to safe drinking water s and more than 340 million people lack access to improved water supply (WHO and UNICEF, 2014).

The Nigerian government, as part of its development agenda, implemented many rural and urban water projects through the construction of dams and reservoirs. However, 53% of the populace in rural and 28% in urban areas have no access to improved water sources and their continuous dependence on other sources of water, such as streams and rivers, increases their exposure to pathogenic organisms and other pollutants (Onabolu *et al.*, 2011). Most of the natural water bodies have been polluted with industrial effluent, municipal sewage

discharge, agricultural waste or pathogenic microbial substances that pose a substantial risk to the users, aquatic animals and even microorganisms. Water contaminated by microbiological pollutants causes diseases such as dysentery, cholera, and typhoid. The declining quality of these water systems threatens their sustainability and is therefore a cause for concern. Many communities around the world traditionally take their water supply from rivers, streams, springs or from shallow dug wells (WHO and UNICEF, 2006; Aneck-Hahn *et al.*, 2009; Sun *et al.*, 2009). Even though rivers are self-sustaining ecosystems that, without any human interference and natural disasters, could support both themselves and all life forms within them; nonetheless, increasing pollution from urban, industrial, and agricultural sources is rendering them unsafe and dangerous to health (Zangina and Ali, 2021).

The only realistic option for meeting water demands is through groundwater exploitation because it is cheap to dig, but not all can afford it (MacDonald *et al.*, 2012). However, its quality can be impacted by climate, slope, drainage conditions, water-rock interactions, and anthropogenic activities (Balamurugan *et al.*, 2020). Factors such as storm water runoff, leakage of animal waste into the environment, agricultural practices, industry, energy production, mining, wastewater, and infiltration of inadequately treated domestic sewage can lead to the introduction of toxic metals or nutrients into underground water sources (Odiyo and Makungo, 2018). The toxic and trace metals are constituents of the Earth's crust, commonly found in the environment in trace amounts (*i.e.*, up to a few ppm) but can be toxic at higher concentrations, and their concentration can be elevated in the groundwater due to human activities (Martino *et al.*, 2020). Lead is one of the excess elements of the earth's crust, and pollution of this may be as a result of rock

weathering that enters the groundwater through surface runoffs or from the rusting of the pipes used in pumping water out from the underground water. It is responsible for chronic neurological disorders in foetuses and children, especially when it is greater than 0.1 mg/l. Monitoring physico-chemical parameters of water resources to evaluate water quality and identify deficiencies is important for the protection of both humans and animals. The protection of water quality as a vulnerable resource essential to sustainable development is of utmost importance to prevent further pollution and degradation of groundwater resources.

MATERIALS AND METHODS

Study Area

The Zango community is located within the Sabon Gari Local Government Area, Kaduna State. It lies on Longitude 007°70'23"E. and latitude of 11°12'52"N, in the Jama'a ward of Sabon Gari Local Government of Kaduna State along Sokoto Road. It has a tropical climate with well-defined wet and dry seasons, with mean monthly temperature ranging from 13.8 °C to 36.7 °C and annual rainfall of 1090 mm (Shweta *et al.* 2013, Adesakin *et al.* 2020). The pattern of climate in this area supports farming activities; therefore, the main dwellers/settlers are farmers. It is a culturally rich and diverse urban settlement known for its historic significance and vibrant social fabric. The community is one of the developing areas in Sabon Gari Local Government with approximately 20,000 people living in this Area (NPC, 2019), and the majority of them are settlers from different ethnic groups living together in peace and harmony. Due to a lack of provision of potable drinking water by the government, the people living in this area rely on underground water as a source of water used for domestic purposes.

Water Sample Collection and Analysis

The random sampling method was adopted in this study, and water samples were collected from boreholes (5), wells (3) and community hand-dug boreholes (3) within the Zango community, to ensure representation of different water sources from each street. The bottles and their covers were washed thoroughly and sterilized before being used for sample collection. During the collection of the samples, the sterile bottles were cleaned with water to be sampled three times before the final collection of the samples. Water samples were collected using 1 L sample bottles for physico-chemical and bacteriological analysis, and it was analyzed using the standard methods of APHA (1995). Water temperature was determined using a mercury-in-glass thermometer. analysis.

A concentration of 0.2 ml of sodium thiosulphate solution was added to each bottle of water sample before sterilization to stop the action of residual chlorine on *Escherichia coli* (*E. coli*) in the water sample for bacteriological analysis (Edeki *et.al.*, 2023). The water samples were stored in coolers containing ice packs and transported within an hour to the designated laboratory for further

Water Physico-Chemical Parameters Analysis

The physico-chemical parameters, like water temperature, were determined by mercury in glass thermometer, pH was determined using a benchtop pH Meter, Electrical conductivity and TDS was determined by Conductivity Meter, nitrate was determined by Brucine method, phosphorus was analyzed by Spectrophotometer while heavy metals were analysis by Atomic Absorption Spectrophotometer (AAS) (Adesakin *et al.*, 2023).

Water Digestion and Heavy Metals Analysis

Water samples were filtered through a 0.45µm membrane filter immediately after collection. 50 ml was pipetted from each bottle and placed in a Glassware for testing, and 5 ml of HNO₃ was added, then heated until all the water had evaporated to dryness and allowed to cool, then another 3 ml of HNO₃ was added. Then the solution was heated again until completely absorbed, and 2 ml of HCl (1+1) was added to the residue, then heated gently again to dissolve the residue. The solution was allowed to cool, and deionized H₂O was added and then filtered. The concentrations of each metal were then analyzed using an Atomic Absorption Spectrophotometer (AAS) at each metal specific wavelength (nm).

Determination of Total Coliform Bacteria and Faecal Coliforms

Faecal and total coliform counts were performed using the standard membrane filtration technique. The 100 ml water sample was filtered using a 0.45 mm pore size, 47 mm diameter filter membrane. About 100 ml of the water samples will be filtered through a membrane filter with the aid of a vacuum pump. The filter membrane was placed in a MacConkey agar plate. This was then incubated using an incubator pre-set to 44.5 ± 2 °C for 24 hours. Observation was made for colony development on the filter membrane. The colonies were then counted as colony-forming units per 100 ml (Meyer *et al.*, 2023).

Isolation and Identification of Bacterial Isolates

Microbial isolation was performed from the water samples collected from the Hanwa GRA stream. (Latitude of 11°09'42"N and Longitude of 7°65'19"E). The culture media to be used are: MacConkey agar, eosin methylene blue (EMB) agar, *Salmonella-Shigella* agar and brilliant green agar. Isolation was achieved by the streak plate technique. The cultures were incubated at 37

°C overnight. After the incubation time, a new isolation was done in the same culture media, and the morphology was analyzed to identify the bacterial genera (Gutierrez-Lucas *et al.*, 2017).

Biochemical Tests

Biochemical tests, including the indole, methyl red, Voges-Proskauer, citrate, and motility tests, were conducted using APHA (2011) to further identify bacterial species.

Statistical Analysis

The results obtained from this study were subjected to descriptive and inferential analysis. One-way analysis of variance (ANOVA) was used to check for the significant differences ($p < 0.05$) in the mean values of physico-chemical parameters of groundwater, heavy metals and microbial load across the stations. Pearson Correlation Matrix was utilized to determine the inter-relationships between physico-chemical parameters, and bacteriological quality was analyzed using SPSS version 29.

RESULTS

Spatially, the pH values recorded in this study vary from 5.98 to 8.04, with the highest average mean value of 7.54 ± 0.51 recorded from the water sample from hand-dug wells, and there were no significant differences ($p < 0.05$) across the sampling stations. The EC, TDS, DO, nitrate, phosphate, TCC and FCC were higher in the well-water compared with the other groundwater samples, while the highest mean value of water temperature was observed in the community hand-dug water sample and the highest mean concentration of Pb was recorded in borehole water (Table 1). Significantly, TCC and FCC were higher in well water compared with the other sampling locations, and there are significant differences ($p < 0.001$) among the mean values of TCC and FCC (Table 1). *Proteus* Sp and *E. coli* are bacterial organisms

identified from all three sampling stations during the period of this study.

In well-water samples, the highest pH value was recorded in the wet season, while DO and Pb concentration were at peak in the wet season, nitrate was higher in the wet season, and phosphate concentration was at maximum in the dry season (Figure 2a). The highest pH mean concentration was observed in the wet season, while parameters like DO, nitrate, phosphate and Pb were higher in the wet season from the Hand-dug water samples

(Figure 2b). The pH mean value was recorded in the dry season, while DO, nitrate, phosphate and Pb were higher in the wet season from borehole water samples (Figure 2c). The highest TDS and EC were recorded in the dry season for water samples collected from well-water and hand-dug reservoirs, while in the borehole, it was highest in the dry season (Figure 2d). Seasonally, the low pH mean concentration was recorded during the dry season, while a high mean value was observed in the wet season (Table 2).

Table 1. Spatial variation of physico-chemical parameters and Bacteriological quality of groundwater sources in Zango community

Parameters	Well-water		Hand-dug		Borehole		Anova		WHO
	Min.-Max.	Mean	Min.-Max.	Mean	Min.-Max.	Mean	F	Sig.	
pH	6.03-8.03	7.16 ± 0.76	6.89-8.04	7.54 ± 0.51	5.98-8.00	7.48 ± 0.83	0.471	0.633	6.50 - 8.72
Temp. (°C)	23.90-26.89	25.07 ± 0.98	23.98-27.04	25.54 ± 1.09	23.9-25.90	25.22 ± 0.78	0.38	0.698	
TDS (mg/l)	280.00-600.00	960.40 ± 121.56	194.00-400.60	312.33 ± 97.43	296.00-500.67	425.28 ± 81.56	3.485	0.057	500
EC (µS/cm)	798.00-1785.00	1178.10 ± 382.96	593.00-1000.00	808.13 ± 160.21	600.00-1023.00	876.67 ± 184.83	3.377	0.062	1000
DO (mg/l)	1.80-2.60	2.18 ± 0.34	1.33-2.70	1.86 ± 0.57	1.40-2.60	1.89 ± 0.42	0.933	0.415	
Nitrate (mg/l)	2.24-6.98	5.95 ± 2.03	2.42-7.91	4.83 ± 2.31	2.61-5.94	3.6 ± 1.29	0.554	0.586	50
Phosphate (mg/l)	2.75-7.09	8.17 ± 1.98	1.76-9.20	4.65 ± 3.22	2.01-10.01	5.22 ± 3.69	0.186	0.837	50
Pb (mg/l)	0.10-0.87	0.36 ± 0.27	0.22-0.42	0.32 ± 0.09	0.21-0.65	0.39 ± 0.19	0.196	0.824	0.01
Cd (mg/l)	0.003-0.06	0.02 ± 0.02	0.002-0.08	0.04 ± 0.03	0.002-0.10	0.04 ± 0.03	0.734	0.497	0.003
TCC (cfu/ml)	0.00 - 1310	1211 ± 589.3b	0.00-701	668 ± 473.8b	0.00-400	296 ± 262.3b	0.920	0.003**	0
FCC (CFU/ml)	0.00- 2.13×10 ⁶	1.58 ×10 ⁶ ± 6.78 ×10 ^{5b}	0.00- 1.95×10 ⁶	1.32 ×10 ⁶ ± 7.83 ×10 ^{5b}	0.00- 1.10×10 ⁶	1.06 ×10 ⁶ ±7.25×10 ^{5b}	0.562	0.041*	0

Table 2. Seasonal variation of physico-chemical parameters and Bacteriological quality of groundwater sources in Zango community

Parameters	Well-water			Hand-dug well			Borehole		
	Dry season		t-test	Dry season		t-test	Dry season		t-test
	Mean±SD	Mean±SD		Mean±SD	Mean±SD		Mean±SD	Mean±SD	
pH	6.98±1.00	7.34±0.59	0.628	7.32±0.63	7.75±0.37	0.365	6.97±0.98	7.98±0.03	0.154
Temp. (°C)	25.53±1.19	24.60±0.61	0.294	26.28±0.66	24.79±0.93	0.086	25.53±0.55	24.90±0.95	0.378
TDS (mg/l)	537.74±56.42	383.07±125.77	0.124	362.10±59.88	262.57±112.75	0.248	463.07±54.92	387.50±96.60	0.304
EC (µS/cm)	1444.00±372.60	912.20±125.34	0.079	924.17±120.43	692.10±96.29	0.060	894.33±184.46	859.00±224.59	0.844
DO (mg/l)	2.20±0.36	2.17±0.40	0.920	1.61±0.35	2.11±0.70	0.332	1.69±0.30	2.09±0.47	0.279
Nitrate (mg/l)	3.76±1.99	4.73±2.38	0.615	3.88±1.45	5.77±2.94	0.373	3.13±0.77	4.18±1.67	0.379
Phosphate (mg/l)	4.31±2.41	4.93±1.97	0.882	3.28±2.35	6.02±3.83	0.351	3.53±3.76	4.91±4.43	0.863
Pb (mg/l)	0.33±0.09	0.40±0.41	0.800	0.32±0.09	0.32±0.10	0.938	0.39±0.20	0.39±0.23	0.972
Cd (mg/l)	0.01±0.03	0.03±0.01	0.212	0.02±0.02	0.05±0.04	0.393	0.04±0.03	0.05±0.05	0.792
TCC (cfu/ml)	671.00±287.00	1374.00±754.00	0.067	669.00±474.00	891.10±763.00	0.001	101.00±76.00	301.10±290.01	0.010
FCC (CFU/ml)	0.93×10 ⁶ ± 0.03×10 ⁶	2.47×10 ⁶ ± 1.21×10 ⁶	0.001	0.71×10 ⁶ ± 0.86×10 ⁶	1.79×10 ⁶ ± 1.13×10 ⁶	0.002	0.43×10 ⁶ ± 0.03×10 ⁶	1.53×10 ⁶ ± 0.93×10 ⁶	0.005

Table 3: Biochemical Analysis of Groundwater Sources from Zango Community

	Well-water			Hand-dug well			Borehole		
	1	2	3	1	2	3	1	2	3
IND	+	+	+	+	+	+	+	+	+
MR	+	+	+	+	+	+	+	+	+
VP	-	-	-	-	-	-	-	-	-
CIT	+/-	-	-	-	+	+	-	-	+
MOT	+	+	+	+	+	+	+	+	+
Bacterial Organism	<i>Proteus</i> Sp	<i>E. coli</i>	<i>E. coli</i>	<i>E. coli</i>	<i>Proteus</i> Sp	<i>E. coli</i>	<i>E. coli</i>	<i>Proteus</i> Sp	<i>Proteus</i> Sp

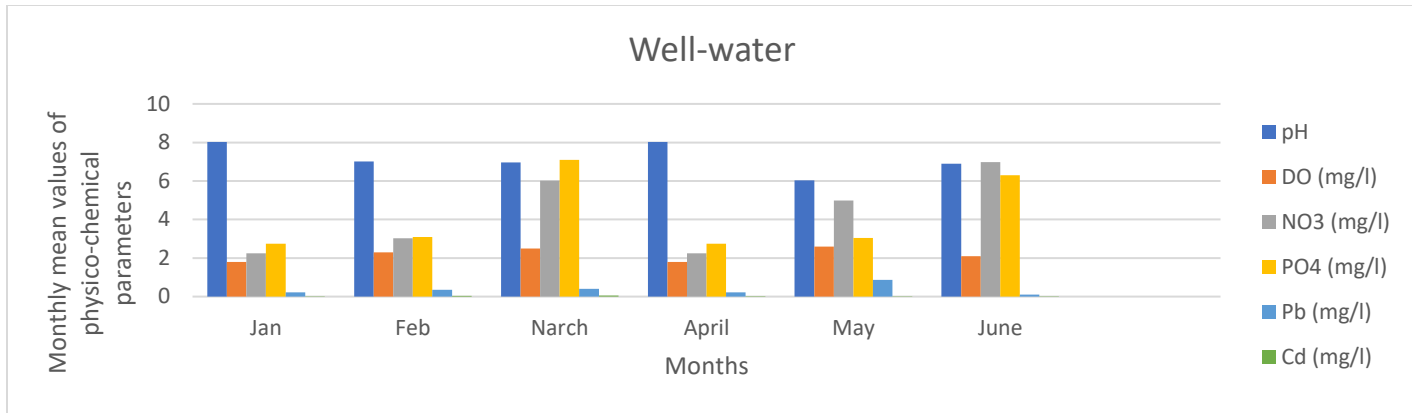


Figure 2a: Monthly variation of physico-chemical parameters of groundwater samples from Zango Community

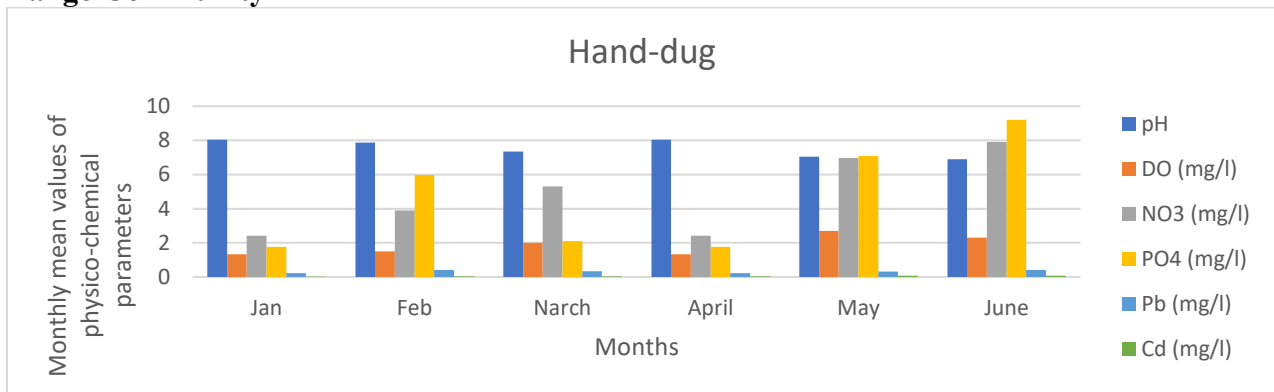


Figure 2b: Monthly variation of physico-chemical parameters of groundwater samples from Zango Community

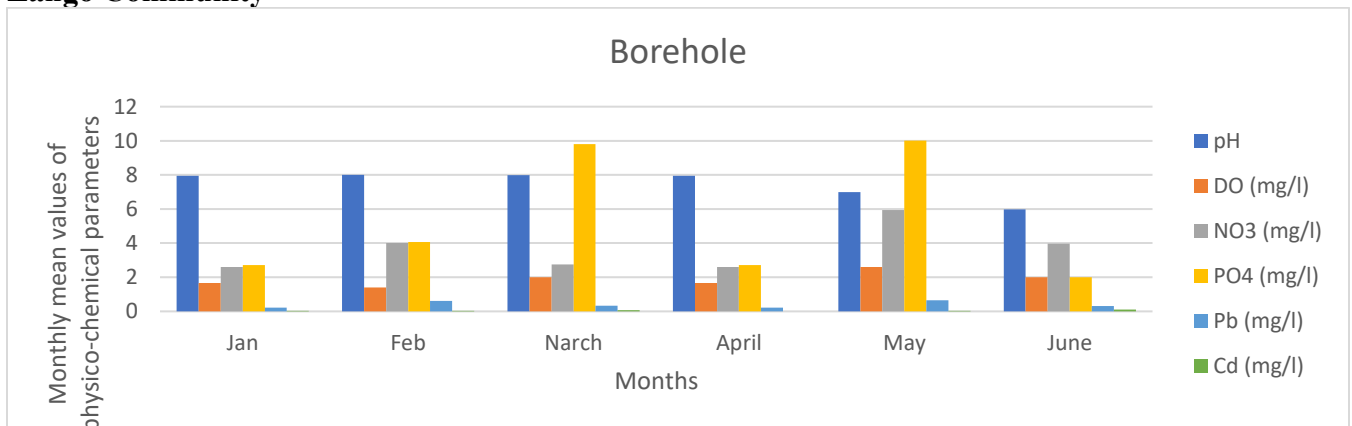


Figure 2c. Monthly variation of physico-chemical parameters of groundwater samples from Zango Community

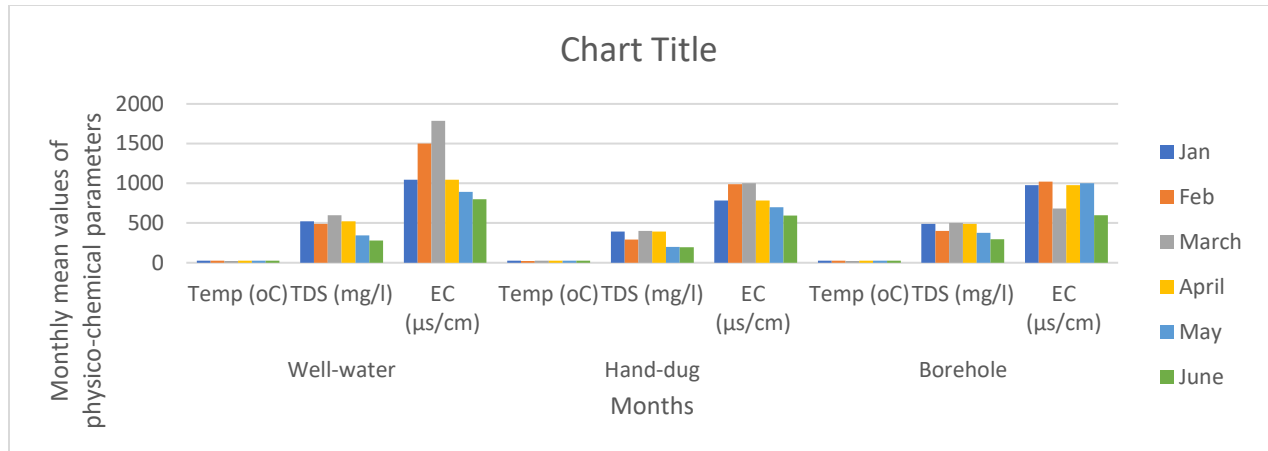


Figure 2d. Monthly variation of physico-chemical parameters of groundwater samples from Zango Community

The nitrate, phosphate, Pb, TCC and FCC mean values were lower in the dry season compared with the wet season, which were higher. Comparison of the mean values of TCC and FCC for both seasons indicates there were significant differences ($p < 0.05$) among the seasonal variations. The CCA showed the relationship between the physico-

chemical parameters, heavy metals and bacterial quality, which revealed that water temperature, pH, nitrate, phosphate and Cd correlated together with Hand-dug, while FCC and TDS correlated with well-water and DO, Pb, and EC correlated with Borehole (Figure 3).

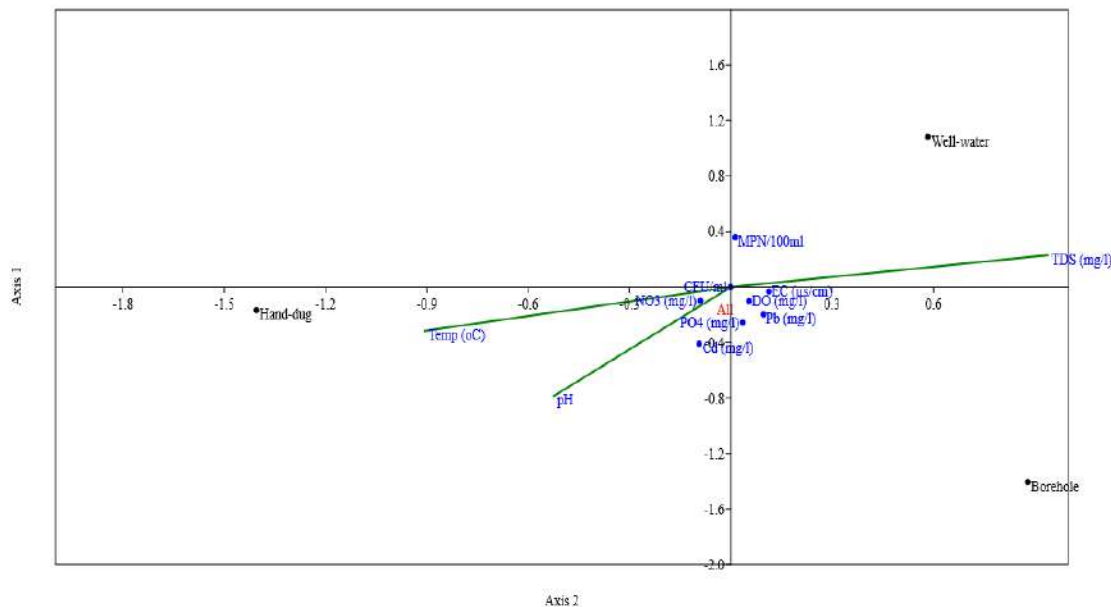


Figure 3. Principal Component Analysis (PCA) shows the interrelationship between physico-chemical parameters, heavy metals, and bacteriological load across sampling stations

DISCUSSION

The range of pH values obtained from this study is below the WHO (2011) and NSDWQ (2015) acceptable limit range for drinking water. It is slightly acidic to moderately alkaline, and may be due to the land use, contamination from human activities or geological formation of this area that allows ions to dissociate from the soil composition into the aquifer water, which leads to a low pH value obtained. The pH means concentrations recorded in all sampling stations were similar to the work of Adesakin *et al.* (2020), who report an average pH of 7.01 to 7.60 in well water within the ABU community Zaria and also aligned with the report of Fadili *et al.* 2019. The average water temperature recorded in all the sampling stations was below 26 °C, which is within the values reported for many African underground waters by many researchers. The results could be influenced by rainfall pattern, climatic change, season, time of the sampling and reactions taking place within water itself and soil. The EC and TDS results recorded in this study were similar to Abdulkadir *et al.* (2015), who reported EC values ranging of 360 to 6000 $\mu\text{S}/\text{cm}$ from groundwater samples in Dala Local Government Area of Kano state, Nigeria, but notably higher than those of a similar study by Fadiji *et al.* (2019), who reported TDS value ranged of 2.77 ± 0.15 to 4.5 ± 0.07 mg/l from wells in Ijero-Ekiti, Ekiti State, Nigeria. The findings of this study indicate that electrical conductivity mean values obtained in all the sampling stations fell within the range of 300 - 2230 $\mu\text{S}/\text{cm}$ reported by Musa *et al.* (2023). The overall dissolved oxygen observed during this study might be due to the shallow depths of most of these wells, which allow oxygen in the air to dissolve in the underground water and low organic matter. High turbidity and increased suspended material have also been reported to affect the dissolution of oxygen and the

penetration of sunlight into the water and thereby reducing the photosynthetic rate in bottom water. This aligns with the report of Ekute, (2021) in groundwater in the Vicinity of an Industrial Area of Mopin Community, Ota, Southwest Nigeria.

The mean of nitrate and phosphate concentrations recorded in all stations during this study were below WHO standard for drinking water. The low values of nitrate and phosphate observed in this study could be due to fewer human activities around sampling locations. Nitrate is poisonous to infants younger than 6 months old, while excess phosphate in water could cause an algae bloom, which can pollute the water can giving the water a taste and smell. Nitrate is harmless at lower concentrations than permissible limits, but if it exceeds the limits, it is harmful because of the lowering in nitrites, which can be with amines and amides to form “N-nitroso” composites, which is the major cause of cancer of the stomach (Aires *et al.*, 2013). The Pb and Cd mean concentrations obtained in all the sampling stations are above the WHO standard of 0.01 mg/l and 0.003 mg/l for drinking water. The mean values of TCC and FCC recorded from all the groundwater samples were above the 0 CfU/ml value as recommended by WHO (2011) and NSDWQ (2015) for drinking water. However, the possibility of contamination is less with the sources which are properly covered at the top and as well as surface runoffs contaminated with Faecal matter infiltrate the soil and pollute the ground waters. The finding of this study is in agreement with the study carried out by Dzwauro *et al* (2002). The presence of *E. coli* and *Proteus* Sp from the water samples examined during this study could be a result of pathogens and bacteria from seepage from pit latrine infiltrating the soil and contaminating the groundwater. The result of these findings corroborated with the work of Some *et al.* (2021); Belina *et al.*

(2023) and Wamyil *et al.* (2023) who reported *Escherichia coli*, *Shigella spp* and *Salmonella spp* as the most common isolated bacterial species in water sources.

The highest water temperature was observed in the dry season compared with the wet season could be due to climate change as a result of an increase in average global temperature, which has contributed to high air temperature that could influence an increase in groundwater temperature. The result of this study is similar to the findings of Gongden and Lohdip (2015) in Plateau State reported a comparable temperature value of 25.67 ± 3.03 °C. The EC and TDS were higher during the dry season might be attributed to the reduced water level during this season and the dissociation of ions in the soil into the groundwater. The highest mean concentrations of pH, nitrate, phosphate, Pb, Cd, TCC and FCC were higher in the wet season than in the dry season could be due to high runoffs as a result of excess rainfall during this period which leads to supersaturation of the soil to absorb excess water that over flood most the wells and borehole. The anthropogenic activities, such as agricultural runoff, industrial waste, domestic waste petroleum from the mechanic workshop, which contain Pb content. The pollutants are washed off by runoffs during this season and infiltrate the groundwater, leading to its contamination. The phosphate value in this study suggests contamination of groundwater with potentially human or animal waste. The lead (Pb) concentration exceeded the World Health Organization's (WHO) permissible limits (0.01 mg/L) in all water sources. Ingestion of lead through food or water or exposure, even at low concentrations, poses severe health risks, particularly to children and pregnant women, as it can lead to developmental problems, kidney damage, and neurological disorders. Cadmium concentrations were above WHO limits. If it becomes bioaccumulation due to

long-term exposure can cause kidney damage and bone demineralization. These findings are conformed with Hamidu *et al.* (2017), where groundwater was found to contain elevated levels of trace metals, such as cadmium, posing similar health risks.

The high TCC and FCC observed well-water sample indicate that groundwater in this sample area is contaminated with faecal matters as a result of most of these wells not being covered or being improperly handled. It aligns with the work of Usman and Aliyu (2020), who recorded high coliform bacterial counts from groundwater in Nguru town, Nguru Local Government Area, Yobe State, Nigeria. It contradicts the report of Jayalakshmi *et al.* (2011), who found that borehole water with the highest total coliform count also has the highest faecal coliform count (Rogbesan *et al.*, 2002). A study of coliform contaminants in Ibadan city, Nigeria, by Oyedum (2010) and supported by Boman (2012), showed that the pollution of boreholes was due to indiscriminate drilling of boreholes near pit latrine toilets and poor drainage systems. These bacteria species identified in the study are pathogens that cause gastrointestinal infections and other waterborne diseases, that of health risk for residents who consume this water without treatment. The findings align with a previous study of Shayo *et al.* (2023), which also reported microbial contamination in water sources, causing diseases and leading to the death of many people in developing countries if not treated on time.

CONCLUSION

The quality of groundwater in the Zango community, Kaduna State, Nigeria, poses several serious public health concerns, particularly concerning microbial contamination and heavy metals. Although some physico-chemical parameters, such as pH are within acceptable limits, the high electrical conductivity and low dissolved

oxygen levels indicate potential water quality deterioration over time. These findings suggest the need for immediate intervention, including improved water treatment, sanitation infrastructure, and regular monitoring to ensure that residents have access to safe drinking water.

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IDENTIFICATION OF HOTSPOTS AND SETTING PRIORITIES FOR CONSERVATION IN RELATION TO PLASTIC POLLUTION AND BIODIVERSITY LOSS

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ABSTRACT

Plastic pollution poses a significant threat to biodiversity, demanding the identification of hotspots and the establishment of conservation priorities for effective mitigation. This study synthesises existing research on the relationship between plastic pollution and biodiversity decline, with a focus on hotspot identification and priority setting. It also discusses the multiple effects of plastic pollution on biodiversity, such as direct injury, chemical contamination, and habitat destruction in terrestrial, freshwater, and marine environments. It goes into contemporary studies to conduct an analysis of hotspots, taking into account spatial distribution and ecological fragility. Furthermore, it investigates how plastic pollution adversely impacts vulnerable species and fragile habitats, compounding biodiversity loss. The evaluation, based on conservation science principles, identifies priority areas for intervention and management, highlighting the necessity of focused initiatives and inter-disciplinary collaboration. The study provides a framework for prioritising conservation measures to alleviate the negative effects of plastic pollution on global biodiversity by combining insights from plastic pollution research and biodiversity conservation.

Keywords: Biodiversity decline; Conservation priorities; Hotspot identification; Plastic pollution.

INTRODUCTION

Plastic pollution has emerged as a pressing environmental concern, posing significant threats to biodiversity worldwide. Plastic production has increased substantially since large-scale industrial manufacture started in the early 1950s. In recent years, plastics have been widely used by society with immense applications in different industries due to their excellent physical and chemical properties. Globally, plastic production has increased dramatically over the last few decades, starting from 1.5 million tons in 1950s to 490 million tonnes in 2023. Owing to the exceptional features such as lightness, durability and low thermal conductivity; plastics have been utilized in a vast number

of industries across the globe including medicine, technology, electronics, clothing and agriculture. (Khan *et al.*, 2024; Hannah *et al.*, 2023; Alberghini *et al.*, 2022; Makhdoumi and Pirsaeheb, 2022; Ward and Reddy, 2020, Nations 2018). Despite the great applications with plastics usage, there has been several pollution challenges related with plastics. Additionally, plastics enter the environment both during their manufacturing process and following their use, rendering them among the most abundantly produced urban waste materials. This contributes significantly to environmental contamination and the pollution of natural habitats, ultimately leading to adverse effects on the organisms inhabiting these ecosystems (Khan *et al.*, 2024; Makhdoumi and Pirsaeheb, 2022; Fältström *et al.*, 2021).



Figure 1: European plastic converters demand by segment totaling 51.2 Mt (Plastics Europe, 2018).

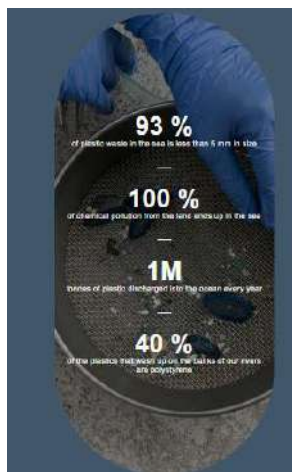


Figure 2: Plastics in data (Fondation Tara Océan, 2023)

PLASTIC POLLUTION AND BIODIVERSITY DECLINE

The current period of human is the plastic age and scientists have termed this new era as the *plastisphere* (Zettler, 2023; Cozar *et al.*, 2014). Plastics, being synthetic organic polymers, possess the versatility to be molded into diverse shapes and products, serving a wide range of purposes. Having originated more than a century ago, plastics have risen to prominence as the most extensively utilized synthetic materials, permeating every aspect of our daily existence.

The first commercially significant fully

synthetic polymer, Bakelite, was invented by Leo Baekeland in 1907 who also coined the term "plastics," derived from the Greek word "*plastikos*," meaning moldable. Initially, plastics posed no environmental threat. However, over subsequent decades, with inadequate disposal methods, the release of plastics into the environment has led to a plethora of associated issues. Plastic pollution is now widely acknowledged as a significant environmental challenge, in both terrestrial and aquatic environments. The biophysical breakdown of plastics in oceans has enduring and severe effects, including ingestion, entanglement, and habitat

degradation, profoundly impacting marine biodiversity.

Globally, a century of waste is accumulating in various locations including landfills, agricultural lands, streets, waterways, rivers, and the ocean. This is a result of over 79 per cent of plastic being dumped in the environment and this volume continues to increase yearly— for example, over 8 million tons of plastic waste seep into the ocean annually. In fact, out of the estimated 6.3 billion tons of global plastic waste produced; only approximately 9 per cent has been recycled, 12 per cent has been subject to incineration which leads to extremely high emissions of greenhouse gases making it a primary contributor to emissions to plastic waste management. (Hira et al 2022).

Studies have shown that over 5 billion tons of plastics enter in the environment. Organisms are at a higher risk of mistaking larger debris of plastics (macroplastics) for food and are ingested or entangled in the process causing asphyxiation or other respiratory difficulties, injuries, infections and possibly death. Furthermore, microplastics (plastics of size < 5mm) are increasingly becoming a significant concern for both marine and freshwater ecosystems. They infiltrate water bodies and the surrounding environment due to the widespread usage of plastic in modern society. These tiny particles enter our water systems via various pathways, including direct sources like particles from tire wear on roads and microfibers shed from synthetic clothing during washing, as well as indirect sources like the degradation of larger plastic items such as litter entering drainage systems. In the marine environment, microplastics often stem from the breakdown of single-use plastic products, which gradually deteriorate through abrasion and exposure to saltwater. Additionally, plastic fragments pose a greater threat to marine biodiversity, as they can be

ingested by marine organisms, leading to digestive blockages and other harmful effects. Plastics claim the lives of millions of animals annually, spanning from birds and fish to various marine organisms. Almost 700 species, some of which are endangered, have been documented to suffer from the impacts of plastics. Virtually every species of seabirds has been observed consuming plastic materials.

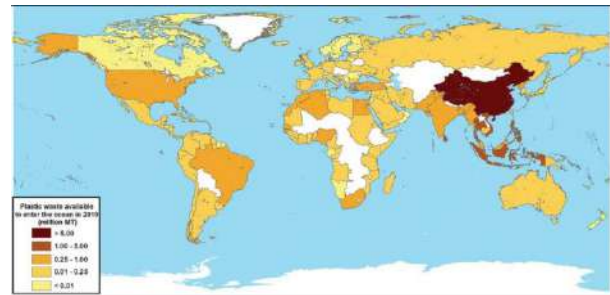


Figure 3: Global map with each country shaded according to the estimated mass of mismanaged plastic waste [millions of metric tons (MT)] generated in 2010 by populations living within 50 km of the coast. We considered 192 countries. Countries not included in the study are shaded white (Jambeck et al., 2015).

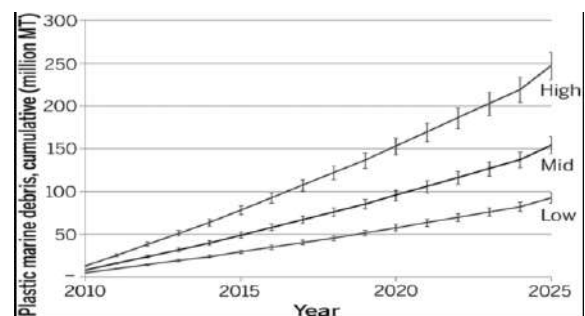


Figure 4: Estimated mass of mismanaged plastic waste (millions of metric tons) input to the ocean by populations living within 50 km of a coast in 192 countries, plotted as a cumulative sum from 2010 to 2025 (Jambeck, et al., 2015).

IMPACT OF PLASTIC POLLUTION ON BIODIVERSITY HOTSPOTS

Biodiversity hotspots are regions characterized by well-preserved natural ecosystems where native species and communities are abundant and diverse. They are also areas with a high diversity of locally endemic species. Overpopulation, overexploitation of natural resources, pollution amongst other problems affect our biodiversity hotspots. Decreased diversity can also diminish the resilience of ecosystems and the human communities reliant upon them. As species vanish, so does the health security of every human too. (Mittermeier et al., 2011).

The presence of plastics in the marine ecosystem is a raising alarm due to their persistence and their impact on oceanic environments, wildlife, and potentially human health. Plastic waste is found along coastlines, embedded within Arctic Sea ice, floating on the sea surface, and scattered across the seabed. Over time, the breakdown of plastic debris through weathering results in the formation of smaller particles, which can be ingested even by tiny marine invertebrates (Jambeck, et al., 2015). Plastic waste poses a considerable danger to biodiversity, impacting ecosystems and various animal and plant species, hindering their capacity to provide crucial services to humans. While much research has focused on the consequences of plastic entering the ocean and its effects on marine life, it is important to recognize that plastic pollution also affects freshwater and land-based ecosystems. Plastics have been consumed by land-based animals, including elephants, hyenas, zebras, tigers, camels, cattle, and other large mammals which has resulted in significant mortality rate. Microplastics have been reported to be present in terrestrial food webs including the digestive tracts of birds, chicken faces, earthworm casts, filamentous

fungi, yeasts, human placenta, dogs, rabbits, and small rodents. Accidental microplastic ingestion might indeed be of concern to human health. Microplastics have also been reported in seafood, salt, sugar and beers (De Souza Machado et al., 2018).

ENVIRONMENTAL EFFECTS OF PLASTICS

The environmental effects can vary significantly and may manifest directly or indirectly. Direct impacts occur when marine organisms are physically harmed by marine debris, either by ingestion or entanglement, such as when a turtle mistakenly consumes a plastic bag as food, or when debris alters sensitive ecosystems, like a fishing net damaging a coral reef as it's dragged by ocean currents. Additionally, environmental impacts can be indirect, such as when cleaning up marine debris leads to ecological shifts.

- **Ingestion:** Seabirds, sea turtles, fish, and marine mammals often ingest marine debris that they mistake for food. Ingesting marine debris can seriously harm marine life. For example, whales and sea turtles often mistake plastic bags for squid, and birds often mistake plastic pellets for fish eggs. Consuming marine debris can result in starvation or malnutrition for animals when the debris accumulates in their stomach, giving them a false sense of fullness. This can prevent the absorption of vital nutrients, leading to starvation. Additionally, ingestion of marine debris can cause internal injuries and infections. Certain types of marine debris, particularly certain plastics, may contain harmful toxins that can lead to death or reproductive issues in fish, shellfish, or other marine organisms. The International Union

for Conservation of Nature (IUCN) Red List, at least 17% of species affected by entanglement and ingestion were listed as threatened or near threatened.

- **Entanglement:** It involves the interaction with human-made debris such as plastic bags, ropes, fishing nets or strapping bands, leading to animals being trapped or having their appendages caught within the loops and openings of the debris (Bottari et al., 2024). This can lead to various consequences, including suffocation, starvation, drowning, heightened susceptibility to predators, or other forms of injury. When an animal becomes entangled, the debris may restrict its movement, leading to exhaustion or the development of infections from deep wounds caused by the tightening of the material. Reports show that over 443 animals and birds were entangled or trapped by marine debris (2008 ICC Report, Ocean Conservancy).
- **Ecosystem Alteration:** The detrimental effects of marine debris extend beyond mobile animals and can also harm plants, other immobile organisms, and delicate ecosystems.

For instance, coral reefs may suffer damage from abandoned or broken fishing gear, which can break or suffocate the coral. Plastic bags and fishing nets can smother plants, while abandoned vessels or other marine debris can damage and alter ocean floor ecosystems through their movement.

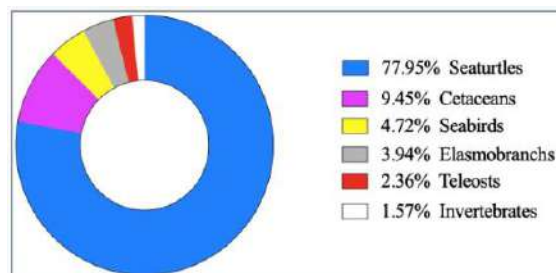


Figure 5: Percentage of records in marine biota (Bottari et al., 2024b)

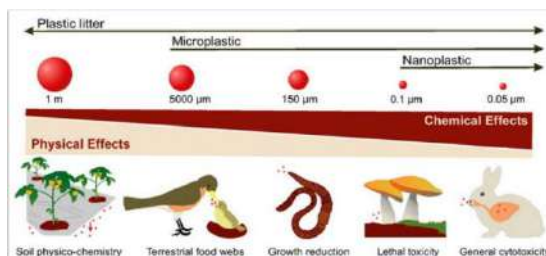


Figure 6: Microplastics as trigger of combined physical or chemical-like effects (De Souza Machado et al., 2018)

CONCLUSION

Plastics have always followed the same linear direction over the years: take, make, waste. The exponential increase in plastic production has precipitated a global crisis of plastic pollution, posing significant threats to biodiversity and ecosystem health.

Despite the indispensable role that plastics play in various industries, their mismanagement and inadequate disposal have led to pervasive contamination of terrestrial, freshwater, and marine

environments. From ingestion and entanglement to habitat degradation, the adverse impacts of plastic pollution on wildlife are profound and far-reaching. There would be a great need to mitigate these impacts through law enforcement and practicing the 3Rs: reduce, reuse, recycle and proper disposal methods as this would create proper channel for waste disposal. The urgency of addressing plastic pollution is underscored by its detrimental effects on biodiversity hotspots, which serve as critical reservoirs of endemic species and essential

ecosystem services. As species disappear and ecosystems falter, the repercussions extend beyond ecological balance to encompass human health and well-being.

By recognizing the interconnectedness of environmental, social, and economic factors, we can work towards a future where plastic pollution is minimized, biodiversity is protected, and ecosystems thrive. Only through concerted action and unwavering commitment can we hope to address the global challenge of plastic pollution and ensure a sustainable future for generations to come and make our planet more habitable.

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CLIMATE CHANGE MITIGATION THROUGH GREEN INFRASTRUCTURE: COMBINING COMMUNITY ENGAGEMENT AND SPATIAL TECHNOLOGY IN URBAN PLANNING

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ABSTRACT

Climate change poses significant threats to urban areas, particularly in Samaru Zaria, Nigeria. Rapid urbanization has led to the dominance of Gray infrastructure, which has been exacerbating these issues. This study explores the potential of transitioning to green infrastructure for sustainable climate change mitigation. GIS was utilized to analyse land use patterns, urban heat islands, flood-prone areas, and vegetation coverage, while participatory mapping incorporated community involvement in identifying green infrastructure interventions. It highlights the importance of green infrastructure components like urban forests, pavements, roofs, and wetlands in reducing environmental impact and enhancing climate resilience. This study discusses challenges to green infrastructure implementation in Samaru, including limited public awareness, inadequate policies, and funding constraints. The study recommends integrating green infrastructure principles into urban planning policies and combining participatory approaches with cutting-edge spatial technology like GIS to provide data-driven, community-inclusive planning. The research highlights the importance of prioritizing green infrastructure for a sustainable, climate-resilient city, enhancing urban liveability, and promoting sustainable development.

Keywords: Climate resilience, GIS, Green infrastructure, Land use, Stormwater management Urbanization

INTRODUCTION

Urban areas are increasingly bearing the brunt of climate change impacts, including extreme heat events, urban flooding, and reduced air quality. These effects are particularly pronounced in rapidly urbanizing regions of the Global South, such as Samaru, Zaria, Nigeria. The dominance of Gray infrastructure—built environments composed of impermeable surfaces such as roads and concrete buildings—has amplified these issues, resulting in urban heat islands (UHIs) and exacerbating the risk of flooding (UN-Habitat, 2020). Addressing these issues requires a shift towards green infrastructure, which provides nature-based solutions to enhance urban resilience while promoting sustainability.

Green infrastructure refers to a strategically planned network of natural and semi-natural areas that deliver a wide range of ecosystem services, such as climate regulation, water management, and biodiversity conservation (European Environment Agency [EEA], 2021). Examples include urban forests, green roofs, permeable pavements, and constructed wetlands. These systems not only mitigate the impacts of climate change but also provide co-benefits, such as improved air quality, enhanced public health, and increased aesthetic value in urban areas (Kabisch et al., 2017).

This study investigates the potential of green infrastructure to mitigate climate change impacts in Samaru, Zaria, leveraging spatial technology and participatory approaches. Geographic Information Systems (GIS) were employed

to analyse critical urban dynamics, including land use patterns, vegetation coverage, and areas prone to flooding and extreme heat. Furthermore, participatory mapping engaged local communities in identifying priority areas for green infrastructure interventions, fostering a sense of ownership and ensuring context-specific solutions.

Despite its proven benefits, green infrastructure adoption in Nigerian cities faces numerous barriers. These include limited public awareness, fragmented urban planning frameworks, and inadequate funding mechanisms (Olawuyi and Adedeji, 2022). Addressing these barriers is essential to realize the full potential of green infrastructure in fostering climate-resilient cities.

This paper contributes to the growing body of knowledge on climate change mitigation through green infrastructure by highlighting the synergy between community engagement and spatial technology in urban planning. The findings emphasize the importance of integrating green infrastructure principles into urban policies, particularly in rapidly urbanizing areas like Samaru, to enhance urban liveability, promote sustainable development, and mitigate climate-related risks.

LITERATURE REVIEW

The role of green infrastructure in addressing climate change impacts has garnered significant attention in recent years. Numerous studies underscore its effectiveness in mitigating urban heat islands, managing stormwater, and enhancing biodiversity (Zölch et al., 2017). Green roofs, for instance, have been shown to reduce building energy consumption by providing insulation, while urban forests contribute to carbon sequestration and air purification (Berardi et al., 2014).

In developing regions, including sub-Saharan Africa, the implementation of green infrastructure is often constrained by

institutional, financial, and social challenges (Lwasa, 2020). Limited awareness and a lack of technical expertise frequently hinder the adoption of these solutions. Additionally, urban planning policies in many African cities remain fragmented, with insufficient integration of sustainability principles (Olawuyi and Adedeji, 2022).

Recent advancements in spatial technology, particularly GIS, have facilitated more precise and data-driven urban planning. GIS has been used to map flood-prone areas, identify urban heat islands, and assess vegetation cover, providing critical insights for green infrastructure interventions (Coutts et al., 2016). Participatory mapping has further enriched this process by incorporating local knowledge, ensuring that proposed solutions align with community needs and priorities (Ramaswami et al., 2016).

However, the transition from gray to green infrastructure requires a paradigm shift in urban development. Policies must prioritize nature-based solutions, and funding mechanisms should be restructured to support long-term sustainability. Public-private partnerships have emerged as a viable model for financing green infrastructure projects, with examples from cities like Singapore and Melbourne demonstrating their potential (Tan and Jim, 2019).

The literature also highlights the co-benefits of green infrastructure. In addition to mitigating climate change impacts, these systems enhance urban aesthetics, promote physical and mental well-being, and foster social cohesion (Kabisch et al., 2017). Such benefits make green infrastructure a holistic solution that addresses environmental, social, and economic dimensions of urban sustainability.

In the context of Samaru, Zaria, existing studies indicate significant opportunities for green infrastructure deployment. The area's rapid urbanization and associated

environmental challenges necessitate innovative approaches to urban planning. Integrating GIS and participatory methods can provide a robust framework for identifying and implementing green infrastructure solutions, addressing both environmental and socio-economic needs.

METHODOLOGY

This study employs quantitative methods to comprehensively examine the role of green infrastructure in mitigating climate change impacts in Samaru, Zaria, Nigeria. The research utilizes Geographic Information Systems (GIS) analysis, remote sensing, and statistical modelling to assess urban climate risks and evaluate the effectiveness of green infrastructure interventions in enhancing climate resilience (Creswell and Creswell, 2018). This approach provides a data-driven framework for understanding land-use patterns, environmental stressors, and sustainable urban planning strategies.

Study Area

The research focuses on Samaru, Zaria, Nigeria, a rapidly urbanizing area experiencing urban heat island (UHI) effects, increased flooding, and declining air quality due to the dominance of Gray infrastructure. The region experiences a tropical climate, with average temperatures exceeding 35°C and seasonal rainfall between 900 - 1,200 mm per year (Abubakar et al., 2021). Limited green space and poor urban planning exacerbate climate risks, making green infrastructure interventions essential for urban sustainability (Rahman et al., 2022).

Data Collection and Analysis

green infrastructure for climate change mitigation. Primary data collection includes field observations to assess urban land use patterns, vegetation coverage, and areas affected by urban heat islands (UHIs) and flooding. participatory mapping engages community members in identifying priority areas for green infrastructure interventions, ensuring locally tailored solutions

(Ramaswami et al., 2016). Secondary data sources include satellite imagery and GIS data, which are used to analyze urban vegetation distribution, land surface temperatures, and flood-prone areas (Coutts et al., 2016).

The study utilizes quantitative analysis, incorporating GIS and remote sensing techniques to map urban heat island (UHI) intensity, green space distribution, and flood-prone areas, facilitating the identification of key intervention zones for climate resilience (Coutts et al., 2016).

RESULTS AND DISCUSSION

Samaru Land Use Cover

The land use cover analysis of Samaru, Zaria, derived from the LANDSAT map (Figure 1), highlights the spatial distribution of land cover types essential for assessing the potential of green infrastructure for climate change mitigation, categorizing the land into built-up areas (6.23 km², 15%), vegetation cover (11.20 km², 27%), water bodies (0.43 km², 1%), and farmland (23.89 km², 57%).

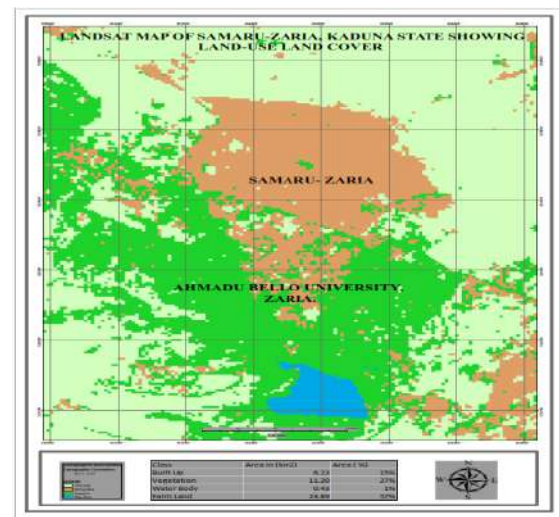


Figure 1: Samaru Land Use Cover
Source: Authors (2025)

The land use cover analysis of Samaru, Zaria has significant implications for green infrastructure planning and climate change mitigation, highlighting the urgent need for sustainable urban interventions. The limited

vegetation cover (27%) is insufficient to counteract urban heat island (UHI) effects, particularly with 15% of the area occupied by built-up infrastructure, which contributes to higher land surface temperatures, reduced air quality, and increased energy demand for cooling (Kabisch et al., 2017). Expanding urban forests, green roofs, and vegetative buffer zones is essential for mitigating heat stress and improving microclimatic conditions. Additionally, with 57% of the land area designated as farmland, incorporating agroforestry and climate-smart agricultural practices could enhance carbon sequestration, biodiversity conservation, and water retention, while techniques such as permeable farming surfaces and riparian buffers could reduce soil erosion and improve irrigation efficiency (Lwasa, 2020). However, the scarcity of water bodies (1%) raises concerns about stormwater regulation and urban cooling, necessitating the implementation of blue-green infrastructure, such as constructed wetlands, rain gardens, and permeable pavements, to improve flood management and water conservation (Coutts et al., 2016). The expansion of built-up areas (15%) further underscores the importance of integrating sustainability principles into urban planning to prevent unregulated development and environmental degradation. Leveraging spatial technology, such as GIS-based urban planning, alongside community-led afforestation efforts, can facilitate climate-resilient city development by ensuring equitable green space distribution and environmentally responsible land-use planning (Ramaswami et al., 2016).

Findings and Recommendations

- a. With only 27% vegetation cover, Samaru's green spaces are insufficient to effectively mitigate urban heat island (UHI) effects, leading to increased environmental stress. Additionally, the 15% built-up area, dominated by roads, buildings, and other impermeable surfaces, exacerbates higher land surface temperatures, reduced air quality, and increased energy demand for cooling, further intensifying climate-related challenges in the region (Kabisch et al., 2017).
- b. With 57% of the land designated as farmland, Samaru has significant potential for agroforestry, carbon sequestration, and biodiversity conservation. Integrating climate-smart agricultural techniques, such as permeable farming surfaces and riparian buffers, can enhance soil moisture retention, reduce erosion, and improve irrigation efficiency, contributing to more sustainable land management practices (Lwasa, 2020).
- c. With water bodies covering only 1% of the total area, Samaru faces significant challenges in stormwater management and urban cooling. To address these issues, implementing blue-green infrastructure, such as constructed wetlands, rain gardens, and permeable pavements, is essential for enhancing flood control and improving water conservation (Coutts et al., 2016).
- d. With 15% of the land designated as built-up areas, Samaru faces the risk of unregulated urban expansion, which could lead to environmental degradation and the loss of green spaces. To promote sustainable urban development, it is crucial to integrate sustainability principles into urban planning by leveraging spatial technology (GIS) and community-led afforestation programs to ensure ecologically responsible land use and climate resilience (Ramaswami et al., 2016).

RECOMMENDATIONS

- a. Expanding urban forests, green roofs, and vegetative buffer zones is essential for mitigating heat stress and enhancing air quality in Samaru. Additionally, promoting community-led tree planting programs can significantly increase vegetation cover and improve urban microclimates, fostering a more climate-resilient and sustainable urban environment.
- b. Encouraging agroforestry and sustainable farming techniques can

significantly enhance carbon sequestration, biodiversity conservation, and soil retention in Samaru. Additionally, implementing permeable farming surfaces and riparian buffers will help reduce erosion and improve water retention, promoting more resilient and environmentally sustainable agricultural practices.

- c. Developing blue-green infrastructure, such as constructed wetlands and rain gardens, is crucial for improving stormwater regulation and flood control in Samaru. Additionally, increasing rainwater harvesting systems and promoting sustainable water resource management in urban planning will enhance water conservation and resilience to extreme weather conditions.
- d. Integrating GIS-based spatial planning is essential for ensuring the equitable distribution of green spaces and promoting sustainable urban expansion in Samaru. Additionally, implementing strict land-use policies will help prevent unregulated development and preserve ecological balance, supporting long-term environmental sustainability.

Summary and Conclusion

This study highlights the critical role of green infrastructure in mitigating climate change impacts in Samaru, Zaria, Nigeria, with a focus on urban heat island (UHI) effects, flood management, and sustainable land use planning. The findings reveal that insufficient vegetation cover (27%) and the expansion of built-up areas (15%) contribute to higher temperatures, reduced air quality, and increased energy consumption. Meanwhile, high farmland coverage (57%) presents opportunities for climate-smart agricultural practices, such as agroforestry and soil conservation techniques to enhance carbon sequestration and water retention. However, the scarcity of water bodies (1%) poses a significant challenge to stormwater regulation and urban cooling, emphasizing the need for blue-green infrastructure solutions, such as

constructed wetlands and permeable pavements.

To address these challenges, the study recommends expanding urban forests, green roofs, and vegetative buffer zones to mitigate UHI effects, promoting community-led afforestation programs, and leveraging GIS-based urban planning to ensure sustainable land use and equitable green space distribution. Additionally, climate-smart agricultural techniques, such as permeable farming surfaces and riparian buffers, should be integrated into farmland management to enhance biodiversity and soil conservation. Furthermore, stormwater management strategies, including rain gardens and water harvesting systems, must be incorporated into urban planning to improve water conservation and flood resilience.

In conclusion, the integration of spatial technology and community engagement in green infrastructure planning is crucial for enhancing climate resilience, promoting sustainable development, and improving urban liveability in Samaru. By adopting nature-based solutions and data-driven urban planning strategies, cities in Nigeria can transition toward sustainable urban environments that are better equipped to withstand climate-related challenges while ensuring environmental, economic, and social sustainability.

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IMPACT OF CRUDE OIL EXPLOITATION ON PLANT DIVERSITY STOCK IN WETLAND ECOSYSTEMS IN BAYELSA STATE, NIGERIA

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ABSTRACT

This study investigated the impact of crude oil exploitation on plant diversity stock in wetland ecosystems in Bayelsa State, Nigeria. Three crude oil-impacted communities—Ayamasa, Ibelebiri, Ikarama, and Okumbiri—that have never experienced a crude oil spill served as a control in this study. To get the required data, four 50 x 10 m line transects were set up at each study site, 20 meters apart. From each of the 50 × 10 m plots, five 10 × 10 m subplots were additionally marked out (labelled A, B, C, D, and E). A measuring tape was used to determine the girth of each tree in each of the designated transects at breast height (trees with DBH were divided as 1-10 cm, 11-20 cm, 21-30 cm, 31-40 cm, 41-50 cm, and 50 cm and above). The data was processed using Palaeontological Statistical Software (PAST). The findings showed that, in dry season samples, there were more trees in the control area than in crude oil-impacted areas (8<14<16<28); in wet season samples, the numbers were similar (8<14<19<28). Herbs were more prevalent in the sites of the crude oil spill than in the control area. Plant species in the control group exhibit more diversity as measured by the Shannon-Weiner Index (3.695/3.987), whereas regions that have previously undergone cleanup efforts for crude oil spills showed signs of rapid recovery with a comparatively high diversity index (2.312/3.629) in both sample seasons. In total there was more plant abundance in the control compared to the crude-oil-impacted sites. The family Poaceae was dominant throughout the studied area in both the dry and wet seasons, with a total of 44 plant families found in the dry season and 56 in the rainy season. Results showed crude oil spills are detrimental to plant variety. As a result, precautions must be taken to prevent future spills, and stakeholders should approach crude oil spill remediation projects proactively rather than reactively.

INTRODUCTION

Nigeria is one of the countries in Africa that is blessed with diverse, abundant natural resources, with the oil and gas sector contributing 65 percent of the country's tax revenue (Adegbola, Fakile, Eluyela, Onabote, John, and Ifeanyichukwu, 2023). Despite the huge revenue derived from the oil and gas

sector in the country, the poor management of the sector has led to a series of environmental crises related to oil spills and gas flaring in oil-bearing communities of the Niger Delta. Nweze and Edame (2016) opined that all the phases of oil operations, from discovery to drilling to transportation, lead to the extinction of flora diversity in the Niger Delta. The extinction or degradation of

flora diversity has become endemic because crude oil (petroleum) hydrocarbons are one of the common groups of persistent organic pollutants in the environment of the Niger Delta today. However, plants may respond differently to the presence of crude oil because of the mutagenic and carcinogenic properties it possesses (Skrypnik, Maslennikov, Novikova, and Kozhikin, 2021).

It is imperative to note that plant species have different varying tolerance capacities for toxicity. However, the concentration levels of low-boiling compounds, unsaturated compounds, aromatics, and acids to a large extent determine the toxic impacts on plants (Odiyi, Giwa, Abiya, and Babatunde, 2020). When oil spills occur, the pollutant penetrates into the plant; the oil may travel in the intercellular spaces and possibly also in the vascular system. Cell membranes are damaged by penetration of hydrocarbon molecules, leading to leakage of cell contents, and oil may enter the cells. Oils reduce transpiration rate, probably by blocking stomata and intercellular spaces (Odukoya, Lambert, and Skrabani, 2019). These penetrations into the plant system destabilize the plant's metabolism. In a study by Tanee and Albert (2015) on the long-term effects of crude oil spills on plant composition at Kwawa, Ogoni, it was reported that crude oil spills reduce plant growth, affect photosynthetic processes, increase oxidation stress, and alter nutrient uptake mechanisms, among others.

On account of these, Obi-Iyeke (2022) recognized and subsequently submitted that plant species react differently to disturbances and alterations in their environment; hence,

the knowledge of species diversity is helpful for ascertaining the impact of biotic disturbances, the rate of succession, and environmental stability. In view of this, the aim of this study is to investigate the effects of crude oil spills on plant diversity in the wetland ecosystems in Bayelsa State, Nigeria.

MATERIALS AND METHODS

Study Area

The study area includes the following communities: Ayamasa in Ekeremor LGA, Ibelebiri in Ogbia LGA, Ikarama in Yenagoa LGA, and Okumbiri in Sagbama LGA. The latter serves as a control because it has no history of crude oil pollution. Bayelsa State, located in the south-south part of Nigeria, is situated in the core of the Niger Delta. The waters of the Atlantic Ocean dominate its southern and western borders, and it shares a border with Rivers State to the east and Delta to the north (Alexander, Dada, and Oluwasegun, 2017). It has a total area of 21,100 square kilometers (Kadafa, 2012). It is geographically positioned on latitude $04^{\circ} 15^1$ North, $05^{\circ} 23^1$ South, and longitude $05^{\circ} 22^1$ West and $06^{\circ} 45^1$ East (Figure 1). The region is largely made up of tropical rainforests, with more than three quarters of the region covered by water, with a somewhat low terrain spanning from Ekeremor to Nembe. According to the Niger Delta Development Commission (Esara, Asuquo, and Udoh, 2024), the region's main ecological zones are the lowland rainforest zone, the derived savannah zone in the north, the freshwater swamp forest zone, the mangrove forest and coastal vegetation zone, and others.

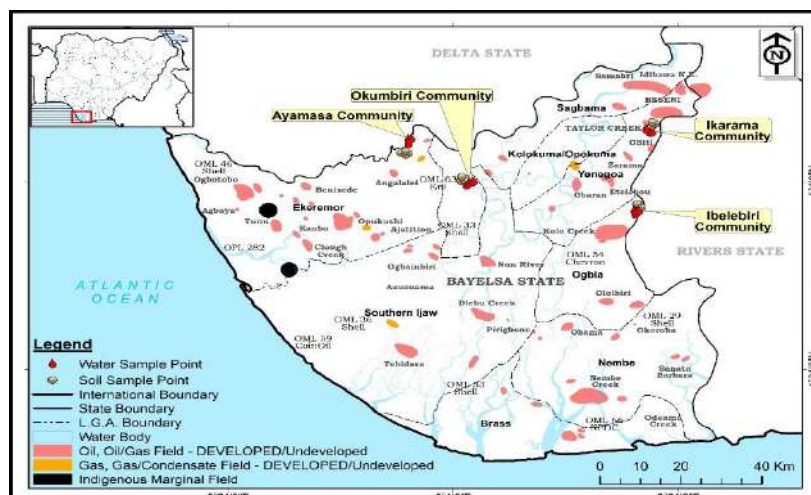


Figure 1: Sample Areas and Oil and Gas Fields in Bayelsa State

Source: Modified from Nigeria-Sao Tome Joint Development Zone Map, 2005

The region is completely below sea level and is home to an intricate network of wetlands made up of mangroves and swiftly moving rivers (Esara et al., 2024). Among the many creeks and rivers in the south that flow into the Atlantic Ocean are significant ones such as San Bartholomew, Brass, Nun, Ramos, Santa Barbara, St. Nicholas, Sangana, Fishtown, Ikebiri Creek, Middleton, Digatoro Creek, Pennington, and Dobo (Nweze and Edame, 2016).

The average yearly rainfall in the state ranges between 2000 and 2800 mm, while it occasionally exceeds 2900 mm (Bello and Nwaeke, 2023). Rainfall often starts in February and lasts until November, with July and September frequently being the wettest months. The average monthly temperature ranges from 21 °C to 23 °C for the minimum and 28 °C to 38 °C for the highest (Esara et al., 2023). Relative humidity is high, and it increases when progress is made towards the coast (ibid).

Sample Design and Data Collection

Based on the accepted procedure for gathering ecological data, the stratified random sample approach was applied in this

investigation. Four sites were specifically chosen, one from each of the state's senatorial districts. The locations include the Okumbiri community, which acts as the control; the Ibelebiri community in Bayelsa East; the Ikarama community in Bayelsa Central; and the Ayamasa community in Bayelsa West district. It is important to remember that one area was utilized as the control, and three of the sample locations had a history of crude oil spillage activity.

Data on the flora species were gathered at each research location using four line transects that were 50 meters by 10 meters (50 x 10 m) and 20 meters apart. From each of the 50 x 10 m plots, five 10 x 10 m subplots were also plotted out, and they were designated as A, B, C, D, and E. All tree species, shrubs, and herbs in the designated line transects and subplots were identified with the help of botanists from the University of Calabar using identification guides by Nyananyo (2006).

Additional information pertinent to each plant species collected in the field includes the date of collection, the latitude and longitude of each plot, the general condition of the vegetation, and the number of each

species. A measuring tape was used to measure the girth of every tree in each of the designated transects. Trees with breast heights of 1–10 cm, 11–20 cm, 21–30 cm, 31–40 cm, and 41–50 cm, as well as those with DBH of 50 cm and more, were measured at breast height (3.5 m). Through this measurement, the researcher was able to gain a deeper comprehension of the dynamics of anthropogenic activity in the studied regions.

Estimation of Flora Species

Species Density: This represents the total number of distinctive plant species present in a particular location. It is an estimate of the amount of vegetation in a transect that indicates how strong the ecosystem is (Obi-Iyeke 2022). It helps by offering a guide on the overall number of species, their composition, and their abundance in the environment of polluted oil fields and the control. According to Obi-Iyeke (2022), vegetation changes brought on by anthropogenic disturbances like oil pollution, climate change, or any other human-induced environmental impact can be identified using density. We used the formula below to estimate flora species density in this study:

Density = total number of individual species/total number of transects studied

Species Abundance: This is the total number of individuals of each species in the community per unit area. It is calculated as:

Abundance = total number of individuals of each species in all transects / total number of transects in which the species occurs.

Percentage Frequency: This is a measure of how often a species occurs in a sample. It was calculated using the formula thus:

Number of transects in which species occurred / Total number of transects studied * 100.

Species Diversity: The species diversity index ('H') was computed using the Shannon Wiener index (1949). The formula for the estimation of the Shannon Wiener index (H) is:

$$H = - \sum_{i=1}^{S_{obs}} p_i \log_e p_i$$

Where:

H=Shannon diversity index

S= the total number of species in the habitat

P_i= proportion S (species in the family) made up of the *i*th species

Ln= natural logarithm.

Species evenness (E): This was calculated by adopting Shannon's equitability (EH) thus:

EH = H/ log(S).

Methods of Data Analysis

The Paleontological Statistics software program developed by Hammer *et al.* (2001) was used to analyze the terrestrial plant diversity indices used in this investigation.

RESULTS AND DISCUSSION

The flora structures of the sampled places throughout the dry and wet seasons are shown in Tables 1a and 1b, respectively. According to the table, there are more trees in the control area with no history of a crude oil spill than in other areas where there are current reports of previous crude oil spills. Ayamasa has, nevertheless, demonstrated positive signs of recovery following remediation. Climate factors may have also played a role in the limited number of plant stands counted in the dry season (Table 1a), as evidenced by the reasonably high number of plant stands seen in the wet season samples (Table 1b). According to earlier

research, the low number of trees in areas affected by crude oil spills is caused by lower regeneration, tree mortality, and vegetation structure change (Obi-Iyeke, 2022). Furthermore, oil spills have been known to cause defoliation, limb loss, and ultimately

the collapse of large trees (Skrypniuk *et al.*, 2021). This could be the path taken in the event of crude oil spills in the areas examined, which would account for the limited stands seen in this investigation.

Table 1a: Species identified across the four sampled communities in Bayelsa State during the dry season.

S/N	Family	Name of Species	Life Form	AY	IB	IK	OK (Cont)	RF(%)
1	Anacardiaceae	<i>Lannea nigritana</i>	Tree	0	0	4	0	0.66
		<i>Spondias mombin</i>	Tree	0	7	8	3	1.99
2	Annonaceae	<i>Cleistopholis patens</i>	Tree	5	0	3	13	1.99
3	Apocyanaceae	<i>Alstonia boonei</i>	Tree	5	0	0	7	1.32
		<i>Alstonia macrophylla</i>	Tree	2	0	0	0	0.66
		<i>Funtumia elastica</i>	Tree	1	0	0	7	1.32
		<i>Saba senegalensis</i>	Climber	0	0	0	6	0.66
4	Arecaceae	<i>Calamus deerratus</i>	Climber	0	0	0	20	0.66
		<i>Elaeis guineensis</i>	Tree	0	0	14	20	1.32
		<i>Raphia hookeri</i>	Tree	3	0	0	0	0.66
5	Asclepiadaceae	<i>Gongronema latifolium</i>	Climber	10	0	2	0	1.32
6	Aspleniaceae	<i>Asplenium nidus</i>	Fern	0	0	0	11	0.66
7	Asteraceae	<i>Aspilia africana</i>	Herb	72	67	0	13	1.99
		<i>Chromolaena odorata</i>	Herb	34	104	0	0	1.32
8	Caesalpinioideae	<i>Albizia adianthifolia</i>	Tree	0	0	0	2	0.66
		<i>Anthonotha macrophylla</i>	Tree	0	0	4	2	1.32
9	Cannabaceae	<i>Trema orientale</i>	Shrub	0	7	0	0	0.66
10	Clusiaceae	<i>Allanblackia gabonensis</i>	Tree	0	0	0	11	0.66
		<i>Harungana madagascariensis</i>	Tree	12	5	0	7	1.99
		<i>Symphonia globulifera</i>	Tree	3	0	5	15	1.99
11	Combretaceae	<i>Combretum racemosum</i>	Climber	26	0	0	39	1.32
		<i>Combretum tomentosum</i>	Climber	24	0	0	0	0.66
12	Costaceae	<i>Costus afer</i>	Herb	28	10	0	13	1.99

13	Cyperaceae	<i>Cyperus</i> sp.	Sedges	47	0	0	0	0.66
14	Davalliaceae	<i>Nephrolepis biserrata</i>	Fern	24	0	19	39	1.99
15	Detarioideae	<i>Hymenaea courbaril</i>	Shrub	2	0	0	0	0.66
16	Dilleniaceae	<i>Tetracera alnifolia</i>	Climber	3	0	5	28	1.99
17	Ebernaceae	<i>Diospyros crassiflora</i>	Tree	0	0	0	5	0.66
18	Euphorbiaceae	<i>Alchornea cordifolia</i>	Shrub	52	25	34	48	2.65
		<i>Alchornea latifolia</i>	Shrub	0	0	9	0	0.66
		<i>Macaranga barteri</i>	Tree	0	0	0	18	0.66
		<i>Ricinodendron heudelotii</i>	Tree	0	1	0	0	0.66
		<i>Uapaca heudelotii</i>	Tree	0	0	0	7	0.66
19	Lauraceae	<i>Cinnamomum cassia</i>	Tree	0	0	0	7	0.66
20	Lecythidaceae	<i>Napoleonaea imperialis</i>	Shrub	0	0	4	17	1.32
21	Longanaceae	<i>Anthocleista djalensis</i>	Tree	6	0	0	0	0.66
		<i>Anthocleista procera</i>	Tree	0	0	4	3	1.32
22	Malvaceae	<i>Ceiba pentandra</i>	Tree	0	0	0	4	0.66
		<i>Glyphaea brevis</i>	Shrub	0	0	0	3	0.66
		<i>Grewia flavescens</i>	Shrub	8	0	0	0	0.66
		<i>Sterculia tragacantha</i>	Tree	0	0	0	18	0.66
		<i>Triplochiton scleroxylon</i>	Tree	0	0	0	4	0.66
		<i>Triumfetta rhomboidei</i>	Shrub	8	13	0	0	1.32
23	Marantaceae	<i>Marantochloa congensis</i>	Herb	0	0	0	22	0.66
		<i>Marantochloa purpurea</i>	Herb	0	0	7	26	1.32
24	Melastomataceae	<i>Melastoma malabathricum</i>	Shrub	24	0	0	0	0.66
25	Meliaceae	<i>Carapa procera</i>	Tree	5	0	0	23	1.32
26	Menispermaceae	<i>Anamirta Cocculus</i>	Shrub	0	0	5	0	0.66
27	Mimosoideae	<i>Mimosa pigra</i>	Herb	0	0	144	0	1.32
28	Moraceae	<i>Ficus exasperata</i>	Tree	0	9	0	0	0.66
		<i>Ficus polita</i>	Tree	0	2	0	0	0.66
		<i>Ficus sur</i>	Tree	12	9	12	0	1.99

29	Myrtaceae	<i>Psidium guajava</i>	Tree	0	0	2	0	0.66
30	Onagraceae	<i>Ludwigia decurrens</i>	Herb	42	69	0	0	1.32
31	Papilionoideae	<i>Baphia nitida</i>	Shrub	12	0	0	12	1.32
		<i>Dalbergia horrida</i>	Shrub	0	0	4	1	1.32
		<i>Millettia aboensis</i>	Tree	0	6	9	10	1.99
		<i>Philenoptera cyanescens</i>	Shrub	42	0	0	0	0.66
		<i>Pterocarpus santalinoides</i>	Tree	0	0	2	0	0.66
32	Passifloraceae	<i>Smeathmannia pubescens</i>	Shrub	0	0	8	37	1.32
33	Phyllanthaceae	<i>Bridelia micrantha</i>	Tree	11	0	0	6	1.32
		<i>Margaritaria discoidea</i>	Tree	0	0	0	2	0.66
		<i>Spondianthus preussii</i>	Tree	5	0	0	21	1.32
34	Poaceae	<i>Coix lachrymal</i>	Herb	61	21	29	10	2.65
		<i>Echinochloa crus-pavonis</i>	Herb	0	0	161	0	0.66
35	Polypodiaceae	<i>Platyserium staghorn</i>	Fern	0	0	0	10	0.66
36	Rubiaceae	<i>Brenania brieyi</i>	Tree	0	0	2	0	0.66
		<i>Mitragyna ledermannii</i>	Tree	6	0	0	0	0.66
		<i>Mussaenda polita</i>	Shrub	3	2	4	12	2.65
		<i>Oxyanthus speciosus</i>	Shrub	0	0	3	0	0.66
		<i>Oxyanthus unilocularis</i>	Shrub	0	0	0	3	0.66
		<i>Pauridiantha floribunda</i>	Shrub	16	5	6	8	2.65
		<i>Pausinystalia macroceras</i>	Shrub	0	0	0	6	0.66
		<i>Psychotria nervosa</i>	Shrub	0	0	9	2	1.32
		<i>Tabernaemontana pachysiphon</i>	Shrub	0	0	0	1	0.66
		<i>Villaria odorata</i>	Shrub	6	0	7	17	1.99
37	Sapindaceae	<i>Allophylus africanus</i>	Tree	0	0	7	5	1.32
		<i>Paullinia pinnata</i>	Climber	24	6	7	34	2.65
38	Sapotaceae	<i>Pouteria campechiana</i>	Tree	5	0	0	6	1.32
39	Smilacaceae	<i>Smilax anceps</i>	Climber	23	7	7	41	2.65
40	Solanaceae	<i>Solanum torvum</i>	Shrub	0	5	0	0	0.66

41	Sterculiaceae	<i>Cola laurifolia</i>	Tree	0	0	1	0	0.66
42	Strelitziaceae	<i>Strelitzia reginae</i>	Herb	0	0	0	13	0.66
43	Urticaceae	<i>Musanga cecropioides</i>	Tree	4	2	0	7	1.99
		<i>Myrianthus arboreus</i>	Tree	0	0	0	7	0.66
44	Verbanaceae	<i>Vitex doniana</i>	Tree	2	0	0	6	1.32
Total	Families (44)	Plant Species (86)		678	382	551	738	100.00

Table 1b: Species identified across the four sampled communities in Bayelsa state during the wet season

S/N	Family	Name of Species	Life Form	AY	IB	IK	OK (Cont)	RF (%)
1	Anacardiaceae	<i>Lannea nigritana</i>	Tree	0	0	4	0	0.46
		<i>Spondias mombin</i>	Tree	0	7	8	3	1.39
2	Annonaceae	<i>Cleistopholis patens</i>	Tree	2	0	3	13	1.39
3	Apocynaceae	<i>Alstonia boonei</i>	Tree	2	0	0	7	0.93
		<i>Alstonia macrophylla</i>	Tree	1	0	0	0	0.46
		<i>Funtumia elastica</i>	Tree	1	0	0	7	0.93
		<i>Saba senegalensis</i>	Climber	0	0	0	6	0.46
		<i>Angadenia berteroi</i>	Herb	0	8	0	0	0.46
		<i>Rauvolfia vomitoria</i>	Shrub	0	0	4	0	0.46
4	Arecaceae	<i>Calamus deerratus</i>	Climber	0	0	0	20	0.46
		<i>Elaeis guineensis</i>	Tree	0	0	14	20	0.93
		<i>Raphia hookeri</i>	Tree	2	0	0	0	0.46
5	Asclepiadaceae	<i>Gongronema latifolium</i>	Climber	10	0	2	0	0.93
6	Aspleniaceae	<i>Asplenium nidus</i>	Fern	0	0	0	11	0.46
7	Asteraceae	<i>Ageratum conyzoides</i>	Herb	0	33	0	0	0.46
		<i>Aspilia Africana</i>	Herb	42	23	50	13	1.85
		<i>Chromolaena odorata</i>	Herb	34	16	0	0	0.93
		<i>Conyza sumatrensis</i>	Herb	0	17	0	0	0.46
		<i>Crassocephalum crepidioides</i>	Herb	0	10	0	0	0.46
		<i>Cyanthillium cinereum</i>	Herb	0	27	0	0	0.46
		<i>Emilia sonchifolia</i>	Herb	0	0	38	0	0.46
8	Caesalpinioideae	<i>Albizia adianthifolia</i>	Tree	0	0	0	2	0.46
		<i>Anthonothea macrophylla</i>	Tree	0	0	4	2	0.93

9	Cannabaceae	<i>Trema orientale</i>	Shrub	0	7	0	0	0.46
10	Clusiaceae	<i>Allanblackia gabonensis</i>	Tree	0	0	0	11	0.46
		<i>Harungana madagascariensis</i>	Tree	5	5	0	7	1.39
		<i>Symphonia globulifera</i>	Tree	3	0	5	15	1.39
11	Colchicaceae	<i>Gloriosa superba</i>	Liana	0	0	11	0	0.46
12	Combretaceae	<i>Combretum racemosum</i>	Climber	10	0	0	19	0.93
		<i>Combretum tomentosum</i>	Climber	13	0	0	0	0.46
13	Convolvulaceae	<i>Ipomea involucrata</i>	Liana	35	14	0	0	0.93
		<i>Ipomoea indica</i>	Liana	0	16	0	0	0.46
		<i>Ipomea ratan</i>	Liana	0	0	30	0	0.46
14	Costaceae	<i>Costus afer</i>	Herb	28	10	0	13	1.39
15	Cucurbitaceae	<i>Sicyos angulatus</i>	Liana	9	0	0	0	0.46
16	Cyatheaceae	<i>Sphaeropteris cooperi</i>	Fern	0	0	0	15	0.46
17	Cyperaceae	<i>Cyperus haspan</i>	Herb	0	22	59	0	0.93
		<i>Cyperus sp.</i>	Sedges	71	0	0	0	0.46
		<i>Scleria depressa</i>	Herb	0	15	0	0	0.46
18	Davalliaceae	<i>Nephrolepis biserrata</i>	Fern	84	0	19	39	1.39
19	Detarioideae	<i>Hymenaea courbaril</i>	Shrub	3	0	0	0	0.46
20	Dilleniaceae	<i>Tetracera alnifolia</i>	Climber	3	0	5	28	1.39
21	Dryopteridaceae	<i>Ctenitis sp</i>	Fern	0	0	0	37	0.46
22	Ebernaceae	<i>Diospyros crassiflora</i>	Tree	0	0	0	5	0.46
23	Euphobiaceae	<i>Spondianthus preussii</i>	Shrub	5	0	3	21	1.39
		<i>Alchornea cordifolia</i>	Shrub	42	15	34	48	1.85
		<i>Alchornea latifolia</i>	Shrub	0	0	9	0	0.46
		<i>Croton hirtus</i>	Herb	0	9	0	0	0.46
		<i>Macaranga barteri</i>	Tree	4	0	0	18	0.93
		<i>Riciodendron heudelotii</i>	Tree	0	1	0	0	0.46
		<i>Uapaca heudelotii</i>	Tree	2	0	0	7	0.93
24	Fabaceae	<i>Dioclea reflexa</i>	Liana	0	11	0	0	0.46
		<i>Sindora wallichii</i>	Shrub	3	0	0	0	0.46
25	Irvingiaceae	<i>Klainedoxa gabonensis</i>	Tree	1	0	0	0	0.46
26	Lamiaceae	<i>Coleus monostachyus</i>	Herb	0	16	0	0	0.46
27	Lauraceae	<i>Cinnamomum cassia</i>	Tree	0	0	0	7	0.46

28	Lecythidaceae	<i>Napoleonaea imperialis</i>	Shrub	0	0	14	17	0.93
29	Longanaceae	<i>Anthocleista djalensis</i>	Tree	2	0	0	0	0.46
		<i>Anthocleista procera</i>	Tree	0	0	4	3	0.93
30	Lygodiaceae	<i>Lygodium microphyllum</i>	Fern	13	0	0	16	0.93
		<i>Lygodium smithianum</i>	Fern	19	0	0	38	0.93
31	Malvaceae	<i>Ceiba pentandra</i>	Tree	0	0	0	4	0.46
		<i>Glyphaea brevis</i>	Shrub	0	0	0	3	0.46
		<i>Grewia flavescens</i>	Shrub	8	0	0	0	0.46
		<i>Sterculia tragacantha</i>	Tree	0	0	0	18	0.46
		<i>Triplochiton scleroxylon</i>	Tree	0	0	0	4	0.46
		<i>Triumfetta rhomboidei</i>	Shrub	8	19	0	0	0.93
		<i>Urena lobata</i>	Herb	0	27	56	0	0.93
32	Marantaceae	<i>Marantochloa congensis</i>	Herb	0	0	0	42	0.46
		<i>Marantochloa purpurea</i>	Herb	0	11	7	36	1.39
33	Melastomataceae	<i>Melastoma malabathricum</i>	Shrub	5	0	0	0	0.46
34	Meliaceae	<i>Carapa procera</i>	Tree	2	0	0	23	0.93
35	Menispermaceae	<i>Anamirta Cocculus</i>	Shrub	0	0	5	0	0.46
36	Mimosoideae	<i>Mimosa pigra</i>	Herb	0	0	68	0	0.46
37	Moraceae	<i>Ficus exasperata</i>	Tree	0	9	0	0	0.46
		<i>Ficus polita</i>	Tree	0	2	0	0	0.46
		<i>Ficus sur</i>	Tree	12	9	12	0	1.39
38	Myrtaceae	<i>Psidium guajava</i>	Tree	0	0	2	0	0.46
39	Onagraceae	<i>Ludwigia decurrens</i>	Herb	62	20	51	0	1.39
40	Papilionoideae	<i>Baphia nitida</i>	Shrub	4	0	0	32	0.93
		<i>Dalbergia horrida</i>	Shrub	6	0	4	1	1.39
		<i>Millettia aboensis</i>	Tree	0	6	9	10	1.39
		<i>Philenoptera cyanescens</i>	Shrub	18	0	0	0	0.46
		<i>Pterocarpus santalinoides</i>	Tree	0	0	2	0	0.46
41	Passifloraceae	<i>Smeathmannia pubescens</i>	Shrub	0	0	8	37	0.93
42	Phyllanthaceae	<i>Bridelia micrantha</i>	Shrub	6	0	3	26	1.39
		<i>Margaritaria discoidea</i>	Tree	0	0	0	2	0.46

		<i>Phylanthus amarus</i>	Herb	58	17	27	0	1.39
43	Poaceae	<i>Cenchrus purpureus</i>	Herb	0	0	36	0	0.46
		<i>Coix lachrymal</i>	Herb	51	21	29	10	1.85
		<i>Dactylis glomerata</i>	Herb	0	24	0	0	0.46
		<i>Dichantherium clandestinum</i>	Herb	19	0	0	0	0.46
		<i>Digitaria ciliaris</i>	Herb	0	42	0	0	0.46
		<i>Digitaria horizontalis</i>	Herb	0	24	0	0	0.46
		<i>Digitaria ischaemum</i>	Herb	0	39	0	0	0.46
		<i>Digitaria radicata</i>	Herb	0	26	0	0	0.46
		<i>Digitaria sanguinalis</i>	Herb	0	34	0	0	0.46
		<i>Echinochloa colona</i>	Herb	25	29	0	0	0.93
		<i>Echinochloa crus-galli</i>	Herb	32	43	0	0	0.93
		<i>Echinochloa crus-pavonis</i>	Herb	0	0	21	0	0.46
		<i>Leersia oryzoides</i>	Herb	0	36	40	0	0.93
		<i>Megathyrus maximus</i>	Herb	0	0	77	0	0.46
		<i>Paspalum notatum</i>	Herb	41	0	0	0	0.46
		<i>Pleuropogon californicus</i>	Herb	0	32	0	0	0.46
		<i>Sacciolepis Africana</i>		0	0	42	0	0.46
		<i>Sorghum halepense</i>	Herb	0	4	0	0	0.46
44	Polypodiaceae	<i>Drynaria laurentii</i>	Fern	0	0	0	17	0.46
		<i>Phlebodium aureum</i>	Fern	0	0	0	15	0.46
		<i>Platynerium coronarium</i>	Fern	0	0	0	11	0.46
		<i>Platynerium staghorn</i>	Fern	0	0	0	10	0.46
45	Pteridaceae	<i>Adiantum caudatum</i>	Fern	0	0	0	12	0.46
		<i>Pteris atrovirens</i>	Fern	0	0	0	19	0.46
46	Rubiaceae	<i>Brenania brieyi</i>	Tree	0	0	2	0	0.46
		<i>Mitragyna ledermannii</i>	Tree	3	0	0	0	0.46
		<i>Mussaenda polita</i>	Shrub	2	2	4	22	1.85
		<i>Nauclea diderrichii</i>	Tree	3	0	0	0	0.46
		<i>Oxyanthus speciosus</i>	Shrub	0	0	3	0	0.46
		<i>Oxyanthus unilocularis</i>	Shrub	0	0	0	23	0.46
		<i>Pauridiantha floribunda</i>	Shrub	10	5	16	18	1.85

		<i>Pausinystalia macroceras</i>	Shrub	0	0	0	26	0.46
		<i>Psychotria nervosa</i>	Shrub	0	0	9	22	0.93
		<i>Spermacoce ocymifolia</i>	Herb	58	0	0	0	0.46
		<i>Tabernaemontana pachysiphon</i>	Shrub	0	0	0	19	0.46
		<i>Villaria odorata</i>	Shrub	6	0	7	17	0.00
47	Sapindaceae	<i>Allophylus africanus</i>	Tree	0	0	7	25	0.93
		<i>Paullinia pinnata</i>	Climber	14	6	7	24	1.85
48	Sapotaceae	<i>Pouteria campechiana</i>	Tree	3	0	0	26	0.93
49	Smilacaceae	<i>Smilax anceps</i>	Climber	8	7	7	31	1.85
50	Solanaceae	<i>Solanum torvum</i>	Shrub	0	5	0	0	0.46
51	Sterculiaceae	<i>Cola laurifolia</i>	Tree	0	0	1	0	0.46
52	Strelitziaceae	<i>Strelitzia reginae</i>	Herb	0	0	0	13	0.46
53	Tectariaceae	<i>Tectaria fernandensis</i>	Fern	0	0	0	37	0.46
54	Urticaceae	<i>Musanga cecropioides</i>	Tree	2	2	0	7	0.93
		<i>Myrianthus arboreus</i>	Tree	0	0	0	7	0.46
55	Verbanaceae	<i>Vitex doniana</i>	Tree	2	0	0	6	0.93
56	Vitaceae	<i>Cissus glaucophylla</i>	Liana	0	0	0	40	0.46
		<i>Cissus verticillate</i>	Liana	0	5	0	48	0.93
Total	Families (56)	Plant Species (137)		917	788	882	1211	100.00

Table 2a: Flora community structure sampled in dry season

Index	Ayamasa	Ibeleberi	Ikarama	Okumbiri (Control)
Trees	16	8	14	28
Shrubs	10	6	11	13
Herbs / Sedges	6	5	4	6
Climbers /Lianas	6	2	4	6
Ferns	1	0	1	3

Ratio of Woody to weak-stem species	2.55	2.00	2.78	3.67

Source: Field survey by the authors (2024)

Table 1b: Flora community structure sampled in wet season

Index	Ayamasa	Ibelebiri	Ikarama	Okumbiri (Control)
Trees	19	8	14	28
Shrubs	13	6	14	13
Herbs / Sedges	12	28	14	6
Climbers / Lianas	8	6	6	6
Ferns	3	0	1	15
Ratio of Woody to weak-stem species	1.57	0.41	1.33	1.83

Source: Field survey by the authors (2024)

Terrestrial flora diversity

Tables 2a and 2b show the diversity of terrestrial flora observed throughout the wet and dry seasons. The tables indicate that, in comparison to areas contaminated by crude oil, a greater number of species families were found in the control group in both season samples (32/41). However, in both sampled campaigns, the control did not exhibit a significant difference in species composition from Ayamasa.

For the dry season sample, the control (Okumbiri) has a Shannon Wiener Index value of 3.695, followed by Ayamasa at 3.103, Ikarama at 2.473, and Ibelebiri at 2.312. Okumbiri (Control) had the highest diversity index (3.984) in wet season samples, followed by Ibelebiri ('H' of 3.316), Ayamasa ('H' of 3.279), and Ikarama (2.813). It's important to remember that the more varied the flora components, the higher the Shannon-Wiener value.

Table 2a: Terrestrial Flora Diversity Index in the dry season

Index	Ayamasa	Ibelebiri	Ikarama	Okumbiri (Control)
Taxa_S	39	21	34	56

Families	28	16	24	32
Individuals/ (n)	788	382	551	738
Density (m ⁻²)	0.394	0.191	0.276	0.369
Dominance _D	0.062	0.150	0.165	0.031
Simpson _1-D	0.938	0.850	0.835	0.969
Shannon _H	3.103	2.312	2.473	3.695
Evenness _e ^{H/S}	0.571	0.481	0.349	0.719
Equitability _J	0.847	0.760	0.701	0.918
Margalef	5.698	3.364	5.228	8.328

Source: Field survey by the authors (2024)

Sampled area (a) = 2(5m) × 4(50m) = 10m×200m = 2,000m² Density = n/a

Table 2b: Terrestrial Flora Diversity Index in the wet season

Index	Ayamasa	Ibelebiri	Ikarama	Okumbiri (Control)
Taxas _S	55	48	49	68
Family	33	23	31	41
Individuals/abundance (n)	1536	3077	1746	1083
Density (m ⁻²)	0.768	1.539	0.873	0.543
Dominance _D	0.049	0.050	0.094	0.025
Simpson _1-D	0.951	0.950	0.906	0.975
Shannon _H	3.279	3.316	2.813	3.894
Evenness _e ^{H/S}	0.658	0.574	0.340	0.722
Equitability _J	0.808	0.857	0.723	0.923
Margalef	7.770	5.852	6.430	9.589

Source: Field survey by the authors (2024)

Sampled area (a) = $2(5\text{m}) \times 4(50\text{m}) = 10\text{m} \times 200\text{m} = 2,000\text{m}^2$ Density = n/a

The fact that rainy season samples exhibited more species diversity than dry season samples can be verified by closely examining the tables. This proves that in addition to human-caused influences, climate variables like air temperature and rainfall may have an impact on the quality-of-life forms. This finding is consistent with a prior study by Obi-Iyeke (2022), in which the Shannon-Wiener index likewise demonstrated that the vegetation in the control site was more varied and diversified than the vegetation in locations affected by crude oil. In contrast to what was found in this investigation, the author reported a greater Shannon-Wiener index.

Floristic inventory of the coastal environment

The floristic component of the four sampled locations shows that 86 plant species from 44 families were identified and counted during the dry season, while 137 plants from 56 families were enumerated during the wet season. The Poaceae family was the most represented, which may be explained by its ability to tolerate and regenerate. Following this were the Asteraceae, Euphorbiaceae, and Mimosoideae. Obi-Iyeke (2022) also recorded the prevalence of Poaceae in sites affected by crude oil in the Niger Delta. Poaceae families accounted for 52% of all families in the area under study, according to Obi-Iyeke.

In another study, Patra, Acharya, Pradhan, and Patra (2021) verified that Poaceae are highly tolerant of crude oil pollution and have proved effective in cleaning contaminated environments due to their ease of cultivation, high biomass, quick development, and

tolerance to hazardous environments. Additionally, they have the ability to accumulate a large quantity of hazardous metals in the rhizosphere while transferring them to the shoot with minimal movement. Due to their sensitivity to the presence of crude oil, some families, such as the Sterculiaceae, Davaliaceae, Ebernaceae, and Caesalpinioideae, have the lowest frequency.

Conclusion and Policy Recommendations

The study examined how Bayelsa State's flora diversity was impacted by crude oil spills. The study's findings, which followed a tried-and-true methodology, demonstrated that the flora species in areas that had not experienced past instances of crude oil activity were significantly diverse. Furthermore, stand features were higher in the control group, but sites with effective remedial exercises demonstrated rapid recovery. Overall, the loss or degradation of mangrove forests as a result of crude oil exploration and exploitation affects not only the Niger Delta's flora diversity but also the ability of more than 70% of the rural population, who depend on agriculture for their livelihood, particularly piscatorial subsistence (Federal Republic of Nigeria, n.d.). Thus, the ongoing devastation of the intertidal coastal ecosystem, which serves as a haven for a wide variety of species, will also have an effect on the inhabitants' quality of life. In order to prevent future spills, oil corporations and the government at all levels must adopt preventative measures and approach crude oil spill cleanup projects proactively rather than reactively.

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EFFECTS OF MACA ROOT POWDER AS ADDITIVE ON THE WATER QUALITY PARAMETERS OF *Clarias gariepinus* REARED IN PLASTIC TANKS

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ABSTRACT

Effects of Maca root powder as additive on the water quality parameters of *Clarias gariepinus* reared in plastic tanks was elucidated five (5) isonitrogenous (40% crude protein) diet was formulated, where Maca root powder in form of additive was incorporated at 0.0g/100g (tm₀), 0.25g/100g (tm₁), 0.5g/100g (tm₂), 0.75g/100g (tm₃) and 1.0g/100g (tm₄) inclusion levels, diet without Maca root powder (tm₀), served as the control diet. formulated diet was fed to *C. gariepinus* fingerlings (n = 300, 10.0±0.00g) in fifteen (15) plastic tanks (n = 20) at a fixed feeding rate of 3% body weight twice daily between the hours of 8:00 - 9:00am and 4:00 - 5:00pm at regular interval and adjusted after every two (2) weeks of sampling for a period of twelve (12) weeks. water temperature, pH, dissolved oxygen, and ammonia were measured at the beginning of the experiment after which they were measured weekly throughout the period of the experiment. Data obtained were analysed using one - way analysis of variance (ANOVA) at P = 0.05. Water temperature values range from; 27.79 – 27.90°C, pH (7.72 – 7.80), dissolved oxygen (5.56 – 5.65 mg/L) and ammonia (0.03 – 0.04 mg/L) respectively. Findings from this study indicated that Maca root powder at 0.0g/100g (TM₀), 0.25g/100g (TM₁), 0.5g/100g (TM₂), 0.75g/100g (TM₃) and 1.0g/100g feed (TM₄) inclusion levels into the diet of *C. gariepinus* does not have any significant effects on the water quality parameters as elucidated in this study.

Keywords: Ammonia, Dissolved Oxygen, Feeding trial, Temperature, Meca root powder

INTRODUCTION

Feeding trial are mostly carried out in regulated environments to avoid any environmental interference which could include; natural food organisms, temperature and other water quality parameters with the variable being studied (Ali, 2022). Feeding trial is mostly conducted in tanks placed indoor or outdoor for easy and reliable data collection (Salisu *et al.*, 2024)). Considerable

attention is received in recent years particularly in Nigeria on the effects of water quality on feeding fish in intensive system (Ali, 2022). Temperature, pH, dissolved oxygen and ammonia are the key water quality parameters which affects all life the phases of fish (Babale, 2016). Temperature is a basic parameter in all aquatic environments. It is the main regulator of nearly all physio-chemical cycles and consequently of metabolism and fish pond productivity,

tropical fish require water with a temperature range of 25 – 32°C to grow and reproduce (Ali, 2022). pH is a measure of acidity or alkalinity of water, water with a pH less than 7 is acidic, above 7 is alkaline while 7 is neutral, water with a pH value of about 6.5 – 9 is the best for fish culture (Elezu, 2016). The dissolved oxygen content of the pond water is one of the most critical factors in fish culture (Babale, 2016). Fish require adequate dissolved oxygen in the water. 5 – 6ppm (mg/L) of oxygen is considered to be an absolute minimum requirement for fish (Elezu, 2016). Ammonia is a nitrogenous waste produced by either the pond organisms (including fish) or decomposition of organic matter (Babale, 2016). For catfish culture, unionized ammonia level in ponds should be maintained at less than 0.05 ppm (Elezu, 2016). Both water quality and quantity have the potential to significantly affect fish metabolism, survival and growth (Ekundayo *et al.*, 2014; Babale, 2016). It is therefore pertinent to ensure good water quality for optimum fish growth, survival and yield. It is always needful to change 40 – 50% of the water in the culture receptacle bi - weekly; this is because fresh water replenishes trace minerals that are used up in the tanks by fish, flora and fauna (Ali, 2022). This study elucidates effects of maca root powder as additive on the water quality parameters of *C. gariepinus* reared in plastic tanks was evaluated.

MATERIALS AND METHODS

Study Area

The research was conducted at the Lay – Joy Fish Farm, Gombe – Yola road, Billiri local government area (LGA), Gombe State Nigeria. Billiri LGA lies within Lat. 9°50'N; 11°09'E and Long. 9.833°N 11.150°E. It covers an area of 737km² (285 sq. m) and is 50 km away from Gombe the State capital.

Experimental Fish

Three hundred (300) *C. gariepinus* fingerlings with mean initial weight (10.0±0.00g) were stocked at twenty (20) fingerlings per tank in triplicates per treatment after one (1) week of acclimatization, the study lasted for a duration of twelve (12) weeks.

Experimental Diets

The experimental diets contained fish meal (FM), soybean meal (SBM), yellow maize meal (YMM), groundnut cake meal (GNCM) and Maca root powder. All the ingredients were grounded into a fine powder using a hammer mill and sieved by a 0.25 mm sieve. Fish meal, soybean meal, groundnut cake meal and yellow maize meal were obtained from commercial suppliers in Gombe, the vitamin/mineral premix, fish oil and chromic oxide (Cr₂O₃) were purchased from TTS Integrated Farms Nigeria Limited, Agege - Lagos, while the Maca root powder naturally derived from dry Maca (*Lepidium meyenii*) root was obtained from BonAmour Pharmacy Limited Lagos, Nigeria, imported from Piping Rock Health Products, Ronkonkoma, New - York, USA. Five (5) isonitrogenous and isocaloric diets were prepared, each diet with crude protein (CP) content at 40% CP as calculated according to Pearson's square method and gross energy content at 1,732kcal kg⁻¹ respectively for the feeding the experimental *C. gariepinus* as recommended by Ali (2022) was prepared, where the Maca root powder in form of feed additive was incorporated into the diets at 0.0g/100g (TM₀), 0.25g/100g (TM₁), 0.5g/100g (TM₂), 0.75g/100g (TM₃) and 1.0g/100g (TM₄) inclusion levels, diet without Maca root powder (TM₀), served as the control diet. (Table 1).

Experimental Design

The *C. gariepinus* fingerlings were cultured in fifteen (15) rectangular white plastic tanks (flow - through system) with a water holding capacity of one thousand litres (1,000L) each

in a complete randomized design (CRD). Each tank was washed thoroughly with salt, filled to just a little over 1/3 (350 litre) capacity and stocked with twenty (20) fingerlings of *C. gariepinus* with mean initial weight (10.0 ± 0.00 g). The *C. gariepinus* fingerlings were fed the experimental diet at 3% body weight two (2) times daily between the hours of 8:00 – 9:00am and 4:00 – 5:00pm for a period of twelve (12) weeks. The quantity of feed was adjusted accordingly after every two (2) weeks of sampling for growth performance and survival rate (mean body weight and mortality). Water temperature, pH, dissolved oxygen, and ammonia were measured at the beginning of the experiment after which they were measured weekly throughout the period of the experiment. Water temperature, dissolved oxygen and pH were measured using Horiba U-22 XD multi - parameter water quality checker while ammonia was measured using freshwater aquaculture test kit (Model AQ-2, Code 3633-03, Lamotte U. S. A).

Statistical Analysis

The data obtained were subjected to one - way analysis of variance (ANOVA) using the GraphPad instant package for windows 2010 of statistical analysis system (SAS, 2010). Mean separation was done (at $P = 0.05$) using Fisher's least significance difference (LSD) to separate the means in cases of significant difference.

Table 1: Ingredient Percentage Composition (g/100g) of Experimental Diets with Different Levels of Maca Root Powder as Additive

Ingredients (%)	TM ₀	TM ₁	TM ₂	TM ₃	TM ₄
Fish meal	20.00	20.00	20.00	20.00	20.00
Soybean meal	21.50	21.25	21.00	21.00	21.00
Groundnut cake meal	23.00	23.00	23.00	23.00	23.00
Yellow maize	30.00	30.00	30.00	29.75	29.50
Maca root powder	0.00	0.25	0.50	0.75	1.00
Fish Oil	1.00	1.00	1.00	1.00	1.00
Vegetable oil	1.00	1.00	1.00	1.00	1.00
Starch	1.00	1.00	1.00	1.00	1.00
Lysine	0.25	0.25	0.25	0.25	0.25
Methionine	0.25	0.25	0.25	0.25	0.25
*Vitamin/premix	1.00	1.00	1.00	1.00	1.00
Salt	0.50	0.50	0.50	0.50	0.50
C ₁₂ O ₃	0.50	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00

Keys: TM₀ - Maca root powder (0.0g/100g), TM₁ - Maca root powder (0.25g/100g), TM₂ - Maca root powder (0.5g/100g), TM₃ - Maca root powder (0.75g/100g), TM₄ - Maca root powder (1.0g/100g).

RESULTS

The results of the effects of maca root powder as additive on the water quality parameters of *C. gariepinus* reared in plastic tanks is presented in Table 2. Initial water temperature value was 27.76°C. This increased in all the diets with Maca root powder and the control diet (TM₀) final values at the end of the 12 week's period of the study to a narrow range of 27.79°C – 27.90°C. There were no significant differences ($p > 0.05$) in the mean water temperature values of the experimental tanks during the feeding trial. Initial water pH value was 7.51. This increased only in the control diet (TM₀) and decreased in all the diets with Maca root powder final values to a narrow range of 7.72 – 7.80. There were no significant differences ($p > 0.05$) in the mean water pH values of the experimental tanks during the feeding trial. Initial dissolved oxygen value was 5.67 mg/L. This decreased in all the diets with Maca root powder and the control diet (TM₀) final values to a narrow range of 5.56 – 5.65 mg/L. There were no significant differences ($p > 0.05$) in the mean water dissolved oxygen values of the experimental tanks during the feeding trial. Initial ammonia value was 0.02 mg/L. This increased in all the diets with Maca root powder and the control diet (TM₀) final values to a narrow range of 0.03 – 0.04 mg/L. There were no significant differences ($p > 0.05$) in the mean water ammonia values of the experimental tanks during the feeding trial.

Table 2: Effects of Maca Root Powder as Additive on the Water Quality Parameters of *C. gariepinus* Reared in Plastic Tanks

Parameters	Initial	TM ₀	TM ₁	TM ₂	TM ₃	TM ₄
Temperature (°C)	27.76 ^a	27.79 ^a	27.83 ^a	27.86 ^a	27.89 ^a	27.90 ^a
pH	7.51 ^c	7.80 ^c	7.77 ^c	7.79 ^c	7.75 ^c	7.72 ^c
Dissolved oxygen (mg/L)	5.67 ^b	5.65 ^b	5.63 ^b	5.61 ^b	5.59 ^b	5.56 ^b
Ammonia (mg/L)	0.02 ^d	0.03 ^d	0.03 ^d	0.03 ^d	0.04 ^d	0.04 ^d

All Means values are not significantly different ($p > 0.05$).

Keys: TM₀ - Maca root powder (0.0g/100g), TM₁ - Maca root powder (0.25g/100g), TM₂ - Maca root powder (0.5g/100g), TM₃ - Maca root powder (0.75g/100g), TM₄ - Maca root powder (1.0g/100g).

DISCUSSION

The water temperature values, 27.79 – 27.90°C recorded from this study were

comparable with the values, 27.78 – 27.88 °C reported by Ali (2022) for *C. gariepinus* reared in plastic tanks. All the water temperature values recorded from this study were within the acceptable recommended range. The water pH values, 7.72 – 7.80 recorded from this study were comparable with the values, 7.22 – 7.8 reported by Salisu *et al.* (2024) for *C. gariepinus* reared in rectangular plastic tanks. All the water pH values recorded from this study were within the acceptable recommended range. The dissolved oxygen (DO) values, 5.56 – 5.65 mg/L recorded from this study were comparable with the values, 4.80 – 6.0 mg/L reported by Ogundele *et al.* (2014) for *C. gariepinus* reared in aquaria tanks. All the DO values recorded from this study were within the acceptable recommended range. The ammonia (NH₃) values, 0.03 – 0.05 mg/L recorded from this study were comparable with the values, 0.03 – 0.05 mg/L reported by Fakunle *et al.* (2014) for *C. gariepinus* fingerlings reared in plastic tanks. All the NH₃ values recorded from this study were within the acceptable recommended range. The good water quality parameters recorded at the end of the 12 weeks' period of the study from all the diets with Maca root powder and the control diet (TM⁰) indicated that the inclusion of different levels of Maca root powder as additive used in this study does not have any negative effects on the water quality parameters.

CONCLUSION

Maca root powder at 0.0g/100g (TM₀), 0.25g/100g (TM₁), 0.5g/100g (TM₂), 0.75g/100g (TM₃) and 1.0g/100g feed (TM₄) inclusion levels into the diet of *C. gariepinus* does not have any significant effects on the water quality parameters of the culture tanks as observed in this study.

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PHYTOCHEMICAL SCREENING OF MORINGA OLEIFERA LEAVES AND ITS MEDICINAL BENEFITS IN NASARAWA LOCAL GOVERNMENT AREA, KANO STATE, NIGERIA

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ABSTRACT

Moringa oleifera Leaf extracts exhibits the greatest antioxidant activity, and various safety studies in animals involving aqueous leaf extracts indicate a high degree of safety. People think traditional medicines are harmful, due to lack of research, not knowing that traditional medicines are considered as being safe, with few or no side effects and have been found to improve people's quality of life and help maintain good health. The research was conducted to assess the phytochemical composition of moringa leaves and to its medicinal values in Nasarawa local government area of Kano state. Fresh Leaves samples were plugged from trees in dakata, kawaji and Tudun wada wards dried at room temperature, grinded into powder and were used for the laboratory test and a semi structured questionnaire was administered, simple random sampling was used to elicit a sample frame of 120 respondents in the study area to assess the medicinal values of moringa oleifera. The results of the phytochemical screening show that flavonoid, saponin, carbohydrate, alkaloid, tannin, cardiac glycoside, terpenoid, and steroid were present in the three wards, while anthraquinones is absent in the study area. Majority of the respondents are female (57.5%), single (65.7%), relatively educated (47.5%) and (90%) are aware of medicinal value of moringa. This study concludes that moringa oleifera has many medicinal values, and suggest that research work should be conducted to know the reasons why some of the respondents do not use moringa as a medicine.

Keyword: phytochemical screening, *Moringa oleifera*, traditional medicine

INTRODUCTION

Herbal plants in medicine, also known as phytomedicine, are still reliable and commonly used as a low-cost alternative to pharmaceuticals. Medicinal plants have been used by mankind for the treatment of various ailments for thousands of years (Siew. 2014). *Moringa oleifera*, a member of the Moringaceae family, is native to the South Asian continent and is known to be cultivated primarily in the Himalayan foothills. It has long been known that it can be used as a nutritional supplement for nursing mothers and new born. *Moringa* (Singh and Omer, 2023). Nearly thirteen species of *Moringa* are included in the family Moringaceae (Farooq,

et al., 2012). *Moringa* leaves contain secondary metabolites such as flavonoids, polyphenols, and carotene, which can be antioxidants. Apart from having antioxidant activity, *Moringa* leaves are *Moringa* leaves are reported to have antibacterial and antifungal activities (Fachriya *et al.*, 2020). The value of medicinal plants in drug discovery is known to us well and the human being used them for various purposes from the beginning of the human history. Traditional folk remedies from plants have always guided scientists to search for new medications in order to maintain and promote healthy life for human and animals (Jaradat, *et al.*, 2015). It is one of the richest plant

sources of Vitamins A, B, C, D, E and K (Dixit, *et al.*, 2016). The vital minerals present in *Moringa* include Calcium, Copper, Iron, Potassium, Magnesium, Manganese and Zinc. It has more than 40 natural antioxidants. *Moringa* has been used since 150B.C. by ancient kings and queens in their diet for mental alertness and healthy skin.

Despite the numerous benefits of *Moringa*, there is a lack of public awareness on its traditional medicinal uses. People think that traditional medicines are harmful, due to lack of research in the community, not knowing that traditional medicines are considered as being safe, with few or no side effects and have been found to improve people's quality of life and help maintain good health. With a continuous research on the medicinal values of *Moringa oleifera* the obstacles can be overcome.

MATERIALS AND METHODS

Study area

Nasarawa is one of the forty-four local government areas of Kano state and is located on Lat 12° 5'N and Long 8°4'E, the area has a population of 1,828,861 (National Population Commission, 2006). Its area covers 499 km² and the principal inhabitants of these areas are the Hausa people. The area has a mean annual rainfall of about 696.4mm that lasts usually for three to five months, the mean temperature ranges from 26°C to 33°C. The area is characterized by four distinct seasons (Yahaya, 2019; Bello, 2021).

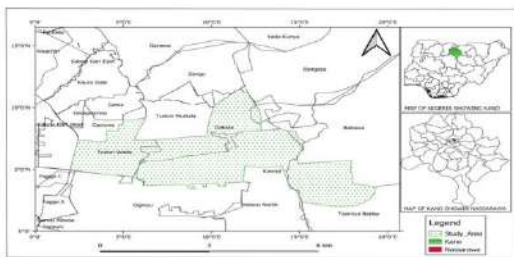


Figure 1: Map of the study area
The map above shows the location of the Nasarawa local government area of Kano state, with the 11 wards and their boundaries, demarcating the study area dakata, kawaji and tudun Wada.
Source: GIS CDA BUK (2024)

Materials

The materials used in this study were samples of moringa leaves, distilled water, concentrated H₂SO₄, acetic acid, ammonium solution, chloroform, filter, test tube, blender and conical flask

Sampling procedures

The research procedure is predominantly a lab work and a questionnaire was used to assess the medicinal benefit of moringa.

Data collection

The leaf samples were collected from a tree in three different wards in Nasarawa local government area in Kano state, Nigeria (Dakata, Kawaji and tudun wada ward) through plugging

Then, the samples were taken to pharmacology lab for screening. The data were collected based on simple random sampling. The specimens of *Moringa oleifera* Lam were collected. The fresh specimens were used for identification and taxonomical description. The specimens were dried at room temperature for about two days. After being completely dried, they were later grinded to get powder with a blender. Phytochemical investigation of the leaves of *Moringa oleifera* Lam. was carried out with various chemical tests. The presence or absence of alkaloids, glycosides, reducing sugars, sterols, saponins, flavonoids, phenolic compounds, terpenes, lipophilic and polyphenols was studied according to the method of Harborne (1984):

Flavonoids: A sample of 5 g was accurately weighed and stirred with a few drops of magnesium strips. The presence of flavonoid was confirmed when a yellowish color was observed on addition of concentrated hydrochloric acid. **Steroids:** Into 2 ml of chloroform, 5 g of sample was added, and the presence of steroids was confirmed on addition of sulphuric acid (a bluish green

color at the interface). **Saponins:** 5 g of powdered leaf sample was placed in a test tube containing 10 ml of water (distilled) and warmed. The presence of saponins was confirmed upon the formation of froth. **Anthraquinone:** 5 g of leaf sample was accurately weighed. 10 ml of benzene was added, shaken and filtered. 5 ml of ammonia was added. A grey of benzene was added and filtered. 5 ml of ammonia was added. A greenish yellow coloration indicated the presence of anthraquinone. **Alkaloids:** 2 ml of chloroform was added to a test tube containing the sample (leaf). About 3–4 drops of Wagner's reagent was added to the mixture, and a reddish-brown coloration confirmed the presence of alkaloids. **Carbohydrates:** Benedict's test – Test solution was mixed with few drops of Benedict's reagent (alkaline solution containing cupric citrate complex) and boiled in water bath, presence reddish-brown precipitate indicates a positive result.

Analysis of data: Data obtained from the laboratory was summarize and presented in tables, semi-structured questionnaire was analyzed using descriptive statistics (frequencies and percentages) with the help of Microsoft excel

RESULTS

Phytochemical composition

Table 1 below shows the chemicals present and absent in dry moringa leaves in three different locations in Nasarawa local government area of kano state. The test conducted includes carbohydrates, saponin, flavonoid, tannin, cardiac glycoside, anthraquinones, steroids, terpenoids and alkaloid.

Table 1: Phytochemical composition of dry moringa leaves.

S/N	TEST	A	B	C
1	Carbohydrates	+	+	+
2	Saponin	+	+	+
3	Flavonoid	+	+	+
4	Tannin	+	+	+
5	Cardiac glycoside	+	+	+
6	Anthraquinones	-	-	-
7	Steroids	+	+	+
8	Terpenoids	+	+	+
9	Alkaloid	+	+	+

Key: + = present, - = absence, A= Kowaji, B= Dokata, C= Tudun Wada.

Source: BUK Pharmacology Lab (2024) |

The table 2 below shows the respondent frequency and percentage with respect to age, gender, educational background, occupation and marital status in three wards in Nasarawa local government area of Kano state. the result shows that 50% of the respondent are between 18 to 30years, 20% are under 18 and respondents in the age range of 46 to 60 above has less frequency. Female have higher frequency than male.

Table 2: Demographic Information of the Respondents

Variable	Frequency	Percentage
AGE		
Under 18	25	20.833
18-30	61	50.833
31-45	24	20
46-60	9	7.5
60 above	1	0.83
Total	120	100%
GENDER		
Female	69	57.5
Male	51	42.5
Total	120	100%
Educational background		
No formal education	9	7.5
Primary school	2	1.67
Secondary school	32	26.67
College/university	57	47.5
Postgraduate	20	16.66
Total	120	100%
Occupation		
Student	63	52.5
Unemployed	15	12.5
Self-employed	35	29.17
Retired	3	2.5
Total	120	100%
Marital status		
Single	79	65.833
Married	37	30.833
Divorce	2	1.666
Widow	1	0.833
Single parent	1	0.833
Total	120	100%

Source: Field Survey 2024

57 of the respondents attend college, 32 secondary, 20 postgraduate only few are in primary school. Majority are students and only 2 out of the respondents retired. 79 single, 37 married, 2 divorce and only 1 of the respondents are single and widow in terms of marital status.

Table 3 shows the frequency and percentage of the respondents towards use of moringa for

medicine, the result shows that majority of the respondent use moringa to lower blood pressure.

Table 3: MEDICINAL USES

VARIABLES	FREQUENCY	PERCENTAGE
Which illness do you use it for		
Hypertension	56	46.67
Malaria	18	15.00
Sickle cell	10	8.33
Typhoid	25	20.83
None	11	9.17
Total	120	100%
How often do you take it		
Daily	24	20
Weekly	32	26.67
Seasonal	44	36.67
Monthly	11	9.17
None	9	7.5
Total	120	100%
How do you use it		
Liquid	38	31.67
Powder	14	11.67
Extract	28	23.33
Raw	31	25.83
None	9	7.50
Total	120	100%

Source: Field Survey (2024)

DISCUSSION

The phytochemical analysis of *Moringa oleifera* leaves revealed the presence of carbohydrates, saponins, flavonoids, tannins, alkaloids, steroids, and cardiac glycosides in all tested locations, while anthraquinones were absent. The study confirmed tannins, saponins, phenols, alkaloids, and phlobatannins as major secondary metabolites, aligning with previous research. These phytochemicals contribute to the plant's medicinal properties, with alkaloids aiding in the treatment of diseases like malaria, hypertension, and cancer, while phenols serve various pharmaceutical and cosmetic purposes. This is in agreement with the findings of Oladeji *et al.*, (2020) and Akpuaka (2009).

Studies on the phytochemical constituents of plants have explored their medicinal benefits, focusing on antioxidant, anti-inflammatory, antimicrobial, and anticancer properties. Phenolic compounds, a major bioactive component in plants, are particularly known for their antimicrobial, antifungal, anti-

inflammatory, antioxidant, and anticancer effects. The questionnaire results from 120 respondents in three wards of Nasarawa, Kano State, show that the majority (50.83%) are aged 18–30, with over 50% being female and university-educated. Most respondents are students and single. The study aligns with previous research by Moyo *et al.* (2011) indicating a high proportion of female respondents in their productive years. About 90% of respondents are aware of Moringa's medicinal benefits, mainly through social media and local events. Around 75% have used Moringa medicinally, with hypertension (46.67%) being the most common condition treated followed by typhoid (20%), and malaria (15%), Sickle cell has the least with 8.33%, this corroborates with the findings of (Osewa *et al.*,2013). The majority use Moringa in liquid form, often seasonally. Most respondents believe Moringa benefits the local community and acknowledge cultural influences on its use. Moringa is recognized for treating various ailments, including ulcer, diabetes, stomach issues, skin nourishment, liver protection, inflammation, and more. These findings align with previous studies of Khawaja *et al.*, (2010), Hamza, (2010), and Singh *et al.*, (2012) on Moringa's medicinal applications. Among the respondents, 79 have additional knowledge of Moringa's medicinal properties, while the rest do not.

CONCLUSIONS AND RECOMMENDATIONS

Moringa oleifera is a highly beneficial plant with significant medicinal and culinary potential. Its leaves contain various bioactive compounds, including alkaloids, flavonoids, tannins, and cardiac glycosides. Over 50% of respondents are aware of its medicinal benefits, and many use it to treat various illnesses. Scientific studies highlight its antibacterial, anti-inflammatory, antiviral, antioxidant, cardio-protective, anti-diabetic, and anti-carcinogenic properties. However,

its medicinal applications remain underutilized and poorly advertised. Most respondents are female, middle-aged, single, and moderately educated. They recognize Moringa's high protein and vitamin content, consuming it fresh, dried, or cooked, with information primarily sourced from social media, TV, newspapers, and local events.

This research recommends incorporating Moringa into daily diets, especially for pregnant women and overall well-being, by consuming 1 teaspoon to 1 tablespoon of pure Moringa powder daily. Further studies should explore why some individuals do not use Moringa medicinally. Additionally, raising awareness through educational programs can help urban and rural communities understand its health benefits. Lastly, promoting the sustainable use of Moringa for medicinal purposes should be encouraged among citizens.

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Carbon Emissions Trading (CET) Practices as Mitigation Strategy to Climate Disorders: Assessing the Construction Industry Response

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ABSTRACT

This study examines the potential of carbon emissions trading (CET) to mitigate climate disorder from greenhouse gas emissions in the construction industry. As the world shifts towards a low-carbon economy, the construction industry must respond with sustainable practices to minimize its environmental footprint. CET, a market-based approach that enables companies to buy and sell carbon credits, has been widely adopted in various industries, but its application in construction is still in its early stages. The research employs a quantitative design, using a questionnaire to gather data from construction industry professionals. The analysis reveals the current state of CET adoption, identifies factors to mitigation strategies, and explores potential benefits. By investigating the construction industry's response to CET practices, this study aims to inform strategies for reducing carbon emissions and promoting sustainable development. The findings of this research contribute to a deeper understanding of CET's effectiveness in the construction industry. The study's results have significant implications for policymakers, industry practitioners, and researchers seeking to mitigate climate change. Ultimately, this research provides valuable insights into the role of CET in reducing greenhouse gas emissions and promoting sustainable development in the construction industry.

Keyword: Carbon emission trading, Climate disorder, Construction industry, Mitigation strategy, Carbon marketing

INTRODUCTION

Climate disorder is one of the most pressing global issues of our time, with far-reaching consequences for the environment, human health, and the economy (IPCC, 2021). The construction industry is a significant contributor to greenhouse gas emissions, accounting for around 38% of global carbon emissions (United Nations Environment Programme, 2020). As the world transitions towards a low-carbon economy, the construction industry must adopt sustainable practices to reduce its carbon footprint (Kibert, 2016). One strategy that has gained

attention in recent years is carbon emissions trading (CET), a market-based approach that allows companies to buy and sell carbon credits (Zhang et al., 2020). CET has been widely adopted in various industries, including energy, manufacturing, and aviation (European Commission, 2022). However, its application in the construction industry is still in its infancy (Wang et al., 2020). The construction industry's unique characterization, such as project-based production and complex supply chains, pose challenges to implementing CET practices (Liu et al., 2022). Despite these challenges,

CET has the potential to incentivize construction companies to adopt low-carbon practices, invest in clean technologies, and reduce their carbon emissions (Zhang et al., 2020). This paper attempts to assess the construction industry's response to CET practices as a mitigation strategy for climate disorder. Specifically, this study will investigate the current state of CET adoption in the construction industry, identify the barriers and challenges to its implementation, and explore the potential benefits and opportunities of CET for construction companies. The significance of this research lies in its potential to contribute to the development of effective climate disorders mitigation strategies for the construction industry (Kibert, 2016).

The background and context of this research underscores the urgent need for climate disorders mitigation strategies in the construction industry. Climate disorder is a pressing global issue that requires immediate attention and action (IPCC, 2021). The construction industry's contribution to greenhouse gas emissions, primarily due to energy consumption and material usage associated with building construction and operation, underscores the need for effective climate disorders mitigation strategies (United Nations Environment Programme, 2020). The research literature surveys the current state of CET adoption in the construction industry, identify the barriers and challenges to implementing CET practices, and explore the potential benefits and opportunities of CET for construction companies. By achieving these objectives, this research will provide a comprehensive understanding of the role of CET in reducing carbon emissions in the construction industry. In the end, this paper assesses the construction industry's CET practices as a mitigation strategy for climate disorder. The study will provide valuable insights into the effectiveness of CET in reducing carbon

emissions in the construction industry, contributing to the development of effective climate disorders mitigation strategies for the industry (AfDB et al., 2002).

LITERATURE REVIEW

Current State of Affairs of Carbon Emissions Trading CET Adoption in the Construction Industry

The construction industry is a significant contributor to greenhouse gas emissions, accounting for around 38% of global carbon emissions. Carbon Emissions Trading (CET) has emerged as a market-based approach to reduce emissions, allowing companies to buy and sell carbon credits. CET is a policy instrument that enables companies to trade carbon credits, providing a financial incentive for reducing emissions. The construction industry's high energy consumption and emissions make it an ideal sector for CET adoption. Research has shown that CET can significantly improve green total factor productivity (GTFP) in construction enterprises, promoting sustainable development. Studies have investigated the impact of CET on the construction industry, with a focus on China, which has become the world's largest carbon market. Research by Tian et al. (2024) found that CET implementation significantly improved GTFP in listed Chinese construction companies, with a coefficient of 0.0089 at the 1% significance level. The study highlighted the importance of unified market development and tailored governance strategies. GTFP is a widely used indicator for assessing green development in enterprises. It encompasses economic development, energy consumption, and environmental degradation. Researchers have employed various methods to measure GTFP, including the Solow residual method, nonparametric frontier analysis, and the Malmquist-Luenberger index (ML). The SBM-ML model, which combines the

Slacks-Based Measure (SBM) with undesirable outputs and a fixed ML index, provides a comprehensive tool for analysis. Studies have shown that CET can have a positive impact on construction enterprises' green development. The policy's impact is more pronounced in large-scale, state-owned, highly indebted enterprises, and those located in the eastern region or receiving government subsidies. CET promotes green innovation, encourages companies to adopt low-carbon practices, and provides economic support for sustainable development. Despite the benefits of CET, several challenges hinder its adoption in the construction industry. These include: Controversies exist regarding the measurement of GTFP and the incorporation of environmental factors into production functions, the construction industry's unique features, such as project-based production and complex supply chains, pose challenges to CET implementation, and further studies are needed to explore CET's nuanced impacts across different sectors and regions.

Potential Benefits and Opportunities of Carbon Emissions Trading in the Construction Industry

Carbon Emissions Trading (CET) has emerged as a market-based approach to reduce greenhouse gas emissions in various industries, including construction. The construction industry is a significant contributor to global carbon emissions, accounting for around 38% of global carbon emissions (United Nations Environment Programme, 2020). CET offers a promising approach to reducing carbon emissions in the construction industry, providing several benefits and opportunities. CET can provide economic benefits to construction companies by allowing them to buy and sell carbon credits. This can help companies to reduce their carbon footprint while also generating revenue (Zhang et al., 2020). A study by Liu et al. (2022) found that CET can significantly improve the green total factor productivity of

construction enterprises, promoting sustainable development. CET can also provide environmental benefits by reducing greenhouse gas emissions in the construction industry. By incentivizing companies to adopt low-carbon practices, CET can help to reduce the industry's carbon footprint (Kibert, 2016). A study by Wang et al. (2020) found that CET can lead to significant emissions reductions in the construction industry, particularly in companies that are highly indebted or located in the eastern region. CET offers opportunities for sustainable development in the construction industry by promoting green innovation and low-carbon practices. A study by Hao et al. (2023) found that digital twin technology, which can be integrated with CET, can improve green total factor productivity in construction enterprises. CET can also provide opportunities for construction companies to invest in clean technologies and reduce their reliance on fossil fuels (Zhang et al., 2020).

Despite the benefits and opportunities of CET, there are several challenges and limitations to its adoption in the construction industry. These include the complexity of implementing CET systems, the need for accurate emissions monitoring, and the potential for market volatility (Liu et al., 2022). A study by Jiang et al. (2022) found that incorporating high oil-consuming and natural gas industries into CET systems can have socio-economic and environmental effects that need to be carefully managed. Future research should focus on exploring the potential benefits and opportunities of CET in the construction industry, as well as addressing the challenges and limitations of its adoption. This could include investigating the impact of CET on different types of construction companies, examining the role of digital technologies in enhancing CET systems, and developing strategies for promoting sustainable development in the industry (Hao et al., 2023). Generally, CET

offers several benefits and opportunities for the construction industry, including economic benefits, environmental benefits, and opportunities for sustainable development. However, there are also challenges and limitations to its adoption that need to be carefully managed. Further research is needed to explore the potential of CET in the construction industry and to develop strategies for promoting sustainable development.

Barriers to Implementation of Carbon Emissions Trading Practices

Carbon Emissions Trading (CET) is a market-based approach to reduce greenhouse gas emissions, and it has been widely adopted in various industries. However, despite its potential benefits, the implementation of CET practices faces several barriers. This literature review aims to identify and discuss the barriers to implementation of CET practices. One of the significant barriers to CET implementation is regulatory uncertainty. A study by Liu et al. (2022) found that unclear or inconsistent regulations can hinder the adoption of CET practices in industries. Regulatory uncertainty can lead to confusion among companies, making it challenging for them to understand the requirements and benefits of CET. Technical barriers are another significant challenge to CET implementation. A study by Wang et al. (2020) found that the lack of technical expertise and infrastructure can hinder the adoption of CET practices. For example, companies may struggle to accurately measure and report their emissions, which is a critical component of CET. Financial barriers can also hinder the implementation of CET practices. A study by Zhang et al. (2020) found that the cost of implementing CET systems can be significant, and companies may be hesitant to invest in these systems due to financial constraints. Additionally, the volatility of carbon prices can make it challenging for companies to

predict their costs and benefits. Institutional barriers can also play a significant role in hindering CET implementation. A study by Jiang et al. (2022) found that the lack of institutional capacity and coordination can hinder the adoption of CET practices. For example, government agencies may need to develop new policies and procedures to support CET implementation. Social barriers can also influence the adoption of CET practices. A study by Kibert (2016) found that social norms and values can shape companies' attitudes towards sustainability and CET. For example, companies may be more likely to adopt CET practices if they perceive it as a social norm. Market barriers can also hinder the implementation of CET practices. A study by Dong and Liang (2013) found that market fluctuations and uncertainty can affect the demand for carbon credits, making it challenging for companies to predict their benefits. The implementation of CET practices faces several barriers, including regulatory, technical, financial, institutional, social, and market barriers. These barriers can hinder the adoption of CET practices and limit their effectiveness in reducing greenhouse gas emissions. Further research is needed to understand these barriers and develop strategies to overcome them.

Climate Disorder, Causes and Impact

Climate disorder, more commonly referred to as climate disorders or climate system disorder encompasses various factors that contribute to disorder in the Earth's climate (McMichael, Woodruff, and Hales, 2006). The main components of the climate system include: the atmosphere which is the layer of gases surrounding the Earth, comprising mostly nitrogen, oxygen, and argon, with trace gases like water vapor and carbon dioxide playing crucial roles in climate regulation (Arnell, 2006). Next is the hydrosphere which encompasses all liquid water on Earth, including oceans, lakes,

rivers, and groundwater, which significantly influences climate patterns. This is followed by the cryosphere which comprises solid water, such as ice sheets, glaciers, sea ice, and snow cover, impacting global temperatures and climate feedback loops (Biggs et al., 2004). Also, the lithosphere which comprises the Earth's crust and upper mantle, shaping global wind patterns, ocean currents, and climate zones through geological features like mountains and valleys. Another is the ocean which plays a crucial role in absorbing heat and carbon dioxide, but this absorption can lead to ocean acidification and disorder in marine ecosystems (Abdalla, 2006). Next is land whose surfaces are affected by disorder in precipitation and temperature, leading to altered vegetation patterns, increased risk of wildfires, and disorder in soil health. Finally is the biosphere which comprises the realm of living organisms, interacting with the climate system through processes like photosynthesis, respiration, and decomposition (IPCC, 2007).

Key factors contributing to climate disorder include: greenhouse gases such as carbon dioxide, methane, and nitrous oxide, primarily emitted through human activities like burning fossil fuels, deforestation, and agriculture, trap heat in the atmosphere, aerosols in which particles in the atmosphere, from natural sources like volcanoes or human activities like biomass burning, affects climate by reflecting sunlight or altering cloud formation (Baylis and Githeko, 2006). Also, land use disorder in the form of deforestation, urbanization, and other human activities altering land cover, influencing local and global climate patterns (Agrawala, 2005). Climate disorder also originates from solar radiation which includes disorder in the sun's energy output impacting the Earth's climate. Volcanic eruptions have also been reported to be a source of climate disorder where large eruptions injecting ash and aerosols into the atmosphere reflects sunlight

and cools the planet (Abeku et al., 2004). Some of the observable impacts of climate disorders are evident in threat to human health including increased risk of heatwaves, extreme weather events, infectious diseases, and malnutrition (Benhin, 2006). Also, the ecosystems disruption can come about from the impact of climate disorders leading to habitat loss, altered species interactions, and biodiversity loss (Adger, Arnell, and Tompkins, 2005). This is also true for societal systems which impacts various societal systems, including agriculture, water resources, infrastructure, and economic stability (Burke, Sanson, and Van Hoorn, 2018). Climate disorders has also been linked to an increase in the frequency and intensity of extreme weather events like heatwaves, floods, droughts, and storms, rising sea levels can inundate coastal areas, displace populations, and damage infrastructure, air quality leading to increased pollution and respiratory problems, mental health with psychological impact, causing anxiety, stress, and depression (Adger and Vincent, 2005). Also, vector-borne diseases arising from disorder in temperature and precipitation from climate disorder can alter the distribution and prevalence of vector-borne diseases like malaria and dengue fever (Arnell, 2004). Finally, it has been observed also that food security has been threatened from climate disorder by disruption of agricultural production, leading to food shortages and malnutrition.

METHODOLOGY

This study employed a quantitative research design to investigate the effectiveness of carbon trading practices in promoting carbon emissions minimization in the construction industry. To collect data, a questionnaire instrument was utilized, targeting construction industry professionals, including civil engineers, builders, urban planners, surveyors, and quantity surveyors. The questionnaire was administered through

a dual approach, leveraging both a Google Form online platform and physical distribution, to ensure a wide reach and maximize response rates. Out of a sample size of 200 professionals, 125 responded, yielding a response rate of 62.5%. This rate is considered satisfactory for analysis, providing a robust foundation for the study's findings. Following data collection, the responses underwent a thorough treatment and cleaning process to ensure accuracy and reliability. Descriptive statistics, including relative importance index and simple percentages, were employed to characterize the demographic profile of respondents. The results were presented using nested bar charts, facilitating clear visualization and interpretation of the data.

To analyze the research objective, exploratory factor analysis (EFA) was employed, measured by principal component analysis (PCA). This statistical technique enabled the identification of underlying factors influencing the effectiveness of carbon trading practices in the construction industry. By applying EFA and PCA, the study aimed to underscore the persistent factors that shape the industry's response to carbon trading practices. The research methodology ensured several key features, including a robust sample size with a satisfactory response rate, the use of descriptive statistics for demographic characterization, and the application of EFA and PCA to identify underlying factors. By adopting this methodology, the study provides a solid foundation for investigating the effectiveness of carbon trading practices in promoting carbon emissions minimization in the construction industry. The findings of this study are expected to contribute valuable insights into the industry's adoption of carbon trading practices and inform strategies for reducing carbon emissions.

DATA ANALYSIS AND INTERPRETATION

This section presents the analysis and results of the data collected. It also explains the method of measurement used, the method of coding, and the time of analysis carried out.

Table 1: Frequency Distribution of the Socio-demographic Characterization of the Respondents

Item	Frequency	Proportion (%)
Gender		
Female	50	40%
Male	75	60%
Grand Total	125	100%
Age group		
20 – 30	47	38%
31 – 40	28	22%
41 – 50	32	26%
Above 50	18	14%
Grand Total	125	100%
Profession		
Architect	20	16%
Builder	28	22%
Civil / Structural Engineer	20	16%
Land Surveyor	7	6%
Project Manager	10	8%
Quantity Surveyor	32	26%
Surveying and Geo-informatics	3	2%
Urban planner	5	4%
Grand Total	125	100%
Years of working experience		
0 – 5	45	36%
11 – 15	3	2%
11 – 15 years	17	14%
16 – 20	7	6%
5 – 10 years	20	16%
6 – 10	13	10%
Above 20	20	16%
Grand Total	125	100%
Categories of Organization		
Academic	25	20%
Client/Corporate Organization	18	14%
Consulting firm	30	24%
Contracting firm	37	30%
Government Agency/ parastatals	15	12%
Grand Total	125	100%
Have you heard of carbon emission trading before?		
No	5	4%
Yes	120	96%
Grand Total	125	100%

The frequency distribution of the socio-demographic characterization of the respondents in Table 1 reveals a diverse sample. In terms of gender, 60% of the respondents are male, while 40% are female. Regarding age distribution, the majority fall within the 20–30 age group, representing 38% of the sample, followed by 26% in the 41–50 age range, 22% in the 31–40 category, and 14% who are above 50 years old. The professional background of the respondents is varied, with the highest proportion being quantity surveyors at 26%. Builders make up 22% of the sample, while civil/structural engineers and architects each account for 16%. Other professions include project managers (8%), land surveyors (6%), urban planners (4%), and those in surveying and geoinformatics (2%). Regarding years of working experience, the most common category is 0–5 years, encompassing 36% of the respondents. The next largest groups are those with more than

20 years of experience and those with 5–10 years, both at 16%. Smaller proportions are found in the 6–10 years (10%), 11–15 years (14%), and 16–20 years (6%) categories. The respondents are also drawn from different types of organizations. Contracting firms have the largest representation at 30%, followed by consulting firms at 24%. Academics make up 20%, client/corporate organizations constitute 14%, and government agencies or parastatals account for 12%. Finally, when asked about their awareness of carbon emission trading, an overwhelming 96% reported that they had heard of it before, while only 4% had not. This suggests a high level of familiarity with the concept among the respondents.

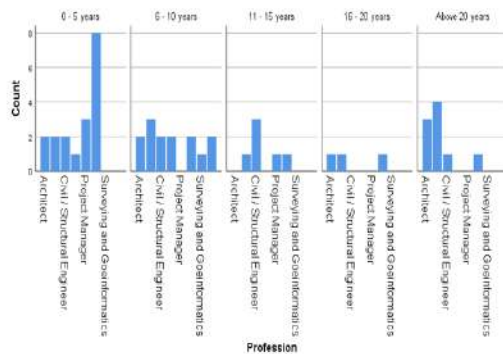


Figure 1: Nested Bar Chart of Profession and Years of Working Experience of the Respondents

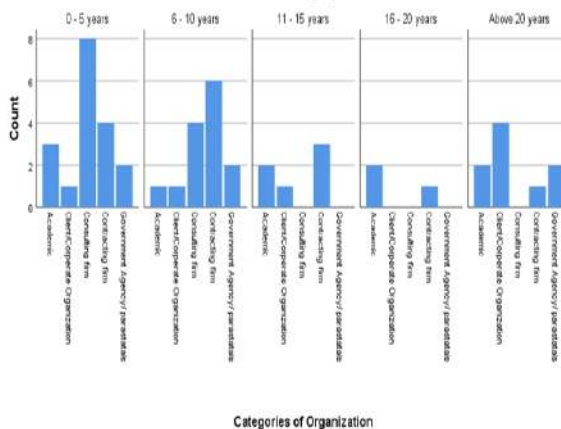


Figure 2: Nested Bar Chart of Categories of Organization and Years of Working Experience of the Respondents

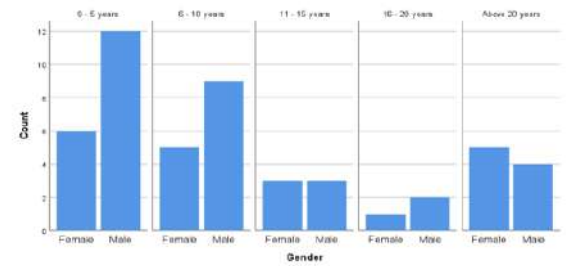


Figure 3: Nested Bar Chart of Gender and Years of Working Experience of the Respondents

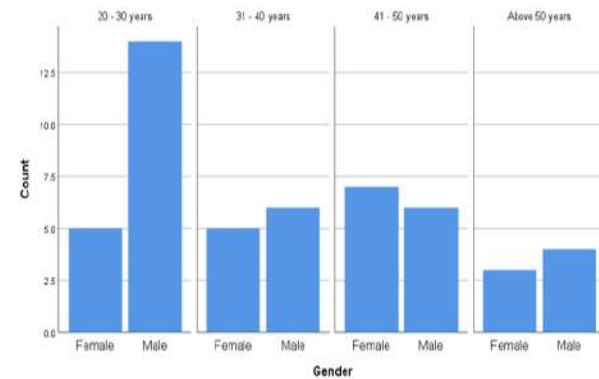


Figure 4: Nested Bar Chart of Gender and Age Group of the Respondents

Table 2: Cronbach's Alpha Reliability Statistics of the Factors that Inhibit Construction industry response and Mitigation strategies of Carbon Emission Trading for Carbon Reduction in Nigeria

Cronbach's Alpha	N of Items
.839	11

Table 3: KMO and Bartlett's Test of Sampling Adequacy for the Responses on the Factors that Inhibit Construction industry response and Mitigation strategies

of Carbon Emission Trading for Carbon Reduction in Nigeria

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.650	
Bartlett's Test of Sphericity	Approx. Square	Chi-	290.940
	Df		55
	Sig.		.000

Table 2 presents the Cronbach's Alpha Reliability Statistics for the responses on the factors that inhibit the construction industry response and mitigation strategies of carbon emission trading for carbon reduction in Nigeria.

$$\alpha = \left(\frac{k}{k-1} \right) \frac{1 - \sum(s^2 i)}{s^2 t}$$

The Cronbach's alpha of 0.839 indicates a high level of internal consistency among the 11 items, suggesting that the items used to assess the factors are reliably measuring the same underlying concept. Table 3 shows the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy estimated from

$$KMO = \frac{\sum(r^2)}{\sum(r^2) + \sum(u^2)}$$

and Bartlett's Test of Sphericity for the same set of responses computed from

$$\chi^2 = - \left\langle \frac{(n-1-(2p+5))}{6} \right\rangle \ln|R|$$

The KMO value of 0.650 suggests that the sample size is adequate for conducting factor analysis, as KMO values above 0.5 are generally considered acceptable. Bartlett's Test of Sphericity has a Chi-Square value of 290.940, with a significance level (Sig.) of 0.000, indicating that the correlation matrix is significantly different from an identity matrix, and thus, factor analysis is appropriate for the

data. Both tables demonstrate that the data used to assess factors to carbon emission trading construction industry response and mitigation strategies is robust and suitable for further statistical analysis, such as factor analysis.

Table 4: Total Variance Explained by the Extracted Components on the Factors that Inhibit Construction industry response and Mitigation strategies of Carbon Emission Trading for Carbon Reduction in Nigeria

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.486	40.785	40.785	4.486	40.785	40.785
2	1.493	13.573	54.358	1.493	13.573	54.358
3	1.303	11.843	66.201	1.303	11.843	66.201
4	1.063	9.660	75.861	1.063	9.660	75.861
5	.909	8.260	84.121			
6	.634	5.761	89.883			
7	.457	4.158	94.040			
8	.240	2.178	96.219			
9	.184	1.673	97.892			
10	.117	1.066	98.959			
11	.115	1.041	100.000			

Extraction Method: Principal Component Analysis.

Table 4 presents the Total Variance Explained by the Extracted Components on the factors that inhibit the construction industry response and mitigation strategies of carbon emission trading for carbon reduction in Nigeria. The table provides the initial eigenvalues and the extraction sums of squared loadings for each component after performing principal component analysis (PCA).



Figure 5: Component Loadings

- Component 1 has an eigenvalue of 4.486, explaining 40.785% of the variance. This indicates that the first component captures the largest portion of the variance in the data.
- Component 2 has an eigenvalue of 1.493, explaining 13.573% of the

variance, bringing the cumulative explained variance up to 54.358%.

- Component 3 explains 11.843% of the variance, with a cumulative variance of 66.201%.
- Component 4 explains 9.660% of the variance, bringing the cumulative variance up to 75.861%.

The remaining components contribute smaller amounts to the total variance:

- Component 5 contributes 8.260%, leading to a cumulative variance of 84.121%.
- Component 6 contributes 5.761%, resulting in a cumulative variance of 89.883%.
- Components 7 through 11 each contribute less, with the final component contributing 1.041%, completing the total variance of 100%.

The first four components together explain 75.861% of the variance, suggesting that they capture the most significant factors inhibiting the construction industry response and mitigation strategies of carbon emission trading. This highlights the importance of these components in understanding the factors faced in this context.

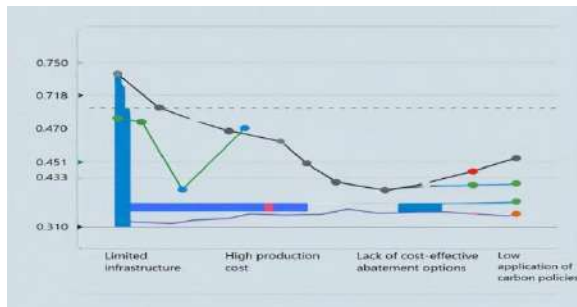


Figure 6: Component Scores

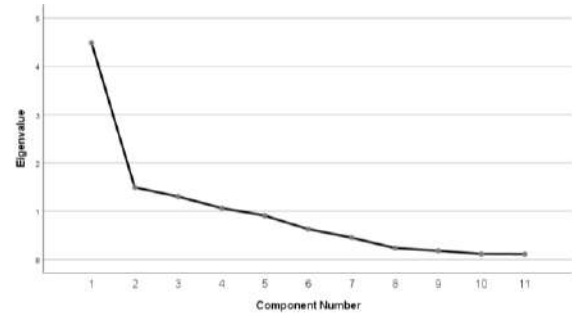


Figure 7: Scree Plot of the Optimum Number of Components to be extracted for Factors that Inhibit Construction industry response and Mitigation strategies of Carbon Emission Trading for Carbon Reduction in Nigeria

Table 5: Component Matrix for the Factor Loadings Scores for Assessing the Factors that Inhibit Construction industry response and Mitigation strategies of Carbon Emission Trading for Carbon Reduction in Nigeria

	Component			
	1	2	3	4
Greenhouse gases	.750	-.107	-.221	.415
Deforestation	.744	-.004	-.056	.032
Burning of fossil fuels	.737	-.442	.111	-.323
Land use changes	.718	.040	-.436	-.226
Industrial agricultural practices	.713	-.388	.204	-.087
Urban and rural population growth	.651	.071	-.173	.581
Industrial processes	.631	.016	-.421	-.387
Transportation waste	.470	.747	.288	.158
Waste management	.538	.578	-.074	-.112
Aerosols	.519	.245	.693	-.318
Volcanic eruptions	.451	-.419	.480	.318

Extraction Method: Principal Component Analysis.

Table 5 presents the Component Matrix for the Factor Loadings Scores for assessing the factors that inhibit the construction industry response and mitigation strategies of carbon emission trading for carbon reduction in Nigeria. The table shows how various factors load onto four components identified through Principal Component Analysis (PCA). The first component, which reflects structural and regulatory factors, includes factors such as Greenhouse gases (0.750), Deforestation (0.744), Burning of fossil fuels (0.737), and Land use changes (0.718). These items strongly suggest that issues related to the system's infrastructure and regulatory frameworks play a significant role in inhibiting the construction industry response of carbon emission trading. Structural

problems, including inadequate infrastructure and monitoring mechanisms, prevent effective participation in carbon markets. The Burning of fossil fuels indicates a gap in providing incentives or motivations to meet emission targets.

The second component highlights financial constraints and innovation factors. It includes factors like the Transportation waste (0.747), Waste management (0.578), and poor innovative ideas to harness the potential of carbon markets (0.651). These factors indicate that waste decomposition factors, combined with the lack of innovative approaches to reduce carbon emissions, are major obstacles to the successful mitigation strategies of carbon trading. Without affordable and accessible technologies for emission reduction, or sufficient access to finance, carbon trading becomes less feasible for professionals in the region. The third component reflects issues related to awareness and the application of carbon policies, factors such as the aerosols (0.693) and the volcanic eruptions (0.480) load strongly onto this component. These findings suggest that awareness gaps and the insufficient application of existing carbon trading frameworks are significant factors. Many construction professionals may not fully understand how carbon trading works or the opportunities it provides for reducing carbon emissions.

The fourth component includes factors such as Industrial agricultural practices (0.713), Industrial processes (0.631), and poor innovating ideas to harness the potential of carbon markets (0.581). These factors reflect a lack of commitment to environmental sustainability and reluctance to engage in carbon trading due to concerns over regulatory changes. The uncertainty regarding the rules of participation and carbon credit allocation creates resistance among professionals. Additionally, a lack of proactive attitudes towards climate action

may inhibit broader participation in carbon trading initiatives. The most significant factors to the construction industry response and mitigation strategies of carbon emission trading in Nigeria revolve around structural and regulatory issues, such as Greenhouse gases and the need for effective monitoring systems. Financial and innovation factors, including the Waste management and the absence of cost-effective emission reduction methods, also pose significant factors. Furthermore, the lack of awareness regarding carbon market opportunities and the low application of carbon policies highlight the need for improved education and policy mitigation strategies. Finally, risk concerns and insufficient commitment to environmental sustainability create additional factors to participation in carbon trading. Addressing these factors is essential for promoting the effectiveness of carbon emission trading in the region.

Summary

Objective	Key Findings	Most Significant Items
The Factors that Inhibit Construction industry response and Mitigation strategies of Carbon Emission Trading for Carbon Reduction in Nigeria	Major factors include: Greenhouse gases, Deforestation, Land use changes, lack of encouragement for emission reduction.	- Greenhouse gases (0.750) - Deforestation (0.744)

CONCLUSION

This research aims to investigate how Carbon Emission Trading enhances the performance of construction enterprises through empirical testing and thorough analysis of its various roles. It seeks to provide direction for Nigeria's construction industry in adopting a green development path that promotes environmental sustainability, energy efficiency, and emission reduction, while also offering meaningful insights to international counterparts pursuing similar goals. The objectives of this study include exploring the current level of awareness and understanding of carbon emission trading

among construction professionals in Nigeria, examining the benefits of carbon trading practices in reducing carbon emissions among construction professionals, identifying the factors inhibiting the construction industry response and mitigation strategies of these practices, and evaluating the impact of carbon emission trading on greenhouse gas reduction. The results reveal that the most significant effects of carbon emission trading are its ability to directly reduce emissions through financial incentives, encourage industrial upgrades, and drive innovation in low-carbon technologies. These outcomes represent the core contributions of carbon trading in this context. Ultimately, carbon trading is viewed as a mechanism that offers both economic and technological benefits, supports emission reduction goals, and promotes environmental sustainability, making it a valuable tool for global industry construction industry response.

RECOMMENDATION

To effectively implement carbon emission trading (CET) in the construction industry, several key recommendations can be made. Firstly, enhanced awareness and training initiatives should be undertaken to educate stakeholders about the benefits, factors, and mitigation strategies of CET. This can be achieved through workshops and seminars that target managers and decision-makers, equipping them with the knowledge necessary to navigate the complexities of carbon trading. Secondly, sector-specific strategies should be developed to address the unique characterization and factors of the construction industry. By tailoring policies and guidelines to the sector's specific needs, the effectiveness of CET can be significantly enhanced. This might involve creating guidelines that account for sector-specific practices and factors in carbon trading. Thirdly, integrating green construction principles with CET practices can promote

sustainable construction. This integration can be encouraged by incentivizing projects that meet certain green certification standards alongside participation in carbon trading programs. By aligning CET with green construction practices, the construction industry can reduce its environmental footprint while also benefiting from carbon trading. Fourthly, a robust monitoring and evaluation framework is essential to assess the effectiveness of CET policies in reducing carbon emissions. This framework should include key performance indicators (KPIs) to track progress over time, allowing for adjustments to be made as needed. By continuously monitoring and evaluating CET policies, the construction industry can ensure that its efforts are yielding the desired outcomes. Finally, collaboration with local governments is crucial to ensure that carbon trading initiatives align with regional sustainability goals. By working together with local authorities, CET strategies can be formulated that cater to specific community needs, enhancing their effectiveness and relevance. Local insights can provide valuable context, enabling the development of more targeted and impactful CET initiatives.

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Mitigating negative impact of a climate change effect, soil salinization, with salicylic acid application in *Arachis hypogaea* L. (groundnut) cultivation

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ABSTRACT

Soil salinization, a resultant effect of climate change, has been reported to limit plant seed germination, growth, yield and nutritional composition. Salicylic acid (SA), a hormone-like substance that regulates a number of physiological processes under environmental stress, may have the potential to mitigate salt stress in some plant species. This research was conducted to assess the potential of SA in mitigating phytotoxic effect of soil salinization on an oil-rich vegetable crop, *Arachis hypogaea* L. (groundnut). Groundnut was grown in perforated polythene pots filled with topsoil, and grouped into two at 3 weeks after planting. Each plant in the first group was irrigated with 250 ml saline water at 0 (control), 5, 10, 15, 20, 25, or 30 mM NaCl solution, followed by 10 ml of 1 mM SA. Plants in the second group received only the saline water without SA. It was a screen house study in a completely randomized design with 5 replicates per treatment. Plants survived under salinity stress either with or without SA application. Salinity generally reduced growth, biomass and yield parameters, which was greatest at 30 mM NaCl. SA application compared to its non-application to soil salinization lowered reduction in plant height (14.74% to 4.97%), number of leaves (20.80% to 14.77%), number of branches (21.43% to 16.67%), stem girth (16.00% to 14.53%), leaf area (10.00% to 8.01%), number of roots (24.43% to 3.74%), and root length (8.78% to 5.71%). It also resulted in less reduction in leaf fresh weight (33.35% to 13.36%), stem fresh weight (51.40% to 29.81%), root fresh weight (37.53% to 28.57%), stem dry weight (37.64% to 35.41%), root dry weight (42.37% to 28.15%), and total biomass (37.05% to 33.35%). It lowered number of pods/plant (54.79% to 19.44%), and number of seeds/plant (55.81% to 20.90%). Seed percentage moisture and crude fibre were not affected by salinity but increased ash and carbohydrate, and reduced crude protein and fat, without significant difference ($p \geq 0.05$) from the control. There was no effect of salinity on K, P and N but caused a significant ($p \leq 0.05$) accumulation of Na^+ and Cl^- . Application of SA had no influence on seed nutritional and proximate compositions under salt stress. Salinity negatively impacted growth, biomass, yield and seed nutritional contents of groundnut. The phytotoxic effects of soil salinization, a product of climate change, can be mitigated through application of salicylic acid to saline soils.

Keywords: Climate change, soil salinity, groundnut, growth, yield, seed nutritional contents.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is a widely cultivated and economically significant legume, grown in numerous countries across six continents. In 2021, it was cultivated on approximately 32.7 million hectares, yielding about 53.9 million tons globally (ICRISAT, 2021). Nutritionally, groundnuts are rich in

high-quality edible oil (36–54%), protein (21–36.4%), and carbohydrates (18%), making them a valuable food and cash crop (Balasubramanian *et al.*, 2024). Also, due to its multiple uses, including oil extraction, soap making, cosmetics, lubricants, and food processing, groundnut is a valuable crop in various industries. It is commonly consumed

raw, roasted, or processed into peanut butter, sauces, and confections (Arya *et al.*, 2016).

Notably, the leading producers of groundnut are China, followed closely by India, highlighting the crop's immense economical and nutritional significance in these regions (ICRISAT, 2021). In Nigeria, groundnut is predominantly grown in the northern states, with over 85% of the country's production coming from Kano, Kaduna, Taraba, Bauchi, Borno, and Adamawa (Abalu and Harkness, 1979). Groundnut-based foods are integral to West African cuisine, including Nigeria's groundnut sauce, Mali's *maafe*, and Ghana's *nkate nkwan* (peanut butter soup). Groundnut is also a key ingredient in *nkate cake*, *kuli-kuli*, and African salad. Beyond its economic and culinary significance, the crop is valued for its ability to fix atmospheric nitrogen in the soil through symbiotic relationships with nitrogen-fixing bacteria, contributing to soil fertility improvement and sustainable agriculture (Witcombe and Tiemann, 2022).

Despite its importance, groundnut production is increasingly threatened by soil salinity, a major environmental stress affecting crop growth and yield. Salinity stress alters soil structure, disrupts nutrient availability, and reduces plant productivity (Akter *et al.*, 2020; Bhaduri *et al.*, 2022).

Globally, soil salinization is a widespread issue, affecting approximately 8.7% of the world's total land area, equating to over 833 million hectares (FAO, 2021a). This issue is particularly pronounced in irrigated regions, with estimates indicating that more than 10% of such croplands are impacted by salinity, posing major risks to food security worldwide (FAO, 2021b). In dry land farming systems, salinity further exacerbates agricultural challenges, severely limiting agricultural productivity. Turkey, for example, faces salinity and sodicity issues across approximately 1.5 million hectares of land (FAO, 2021a).

In Nigeria, large areas of arable land are affected by salinity, particularly in Southern States where measured electrical conductivity (EC) values ranged from 0.031 to 0.200 dS/m, with salinity levels between 0.6 and 0.9 mg/l, rendering them unproductive (Agbasi and Akpabio, 2015). Similarly, irrigated lands in the northern regions are experiencing rising salinity due to excessive fertilization and poor drainage management (Owonubi and George, 2019).

The continued use of saline irrigation water and fertilizer application without adequate soil management has accelerated the salinization process. This problem has contributed to a drastic reduction in groundnut production in Nigeria, which once ranked among the leading exporters of the crop but now struggles to meet local demand (Kayode *et al.*, 2021; Musa *et al.*, 2025).

To mitigate the adverse effects of salinity stress on crop production, the use of plant growth regulators such as salicylic acid (SA) has gained attention in recent years. Salicylic acid is a crucial signaling molecule that naturally occurs in plants and regulates diverse physiological and biochemical processes, including growth, photosynthesis, and stress responses. It plays a significant role in modulating plant defense mechanisms, influencing cell division, and coordinating flowering through its interaction with hormonal pathways (Li *et al.*, 2022). More importantly, SA has been shown to enhance plant tolerance to abiotic stresses, including salinity (Elsisi *et al.*, 2024). It improves photosynthesis efficiency (Keya *et al.*, 2023), regulates stomatal activity, and enhances nutrient uptake and transport (Jangra *et al.*, 2022). Additionally, SA has been reported to delay fruit ripening and increase systemic acquired resistance (SAR), which strengthens plants' defense mechanisms against stress factors (Urban *et al.*, 2022; Li *et al.*, 2024). Research indicates that seed priming with SA enhances germination and seedling vigor by

activating key enzymes involved in metabolic pathways (Biswas *et al.*, 2023). For instance, priming seeds with SA has been reported to significantly increase germination rates and seedling growth under stress conditions, potentially through the activation of α -amylase, which mobilizes starch reserves to supply necessary metabolites and energy for seed germination (Li *et al.*, 2017). The detoxification mechanisms in germinating seeds have also been linked to exogenous SA treatment. Specifically, SA seed priming has been shown to suppress reactive oxygen species (ROS) accumulation and bolster antioxidant defense systems in barley under salt stress conditions (Ellouzi *et al.*, 2023), further underscoring its role in improving crop resilience to salinity stress.

Despite the increasing interest in salicylic acid as a stress-mitigating agent, limited studies have been conducted on its application in salt-stressed groundnut plants (Mimouni *et al.*, 2016). Given the growing concerns over soil salinity and its detrimental impact on crop productivity, it is essential to explore effective solutions that can enhance plant resilience for improved groundnut production. Furthermore, research shows that scientific data exist on salinity effect with application of salicylic acid on several crops like arabidopsis (Rajjou *et al.*, 2016), cowpea (El-Taher *et al.*, 2021), sorghum (Jangra *et al.*, 2022), cotton (Keya *et al.*, 2023), barley (Ellouzi *et al.*, 2023), canola (Ilyas *et al.*, 2024); and tomato (Mimouni *et al.*, 2016; Boorboori and Li, 2025). However, there is limited data on groundnut despite being an important crop. Interestingly, most existing ones only assessed effect of salinity without considering application of salicylic acid (Akter *et al.*, 2020; Bhaduri *et al.*, 2022); a knowledge gap which this research intended to fill. This study was aimed to investigate the influence of salicylic acid on the phytotoxic effects of salinity on *Arachis hypogaea* (groundnut), focusing on its impact on

growth, yield, and seed nutritional composition. The research was hoped to contribute to developing sustainable strategies for enhancing groundnut production in saline soils.

MATERIALS AND METHODS

2.1 Location of the experiment

This experiment was carried out at the screen house of Plant Science and Biotechnology (PSB) Department, Adekunle Ajasin University, Akungba-Akoko (AAUA), Ondo State, Nigeria (latitude 7.2 °N, longitude 5.44 °E).

2.2 Sources of materials for the experiment

Groundnut seeds (local variety, Samut 23) were sourced from a local market in Akungba Akoko, Ondo State, Nigeria. The salt (NaCl) and salicylic acid (SA) were obtained from the laboratory, and the soil used for plant was collected from the experimental plots, all of PSB Department, AAUA. The soil was analysed for physical and chemical properties using the standard methods of AOAC (1990). It was shade-dried and passed through a 2-mm sieve. Total N was analyzed using the macro Kjeldahl procedure; organic carbon by Walkley and Black procedure with percentage derived by multiplying organic carbon content by 1.72; and pH using soil:water ratio of 1:2 with a pH meter. Available phosphorus was got through the Bray 1 method; exchangeable acidity by titration method; exchangeable K, Na, Ca, Al and Mg by extraction with 1 M ammonium acetate at pH 7.0; and the amount of K and Na was measured using a Corning Flame Photometer with appropriate filter, while Ca, Al and Mg were determined using a Perkin-Elmer Atomic Absorption Spectrophotometer (AAS). The electrical conductivity was read with a conductivity meter.

2.3 Experimental setup

Groundnut was grown in perforated polythene pots filled with topsoil. Three weeks after planting, the seedlings were grouped into two: each plant in the first group was irrigated with 250 ml (volume enough to keep the soil moist) of saline water prepared with distilled water to 0 (control), 5, 10, 15, 20, 25, or 30 mM NaCl solution, followed by 10 ml of 1 mM (1000 ppm) SA. Plants in the second group received only the saline water without SA. The choice of 1 mM (1000 ppm) SA was premised on being concentration suitable for growth and stress management for most plant species (El-Taher *et al.*, 2021; Elsisi *et al.*, 2024; Boorboori and Li, 2025). Each treatment was replicated five times, and salt application was carried out twice per week, with salicylic acid applied once weekly. To prevent salt accumulation beyond the intended concentrations, excess salt was flushed out by soaking the pots with water and allowing them to drain on a weekly basis, followed by salinity and SA treatments.

2.4 Data collection

Growth parameters including plant height, stem girth, leaf area, number of leaves and branches, fresh and dry weights as well as number of roots and root length were measured. Plant height was measured from the soil surface to the apical bud using a meter rule; stem girth with a digital vernier caliper at the 5 cm point above the soil level, leaf area with leaf area meter (model LI-COR 300). The number of leaves and branches was manually counted. At harvest, fresh and dry mass were taken, and number of roots counted with their length measured with meter rule. Yield parameters including number of pods per plant, number of seeds per pod, and total seed count per plant were also recorded.

2.5 Plant analysis in the laboratory

Harvested groundnut grains were air-dried, milled and analysed for nutritional and proximate compositions using the standard

laboratory procedures of AOAC (2009). Moisture content was analyzed using the hot oven method; percentage ash by ashing in a muffle furnace at 550 °C for 6 hours; crude fat by using the Soxhlet method with acetone as a solvent; and crude protein through micro-Kjeldahl method, with total nitrogen converted to protein using the factor 6.25. Crude fibre was determined by sequential digestion with acid and alkaline, followed by ashing at 550 °C, and carbohydrate estimated by difference, subtracting the sum of other proximate components from 100%. Minerals including Mg and Ca were analyzed using Atomic Absorption Spectrophotometry while Na and K were by flame photometry, and spectrophotometric analysis at 420 nm for P.

2.6 Data analysis

All data were subjected to One-way Analysis of Variance, and means were separated with Duncan Multiple Range Test using the Statistical Package for Social Sciences (SPSS) version 24.0.

RESULTS

3.1 Soil used for planting

The soil used for planting was a sandy clay loam soil, reach in essential nutrients with physicochemical properties suitable for groundnut cultivation (Table 1).

Table 1: Physico-chemical parameters of soil used for planting

Parameter	Value
Sand (%)	58.15
Clay (%)	28.42
Silt (%)	13.43
Soil Textural class	Sandy clay loam
Soil pH	6.72
Available Al (cmol/kg)	21.64
Available Ca (cmol/kg)	5.66
Available K (cmol/kg)	0.22
Available Mg (cmol/kg)	3.08
Available N (mg/kg)	0.21
Available Na (cmol/kg)	0.40
Available P (mg/kg)	18.31
Electrical Conductivity EC (%)	0.42
Organic Matter (%)	1.93

3.2 Plant survival and growth

All plants survived under salinity stress either with or without salicylic acid application (Table 2). Salinity generally reduced all the growth parameters as salt concentrations increased, and the greatest negative effect was recorded at the highest salt level of 30 mM NaCl solution. Salicylic acid application lowered salt-induced reduction in all the growth parameters (Table 3). Salinity without SA addition compared to SA

application lowered reduction in plant height (14.74% to 4.97%), number of leaves (20.80% to 14.77%), number of branches (21.43% to 16.67%), stem girth (16.00% to 14.53%), leaf area (10.00% to 8.01%), number of roots (24.43% to 3.74%), and root length (8.78% to 5.71%) relative to their respective control treatments.

Table 2: Growth parameters of *Arachis hypogaea* under salinity stress with and without salicylic acid (SA) application

Survival /growth parameter	With/without SA treatment	Salinity (mM NaCl)						
		0	5	10	15	20	25	30
Survival (%)	SA	100	100	100	100	100	100	100
	No SA	100	100	100	100	100	100	100
Plant height (cm)	SA	45.25±4.13 ^a	45.00±1.83 ^a	44.25±1.31 ^a	43.25±0.95 ^a	42.00±1.47 ^a	41.75±2.14 ^a	43.00±1.58 ^a
	No SA	47.50±0.96 ^b	43.50±0.66 ^{ab}	42.50±1.71 ^{ab}	43.50±0.87 ^{ab}	41.50±1.19 ^a	42.75±0.48 ^a	40.50±0.50 ^a
Number of leaves	SA	250.50±38.91 ^a	242.50±24.73 ^a	246.00±22.70 ^a	238.00±12.45 ^a	231.50±19.82 ^a	218.50±16.17 ^a	213.50±6.60 ^a
	No SA	250.00±23.17 ^a	234.00±22.14 ^a	221.50±19.82 ^a	212.50±4.57 ^a	208.50±20.52 ^a	201.50±8.06 ^b	198.00±6.68 ^b
Number of branches	SA	7.50±1.19 ^a	7.00±0.41 ^a	6.75±0.25 ^a	6.75±0.48 ^a	6.25±0.63 ^a	6.25±0.29 ^a	6.25±0.25 ^a
	No SA	7.00±0.41 ^b	6.00±0.41 ^{ab}	5.75±0.25 ^{ab}	5.75±0.25 ^{ab}	5.50±0.29 ^a	5.50±0.29 ^a	5.50±0.29 ^a
Stem girth (cm)	SA	5.85±0.75 ^a	5.75±0.25 ^a	5.50±0.29 ^a	5.25±0.25 ^a	5.00±0.41 ^a	5.25±0.48 ^a	5.00±0.00 ^a
	No SA	6.25±0.25 ^a	5.25±0.25 ^a	5.00±0.00 ^a	5.00±0.41 ^a	4.75±0.48 ^a	5.00±0.00 ^a	5.25±0.25 ^a
Leaf area (cm ²)	SA	22.98±0.63 ^a	22.49±0.76 ^a	21.44±0.87 ^a	22.08±1.07 ^a	21.85±0.73 ^a	21.80±0.68 ^a	21.14±0.86 ^a
	No SA	25.00±1.07 ^a	23.75±1.01 ^a	23.00±0.87 ^a	24.25±1.28 ^a	23.35±1.55 ^a	23.64±1.53 ^a	22.50±0.97 ^a
Number of roots	SA	26.75±3.49 ^a	25.00±2.27 ^a	25.25±1.44 ^a	25.75±1.38 ^a	25.50±1.26 ^a	25.00±4.02 ^a	26.75±1.55 ^a
	No SA	32.75±2.06 ^a	27.00±1.08 ^a	28.00±0.91 ^a	29.50±2.40 ^a	25.75±1.89 ^a	25.00±2.04 ^a	24.75±1.25 ^a
Root length (cm)	SA	37.00±5.08 ^a	33.25±2.69 ^a	44.25±3.20 ^a	33.00±8.55 ^a	32.50±3.07 ^a	32.25±2.46 ^a	33.75±3.57 ^a
	No SA	35.00±3.00 ^a	28.50±0.65 ^a	27.50±2.02 ^a	35.00±3.39 ^a	34.25±2.29 ^a	29.00±2.35 ^a	35.00±2.04 ^a

SA= with salicylic acid application, No SA = without salicylic acid application. Values are means ± standard error for 5 replicates. Means with similar alphabet(s) in superscript on same row are not significantly different ($p \geq 0.05$) from each other (Duncan Multiple Range Test).

Table 3: Relative reduction of growth parameters in *Arachis hypogaea* by salinity stress with and without salicylic acid application

Growth parameter	With/without SA treatment	Salinity (mM NaCl)					
		5	10	15	20	25	30
Plant height (cm)	SA	0.55	2.21	4.42	7.18	7.73	4.97
	No SA	8.42	10.53	8.42	12.63	10.00	14.74
Number of leaves	SA	3.19	1.80	4.99	7.58	12.77	14.77

Number of branches	No SA	6.40	11.40	15.00	16.60	19.40	20.80
	SA	6.67	10.00	10.00	16.67	16.67	16.67
Stem girth (cm)	No SA	14.29	17.86	17.86	21.43	21.43	21.43
	SA	1.71	5.98	10.26	14.53	10.26	14.53
Leaf area (cm ²)	No SA	16.00	20.00	20.00	24.00	20.00	16.00
	SA	2.13	6.70	3.92	4.92	5.13	8.01
Number of roots	No SA	5.00	8.00	3.00	6.60	5.44	10.00
	SA	6.54	5.61	3.74	4.67	6.54	3.74
Root length (cm)	No SA	17.56	14.50	9.92	21.37	23.66	24.43
	SA	0.00	1.43	2.86	5.00	2.86	5.71
	No SA	10.14	7.43	10.81	12.16	12.84	8.78

SA= with salicylic acid application, No SA = without salicylic acid application

3.3 Plant biomass

Likewise, biomass parameters decreased with increase in salt concentration with the highest reduction found at 30 mM NaCl (Table 4). Except leaf dry weight, application of SA lowered reduction in biomass parameters due to salt stress (Table 5).

Salinity without SA application compared to its presence lowered reduction in leaf fresh weight (33.35% to 13.36%), stem fresh weight (51.40% to 29.81%), root fresh weight (37.53% to 28.57%), stem dry weight (37.64% to 35.41%), root dry weight (42.37% to 28.15%), and total biomass (37.05% to 33.35%).

Table 4: Vegetative biomass of *Arachis hypogaea* under salinity stress with or without salicylic acid (SA) application

Biomass parameter (g)		With/without SA treatment	Salinity (mM NaCl)						
			0	5	10	15	20	25	30
Leaf weight	fresh	SA	34.95±5.92 ^a	33.35±1.99 ^a	32.83±2.64 ^a	33.78±2.22 ^a	32.50±2.27 ^a	28.98±2.05 ^a	30.28±4.29 ^a
		No SA	39.13±0.42 ^b	32.08±2.67 ^{ab}	26.38±4.08 ^{ab}	24.48±2.06 ^a	25.63±4.30 ^{ab}	24.15±2.72 ^a	26.08±3.71 ^{ab}
Stem weight	fresh	SA	39.15±8.56 ^a	33.78±0.64 ^a	30.88±2.93 ^a	31.10±3.40 ^a	28.10±4.41 ^a	28.93±4.15 ^a	27.48±3.21 ^a
		No SA	42.35±2.76 ^a	30.95±0.93 ^a	28.65±2.29 ^a	28.08±3.00 ^a	25.33±2.19 ^a	24.95±3.54 ^a	20.58±1.56 ^a
Root weight	fresh	SA	4.13±0.81 ^a	3.75±0.17 ^a	3.70±0.29 ^a	3.38±0.31 ^a	3.05±0.43 ^a	3.50±0.78 ^a	2.95±0.64 ^a
		No SA	4.05±0.63 ^a	3.18±0.19 ^a	2.95±0.45 ^a	3.23±0.40 ^a	2.90±0.36 ^a	2.75±0.47 ^a	2.53±0.27 ^a
Leaf weight	dry	SA	17.18±3.76 ^a	12.75±0.95 ^a	12.15±0.73 ^a	11.25±0.70 ^a	10.95±0.73 ^a	10.88±0.60 ^a	10.80±0.73 ^a
		No SA	16.30±1.81 ^b	12.38±1.13 ^{ab}	9.18±1.74 ^a	10.03±0.64 ^{ab}	10.93±1.78 ^{ab}	10.30±1.28 ^{ab}	10.30±0.98 ^{ab}
Stem weight	dry	SA	17.00±2.38 ^a	14.85±1.66 ^a	13.63±1.62 ^a	12.75±1.21 ^a	11.45±1.23 ^a	10.83±1.76 ^a	10.98±1.33 ^a
		No SA	17.80±5.66 ^a	15.33±1.66 ^a	13.40±1.84 ^a	12.93±1.71 ^a	11.43±1.81 ^a	10.90±1.60 ^a	11.10±1.48 ^a
Root weight	dry	SA	1.35±0.27 ^a	1.21±0.14 ^a	1.13±0.14 ^a	1.03±0.18 ^a	1.05±0.16 ^a	0.95±0.27 ^a	0.97±0.42 ^a
		No SA	1.18±0.20 ^a	1.05±0.10 ^a	1.03±0.33 ^a	0.85±0.06 ^a	0.78±0.11 ^a	0.67±0.11 ^a	0.68±0.12 ^a
Total biomass		SA	34.48±4.39 ^b	28.28±2.89 ^c	26.84±3.69 ^a	24.63±1.91 ^a	23.16±3.12 ^a	21.80±3.15 ^a	22.98±2.43 ^a
		No SA	36.33±9.69 ^b	29.36±2.75 ^a	26.72±2.71 ^a	25.21±2.59 ^a	23.43±2.70 ^a	22.73±2.47 ^a	22.87±2.63 ^a

SA= with salicylic acid application, No SA = without salicylic acid application. Values are means ± standard error for 5 replicates. Means with similar alphabet(s) superscript on same row are not significantly different ($p \geq 0.05$) from each other (Duncan Multiple Range Test).

Table 5: Relative reduction of biomass parameters in *Arachis hypogaea* by salinity stress with and without salicylic acid application

Biomass parameter	With/without SA treatment	Salinity (mM NaCl)					
		5	10	15	20	25	30
Leaf fresh weight	SA	4.01	6.07	3.35	7.01	17.08	13.36
	No SA	18.02	32.58	37.44	34.50	38.28	33.35
Stem fresh weight	SA	13.72	21.12	20.56	28.22	26.10	29.81
	No SA	26.92	32.35	33.70	40.19	41.09	51.40
Root fresh weight	SA	9.20	10.41	18.16	26.15	15.25	28.57
	No SA	21.48	27.16	20.25	28.40	32.10	37.53
Leaf dry weight	SA	25.79	29.28	34.52	36.26	36.67	37.14
	No SA	36.32	43.68	38.47	32.94	36.81	36.81
Stem dry weight	SA	12.65	19.82	25.00	32.65	36.29	35.41
	No SA	13.88	24.72	27.36	35.79	38.76	37.64
Root dry weight	SA	10.37	16.30	23.70	22.22	29.63	28.15
	No SA	11.02	12.71	27.97	33.90	43.22	42.37
Total biomass	SA	17.98	22.16	28.57	32.83	36.77	33.35
	No SA	19.19	26.45	30.61	35.51	37.43	37.05

SA= with salicylic acid application, No SA = without salicylic acid application

3.4 Yield parameters

Similar trend was also recorded for yield parameters where yield decreased with increase in salt concentration, with the highest reduction obtained at 30 mM NaCl (Table 6). Except number of seeds per pod

that was not affected, the 54.79% reduction in number of pods/plant without SA application was lowered to 19.44% when SA was applied (Table 7). In the same vein, 55.81% reduction in number of seeds per plant when SA was not added reduced to 20.90% under its addition.

Table 6: Yield parameters of *Arachis hypogaea* under salinity stress with or without salicylic acid (SA) application

Yield parameter	With/without SA treatment	Salinity (mM NaCl)						
		0	5	10	15	20	25	30
Number of pods/plant	SA	9.00±2.35 ^a	8.75±0.85 ^a	7.75±1.11 ^a	7.75±1.03 ^a	7.50±0.87 ^a	7.50±0.96 ^a	7.25±0.95 ^a
	No SA	18.25±2.95 ^b	14.50±3.18 ^{ab}	10.75±2.14 ^{ab}	10.50±1.30 ^{ab}	11.50±0.65 ^{ab}	8.00±1.35 ^a	8.25±0.85 ^a
Number of seeds/pod	SA	1.77±0.30 ^a	1.33±0.21 ^a	1.60±0.15 ^a	1.25±0.16 ^a	1.65±0.20 ^a	1.38±0.09 ^a	1.83±0.10 ^a
	No SA	1.73±0.17 ^a	1.63±0.14 ^a	1.53±0.05 ^a	1.45±0.12 ^a	1.53±0.12 ^a	1.53±0.06 ^a	1.62±0.11 ^a
Number of seeds/plant	SA	16.75±3.64 ^a	15.12±1.87 ^a	12.50±1.19 ^a	11.75±1.44 ^a	13.00±2.48 ^a	10.50±1.26 ^a	13.25±1.49 ^a
	No SA	10.75±2.06 ^b	8.50±1.26 ^{ab}	7.25±1.55 ^{ab}	7.00±0.71 ^{ab}	7.50±0.65 ^{ab}	5.25±0.95 ^{ab}	4.75±0.48 ^a

SA= with salicylic acid application, No SA = without salicylic acid application. Values are means ± standard error for 5 replicates. Means with similar alphabet(s) in superscript on same row are not significantly different ($p \geq 0.05$) from each other (Duncan Multiple Range Test).

Table 7: Relative reduction of yield parameters in *Arachis hypogaea* by salinity stress with and without salicylic acid application

Yield parameter	With/without SA treatment	Salinity (mM NaCl)					
		5	10	15	20	25	30
Number of pods/plant	SA	13.89	13.89	13.89	16.67	16.67	19.44
	No SA	20.55	41.10	42.47	36.99	56.16	54.79
Number of seeds/pod	SA	2.26	4.52	6.78	6.78	10.73	7.91
	No SA	0.00	11.56	16.18	11.56	11.56	6.36
Number of seeds/plant	SA	9.73	25.37	29.85	22.39	37.31	20.90
	No SA	20.93	32.56	34.88	30.23	51.16	55.81

SA= with salicylic acid application, No SA = without salicylic acid application

3.5 Nutritional and proximate composition

Table 8 shows the influence of salinity with and without salicylic acid application on the nutritional and proximate composition of *Arachis hypogaea* seeds. Percentage moisture and crude fibre were not affected by salt application. Meanwhile, percentage ash and carbohydrate were increased by salinity, but the difference was not significant ($p \geq 0.05$) when compared to the control treatment. In contrast, salinity reduced crude protein and fat, there was also no significant difference

from the control. Results indicated that there was no effect of salinity on the nutrients including K, P and N, it however led to a significant accumulation of Na^+ and Cl^- in the seeds with values that significantly differed ($p \leq 0.05$) from the control treatments. Meanwhile, there was no influence of application of SA on nutritional and proximate compositions of seeds of plants grown under salt stress, except for minimal reduction of Na^+ and Cl^- accumulation recorded in plants grown with SA over those without it.

Table 8: Nutrient and proximate composition of *Arachis hypogaea* seeds under salinity stress with or without salicylic acid (SA) application

Nutritional/proximate composition (%)	With/without SA treatment	Salinity (mM NaCl)			
		0	5	15	30
Moisture content	SA	5.79±0.01 ^a	5.52±0.02 ^a	5.15±0.02 ^a	3.93±0.02 ^a
	No SA	5.83±0.01 ^a	5.61±0.01 ^a	4.74±0.01 ^a	3.78±0.02 ^{ab}
Ash content	SA	2.84±0.01 ^a	2.96±0.01 ^a	4.66±0.01 ^a	6.17±0.02 ^{ab}
	No SA	2.89±0.01 ^a	3.20±0.01 ^a	5.48±0.01 ^a	6.82±0.01 ^a
Crude fibre	SA	3.14±0.03 ^a	3.11±0.02 ^a	3.14±0.01 ^a	3.16±0.01 ^a
	No SA	3.08±0.01 ^a	3.09±0.00 ^a	3.09±0.00 ^a	3.06±0.01 ^a
Fat content	SA	40.16±0.01 ^a	39.49±0.01 ^a	37.62±0.01 ^a	34.24±0.03 ^a
	No SA	39.69±0.02 ^a	37.68±0.02 ^a	34.55±0.07 ^a	33.26±0.33 ^a
Crude protein	SA	38.37±0.08 ^a	34.87±3.70 ^a	37.47±0.07 ^a	35.45±0.02 ^a
	No SA	38.93±0.35 ^a	37.67±0.18 ^a	36.12±0.02 ^a	34.57±0.02 ^a
Carbohydrate	SA	9.70±0.09 ^a	14.05±3.69 ^{ab}	11.96±0.05 ^a	17.05±0.04 ^{ab}

	No SA	9.92±0.05 ^a	12.75±0.19 ^{ab}	15.99±0.05 ^{ab}	18.44±0.30 ^b
Sodium	SA	28.15±0.02 ^a	80.69±0.23 ^b	85.78±0.93 ^b	89.15±0.02 ^b
	No SA	29.85±0.16 ^b	82.79±0.93 ^b	96.65±0.05 ^b	124.75±0.06 ^b
Potassium	SA	910.81±0.79 ^d	902.61±0.03 ^a	900.17±0.03 ^a	884.67±0.29 ^a
	No SA	919.49±0.66 ^a	905.19±0.50 ^a	893.09±0.30 ^a	893.26±1.54 ^a
Phosphorus	SA	334.43±0.21 ^a	334.37±0.63 ^a	331.67±0.77 ^a	332.96±3.25 ^a
	No SA	326.89±0.30 ^a	320.87±0.05 ^a	315.56±0.04 ^a	308.94±0.71 ^a
Nitrogen	SA	3.65±0.02 ^a	3.56±0.14 ^a	3.13±0.01 ^a	2.62±0.02 ^a
	No SA	3.54±0.01 ^a	3.05±0.02 ^a	2.72±0.01 ^a	2.51±0.02 ^a
Chlorine	SA	172.67±0.67 ^a	1330.67±0.67 ^b	1328.00±1.15 ^b	1322.67±2.73 ^b
	No SA	186.76±6.44 ^a	1351.00±2.52 ^b	1377.67±0.88 ^b	1467.33±1.20 ^b

SA= with salicylic acid application, No SA = without salicylic acid application. Values are means $\pm$ standard error for 3 replicates. Means with similar alphabet(s) in superscript on the same row are not significantly different ($p \geq 0.05$) from each other (Duncan Multiple Range Test).

DISCUSSION

Soil salinization is considered one of the major problems in the agricultural world. It has been found to cause severe reduction in seed germination, plant growth and yield as well as reduced nutritional composition of edible plant parts. The findings of this study reveal that soil salinization negatively impacted *Arachis hypogaea*, reducing growth, yield, and seed nutrient composition, with the most severe effects at 30 mM NaCl. The observed reduction in growth and yield due to salinity aligns with previous studies on various crops. Saddidiq *et al.* (2021) documented similar effects in *Triticum aestivum*, while Mimouni *et al.* (2016) and Jekabsone *et al.* (2022) reported growth inhibition in *Solanum lycopersicum* and *Trifolium fragiferum*, respectively. The decline in groundnut growth and biomass under salinity stress is consistent with recent findings on and *Hordeum vulgare* (Hanif *et al.*, 2024) and *Solanum lycopersicum* (Boorboori and Li, 2025), where salinity reduced relative growth rate and dry weight of the crops. This was also corroborated by the reports of Chourasia *et al.* (2022) on underground vegetable crops and Rodriguez Coca *et al.* (2023) on *Oryza sativa*, where high salinity inhibited germination and early

growth. The negative effects of salinity on groundnut might be due to physiological changes as earlier confirmed that salinity disrupts plant physiological processes, leading to osmotic stress and nutrient imbalances, making it a significant challenge for crop production (Chaudhary *et al.*, 2024).

Interestingly, application of SA has shown to counteract the negative effects of salinity, as demonstrated in this study, and its role in alleviating these adverse effects has been well documented. In this study, SA-treated *A. hypogaea* showed a limited reduction in growth parameters like leaf area expansion by salinity, reinforcing its protective role in maintaining plant growth under stress. In addition, Ilyas *et al.* (2024) reported that SA treatment diminished the negative effects of salinity in *Brassica napus*, enhancing its biomass, enzymatic, osmolyte and ionic activities. This is also similar to the findings of Keya *et al.* (2023) which demonstrated that SA improved cotton tolerance to salinity by enhancing physiological responses, including net photosynthetic rate, stomatal conductance, transpiration rate, water-use-efficiency and chlorophyll content, resulting in better growth performance. Similarly, Jangra *et al.* (2022) found that SA application increased the photosynthetic rate,

transpiration rate and stomatal conductance in *Sorghum bicolor*, while El-Taher *et al.* (2021) reported enhanced chlorophyll and pigment content in *Vigna unguiculata* with SA treatment.

Na⁺ and Cl⁻ accumulation in seeds under soil salinization might have been as a result of nutrient imbalances, affecting *A. hypogaea* growth and yield. This is comparable to findings by Ehtaiwesh (2022) in crop plants, where excess ions of sodium and chlorine were found to reduce nutrient uptake. Additionally, nitrogen depletion under salt stress, likely due to ion competition, mirrors previous reports on salinity-induced nutrient imbalances (Saidi *et al.*, 2021; Tammam *et al.*, 2022), which might be responsible for reduction in growth and yield performances.

Recent studies have demonstrated that salinity adversely affects potassium (K⁺) uptake in plants, a critical factor for growth and stress adaptation. In the halophyte *Cakile maritima*, Houmani *et al.* (2022) discovered that exposure to high salinity combined with potassium deficiency resulted in reduced K⁺ content in both leaves and roots, while Na⁺ content increased, leading to disrupted ion acquisition and elevated Na⁺/K⁺ ratios. Similarly, research on *Arabidopsis thaliana* by Zhao *et al.* (2020) demonstrated that different salt stresses impacted the uptake and translocation of Na⁺ and K⁺, with specific treatments leading to lower K⁺ concentrations in shoots despite higher external K⁺ availability. The findings of this study support this trend, as *A. hypogaea* plants treated with SA exhibited altered K uptake under salinity, suggesting that SA might have influenced nutrient absorption mechanisms under salt stress. These findings further confirm the potential of SA in alleviating the phytotoxic effects of soil salinization and improving crop resilience and productivity in saline environments. Reduction of crude protein and fat by salinity needs attention because, protein, for instance, acts as a

building block for tissues, muscles, and organs, supporting growth and repair, and playing vital roles in bodily processes like enzyme and hormone production, and immune function. Increased seed ash content can be attributed to Na⁺ and Cl⁻ accumulation, and carbohydrate increase by salinity may be advantageous because it serves as the body's primary energy source, fueling activities like brain and muscle functions.

CONCLUSION

AND

RECOMMENDATIONS

Salinity negatively impacted growth, vegetative biomass, seed yield and nutritional contents of groundnut. This was mainly due to nutrient imbalance occasioned by accumulation of excessive Na⁺ and Cl⁻ in plant tissues. However, the phytotoxic effects of soil salinization, a product of climate change, can be mitigated through application of salicylic acid to saline soils. Therefore, salicylic acid is recommended for use in irrigation of groundnut for its sustainable production in saline soils.

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EVALUATION OF THE EFFECTS OF CLIMATE CHANGE ON ECOSYSTEM SERVICES AND COMMUNITY LIVELIHOODS AROUND NGEL NYAKI FOREST RESERVE TARABA, NIGERIA

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ABSTRACT

Recognized as a trigger of interfacing impacts on various sectors, ecosystem service, livelihood in developing nations, and climate change are closely interlinked. The livelihoods of many poor peoples in developing countries depend heavily on tropical forests. Over the past few decades, mounting evidence of climate change-related stress poses a threat to ecological systems and human livelihoods throughout the world, raising lingering worries about its implications on ecosystem change for human well-being. The human ecology approach is utilized in this study to analyze the influence of climate change on ecosystem services and livelihoods at Ngel Nyaki Forest Reserve in Taraba State, Northeastern Nigeria. The paper reviews the principal drivers of the change observed, the exposure of the communities concerned, and their poor strategies for adaptation. Results of the study indicated that climate change was affecting the quality of NNFR ecosystem services to the people. Water, forest, and agricultural resources are the main livelihood sources affected by climate change. Several coping and adaptation strategies have apparently taken root to support agricultural development, biodiversity conservation, and water resource management in the communities around this reserve in order to minimize the impacts of climate change. This article also recommends strategies that will empower decision-makers to enhance ecosystem services and further research toward a more effective approach to mitigation and adaptation to climate change.

Keywords: Adaptation, Agriculture, Biodiversity, Coping Mechanisms, Human Well-Being

INTRODUCTION

One of the most damaging risks to the planet is climate change, which jeopardizes ecosystem function, biodiversity, and the survival of the majority of impoverished people who live in forested areas of developing countries (UNEP, 2009; IPCC, 2021). Climate change is recognized as one of the world's most pressing environmental, social, and economic challenges. It is now a more immediate and severe threat than previously estimated, particularly in developing regions, with Africa being one of the most vulnerable continents due to its low adaptive capacity and widespread poverty

(Niang *et al.*, 2014; Adebayo *et al.*, 2021). The consequences of climate change are expected to worsen existing issues such as poverty, hunger, and environmental degradation, thereby further reducing the quality of life in affected regions (FAO, 2016; Adger *et al.*, 2003). Impoverished populations are especially vulnerable due to their dependence on ecosystem services and limited access to adaptive resources and technologies (Morton, 2007).

Moreover, changing climatic conditions have intensified the frequency and severity of extreme weather events, such as flooding in both urban and rural settings, which in turn

leads to the destruction of infrastructure and displacement of communities (Douglas *et al.*, 2008; IPCC, 2022). Variability in temperature and precipitation patterns has disrupted ecological balance, resulting in habitat alteration and species extinctions (Walther *et al.*, 2002). Additionally, rising sea levels threaten coastal zones, accelerating shoreline erosion and contaminating freshwater sources (Nicholls and Cazenave, 2010). Nigeria's economy, which is highly dependent on climate-sensitive sectors such as agriculture, is particularly exposed to these impacts. Unpredictable rainfall and temperature changes have led to lower crop productivity, food insecurity, and economic setbacks (Ayanlade *et al.*, 2017). Climate-induced flooding is increasingly affecting both rural and urban infrastructures, further compounding socio-economic vulnerabilities (Olanrewaju *et al.*, 2019). Habitat loss and biodiversity erosion resulting from these changes exacerbate ecological imbalances. Coastal regions face rising salinity and freshwater contamination due to sea-level rise (Odjugo, 2010).

Addressing the effects of climate change on Nigerian communities requires effective and locally grounded adaptation strategies. The purpose of this research is to explore the interlinkages between ecosystem services, community livelihoods, and climate change in the Ngel Nyaki Forest Reserve. Understanding these linkages is essential for designing context-specific adaptation strategies that promote biodiversity conservation and support sustainable livelihoods. The findings will contribute to policy development and enhance local resilience to climate-related challenges.

Climate Change, Ecosystem Services, and Livelihoods

The linkages of climate change with ecosystems and human livelihoods, especially in Africa, are supported strongly

(MEA, 2005; Niang *et al.*, 2014). The ecosystems, which consist of plants, animals, fungi, microorganisms, and the physical environment, provide essential services vital to human existence and sustainable development (Costanza *et al.*, 1997; Daily, 1997). Among the provided services are food, timber, water purification, climate regulation, pollination, and cultural values (MEA, 2005). For most forest and rural societies, livelihoods are based on ecosystems, both physical and spiritual needs (Sunderlin *et al.*, 2005; Chazdon *et al.*, 2009). However, forest ecosystems face increasing pressure from human activities and climate change that undermine their ability to support agriculture, livelihoods, and health (Locatelli *et al.*, 2008). This loss of ecosystem condition jeopardizes food security, enhances poverty, and results in famine and malnutrition for the poor (Reed *et al.*, 2016). The four types of ecosystem services include provisioning (for example, food, water), regulating (for example, climate regulation, regulation of diseases), supporting (for example, cycling of nutrients), and cultural (for example, recreation, spiritual) (TEEB, 2010).

Ecosystem function or structure impact has profound human well-being, human development, and environmental sustainability consequences (MEA, 2005). Conservation of ecosystem services is at the core of the realization of the Sustainable Development Goals like ending poverty, enhancing health, and agricultural resilience to climate change (UN SDGs, 2015). Failure to act to counter with timely response to maintain ecosystems will render these goals unachievable, particularly where ecosystem vulnerability is already expressing itself across sectors (IPBES, 2019).

Overview of the Effects and Implications of Climate Change

Global warming, mainly as a result of human actions like the consumption of fossil fuels

and forest clearing, is one of the main global threats (USAID, 2023). The trapping of greenhouse gases like carbon dioxide, methane, and nitrous oxide distorts climatic trends, causing heatwaves, dryness, and intense rain. Such interference adversely affects agriculture, cutting food production and rising food insecurity, especially in areas like sub-Saharan Africa (Akpan, 2024). Increased temperature also leads to the melting of glaciers and sea-level rise, subjecting coastal communities to erosion, flooding, and saltwater intrusion (Oyelakin, 2023). Warm oceans are also harmful to marine ecosystems, providing overfished stocks and coral bleaching, hence reducing food security and biodiversity (USAID, 2023). Terrestrial ecosystems are also affected since organisms find it hard to adapt to the changing environment, leading to habitat loss and reduced ecosystem services like pollination and water filtration (USAID, 2023).

Climate change also incurs huge health risk, economic loss, and displacement. Nigeria is the most vulnerable because it has low adaptive capacity and structural factors. Agriculture, fisheries, water, health, and energy are hit hardest (Vanguard, 2023). Hydropower is affected by rainfall variability and flooding, while the productivity of crops reduces as land degrades. Water-borne and vector-borne health risks rise especially where there is a lack of proper healthcare (WHO, 2024). Recognition of these cumulative effects is essential to the design of effective adaptation and mitigation strategies to safeguard ecosystems and human communities.

Research Problem

Studies have noted that approximately 70% of ecosystem services are declining, significantly impacting forest-based communities (Falaki *et al.*, 2022). In the context of the Ngel Nyaki Forest Reserve,

climate change and altered rainfall patterns threaten ecosystem functionality, biodiversity, and the livelihoods of those dependent on forest resources. There is the need therefore to investigate how changes in ecosystem services, such as water regulation, soil quality, and biodiversity, affect and disrupt local populations. This research is a step in that direction and aims to: (i) examine the impact of climate change on key ecosystem services; (ii) assess how these impacts influence agriculture, water resources, and local economic activities; and (iii) propose adaptive responses and policy recommendations to mitigate adverse effects and enhance resilience in the study area.

Materials and Methods

Description of the Study Area

The survey was carried out in the Ngel Nyaki Forest Reserve on the west slope of the Mambilla Plateau in Taraba State, Nigeria, between latitudes 6°30' and 7°15' North and longitudes 11°00' and 11°30' East. The reserve is around 46 square kilometers in area between elevations of 1,400 and 1,500 meters above sea level. Access is on foot from Yelwa village. The region has high biodiversity with over 146 vascular plant species documented, out of which four are endangered and endemic trees. Some of the notable plants include *Anthocleista vogelii*, documented for the first time in West Africa. Diverse fauna includes endangered Nigeria-Cameroon chimpanzees, putty-nosed monkeys, and black-and-white colobus monkeys. The reserve has been documented with over 200 species of birds. The reserve, which was declared a local government forest reserve in 1969, is currently being managed by the Taraba State Government and Nigerian Conservation Foundation with assistance from the Nigerian Montane Forest Project. It has a wet season from April to

October and a dry season from November to March (Ihuma *et al.*, 2011).

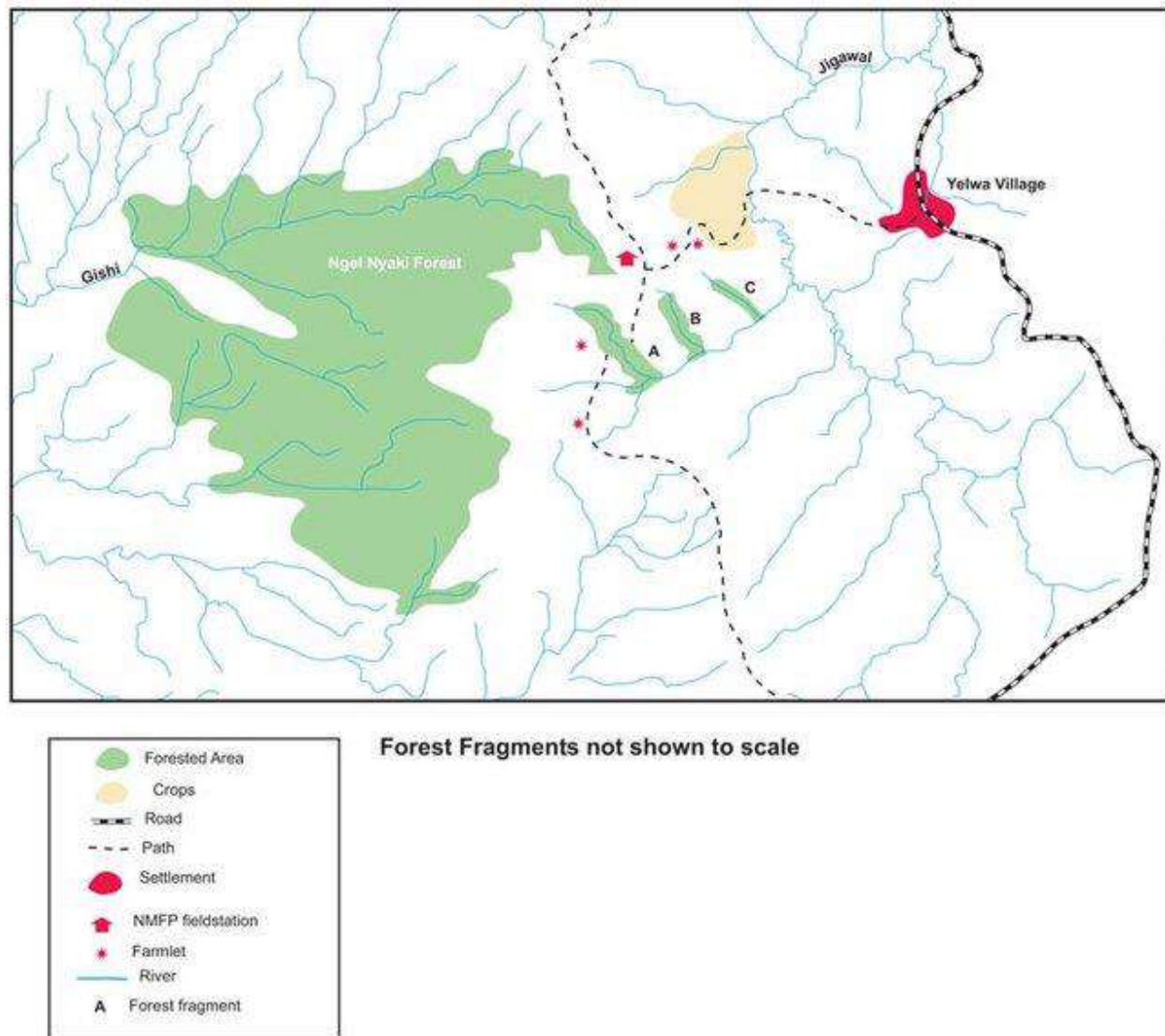


Figure 1: Map of Ngel Nyaki Forest Reserve (Ihuma *et al.*, 2011)

Approach to the Study

To evaluate impacts of climate change on human life and ecosystem services around the Ngel Nyaki Forest Reserve, we employed a combination of field surveys, and socioeconomic analysis. We started with Climate Data Analysis, comparing temperature and precipitation conditions in past and present times as utilized by IPCC

(2014) and Trenberth *et al.* (2015) in their respective studies. Second, for Socioeconomic Impact Assessment, we gathered data from interviews and standardized questionnaires to quantify the impact of changes in ecosystem services on water supply, agriculture, and economic activity as described by Adger *et al.* (2003) and Deressa *et al.* (2008). Third, we analyzed adaptation actions through stakeholder

consultation and local practices towards exploring local and regional climate change adaptation actions as outlined by several workers (Smit and Wandel, 2006; Locatelli *et al.*, 2008).

Conceptual Framework

Conceptual framework of this research investigates the link between ecosystems, climate change, and human beings depending on them. Climate change, through modifications in temperature, rainfall, and extreme climatic conditions, impinges on processes in ecosystems, modifying the quantity and quality of principal resources such as food and water (IPCC, 2023). Such interruptions turn out to be quite risky for neighborhood livelihoods, especially in regions based on natural resources and agriculture (Smit and Wandel, 2006; Adger *et al.*, 2020). Communities adapt using adaptation strategies like changing agricultural practices, migration, or diversification of income (Locatelli *et al.*, 2021). These adaptive strategies influence the behavior of ecosystems, generating a feedback loop between human activity and environmental change (Deryng *et al.*, 2020). Understanding this connection is essential for developing effective policies and interventions that enhance resilience and maintain ecosystem services for generations to come, imagining effective action (Turner *et al.*, 2007). This research intends to evaluate these effects and provide recommendations on minimizing vulnerabilities and maximizing adaptability.

Data Collection

Data utilized in the current study were collected from primary and secondary sources. Nigerian Meteorological Agency (NiMet, 2021) climatic data (1990–2020) were utilized to generate rainfall and temperature trends. 1990 and 2020 satellite

images were utilized to examine land cover changes within and around the Ngel Nyaki Forest Reserve (NNFR) by utilizing standard remote sensing methods (Foody, 2002; Jensen, 2007). Secondary data regarding ecosystem services, climate change, and livelihood of rural people were gathered from literature. Local adaptation methods were also investigated using participatory rural appraisal (PRA) techniques (Chambers, 1994). Primary data were collected in 2022 using field surveys conducted in seven villages, viz., Gembu, Dorofi, Nguroje, Ngelforo, Wakili Buba, Yelwa, and Maisamari. A mixed-method design was employed, involving environmental observation, guided questionnaires, discussion in focus groups, key informant interviews, and consultation with experts (Creswell, 2014). The data collection sample was a stratified random sample of 200 individuals over the age of 30 to ensure that views from individuals with long experience of climate variability were collected (Adger *et al.*, 2003). Interviewees were purposefully selected farmers, elders, and community leaders with environmental background data and first-hand experience of the climatic change.

Focus groups facilitated an understanding of how climate change impacts livelihood, dependence on ecosystem services, and perceived risks. Particular focus was placed on tea and coffee production near Gembu, where the region's only highland tea plantations are located. Effect of climate variability on plantation agriculture was evaluated by examining production trends from 1990 to 2020 (Locatelli *et al.*, 2008). Integrated approach facilitated a broad-level comprehension of climate-driven environmental change and effects on ecosystem sustainability and community livelihood in the NNFR landscape.

Data Analysis

The mixed quantitative and qualitative methods were utilized for the data analysis. Trending of rainfalls and temperature was confirmed with the application of the Mann-Kendall (MK) non-parametric trend test, ideally suited for checking monotonic tendencies in climatic time series (Sneyers, 1990; Hamed and Rao, 1998). Application of the MK test was based on a confidence level of 95%. The MK test fails to provide change magnitude, hence Sen's slope estimator was utilized to calculate the rate of climate variable change (Sen, 1968). To determine the effects of climate on crop yield, multiple regression analysis was employed. Yield information on key crops was analyzed as dependent variables and rainfall and temperature as independent variables—a methodology consistent with conventional agricultural-climate research practice (Lobell and Field, 2007). SPSS 16 and Microsoft Excel were used in statistical analysis and thematic analysis of qualitative data based on interviews and focus group discussion (Braun and Clarke, 2006).

The results of the analyzes of climate change occurrence in the area, communities' knowledge and experiences of the ecosystem services, awareness about climate change, impacts on vulnerabilities and livelihoods, biodiversity, water resources, and adaptation strategies is presented. As it was earlier indicated, a total of 200 respondents participated in the field survey; the age distribution of the respondents ranges between 30 and over 55 years. About 35 % of the respondents were between the ages of 30 and 50 years, whereas 65 % were aged 51 to 60 years. Of these, 65.5 % of the respondents were married, 21.5 % single, 8.5 % divorced, and 4.5 % widowed.

Socio-Demographic Respondents

The table below presents demographic data from a sample of 200 individuals. It categorizes respondents by age group, gender, and education level. The majority of respondents are aged 31-45 (36%) and predominantly male (90.5%). Most have primary education (36.5%), while 26% have no formal education.

RESULTS AND DISCUSSION

Table 1: Socio-Demographic Respondents

Age group	Number	Percent
≤ 20	16	8
21-30	47	23.5
31-45	72	36
46-50	44	22
51-60	12	6
61+	9	4.5
Total	200	100

Gender	Number	Percents

Male	181	90.5
Female	19	9.5
Total	200	100

Education	Number	Percent
No Formal	52	26
Primary	73	36.5
Secondary	53	26.5
Tertiary	22	11
Total	200	100

Analysis of Climatic Trends in Mambila Plateau, 1990–2020

Mambila Plateau in Taraba State is unique due to its climate, particularly when contrasted with the hotter and drier lowland areas of the state. The Plateau remains relatively cooler and experiences more rainfall. Temperature and rainfall records were taken by the Nigeria Meteorological Agency (NiMet) for a thirty-year span from 1990 to 2020. This data indicates an observable pattern of increasing temperatures combined with declining rainfall in parts of the Plateau, notably in the forest zones like Ngel Nyaki (Ayanlade and Jegede, 2016; NiMet, 2020; Oladipo, 2008). On average, annual temperatures ranged between 18 °C and 22 °C.

The Plateau has distinctly wet and dry seasons. The dry season, from November to March, features cooler temperatures typically between 15 °C and 20 °C. During the wet season, from April to October, temperatures range between 20 °C and 25 °C. Though relatively stable, there has been a small increase in average annual temperature over the three decades—most pronounced in the late 1990s. For example, the mean temperature increased from around 19 °C in 1990 to approximately 21 °C by 2020 (NiMet,

2020; Ibe *et al.*, 2023). Rainfall patterns have been seasonal but highly variable from year to year. This variability has important implications for agriculture, water resource management, and climate resilience planning in the Plateau (Ayanlade and Jegede, 2016; Oladipo, 2008).

This trend underlines the exposure of climate-sensitive sectors such as agriculture, human health, water resources, and biodiversity to increasing climatic stress. Projections for the Mambila Plateau include rising temperatures, altered rainfall distribution with more intense wet seasons, and prolonged dry spells, all of which may severely impact crop yields, water availability, and forest-dependent livelihoods (IPCC, 2021; Yusuf *et al.*, 2022).

Mean Annual Precipitation and Temperature (1990–2020)

The Mambila Plateau in northeast Nigeria features a distinctive semi-temperate climate and is one of the coolest places in West Africa. The average annual temperature ranges between 18 °C and 25 °C, rarely exceeding 32 °C during the dry season's peak in February and March (NIMET, 2020). Rainfall occurs primarily from March to October with an annual average of approximately 1600 mm. However,

variations based on elevation are common: areas with higher altitudes may receive up to 1800 mm, while lower elevations might average 1550 mm (Yusuf *et al.*, 2022; Ibe *et al.*, 2023). Specifically for the Ngel Nyaki

Forest Reserve (NNFR), rainfall ranges from 1800 mm to 2200 mm, and the mean temperature has varied narrowly from 19.9 °C to 20.2 °C between 1990 and 2020 (Okeyoyin *et al.*, 2021).

Table 2: Mean Annual Precipitation and Temperature in NNFR

Year	Mean Annual Precipitation (mm)	Mean Annual Temperature (°C)
1990	2000	20.0
1991	2100	20.1
1992	1900	20.0
1993	2200	20.2
1994	1800	19.9
1995	2000	20.0
1996	2050	20.1
1997	1950	20.0
1998	2100	20.1
1999	2000	20.0
2000	2200	20.2
2001	1900	20.0
2002	2000	20.0
2003	2050	20.1
2004	1950	20.0
2005	2100	20.1
2006	2000	20.0
2007	2200	20.2
2008	1900	20.0
2009	2000	20.0
2010	2050	20.1
2011	1950	20.0
2012	2100	20.1
2013	2000	20.0
2014	2200	20.2
2015	1900	20.0
2016	2000	20.0
2017	2050	20.1
2018	1950	20.0
2019	2100	20.1

Year	Mean Precipitation (mm)	Annual Mean Annual Temperature (°C)
2020	2000	20.0

Rainfall and temperature variability analysis

Considering the rainfall trend between 1990 and 2020, April and May receive the most rainfall, at 255 mm and 257 mm respectively (see Figure 2). It slightly decreases in June but rises again in July, with August recording a still higher value of 222 mm. In contrast, October, November, and December are much drier, recording only 91 mm, 68 mm, and 92 mm of precipitation, respectively. Overall, the three months of rainy conditions in March,

April, and May produce more intense rainfall than the three shorter months of rainy conditions in October, November, and December. Adebayo *et al.* (2020) noted that the March–April–May period constitutes the long rainy season, whereas October–November–December is regarded as the short rainy season in northern Nigeria. This pattern aligns with the seasonal migration of the Intertropical Convergence Zone (ITCZ) from the south to the north and then back again (Oguntunde *et al.*, 2017; Adebayo *et al.*, 2020).

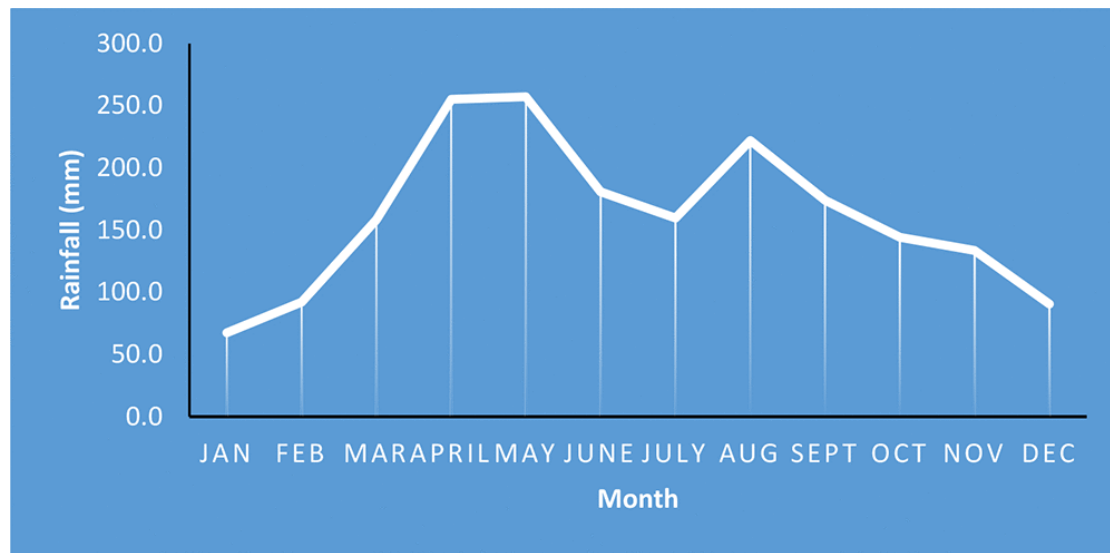


Figure 2: Mean monthly rainfall in Mambila Plateau (1990-2020) (MIMET, 2022).

Knowledge and Experiences of Ecosystem Services

Ecosystem goods and services contribute greatly to the daily needs of these communities, either directly or through contact with ecosystem goods and services. In fact, there are some ecosystem goods and services that, according to respondents, are

very important to the populations. Ngel Nyaki Forest Reserve is a vital provider of goods and services that accrue to the local communities and the environment. For this coexistence between humans and nature to keep going, there is a need to conserve and manage the services. From the same survey, it is evident that an overwhelming number, approximately 85%, of the people know what an ecosystem is and its importance to their

communities, as indicated in Table 3. The most prized benefit derived from the forest is food production with 100%. Cocoa follows with 32.5%, while non-forest products have 15%. Protection of river sources and climate control use 10%, and materials in construction use 7.5%. The lowest priority is in eco-tourism, which uses 0.5%.

Table 3: Ecosystem Services identified by communities that they derive from Ngel Nyaki Forest Reserve

Ecosystem services	Respondents	Percent
Food	200	100
Climate regulation and protection	86	43
Coffee & Tea	40	20
Construction materials	108	54
NTFPs	154	77

Major Livelihood Activities of the Communities

In the surrounding local communities of the reserve, approximately 90% of the population engages in agriculture. They cultivate rice, maize, and cassava, keep animals, fish, and cultivate coffee, honey, and wild fruits. Men are more engaged in coffee cultivation, whereas women cultivate approximately 80% of the food crops. For most people in the region, food production, animal rearing, and coffee production are the central activities of their lives. Apart from coffee, the majority of farmers plant crops just to feed their families. While families may consume a mix of foods, NTFPs contribute approximately 22.5% of food consumed by families. Other families depend solely on the income they get from selling NTFPs such as honey, wild fruits, bush meat, and medicines (Table 4).

Table 4: Main livelihood activities of the communities

Activity	Respondents	Percent(%)
Animal husbandry	50	25
Farming (Agriculture)	184	92
NTFPs collection	45	22.5
Timber	36	18
Total	200	57.5

Awareness of Climate Change and Associated Impacts

Although the science of climate change may not be understood by most farmers, it has made an intense impact in their lives. They experience the impact of declining rain, temperature rise, excessive sunlight, and changed rain patterns seasonally, and these are not subtle. Remarkably, 78 percent of the survey participants are aware of climate change as a fact. To them, climate change is primarily linked to a change in the patterns of rain and more dry spells that have been witnessed over the last twenty years. Why it occurs, 29.5% identified human activities including poor farming practice, bushfires, and overlogging. Conversely, 55.5% of them think climate change is hereditary from natural occurrences, seeing it as the result of mankind's sinfulness or perhaps a sign of the world's apocalypse as described in the Bible. Agriculture is the largest victim of climate change, with forestry, biodiversity, and water resources also suffering its impacts.

Table 5. Awareness and vulnerabilities of climate change impacts livelihoods of the communities

Variable	Respondents	Percent (%)
Aware	156	78
not aware	44	22
Causes		100
Nature	111	55.5
Human	59	29.5
No Idea	30	15
Source		100
Friends	49	24.5
extension	33	16.5
Radio	70	35
Television	21	10.5
Total		86.5

Climate Change Impacts on Vulnerabilities and Livelihoods of the Communities

Climate change has, drastically amplified vulnerabilities and destabilized subsistence livelihoods of people around NNFR. Extreme climate stressors like rising temperatures, erratic rainfall, and unpredictable weather have disrupted the region's entire agricultural, water supply, and forest cover. Food security and economic stability immediately confront any breaking of the season pattern since more than 80% of the population relies on subsistence rain-fed agriculture (IPCC, 2022). Throughout 1990 to 2020, productivity in agriculture and livelihood exposure to the region have been affected by low rainfall as well as irregular weather conditions.

All the above challenges have also been on the rise owing to forest resources loss. Forests deliver invaluable services such as clean water, medicine, fuelwood, non-timber forest products, and climate control. These services have been significantly weakened by overgrazing, invasive species, and deforestation, which has reduced groundwater recharge and increased environmental vulnerability through soil erosion (FAO, 2020).

Table 7: Trends in Coffee and Tea Production in Gembu (1990-2020)

Socioeconomic information confirms these results. Chi-square testing (Table 6) shows occupation, education, and age strongly predict awareness and knowledge about causes of climate change ($p \leq 0.02$) but not gender. They highlight the significance of type of livelihood, level of education, and life experience in influencing environmental perception and responsiveness.

The cost and availability of adaptive technology restrict the application of sustainable solutions, despite the high level of awareness. Capacity development-based, people-oriented, and integrated adaptation strategies that rely on climate-resilient agriculture and forest protection are crucial for enhancing resilience in the NNFR region (UNDP, 2023).

Table 6: Test of Association between socioeconomic characteristics and awareness, and knowledge of causes of climate change

Socioeconomic variable	Chi square	Probability	Remark
1. Awareness			
a. Occupation	30.51	0.01	Significant
b. Education	29.33	0.01	Significant
c. Age	33.99	0.01	Significant
d. Gender	0.82	0.36	not significant
2. Knowledge of causes			
a. Occupation	16.65	0.02	Significant
b. Education	63.64	0.01	Significant
c. Age	86.42	0.01	Significant
d. Gender	1.88	0.17	not significant

Trends of Coffee and Tea Production at Nigerian Highland Tea, Gembu (1990-2020)

The massive input of the company to the local agricultural economy was unequivocally established when negotiating with the Nigerian Highland Tea company and other interested parties. In spite of the challenges posed by COVID-19, global warming, and economic downturns between 2010 and 2020, investment and coffee and tea production increased steadily from 1990 to 2020.

	<i>Trends in Coffee Production</i>	<i>Trends in Tea Production</i>
1990-2000	Stable Production: Coffee production in Gembu remained relatively stable, with small-scale farming being the primary method. Yield Improvements: Introduction of improved coffee varieties and farming techniques led to a gradual increase in yields.	Foundation Years: Tea production was in its foundational years, with initial investments focusing on establishing tea plantations and processing facilities. Moderate Growth: Production increased moderately as the Nigerian Highland Tea company expanded its operations.
2000-2010	Increased Investment: Government and private sector investments in coffee plantations improved infrastructure and access to better farming inputs. Production Growth: This decade saw a significant increase in coffee production, attributed to better management practices and expanded farming areas.	Expansion Phase: Significant expansion of tea plantations, with increased acreage and improved cultivation practices. Quality Improvement: Focus on improving tea quality through better processing techniques and adherence to international standards.
2010-2020	Fluctuating Yields: Production levels experienced fluctuations due to climate variability, pest infestations, and inconsistent government support. Sustainability Practices: Efforts to implement sustainable farming practices and improve processing techniques began, aiming to stabilize and increase yields.	Production Peaks: Tea production peaked during this period, benefiting from stable climatic conditions and sustained investment. Market Challenges: Despite high production levels, market challenges such as fluctuating global tea prices and competition impacted profitability.

The production patterns of tea and coffee depict an overall trend of increasing production with spells of fluctuations due to variation in climate, levels of investment, and market conditions. Sustained attention to sustainable production and market diversification is the basis of guaranteeing future stable and lucrative production.

Habitat Loss and Loss of Biodiversity

The Ngel Nyaki Forest Reserve in the Mambila Plateau in Nigeria is severely impacted by habitat loss and loss of biodiversity. Agriculture expansion, unlawful logging, and firewood harvesting are promoting deforestation and habitat fragmentation required for survival by animals. These factors hinder species reproduction and migration, making them vulnerable to environmental stress (Chapman

et al., 2021; Enemuio *et al.*, 2023). Invasive plants and livestock overgrazing continue to degrade native vegetation, breaking up forest structure and function. The resulting loss of ecosystem services—clean water, soil stability, and carbon sequestration—has direct impacts on local livelihoods and climate change resilience (Chazdon *et al.*, 2020; Costanza *et al.*, 1997). Conservation will demand effective engagement of sustainable land use, community action, and holistic restoration measures to preserve biodiversity and ecosystem services in Ngel Nyaki Forest Reserve.

Impact on Water Resources

Ngel Nyaki Forest Reserve provides water to surrounding communities, particularly in the face of climate change. With over 90% of residents having no access to boreholes or piped water, rivers and streams are their best option, with which they are becoming less and less reliable due to pollution and lack of drainage. Loss of forest results in interference with natural filtration and infiltration processes by water, hence increasing surface runoff, erosion, and decreased groundwater recharge. When vegetation and forests are destroyed, topsoil is left exposed and open to erosion, and there are fewer natural filters to filter water. It means reduced access to clean water for use in drinking, agriculture, and general domestic use. Forest conservation and restoration are therefore important to ensure the sustainability of long-term water and local livelihood availability.

Table 8: Domestic activities affected by climate change

Activity	Number	Percent(%)
Sourcing Water	92	46
Fuel wood Harvesting	71	35.5
Sourcing Fodder	24	12
Others	13	6.5
Total	200	100

Strategies for Livelihood Improvement and Adaptation to the Impacts of Climate Change

Since we have already identified that rain-fed agriculture comprises the majority of sources of income to the region, then NNFR and surrounding towns are highly susceptible to climate change effects. From our field survey, we observed that these communities adopt various adaptation styles as well as adaptation and coping against agricultural complications, maintaining diversity, and irrigation with the general objective of protecting their livelihood from being climate change susceptible. Some of the coping mechanisms that were demonstrated in this study are presented below.

Table 9: Strategies for improving livelihoods and adapting to the impacts of climate change

Options	Number	Percent (%)
Adjusting planting date	101	50.5
Switching crops	42	21
Irrigation	40	20
Saving food/seed	17	8.5
economic trees	57	28.5
sustainable farming	42	21
collaborative forest management	59	29.5

Tree Planting and Non-Timber Forest Products (NTFPs) Farming

Ngel Nyaki farmers increasingly rely on adaptation options like economic trees (28.5%) and agroecology (21%) in climate change adaptation (FAO, 2022). The trees provide shelter, shade, and NTFPs. Approximately 44% now cultivate commercial timber to earn various sources of income and cushion themselves from decreased coffee production risks. Seeing the unsustainability of wild harvesting NTFPs, farmers are cultivating many species—like beekeeping—and propagating medicinal plants enhancing nutrition value and intra-

household food security (Chazdon *et al.*, 2020).

Collaborative forest management (CFM) is the most important government policy for combating climate change and sustaining local livelihoods. It enhances participation, increases timber production, improves buffer zone degradation, and promotes sustainable conservation (Doswald *et al.*, 2014; Locatelli *et al.*, 2008).

Strategies for Improving Climate Change Mitigation and Adaptation

The ways in which societies are adapting may not be sufficient to meet the pace of change that is forecasted by climate change. To assist in diminishing the impacts of this issue, these are some adaptation and mitigation suggestions.

Table 10: Activities to mitigate climate change

Options	Number	Percent
Prayer	97	48.5
Plant trees	50	25
Changing cropping	42	21
Nothing	11	5.5
Total	200	100

Mitigation measures

Successful climate action requires successful policies and successful local involvement. Ghana might be a signatory to global climate agreements now, but local adaptation and local mitigation are not enough (Antwi-Agyei *et al.*, 2018). Policy implementation and stakeholder participation need to be improved for further resilience, although most local communities are unaware of climate-smart activities and the benefits of climate-smart activities (IPCC, 2022). Local tree planting and agroforestry action plans have the potential to enhance ecosystem services, store more carbon, and enhance

livelihood (FAO, 2020; Chazdon *et al.*, 2020). Aggregation ideas such as Payment for Ecosystem Services (PES) offer a motivation for forest rehabilitation as well as maintaining the forest intact at a local community level (Wunder, 2015). National schemes incorporated within the local environment facilitate easy provision of ecosystem restoration and climate resilience in a sustainable manner (Doswald *et al.*, 2014; Reid *et al.*, 2009).

RECOMMENDATIONS

To advance climate change adaptation and mitigation within NNFR communities, it is vital to educate and raise public awareness. As challenges evolve, managing forest ecosystems professionally and understanding the impacts of climate change should become part of community development. This includes capacity building for institutions and individuals in the forest sector. Locally, actions must aim to strengthen the resilience of vulnerable populations, and national as well as district-level climate policies must align with these local realities (UNDP, 2021). Greater community participation in environmental decision-making enhances both livelihoods and the sustainable management of ecosystem services. Involving forest-dependent communities in the cultivation of non-timber forest products (NTFPs) can contribute both to income generation and biodiversity conservation (Shackleton and Pandey, 2014).

CONCLUSION

Climate change is a major threat to the livelihood of forest-dependent communities in Nigeria and Africa. This research examines the influence of climate change on the environment and daily lives of individuals residing around the NNFR. The people are dependent on local resources and susceptible to climate change impacts. Different projections indicate that climate change has the potential to negatively impact

agriculture, biodiversity, and water resources. This could also make living conditions even tougher, leading to more food shortages and poverty. In an effort to counter such negative effects, we should enhance sustainable land management, increase community-conserved landscapes, and promote reforestation. We should assist local communities in adapting to climate change by involving them in programs and educating them on sustainable agriculture. Furthermore, we should make a constant observation of the weather and condition of the environment in an attempt to make improved choices. All these practices together put us in a place where we are capable of enhancing the well-being of the populace surrounding the reserve in the long term as well as safeguarding the natural beauty of the Ngel Nyaki Forest Reserve.

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VEGETATION: THE WEALTH OF THE NATIONS

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ABSTRACT

Vegetation is a fundamental component of the earth's biosphere. Vegetation refers to the plant growth and coverage on the earth's surface, encompassing various types of plants, from tiny micro-organisms to massive trees. It encompasses a diverse array of plant communities that plays critical roles in ecological balance, climate regulation and providing ecosystem services. Vegetation is the collection of plant cover on the earth surface. Vegetation is the backbone of a nation's ecosystem, providing numerous benefits that underpin economic growth, human well-being, and environmental sustainability. It supports biodiversity, regulates water cycles, mitigates climate change, and maintains soil health. Forests, grasslands, aquatic ecosystems including wetlands are the foundation of vegetation which provide essential ecosystem services, including air and water filtration, soil erosion prevention, and carbon sequestration. The paper established that vegetation is a critical source of food, fiber, and medicine, contributing significantly to national economies. The economic benefits of vegetation are substantial. Forests, for example, provide timber, fuel-wood, and non-timber forest products, generating billions of dollars in revenue annually. Vegetation also supports tourism, recreation, and cultural activities, further contributing to national income. The paper maintained that despite its importance, vegetation is facing unprecedented threats, including deforestation, land degradation, climate change among other factors. It is recommended that nations should priorities vegetation conservation and sustainable management to maintain ecosystem services, promote economic growth, and ensure a secured human well-being because when the last plant on planet earth dies, the last animal including man dies too,

Keywords: Vegetation, wealth, backbone, nations, sustainability

INTRODUCTION

Vegetation, a term of popular Origin, refers to the aggregate of all plants found in an area. Vegetation involves the species (population) of the Local flora, which in turn involved different genetic, migration, historical or ecological elements. These may further include aliens, escapes, very wide spread species and endemic species that are usually of special Interest. Floras and their distribution have been interpreted partly in terms of historical factors such as shifting Continental masses, changing sea levels, and orographic and climatic variations over geologic time, as well as theory of island biogeography and the evolution of species

themselves. All of these have affected the development and perpetuation of regional floras. The Vegetation of a region is also Shaped by non-floristic physiological and environment al Influences, including climate, Substrate, soil microbes, and disturbance regimes. To the extent that vegetation constitutes an organized whole at a higher level of Integration than the Separate species and may possess emergent properties not necessarily found in the species themselves such as Competition and other biotic Interactions. As such Vegetation provides not only the physical structure but also the functional frame work of ecosystems. Vegetation is also composed of various plant forms and ecological plant types, reflecting

various sizes, shapes and combinations. Vegetation is the plant cover of the earth and comprises all plant species growing in a very great diversity of assemblages Oladoye (2022). Vegetation may also be defined as the patchwork of plant species, arrayed across the landscape Todd (2023). It includes variety of life forms such as, shrubs, grasses, forbs and non-Vascular plant like mosses. These different life forms are distributed in patterns across the land and result in the structure of the vegetation. Vegetation Consist of plant which can be identified in two ways

Vegetation plays a crucial role in the earth's ecosystems influencing climate, soil composition and providing habitat for diverse animal species. Vegetation means the plants which cover an area. Thus, when we talk of the vegetation of Nigeria, we are talking about the plants covering the country. These plants are made up principally of trees and grasses of various shapes and sizes. Common forms of vegetation are shown in Figure 1.

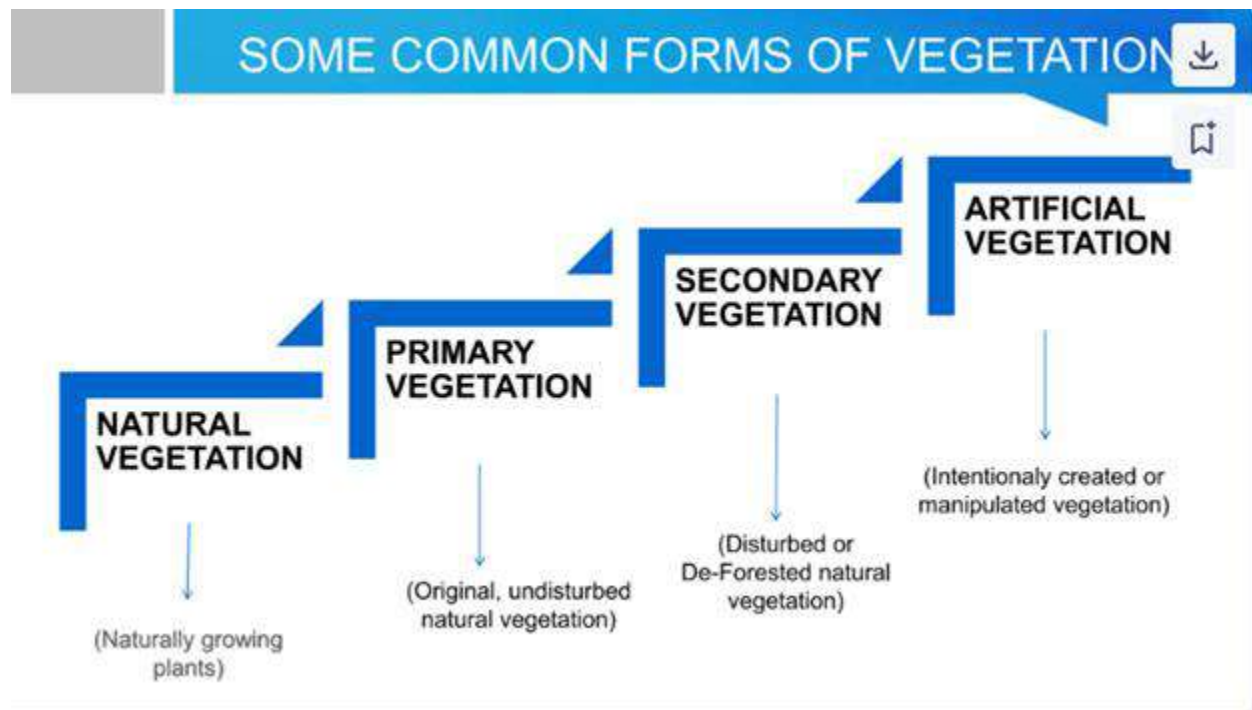


Figure 1: Common forms of vegetation. Source (Malik, 2023)

Some major types of vegetation seen all over the world forest, grassland, desert and aquatic vegetation. The roles of vegetation in world economies are fundamental because life without plants is lifeless. Vegetation refers to the plant growth and Coverage on the earth's surface, encompassing various types of plants, from tiny micro-organisms to massive trees. Vegetation plays a vital role in sustaining life on earth, providing oxygen, food, shelters, and habitat for diverse species Larcher (2003). It includes various types such

as forest, grasslands wetlands, and deserts, each providing unique habitats and contributing to ecosystem services. Vegetation can also be loosely said to be a System of largely spontaneously growing plants. Vegetation also refers to the assemblage of plant life in a particular area, playing a crucial role in maintaining and supporting biodiversity Bronson (2022). The world vegetation communities are into categories: forest and grasslands. They are distributed according to the vegetation zones

and they include tropical, temperate, tundra, desert, mountain and aquatic/ marsh or mangrove vegetation. Vegetation also refers to the assemblage of plant cover in a particular area. It encompasses all the various types of plants including trees, Shrubs, grasses, ferns, mosses and other plant species along with their associated ecosystems. Vegetation plays a crucial role in the earth's ecosystems influencing climate, soil composition and providing habitat for diverse animal species. Vegetation means the plants which cover an area. Thus, when we talk of the vegetation of Nigeria, we are talking about the plants covering the country. These plants are made up principally of trees and grasses of various shapes and sizes.

Natural Vegetation; Natural vegetation refers to the plant life that naturally grows in a particular region or ecosystem, regardless of whether it has been disturbed by human activity or not. It encompasses both primary vegetation and secondary vegetation.

Artificial Vegetation: Artificial vegetation refers to plant life that is intentionally created or manipulated by humans for specific purposes. It is supported by a variety of methods like use of fertilizers, soil amendments, and other resources provided by humans to ensure optimal plant growth and health. Applications are decorative and experimental purposes, high crop yields by fertilizers, plastic plants etc.

Primary Vegetation: Primary vegetation refers to the original, undisturbed vegetation. Well-adapted to the local climate, soil conditions, and ecological processes. They are mostly the most tolerant plants of the region because they are native and well adapted according to that environment. Amazon rainforest is the common example of it.

Secondary Vegetation: Secondary vegetation refers to the plant life that grows after the original. Primary vegetation has

been disturbed by natural or human activities, such as forest fires, deforestation etc. Changamanga jungle in Pakistan is the best example of secondary vegetation because of reforestation in that region.

Roles of vegetation as wealth of nations

Plants constitute all food sources including carbohydrates among, plant proteins, plant fats and essential oils and others for man and his animals. A nation rich in plants is rich in food and ensures food security (Agbogidi, 2019). All flesh is grass. Algae are regarded as the grasses of the seas. Plant products science, furnishes planet earth with all products used by man and his animals. Plants are very important in the lives of people throughout the world meeting the basic human needs as food, clothing, shelter and health care.

Ecological significance of forest vegetation

1. **Habitat and biodiversity:** Forest vegetation provides habitats for numerous species of plants, animals, and microorganisms, contributing to overall biodiversity.
2. **Climate Regulation:** Forests play a crucial role in regulating climate by absorbing carbon dioxide, releasing oxygen, and influencing local and global weather patterns.
3. **Soil Conservation:** The root systems of forest vegetation help prevent soil erosion, maintain soil fertility, and contribute to water retention.
4. **Water Cycle:** Forests influence the water cycle by absorbing and releasing water vapor, contributing to local and regional precipitation patterns.
5. **Carbon Sequestration:** Forests act as carbon sinks, storing significant amounts of carbon and helping mitigate the impacts of climate change.

6. Human Well-being: Forest vegetation provides resources such as timber, medicinal plants, and recreational

opportunities, contributing to human wellbeing.

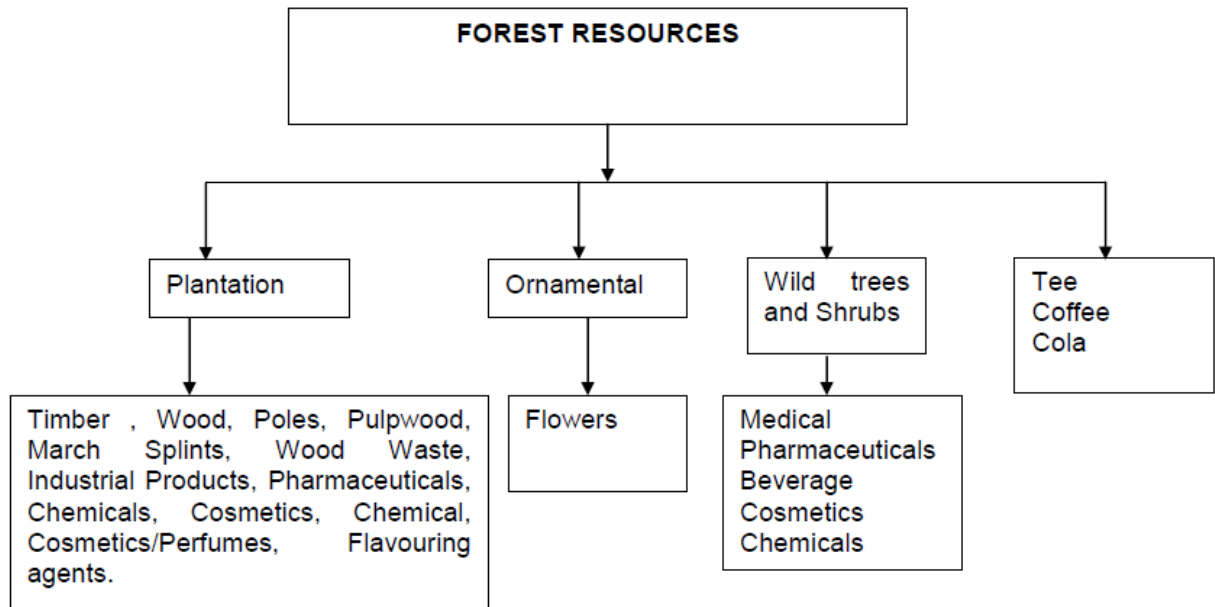


Figure 2: Forest vegetal resources. Source: Onwualu A.P (2009)

Grassland vegetation

Grasslands, also known as prairies, savannas, or steppes, are ecosystems dominated by grasses and herbaceous plants. Grasslands occur in regions with a semi-arid to sub-humid climate. They often experience hot summers and cold winters, with moderate to low annual precipitation. The precipitation is typically not enough to support the growth of forests.

Grassland fauna includes large herbivores like bison and antelope, as well as small mammals, birds, reptiles, and insects. Grasslands provide important ecosystem services. They support agricultural activities by providing grazing land for livestock and areas for crop cultivation. Grasslands also play a role in carbon sequestration, water filtration, and soil stabilization. Figure 3 below shows the distribution of grassland vegetation.

Types of Grassland	Climatic conditions	Common Grass
Tropical grassland (Savannas)	found near the tropical region, high temp. intense sunlight, variable humidity	Elephant Grass (<i>Pennisetum purpureum</i>), Napier Grass (<i>Pennisetum purpureum</i>), Guinea Grass (<i>Panicum maximum</i>),
Temperate grassland (prairies or steppes)	near the temperate region, distinct climate with moderate rainfall	Brome Grass (<i>Bromus</i> spp.), Switchgrass (<i>Panicum virgatum</i>), Big Bluestem (<i>Andropogon gerardii</i>)
Desert grassland (arid grasslands or desert steppes)	arid or semi-arid regions with low rainfall & high temp.	Tobosa Grass (<i>Pleuraphis mutica</i>), Indian Ricegrass (<i>Achnatherum hymenoides</i>), Blue Grama (<i>Bouteloua gracilis</i>)
Alpine meadows	Found in high-altitude mountain regions,	Spike fescue (<i>Leucopoa kingii</i>), Alpine fescue (<i>Festuca brachyphylla</i>), Tufted hairgrass (<i>Deschampsia cespitosa</i>),
Flooded grassland (wet meadows or)	high humidity & rainy regions, normally warm	Cattails (<i>Typha</i> spp.) Rice (<i>Oryza sativa</i>)

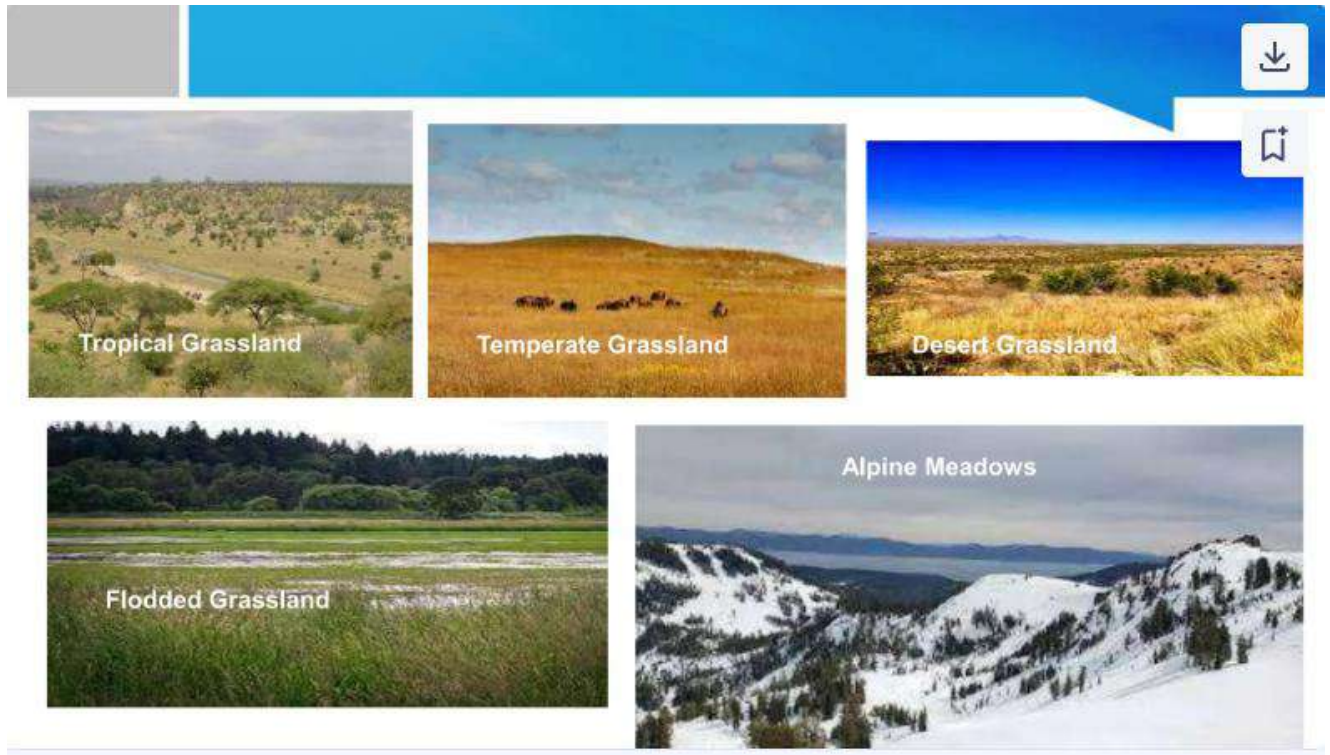


Figure 3: Distribution of grassland vegetation. Source: Malik (2023)

Unique features of grasslands

Tropical grasslands (Savannas): Grasses in tropical grasslands are often adapted to periodic droughts and fires, with deep root systems and the ability to re-sprout after disturbances.

Temperate grasslands: Grasses in temperate grasslands are typically highly resistant to grazing and fire, and many have extensive root systems that allow them to survive dry periods.

Desert grasslands: Grasses of desert grassland ecosystem have adapted some features like heat tolerance, drought tolerance, and resistance against high salinity.

Alpine meadows: Grasses of alpine meadows ecosystem have ability to resist cold temperature stress. These grasses normally grow in shorter size so that they can tolerate strong winds running normally on mountains.

Flooded grasslands (wetlands): Grasses in flooded grasslands often have adaptations for waterlogged conditions, such as hollow stems for buoyancy, aerenchyma tissue for oxygen transport, and the ability to tolerate extended periods of inundation.

Ecological significance of grassland vegetation

Biodiversity: Grasslands support diverse plant species, which in turn provide habitats for a variety of wildlife, including grazing mammals, birds, and insects.

Carbon storage: Grasslands play a role in carbon sequestration, storing carbon in their soils and contributing to the global carbon cycle.

Soil conservation: The deep root systems of grasses help prevent soil erosion, maintain soil structure, and promote water infiltration, contributing to soil conservation.

Water regulation: Grasslands can help regulate water flow and reduce the risk of

flooding by absorbing and holding water, which is important for maintaining hydrological balance.

Agricultural importance: Many grassland areas are used for agricultural purposes, providing grazing land for livestock and supporting agricultural production.

Desert vegetation

Deserts are ecosystems that receive very little rainfall and are characterized by extreme temperatures and sparse vegetation. Deserts are found in regions around the world, like the Sahara in Africa, the Mojave in North America, and the Gobi in Asia. They can occur in both hot and cold climates. Deserts are characterized by hot days and cold nights, with very low precipitation. Some deserts may receive less than 25 millimeters of rain per year. Deserts have unique geological features such as sand dunes, canyons, and rock formations. They also have unique weather patterns, including dust storms and flash floods. The plants of deserts are typically drought-tolerant, with adaptations like deep roots or water-storing stems. Common desert plants include cacti, succulents, and shrubs.

Some major adaptation in desert ecosystem

Succulence: Many desert plants, such as cacti and agaves, have thick, fleshy stems or

leaves that has water. This allows them to survive long periods of drought

Deep roots: Desert plants often have deep roots that can reach water sources deep underground. This allows them to access water that is not available at the surface.

Reduced leaf surface: To reduce water loss through transpiration, many desert plants have reduced leaf surface area or no leaves at all. Instead, they have spines or needles that serve the same purpose.

CAM photosynthesis: Some desert plants use a specialized form of photosynthesis called CAM (Crassulacean Acid Metabolism). This allows them to open their stomata at night when temperatures are cooler and humidity is higher, reducing water loss.

Rapid Growth and Reproduction: Many desert plants have a short lifespan and can grow and reproduce quickly after a rainfall event. This allows them to take advantage of the limited water available in desert ecosystems.

Salt Tolerance: Some desert plants, such as saltbush and pickle weed, are able to tolerate high levels of salt in the soil. This allows them to grow in areas where other plants cannot survive.

DESERT TYPE	EXAMPLE	REFIONS & CLIMATE	VEGETATIVE SPECIES
Hot and Dry Deserts	Sahara Desert, the Arabian Desert, the Mojave Desert	High temperatures and very low rainfall	date palms, desert thorn, camel grass, yucca plants.
Cold Deserts	The Gobi Desert, the Patagonian Desert	They are typically found at higher latitudes or altitudes. They faced extreme temperature variations.	saxaul trees, cushion plants,
Coastal Deserts	Namib Desert, the Atacama Desert	Located along coastlines and are influenced by cool ocean currents. faced foggy conditions, mild temp.	Nara melon, tamarugo tree, Copiapo, Eulychnia
Polar Deserts	The Antarctic Desert	Polar deserts are found near the Earth's poles, where extremely cold temp. snowfall	Usnea, Xanthoria, Chlamydomonas, Prasiola
Semi-arid Deserts	The Chihuahuan Desert, the Great Victoria Desert	Slightly more rainfall than other desert types but still experience long dry periods	Yucca, pear cactus, Desert Marigold, Mulga trees, Desert Oak

Figure 4: Distribution of desert vegetation. Source: Malik (2023)

Ecological significance of desert vegetation

Biodiversity: Despite harsh conditions, desert vegetation supports a variety of specialized plant species, which in turn provide habitats for unique wildlife adapted to arid environments.

Soil stabilization: The roots of desert plants help stabilize the soil, preventing erosion and contributing to soil conservation.

Water conservation: Some desert plants have adaptations for water storage and conservation, influencing the local water cycle and providing resources for other organisms.

Carbon sequestration: Desert vegetation plays a role in carbon storage, contributing to the global carbon cycle.

Cultural Importance: Desert vegetation has cultural significance for indigenous communities, providing resources for food, medicine, and materials for traditional practices.

Aquatic vegetation

Aquatic vegetation refers to plant life that grows in water, including freshwater and marine environments. This type of vegetation has adapted to survive in submerged or floating conditions. Characteristics of aquatic vegetation include specialized root systems for anchorage, buoyant or flexible stems and leaves, and the ability to photosynthesize underwater. These plants provide habitat for aquatic organisms, help maintain water quality, and contribute to the overall health of aquatic ecosystems.

Types of aquatic vegetation

Emergent vegetation: These are plants rooted in the soil underwater but extend above the water's surface, such as cattails and bulrushes.

Submerged vegetation: These plants grow entirely below the water's surface, such as eelgrass and pondweeds.

Floating-leaved vegetation: These plants have leaves that float on the water's surface, such as water lilies and lotus.

Floating vegetation: These are free-floating plants that drift on the water's surface, such as duckweed and water hyacinth.

CHALLENGES VEGETATION

FACING

Deforestation: This is the removal of forest and other natural vegetation from an area without replacing it. It is on the increase in Nigeria as a result of population growth and the increased tempo of economic activities such as timber exploitation, farming, bush burning, firewood collection, urbanization, firewood collection, grazing, construction of roads, dams and other infrastructure, oil exploitation and exploration among others.

Biotic interactions: Competition, predation and mutualism among species also play a role in shaping plant communities. Certain plants may thrive or decline based interactions with other organisms.

Climate: Temperature, Precipitation and sunlight influence the type of vegetation that can thrive in a particular area. For example, desert are characterized by low precipitation, while rainforest require high rain fall.

Topography: The physical features of the land, such as altitude, slope, and aspect impact vegetation distribution. Mountains may have different plant communities at varying elevations

Anthropogenic factors: Anthropogenic factors are human activities that impact the environment, including vegetation. These factors can have both direct and indirect effects on vegetation, leading to changes in its composition, structure, and function.

Anthropogenic factors such as urbanization, agricultural expansion, pollution, and overexploitation bring about soil degradation and loss of biodiversity.

THE WAY FORWARD

It is important to realize that conservation objectives change with time with more knowledge, we have to know that vegetation serve various other purposes such as environmental services, catchment area protection, aesthetics and ethnobotany has become important issues.

Address underlying causes of deforestation: Since the adoption of structural adjustment program in Nigeria there has been a service of retrenchment of workers, especially public servants, there have been factory closure occasioned by reduction in power generation and global economic decline. Job losses mean more pressure on land and forest. There is the need to address economic policies in such a manner that pressure on land is reduced.

Aggressive reforestation: Aggressive reforestation should be revived in the sub humid and arid zones. Indigenous trees should be preferred but where there are constraint species whose environmental impacts are known. Establish a national reforestation program to restore degraded forest and promote afforestation in urban and rural areas. Implement sustainable land management practices, such as agroforestry and permaculture to reduce soil degradation and promote biodiversity. Engage local communities in vegetation management and conservation effort through education and awareness program.

RECOMMENDATIONS

i. Implement sustainable vegetation management practices and policies.

ii. Promote reforestation and afforestation efforts.

iii. Support conservation initiatives and protect land areas.

iv. Encourage Eco-tourism and sustainable land use.

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Evaluation of Vegetative and Phenological Traits of Sixteen Tomato Genotypes

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is a vital vegetable crop with significant nutritional and economic value, but its productivity is influenced by genetic variability and environmental conditions. This study evaluated sixteen tomato genotypes (NHTO 0205, NHTO 0214, NHTO 0222, NHTO 0263, NHTO 0393, NHTO 0394, NHTO 0396, NHTO 0400, NHTO 1056, F1 Thorgal, F1 Cobra 26, F1 Diva, Jos, Cameroon, B52, NHTO 0201) for vegetative and phenological traits in Port Harcourt, Nigeria, to identify high-performing varieties suitable for the region. The experiment was conducted between May and November, 2023 at the Department of Plant Science and Biotechnology Botanical Garden in a completely randomized design (CRD). -week old seedlings of the tomato genotypes were transplanted into polythene bags (55 X 45cm) at one plant per bag/replication with six replications per genotype. Data were collected on key vegetative traits (plant height, number of leaves, number of branches, and leaf area) and phenological traits (days to flowering, days to fruiting, and days to fruit maturity). Results revealed significant ($p = 0.05$) differences among genotypes for all vegetative traits but no significant differences among the tomato genotypes for phenological traits. Plant height ranged from 24.9 cm to 74.4 cm, with NHTO 0396 exhibiting the tallest plants which was significantly different from NHTO 0400 but not the other genotypes. The number of leaves of NHTO 0396 (71 leaves) was significantly different from the other genotypes except NHTO 0222 (66), NHTO 0393 (56), NHTO 0394 (51), NHTO 0263 (47) and NHTO 1056 (46). The number of branches varied between 0.8 and 11.0 per plant while leaf area showed ranges of 47.2–188.0 cm² with the highest number of branches (11.0) and leaf area (188.0) recorded in NHTO 0222. Days to flowering varied from 64 to 85 days, days to fruiting varied from 69 to 90 days while days to fruit maturity ranged between 96 and 122 days. Although there were no significant differences in the phenological traits, NHTO 0222 was the earliest in flowering, fruiting and maturity. The study identified NHTO 0222 and NHTO 0396 as promising due to their early maturity and robust vegetative growth. These findings provide valuable insights for breeders and farmers in selecting superior genotypes to enhance yield and adaptability in the region.

Keywords: Vegetative traits, Phenological traits, Tomato Genotypes

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a globally significant vegetable crop, prized for its nutritional value and economic importance (FAO, 2023). It is a valuable vegetable which could be eaten raw as salad, processed as paste, ketchup, juice, or powder, and cooked as tomato sauce or soup (Rehman *et al.*, 2019). The nutritional importance of

tomato is largely explained by its various health-promoting compounds, including vitamins, carotenoids, and phenolic compounds (Bhandari *et al.*, 2023). In Nigeria, tomato production is vital for food security and income generation, yet yield potential is often limited by genetic constraints and environmental stresses (Eze *et al.*, 2022). Evaluating vegetative and

phenological traits in diverse tomato genotypes is essential for developing improved varieties suited to the agro-ecological conditions of Port Harcourt and similar regions (Ojo *et al.*, 2023). Vegetative traits influence photosynthetic efficiency and overall plant vigour, while phenological traits, including days to flowering and fruit maturity, determine adaptability and yield potential (Aina *et al.*, 2023). Genetic diversity in these traits provides a foundation for breeding programs aimed at enhancing stress tolerance and productivity (Bello *et al.*, 2022). Previous studies in southern Nigeria have identified variability in tomato genotypes, suggesting opportunities for selecting high-performing cultivars (Chukwudi *et al.*, 2023; Goodlife *et al.*, 2024).

Climate variability and pest pressures in Port Harcourt necessitate the development of resilient tomato varieties with optimal growth and fruiting characteristics (Nnodim *et al.*, 2023). Early-maturing genotypes are particularly valuable for avoiding seasonal constraints, while vigorous vegetative growth can improve yield under favorable conditions (Okonkwo *et al.*, 2022). Wild and locally adapted tomato genotypes have shown promise for introgression breeding due to their stress tolerance and desirable agronomic traits (Adeleke *et al.*, 2023). This study evaluates sixteen tomato genotypes for key vegetative and phenological traits in Port Harcourt to identify superior candidates for

breeding programs. Given the region's specific climatic and soil conditions, localized screening is crucial for selecting genotypes with optimal performance (Amadi *et al.*, 2023). The findings will contribute to sustainable tomato production by facilitating the development of high-yielding, climate-resilient varieties tailored to southern Nigeria's agricultural systems.

MATERIALS AND METHODS

Experimental Site and Experimental Material

The experiment was conducted between May and November, 2023 in the open field of the Botanical Garden of the Department of Plant Science and Biotechnology, Rivers State University, Port Harcourt, Rivers State, Nigeria (4.804°N, 6.980°E). The experimental site has an annual temperature range of 25-28°C, annual rainfall of 2,500mm and relative humidity of 80-85%. The sixteen tomato genotypes used were sourced as shown in Table 1. Twenty seeds of each tomato genotype were sown in individual perforated plastic containers (16.5 x 11.5 x 5 cm) containing sandy-loam soil for 5 weeks and seedlings transplanted into black perforated (20 holes per bag) polythene bags (55 x 45 cm) containing 15kg of sandy-loam soil at the rate of one seedling per bag. Poultry manure was applied at the rate of 200g per bag and weeding carried out when necessary.

Table 1: Sources of the Sixteen Tomato Genotypes Evaluated for Yield in Port Harcourt, 2023

Tomato Genotype	Seed Source
NHTO 0205	Genetic Resources Unit, NIHORT, Ibadan
NHTO 0214	Genetic Resources Unit, NIHORT, Ibadan
NHTO 0222	Genetic Resources Unit, NIHORT, Ibadan
NHTO 0263	Genetic Resources Unit, NIHORT, Ibadan
NHTO 0393	Genetic Resources Unit, NIHORT, Ibadan
NHTO 0394	Genetic Resources Unit, NIHORT, Ibadan
NHTO 0396	Genetic Resources Unit, NIHORT, Ibadan
NHTO 0400	Genetic Resources Unit, NIHORT, Ibadan
NHTO 1056	Genetic Resources Unit, NIHORT, Ibadan
F1 Thorgal	Agriseed Ltd., Technisem – France
F1 Cobra 26	East-West Seed International Ltd., Thailand
F1 Diva	Agriseed Ltd., Technisem – France
Tomato Jos	Local market
Cameroon	Local market
B52	Genetic Resources Unit, NIHORT, Ibadan
NHTO 0201	Genetic Resources Unit, NIHORT, Ibadan

NIHORT = National Institute of Horticultural Research and Training

Experimental Design

The bags were arranged in a Completely Randomized Design with each of the sixteen genotypes replicated six times at one seedling per bag per replication, giving a sample size of ninety-six (96) plants.

Data Collection

All genotypes had data recorded weekly following the Distinctiveness, Uniformity

and Stability (DUS) descriptors of tomato as outlined by Lone *et al.* (2021):

Plant height (cm): Plant height was taken using a calibrated measuring tape from the plant base to the shoot tip.

Number of leaves: this was determined by counting all fully formed leaves on each plant.

Leaf area (cm²): was calculated using the formula, $X = 0.5 \times L \times W$ (where X = leaf area, L = leaf length and W = leaf width) in the absence of a planimeter.

Number of branches: was obtained by counting all branches on each plant.

Number of days to First Flowering: number of days from seed sowing until the emergence of the first flower of each plant.

Number of days to first fruit emergence: the number of days from seed sowing until first fruit emergence.

Number of days to first fruit ripening: was determined as number of days taken from seed sowing until ripening of first fruit per plant indicated by the red colour on tomato fruit.

RESULTS AND DISCUSSION

The study revealed significant differences ($P=0.05$) in the vegetative traits among the sixteen tomato genotypes, highlighting their diverse growth characteristics (Plate 1). From Table 2, NHTO 0396 exhibited the tallest plant height (74.4 cm), significantly surpassing NHTO 0400 (24.9 cm) but not differing significantly from other genotypes. This suggests genetic variability in stem elongation, which may be linked to differences in gibberellin sensitivity or internode length, as observed in other tomato cultivars (Li *et al.*, 2022). Leaf production was highest in NHTO 0396 (71.1 leaves), though it was statistically comparable to NHTO 0222 (66.1), NHTO 0393 (55.5), NHTO 0394 (51.1), NHTO 0263 (46.5), and

NHTO 1056 (46.0). The non-significant differences among these genotypes imply a shared genetic predisposition for high leaf proliferation, possibly due to similar cytokinin regulation (Zhang *et al.*, 2023). Branching capacity was most pronounced in NHTO 0222 (11.0 branches), which was not significantly different from NHTO 0396 (9.9), NHTO 0393 (7.7), B52 (7.6), NHTO 0394 (7.4), NHTO 1056 (7.3), NHTO 0263 (6.8), and NHTO 0201 (6.6). This indicates that lateral shoot development in these genotypes may be influenced by auxin-to-cytokinin ratios, as branching patterns in tomatoes are often hormone-mediated (Wang *et al.*, 2021). Leaf area varied significantly, with NHTO 0222 recording the largest leaves (188.0 cm²), significantly exceeding NHTO 1056 (64.5 cm²), Tomato Jos (48.8 cm²), and NHTO 0393 (47.2 cm²). Larger leaf area enhances photosynthetic efficiency, and recent genome-wide association studies (GWAS) have identified key QTLs (Quantitative Trait Loci) associated with leaf expansion in tomato (Chen *et al.*, 2023).

Although phenological traits (flowering, fruiting, and fruit maturity) did not differ significantly among genotypes ($P=0.05$), NHTO 0222 displayed the earliest flowering (64.3 days), fruiting (69.0 days), and fruit maturity (95.8 days) (Table 3). In contrast, Tomato Jos flowered latest (85 days), while Cameroon required the longest period to reach fruiting (90 days) and maturity (121.8 days). These variations may be due to genotype-specific responses to adaptation and environmental cues, such as temperature and photoperiod, as they influence developmental timing in tomato and recent studies highlight genotype-specific responses to tropical growing conditions (Osei *et al.*, 2024). The variability observed in flowering time and fruit development also suggests opportunities for breeding early-maturing or extended-harvest varieties.

Table 2: Vegetative Traits of Sixteen Tomato Genotypes grown in Port Harcourt, 2023

Tomato Genotype	Plant Height (cm)	Number of Leaves	Number of Branches	Leaf Area (cm²)
NHTO 0205	36.2±14.7 ^{ab}	18.7±8.7 ^{def}	2.6±2.7 ^{cde}	75.4±33.5 ^{ab}
NHTO 0214	37.9±14.2 ^{ab}	21.7±9.9 ^{cdef}	4.2±3.5 ^{bcde}	87.6±40.1 ^{ab}
NHTO 0222	68.3±3.7 ^a	66.1±7.8 ^a	11.0±2.1 ^a	188.0±83.6 ^a
NHTO 0263	61.7±14.9 ^{ab}	46.5±20.6 ^{abcd}	6.8±3.1 ^{abcd}	120.6±41.5 ^{ab}
NHTO 0393	57.3±13.8 ^{ab}	55.5±19.0 ^{ab}	7.7±1.9 ^{abc}	47.2±31.7 ^b
NHTO 0394	47.3±6.4 ^{ab}	51.1±16.4 ^{abc}	7.4±2.9 ^{abc}	101.0±49.3 ^{ab}
NHTO 0396	74.4±7.0 ^a	71.1±8.5 ^a	9.9±2.1 ^{ab}	128.1±29.1 ^{ab}
NHTO 0400	24.9±17.9 ^b	17.3±12.8 ^{def}	2.3±3.8 ^{cde}	84.1±113.1 ^{ab}
NHTO 1056	55.5±10.1 ^{ab}	46.0±16.3 ^{abcde}	7.3±4.3 ^{abcd}	64.5±43.2 ^b
F1 Thorgal	68.3±12.2 ^a	14.0±2.5 ^{ef}	1.4±0.5 ^{de}	170.7±38.9 ^{ab}
F1 Cobra 26	51.8±28.6 ^{ab}	11.5±4.8 ^f	1.0±0.0 ^e	97.3±64.7 ^{ab}
F1 Diva	64.1±9.5 ^{ab}	18.4±5.3 ^{def}	1.8±1.0 ^{cde}	163.2±75.7 ^{ab}
Tomato Jos	32.5±13.0 ^{ab}	10.7±2.9 ^f	1.4±1.5 ^{de}	48.8±51.4 ^b
Cameroon	50.0±15.4 ^{ab}	14.6±2.4 ^{def}	1.3±1.4 ^{de}	80.5±62.7 ^{ab}
B52	52.3±4.0 ^{ab}	36.3±3.0 ^{bcdef}	7.6±0.4 ^{abc}	112.4±33.1 ^{ab}
NHTO 0201	50.1±9.6 ^{ab}	34.9±12.3 ^{bcdef}	6.6±3.0 ^{abcde}	84.5±21.8 ^{ab}

Table 3: Phenological Traits of Sixteen Tomato Genotypes grown in Port Harcourt, 2023

Tomato Genotype	Days to Flowering	Days to Fruiting	Days to fruit Maturity
NHTO 0205	73.8±5.4 ^a	75.7±6.1 ^a	106.0±0.0 ^a
NHTO 0214	74.8±4.0 ^a	79.5±0.7 ^a	100.5±0.7 ^a
NHTO 0222	64.3±8.5 ^a	69.0±7.2 ^a	95.8±8.2 ^a
NHTO 0263	71.2±4.1 ^a	77.4±6.2 ^a	102.8±4.5 ^a
NHTO 0393	69.0±5.9 ^a	74.8±8.3 ^a	105.5±8.5 ^a
NHTO 0394	68.3±2.9 ^a	74.5±5.2 ^a	102.8±5.6 ^a
NHTO 0396	69.2±3.6 ^a	73.4±4.5 ^a	101.8±2.2 ^a
NHTO 0400	68.5±6.4 ^a	80.5±16.3 ^a	109.5±16.3 ^a
NHTO 1056	79.2±9.9 ^a	89.3±6.2 ^a	114.2±7.9 ^a
F1 Thorgal	74.0±2.2 ^a	79.8±1.3 ^a	109.0±2.0 ^a
F1 Cobra 26	74.8±5.4 ^a	79.3±6.1 ^a	107.3±3.9 ^a
F1 Diva	77.7±2.3 ^a	82.0±2.5 ^a	110.7±3.1 ^a
Tomato Jos	85.0±5.7 ^a	89.0±0.0 ^a	113.0±0.0 ^a
Cameroon	83.2±7.0 ^a	90.0±8.9 ^a	121.8±10.0 ^a
B52	67.8±0.8 ^a	74.2±3.5 ^a	101.8±3.2 ^a
NHTO 0201	68.0±3.0 ^a	70.8±0.8 ^a	97.8±1.6 ^a



Plate 1: Experimental plot of Sixteen Tomato Genotypes Evaluated in Port Harcourt, Nigeria

in tropical rainforest regions like Port Harcourt.

CONCLUSION

This study underscores the importance of localized genotype evaluations in selecting suitable varieties for specific agro-ecological zones and highlights the genetic variability in vegetative and phenological traits among tomato genotypes in Port Harcourt, with NHTO 0396 and NHTO 0222 showing superior growth and early maturity, respectively. The significant differences in plant architecture and developmental timing highlight potential breeding opportunities for optimizing yield and adaptability. The findings suggest that selecting genotypes with optimal vegetative architecture and shorter maturity periods could enhance tomato productivity in tropical climates. Future research should incorporate molecular markers to identify key genes regulating these traits for precision breeding particularly

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ASSESSMENT OF PHYSICO-CHEMICAL PARAMETERS, HEAVY METALS, AND BACTERIOLOGICAL QUALITY OF GROUNDWATER SOURCES FROM RESIDENTIAL AREA IN ZANGO COMMUNITY, NORTHWEST, NIGERIA

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ABSTRACT

This study aims to assess the effect of human activities on the physico-chemical, heavy metal, and bacteriological quality of drinking water sources from residential areas in Zango community, Zaria, Kaduna State. Water samples were collected in sterilized bottles from wells, hand-dug boreholes, and boreholes, and parameters were analyzed using appropriate standard procedures and methods (APHA, 1995). The results indicated that microbial contamination was prevalent across all water sources, with significant levels of *E. coli* and *Proteus*, posing a high risk for waterborne diseases. The pH values obtained from this study were within the WHO permissible limits; there is significant differences ($p < 0.05$) across all the sampling stations, while the highest electrical conductivity was recorded in well water samples. Additionally, heavy metal analysis revealed lead levels exceeding WHO standards, raising serious public health concerns. The results obtained in this study revealed the impact of land use, especially human activities, on groundwater quality in this community. The study highlights the need for improved water treatment, public awareness, and regular monitoring to ensure safe drinking water for this community.

Keywords: Water quality; Residential area; Safe drinking water; contaminant, groundwater

INTRODUCTION

Access to safe and clean water is a fundamental human right and is crucial for sustaining life as well as an essential for human well-being, promoting public health, and development as recognized by international organization (WHO, 2010; UNESCO, 2017). Increase in human population, industrialization and agriculture around the globe have become alarming and exerted pressures on the quality and quantity of water resources. Water contaminants could jeopardize both the physical and social health of humans, and it is an affront to

human dignity (WHO, 2015). It is estimated that approximately 9 % (1.1 billion) of the world population lack access to safe water supplies, while 2.4 billion cannot adequately access to good sanitation environment, despite it being one of the MDG targets globally to actualize (UNICEF/WHO, 2015). Despite the significant effort made by governments in most developing countries to meet the Millennium Development Goal (MDG) target for drinking water, the report shows that 663 million people still lack improved drinking water sources (WHO, 2018). Even though all nations of the world have a shortage of adequate supplies of safe

water for domestic use, developing countries are the most critically impacted. UNICEF (2019) estimated that in 50 per cent of the developing countries, many of the populations have no access to adequate, safe and clean water.

Furthermore, UN Population Division (2015) reported that of 117 countries, data available in developing nations, most of the population lacks access to safe drinking water. Although the problem of lack of access to a safe water supply exists in many regions of the world, Sub-Saharan Africa is experiencing its devastating impact. The MDGs initiated a program to embark on increase in the use of improved water sources from 76 % to 91 % globally between 1990 to its expiration in 2015. In a recent report outlined by the UNICEF/WHO Joint Monitoring Program (JMP), it is estimated that 79% of the rural population lack improved water sources, whereas 93% rely on surface water for survival (Dempster, 2016; UNICEF/WHO, 2015). It is indicated that an estimated 150 million sub-Saharan African urban dwellers do not have access to safe drinking water s and more than 340 million people lack access to improved water supply (WHO and UNICEF, 2014).

The Nigerian government, as part of its development agenda, implemented many rural and urban water projects through the construction of dams and reservoirs. However, 53% of the populace in rural and 28% in urban areas have no access to improved water sources and their continuous dependence on other sources of water, such as streams and rivers which increases their exposure to pathogenic organisms and other pollutants (Onabolu *et al.*, 2011). Most of the natural water bodies have been polluted with industrial effluent, municipal sewage discharge, radioactive waste or pathogenic microbial substances that pose a substantial risk to the users, aquatic animals and even microorganisms. Water contaminated by

microbiological pollutants causes diseases such as dysentery, cholera, and typhoid. The declining quality of these water systems threatens their sustainability and is therefore a cause for concern. Many communities around the world traditionally take their water supply from rivers, streams, springs or from shallow dug wells (WHO and UNICEF, 2006; Aneck-Hahn *et al.*, 2009; Sun *et al.*, 2009). Even though rivers are self-sustaining ecosystems that, without any human interference and natural disasters, could support both themselves and all life forms within them; nonetheless, increasing pollution from urban, industrial, and agricultural sources is rendering them unsafe and dangerous to health (Zangina and Ali, 2021).

The only realistic option for meeting water demands is through groundwater exploitation because it is cheap to dig, but not all can afford it (MacDonald *et al.*, 2012). Its quality can be impacted by climate, slope, drainage conditions, water-rock interactions, and anthropogenic activities (Balamurugan *et al.*, 2020). Factors such as storm water runoff, leakage of animal waste into the environment, agricultural practices, industry, energy production, mining, wastewater, and infiltration of inadequately treated domestic sewage can lead to deterioration of underground water sources (Odiyo and Makungo, 2018). Monitoring physico-chemical parameters of water resources to evaluate water quality and identify deficiencies is important for the protection of both humans and animals. The protection of water quality as a vulnerable resource essential to sustainable development is of utmost importance to prevent further pollution and degradation of groundwater resources.

MATERIALS AND METHODS

Study Area

The Zango community is located within the Sabon Gari Local Government Area, Kaduna State. It lies on the Longitude 007°70'23"E. and latitude of 11°12'52"N. It is located in the Jama'a ward of Sabon Gari Local Government of Kaduna State along Sokoto Road. It has a tropical climate with well-defined wet and dry seasons, with mean monthly temperature ranges from 13.8 °C to 36.7 °C and annual rainfall of 1090 mm (Shweta *et al.* 2013, Adesakin *et al.* 2020). The pattern of climate in this area supports farming activities, so major dwellers/settlers are farmers (Wikipedia). It is a culturally rich and diverse urban settlement known for its historic significance and vibrant social fabric. The community is one of the developing areas in Sabon Gari Local Government with approximately 20,000 people living in this Area, and the majority of them are settlers from different ethnic groups living together in peace and harmony. Due to a lack of provision of potable drinking water by the government, the people living in this area rely on underground water as a source of water used for domestic purposes.

Sample Collection and Analysis

The random sampling method was adopted in this study, water samples were collected randomly from various boreholes, wells and community hand-dug boreholes within the Zango community, to ensure representation of different water sources from each street. The bottles and their covers were washed thoroughly and sterilized before being used for sample collection. During the collection of the samples, the sterile bottles were cleaned with water to be sampled three times before the final collection of the samples. Water samples were collected using 1 L sample bottles for physico-chemical and bacteriological analysis, and it was analyzed using appropriate standard methods and procedures (APHA, 1995). Water temperature was determined using a mercury-in-glass thermometer.

A concentration of 0.2 ml of sodium thiosulphate solution was added to each bottle of water sample before sterilization to stop the action of residual chlorine on *Escherichia coli* (*E. coli*) in the water sample for bacteriological analysis (Edeki, *et.al.*, 2023). The water samples were stored in coolers containing ice packs and transported within an hour to the designated laboratory for further analysis.

Determination of Total Coliform Bacteria and Faecal Coliforms

Faecal and total coliform counts were performed using the standard membrane filtration technique. The 100 ml water sample was filtered using a 0.45 mm pore size, 47 mm diameter filter membrane. About 100 ml of the water samples will be filtered through a membrane filter with the aid of a vacuum pump. The filter membrane was placed in a MacConkey agar plate. This was then incubated using an incubator pre-set to 44.5 ± 2 °C for 24 hours. Observation was made for colony development on the filter membrane. The colonies were then counted as colony-forming units per 100ml (Meyer *et.al.*, 2023).

Isolation and Identification of Bacterial Isolates

Microbial isolation was performed from the water samples collected from the Hanwa GRA stream. The culture media to be used are: MacConkey agar, eosin methylene blue (EMB) agar, *Salmonella-Shigella* agar and brilliant green agar. Isolation was achieved by the streak plate technique. The cultures were incubated at 37 °C overnight. After the incubation time, a new isolation was done in the same culture media, and the morphology was analyzed to identify the bacterial genera (Gutierrez-Lucas *et.al.*, 2017).

Biochemical Tests

Biochemical tests, including the indole, methyl red, Voges-Proskauer, citrate, and

motility tests, were conducted to further identify bacterial species. The following procedures were used:

Indole Test: A Positive result is indicated by a red ring after adding Kovac's reagent.

Methyl Red Test: A Positive result is indicated by a red colour after adding methyl red indicator.

Voges-Proskauer Test: Red colour development after the addition of alpha-naphthol indicated a positive test.

Citrate Utilisation Test: Deep blue colour indicated positive citrate utilisation.

Motility Test: Cloudiness around the stab line indicated positive motility.

The physico-chemical parameters, like water temperature were determined by mercury in glass thermometer, pH was determined using a benchtop pH Meter, Electrical conductivity and TDS was determined by Conductivity Meter, nitrate was determined by Brucine method, phosphorus was analyzed by Spectrophotometer while heavy metals were analysis by Atomic Absorption Spectrophotometer (AAS).

Statistical Analysis

The results obtained from this study were subjected to descriptive and inferential analysis, while One-way analysis of variance (ANOVA) was used to check for the significant differences ($p < 0.05$) in the mean values of physico-chemical parameters of groundwater, heavy metals and microbial load across the stations. Pearson Correlation Matrix was utilized to investigate the inter-relationships between physico-chemical parameters, and bacteriological quality was analyzed using SPSS version 29.

RESULTS

Spatially, the pH values recorded in this study vary from 5.98 to 8.04, with the highest

average mean value of 7.54 ± 0.51 recorded from the water sample from Hand-dug, and there are no significant differences ($p < 0.05$) across the sampling stations. The EC, TDS, DO, nitrate, phosphate, TCC and FCC were higher in the well-water compared with the other groundwater samples, while the highest mean value of water temperature was observed in the hand-dug water sample and the highest mean concentration of Pb was recorded in borehole water (Table 1). Significantly, TCC and FCC were higher in well water compared with the other sampling locations, and there are significant differences ($p < 0.001$) among the mean values of TCC and FCC, as shown in Table 1. *Proteus* Sp and *E. coli* are bacterial organisms identified from all three sampling stations during the period of this study.

In well-water samples, the highest pH value was recorded in April, while DO and Pb concentration were at peak in May, nitrate was higher in June, and phosphate concentration was at maximum in March (Figure 2a). The highest pH mean concentration was observed in April, while parameters like DO, nitrate, phosphate and Pb were higher in June from the Hand-dug water samples (Figure 2b). The pH mean value was recorded in February, while DO, nitrate, phosphate and Pb were higher in May from Borehole water samples (Figure 2c). The highest TDS and EC were recorded in March for water samples collected from Well-water and Hand-dug, while in the borehole, it was highest in February (Figure 2d).

Seasonally, the low pH mean concentration was recorded during the dry season, while a high mean value was observed in the wet season (Table 2). The nitrate, phosphate, Pb, TCC and FCC mean values were lower in the dry season compared with the wet season, which were higher. Comparison of the mean values of TCC and FCC for both seasons indicates there were significant differences (p

< 0.05) among the seasonal variations. The CCA showed the relationship between the physico-chemical parameters, heavy metals and bacterial quality, which revealed that water temperature, pH, nitrate, phosphate and Cd correlated together with Hand-dug, while FCC and TDS correlated with well-water and DO, Pb, and EC correlated with Borehole (Figure 3).

DISCUSSION

The range of pH values obtained from this study varied from 5.98 to 8.04, which is below the WHO (2011) and NSDWQ (2015) acceptable limit range for drinking water. It slightly acidic to moderately alkaline may be due to the geological formation of this area that allows ions to dissociate from the soil composition into the aquifer water, which leads to a low pH value obtained. The pH means concentrations recorded in all sampling stations were similar to the work of Adesakin *et al.* (2020), who report an average pH of 7.01 to 7.60 in well water within the ABU community Zaria and also aligned with the report of Fadili *et al.* 2019. The average water temperature recorded in all the sampling stations was below 26 °C, which is within values reported for many African underground waters by many researchers could be influenced by rainfall pattern, climatic change, season, time of the sampling and reactions taking place within water itself and soil. The EC and TDS results recorded in this study were similar to Abdulkadir *et al.* (2015), who reported EC values ranging of 360 to 6000 $\mu\text{S}/\text{cm}$ from groundwater samples in Dala Local Government Area of Kano state, Nigeria, but notably higher than those of a similar study by Fadiji *et al.* (2019), who reported TDS value ranged of 2.77 ± 0.15 to 4.5 ± 0.07 mg/l from wells in Ijero-Ekiti, Ekiti State, Nigeria. The findings of this study indicate that electrical conductivity mean values obtained in all the sampling stations fell within the range of 300 - 2230 $\mu\text{S}/\text{cm}$ reported by Musa *et al.* (2023). The

overall dissolved oxygen values ranged from 1.40 to 2.70 observed during this study might be due to the shallow depths of most of these wells, which allow oxygen in the air to dissolve in the underground water and low organic matter. High turbidity and increased suspended material have also been reported to affect the dissolution of oxygen and the penetration of sunlight into the water and thereby reducing the photosynthetic rate in bottom water. This aligns with the report of Ekute, (2021) in groundwater in the Vicinity of an Industrial Area of Mopin Community, Ota, Southwest Nigeria.

The mean of nitrate and phosphate concentrations recorded in all stations during this study were below WHO standard for drinking water. The low values of nitrate and phosphate observed in this study could be due to fewer human activities around sampling locations. Nitrate is poisonous to infants younger than 6 months old, while excess phosphate in water could cause an algae bloom, which can pollute the water can giving the water a taste and smell. Nitrate is harmless at lower concentrations than permissible limits, but if it exceeds the limits, it is harmful because of the lowering in nitrites, which can be with amines and amides to form "N-nitroso" composites, which is the major cause of cancer of the stomach (Aires *et al.*, 2013). The Pb and Cd mean concentrations obtained in all the sampling stations are above the WHO standard of 0.01 mg/l and 0.003 mg/l for drinking water. Lead is one of the excess elements of the earth's crust, and pollution of this may be as a result of rock weathering that enters the groundwater through surface runoffs or from the rusting of the pipes used in pumping water out from the underground water. It is responsible for chronic neurological disorders in fetuses and children, especially when it is greater than 0.1 mg/l. The mean values of TCC and FCC recorded from all the groundwater samples

were above the 0 Cfu/ml value as recommended by WHO (2011) and NSDWQ (2015) for drinking water. However, the possibility of contamination is less with the sources which are properly covered at the top and as well as surface runoffs contaminated with Faecal matter infiltrate the soil and pollute the ground waters. The finding of this study is in agreement with the study carried out by Dzwaïro *et al* (2002). The presence of *E. coli* and *Proteus* Sp from the water samples examined during this study could be a result of pathogens and bacteria from seepage from pit latrine infiltrating the soil and contaminating the groundwater. The result of these findings corroborated with the work of Some *et al.* (2021); Belina *et al.* (2023) and Wamyil *et al.* (2023) who reported *Escherichia coli*, *Shigella spp* and *Salmonella spp* as the most common isolated bacterial species in water sources.

The highest water temperature was observed in the dry season compared with the wet season could be due to climate change as a result of an increase in average global temperature, which has contributed to high air temperature that could influence an increase in groundwater temperature. The result of this study is similar to the findings of Gongden and Lohdip (2015) in Plateau State reported a comparable temperature value of 25.67 ± 3.03 °C. The EC and TDS were higher during the dry season might be attributed to the reduced water level during this season and the dissociation of ions in the soil into the groundwater. The highest mean concentrations of pH, nitrate, phosphate, Pb, Cd, TCC and FCC were higher in the wet season than in the dry season could be due to high runoffs as a result of excess rainfall during this period which leads to supersaturation of the soil to absorb excess water that over flood most the wells and borehole. The anthropogenic activities, such as agricultural runoff, industrial waste, domestic waste petroleum from the mechanic

workshop, which contain Pb content, etc., that pollutant are all washed off by runoffs during this season and infiltrate the groundwater, leading to its contamination. The phosphate value in this study suggests contamination of groundwater with potentially human or animal waste. The lead (Pb) concentration exceeded the World Health Organization's (WHO) permissible limits (0.01 mg/L) in all water sources. Ingestion of lead through food or water or exposure, even at low concentrations, poses severe health risks, particularly to children and pregnant women, as it can lead to developmental problems, kidney damage, and neurological disorders. Cadmium concentrations were above WHO limits. If it becomes bioaccumulation due to long-term exposure can cause kidney damage and bone demineralisation. These findings are conformed with Hamidu *et al.* (2017), where groundwater was found to contain elevated levels of trace metals, such as cadmium, posing similar health risks.

The high TCC and FCC observed well-water sample indicate that groundwater in this sample area is contaminated with faecal matters as a result of most of these wells not being covered and improperly handled by a large population. It aligned with the work of Usman and Aliyu (2020), who recorded high coliform bacterial counts from groundwater in Nguru town, Nguru Local Government Area, Yobe State, Nigeria. It contradicts the report of Jayalakshmi *et al.* (2011), who found that borehole water with the highest total coliform count also has the highest faecal coliform count (Rogbesan *et al.*, 2002). A study of coliform contaminants in Ibadan city, Nigeria, by Oyedum (2010) and supported by Boman (2012), showed that the pollution of boreholes was due to indiscriminate drilling of boreholes near pit latrine toilets and poor drainage systems. These bacteria species identified in the study are pathogens that cause gastrointestinal

infections and other waterborne diseases, that of health risk for residents who consume this water without treatment. The findings align with a previous study of Shayo *et al.* (2023), which also reported microbial contamination in water sources, causing diseases and leading to the death of many people in developing countries if not treated on time.

CONCLUSION

The quality of groundwater in the Zango community poses several serious public health concerns, particularly with respect to microbial contamination and heavy metals. Although some physico-chemical parameters such as pH are within acceptable limits, the high electrical conductivity and low dissolved oxygen levels indicate potential water quality deterioration over time. These findings suggest the need for immediate intervention, including improved water treatment, sanitation infrastructure, and regular monitoring to ensure that residents have access to safe drinking water.

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SPATIO-TEMPORAL EFFECTS OF LAND USE AND LAND COVER CHANGE ON CLIMATE VARIABLES IN NIGER DELTA REGION, NIGERIA

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ABSTRACT

The natural land cover of the oil-producing Niger Delta Region of Nigeria is being altered at an alarming rate despite the strong nexus between land use and land cover change (LU/LCC) and the global climate change. Hence, this study investigated the trend of LU/LCC in the Region and its relationship with climate variables (CVs). Landsat 5, 7, and 8 images of 1986, 2004, and 2022, respectively, were utilized. Thermal bands of the landsats were used for land surface temperature (LST) determination. CVs were acquired from NASA Earth Observatory and WorldClim databases. Supervised Maximum Likelihood was used to classify the landsat dataset into 5 LU/LC types (Dense vegetation (DV), water, wetland, farmland/sparse vegetation (FV), and built-up). Mono-window algorithm and correlation were used to estimate LST, and the relationship between LU/LC and CVs. DV, wetland, and water body lost 1,937.59km², 464.1km², and 164.2km², respectively, while built-up and FV gained 1,423.70 km² and 1,142.15 km², respectively. LSTs were moderately low and exhibited increasing trend within the study period. High LSTs were observed in built-up areas, while moderate to low LSTs were observed in other LU/LC types. The mean rainfall, wind speed, and relative humidity were notably high and exhibited an irregular pattern. Areas closest to the seacoast consistently showed higher rainfall. DV (-1.00), water body (-0.71), and wetland (-0.95) had negative relationship with built-up; FV had negative correlation with DV (-1.00), wetland (-0.96), and water body (-0.68), and a positive relationship with built-up (1.00). Built-up had a direct relationship with LST. Evidently, CVs change with the change in LU/LC types.

Keywords: Climate change, Climate variables, Land surface temperature, NDR, Remote sensing.

INTRODUCTION

Land use and land cover (LU/LC) refer to the utilization and physical attributes of land. All human activities on the land, such as farming, urbanization, and the maintenance of habitats for wildlife and flora are regarded as land use (Kanianska, 2016). To meet human needs, land is used in a variety of ways (for forest, agriculture, bare-land, industrialization, water body, urbanization/built-up, mining, among others). The extent to which an area or region is covered by impermeable surfaces, wetlands, forests, agriculture, and other land and water types is revealed by land cover information (Chowdhury *et al.*, 2020).

Whether for mixed-use, development, or conservation, land use reveals how people use the environment. Thus, (LU/LCC) is the term used to describe the changes in land cover brought about by human modification of land uses. When LU/LC are treated jointly, both represent the physical cover and human imprints on the land (Abbas, 2013).

The process of LULC is complex, influenced by both natural and human factors (Wessels *et al.*, 2004). Many researchers have linked changes in LULC in different areas (such as delta regions) to broader global change phenomena (Dale 1997; Turner *et al.*, 2007; and Alexander

et al., 2018). In recent times, the Niger Delta Region (NDR) has witnessed increasing LU/LC changes, resulting in widespread environmental challenges that require careful mapping (Abbas 2013; Emenyonu *et al.*, 2015). The growing demand for urbanization, industrialization, and agricultural land globally highlights the scarcity of land resources and underscores the need for informed decision-making regarding their optimal utilization in the NDR of Nigeria (Emenyonu *et al.*, 2015).

The Delta regions are recognized as economic and environmental hotspots, covering only 1% of the Earth's surface but accommodating over 7% of the global population (Ericson *et al.*, 2006). Tropical delta areas, such as the Niger Delta, face several pressures, including rise in sea-level, salinity intrusion, erosion, and floods, exacerbated by the climate crisis (Szabo *et al.*, 2016; Nababa *et al.*, 2020). The Niger Delta River (NDR) stands as Africa's largest river delta, witnessing a rapid increase in human population (Nababa *et al.*, 2020). It hosts the continent's largest mangrove forest, crucial for local communities' livelihoods, fisheries, flood protection, and cultural practices (Zabbey *et al.*, 2010; Numbere, 2014; Okonkwo *et al.*, 2015). However, this valuable ecosystem faces threats from oil and gas exploration, mangrove overexploitation, urbanization, and invasive species like the Nipa palm (*Nympa fruticans*), water hyacinth (*Eichhornia crassipes*) (Balogun *et al.*, 2015; Duke, 2016; Nwobi *et al.*, 2020; Onyena *et al.*, 2020).

Despite its significance, reliable and up-to-date information on land cover dynamics, especially regarding mangrove forests, remains scarce in the Niger Delta (Nababa *et al.*, 2020). Few studies have mapped land cover changes in the region concerning

climatic variables. Given the significant changes in LU/LC over the years due to human activities, concerns have emerged regarding their impacts on climatic variables in the Niger Delta (Emenyonu *et al.*, 2015). Understanding the interactions between LU/LCC and climatic variables is crucial for crafting sustainable development strategies and climate resilience planning in the region. Thus, this study evaluated the spatio-temporal effects of LU/LC change on climatic variables in the NDR of Nigeria over 30-year time series.

MATERIALS AND METHODS

The Study Area

The study was conducted in the NDR, which is in southern Nigeria and borders the Gulf of Guinea to the south. The Niger River splits into multiple tributaries, which eventually end at the Atlantic Ocean's coast. It lies between latitudes 4° 20' and 6° 05' N and longitudes 5° 20' and 8° 45' E. The area spans across several states (Delta, Rivers, Bayelsa, Akwa Ibom, Abia, and Cross River) (Hogan, 2013; Umoh *et al.*, 2022). However, the area coverage of this study cut across Rivers, Akwa Ibom and Abia states (Figure 1). The region is one of the most significant wetland areas in the world, characterized by a network of creeks, rivers, swamps, and rich biodiversity (Abbas, 2013; Okonkwo *et al.*, 2015). It is also a petroleum-rich region and has extensive pollution challenges (Chidumeje *et al.*, 2021; Ukhurebor *et al.*, 2021). Oil and mineral exploration, subsistence farming and fishing are the dominant occupation in the region (Fasona, 2003). The temperature ranges between 24°C to 32°C, while the rainfall ranges between 3000- 4500mm (Nwilo and Badejo, 2006).

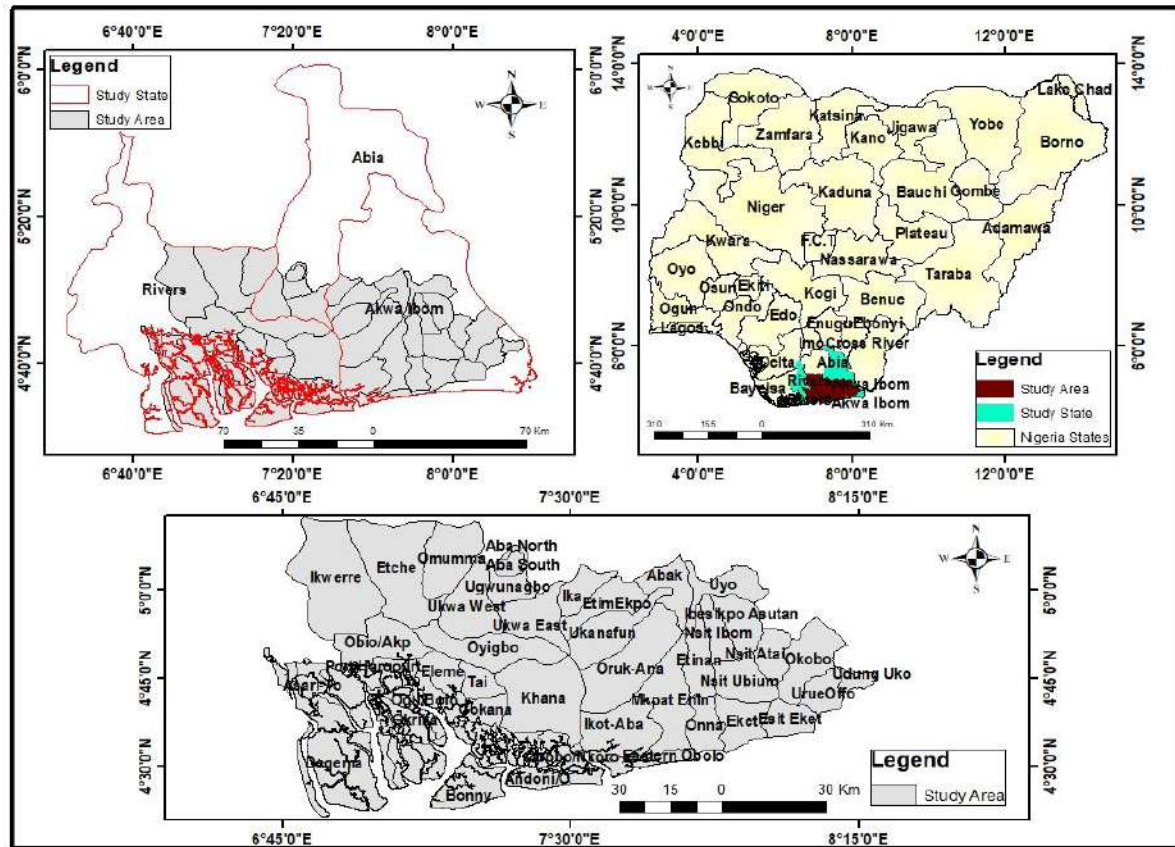


Figure 1: Map of the Study Area

Data Acquisition

Landsat 5, 7 and 8 of same season (path 188 / row 057) in time sequence of 1986, 2004 and 2022 were obtained from United States Geological Survey (USGS). The climatic variables of the study years were acquired

from NASA Earth Observatory and WorldClim databases. Ground truth points were randomly collected from different LULC types with the aid of Garmin Geographic Positioning System (GPS). The attributes of the Landsat imageries used are presented in Table 1.

Table 1: Features of Landsat Imageries

Landsat Features	1986	2004	2022
Scene ID	"LT51880571986353XXX10"	"LE71880572004365AS N00"	LC81880572022036LG N00
Path/row	188/057	188/057	188/057
SpaceCraft ID	Landsat 5	Landsat 7	Landsat 8
Sensor ID	TM	L7_ETM	OLI-TIRS
Spatial Resolution	30m	30m	30m
Acquisition Date	19/12/1986	31-12-2004	12/02/2022
Datum/UTM	WGS84/32	WGS84/32	WGS84/32
Grid cell size	30	30	30
K1	607.76	666.09	774.8853
K2	1260.56	1282.71	1321.079

Data Processing and LU/LC Classification

Landsat imageries were processed, enhanced, and geometrically corrected to the World Geodetic System (WGS) 1984 using Ground Control Points (GCP), and projected to Universal Transverse Mercator (UTM) zone 32N coordinate system in ARCGIS 10.8. The spatial extent of the study area was extracted from the administrative shapefile of Nigeria using “Extract by Mask” function in ARCGIS. Following the field reconnaissance survey and the ground control points on the various LU/LC types, supervised maximum likelihood was adopted to categorize the study area into various LU/LC types in IDRISI and ARCGIS software.

Table 2 shows the various LU/LC types identified and classified. Kappa coefficient was employed to determine the accuracy of

Table2: LULC Types and Description

S/No	LU/LC Types	Description
1	Water body	Areas including river, ocean, sea, stream.
2	Wetland	Ecosystem characterised mainly by swamps, marshes, bogs.
3	Dense vegetation	Areas of thick vegetation types
4	Farmland/sparse Vegetation	Agricultural land, and scattered vegetations
5	Built-up	Areas of physical structures, including settlements, roads, plain surfaces

Land Surface Temperature Retrieval

The LST of the research area within the study periods were retrieved using the thermal bands of 1986, 2004 and 2022. Among other methods of LST estimation, the mono-window algorithm was used

the classification using the ground control points obtained during field ground truth exercise, and the historical map of the study area. Area coverage of each LU/LC types was determined using Raster calculator in Arc toolbox. The changes in each LU/LC category were calculated between two time periods (initial time and subsequent time), Ubaekwe *et al.* (2022), Kindu *et al.* (2013), and Demissie *et al.* (2017), as expressed below.

$$OC(Km2) = X_2 - X_1 \text{ equation} \quad [1]$$

$$RA\left(\frac{Km2}{yr}\right) = \left(\frac{X_2 - X_1}{t}\right) \text{ equation} \quad [2]$$

Where: OC = Observed change; X_1 = Area coverage of LU/LC type at the initial year.

X_2 = Area coverage of LU/LC type at the subsequent year; RA = Rate of change per annum; t = time interval between initial and subsequent years.

based on its precision and wide applications, as used by Liu and Zhang (2011) and Sobrino *et al.* (2004). The described steps below according to Qin *et al.* (2001) were employed:

A: Transformation of Digital Number (DN) to Spectral Radiance

$$\text{Radiance} = \left(\frac{L_{\text{MAX}} - L_{\text{MIN}}}{Q_{\text{CALMAX}} - Q_{\text{CALMIN}}} \right) X (Q_{\text{CAL}} - Q_{\text{CALMIN}}) \quad \text{equation [3]}$$

Where: Radiance = (Watts/m².ster.µm), Q_{CALMIN} = 1, L_{MIN} = minimum spectral radiance at Q_{CAL} = Digital Number, Q_{CAL}, L_{MAX} = maximum spectral radiance at Q_{CAL}, Q_{CALMAX} = 255

B: Conversion from Radiance to Brightness Temperature (in degree Celsius)

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L\tau} + 1\right)} - 273.15 \quad \text{equation [4]}$$

Where T = At-Satellite Brightness Temperature, K₁ = Calibration constant 1 (Wm⁻²sr⁻¹µm⁻¹), Lλ = Top of Atmosphere (TOA) spectral radiance, K₂ = Calibration constant 2 (Kel),

C: Estimation of Land Surface Emissivity (LSE)

$$\text{LSE} = 0.004F_v + 0.986$$

$$FV = \left(\frac{NDVI - NDVI_{\text{Min}}}{NDVI_{\text{Max}} - NDVI_{\text{Min}}} \right)^2 \quad \text{equation [5]}$$

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad \text{equation [6]}$$

Where: F_v = Fraction of vegetation, NDVI = Normalized Difference Vegetation Index

D: Estimation of LST

$$\text{LST} = \frac{BT}{1+w} X \frac{BT}{P} X \ln(e) \quad \text{equation [7]}$$

$$P = h X \frac{c}{s} (1.438 \times 10^2 \text{ mK}) \quad \text{equation [8]}$$

Where: BT = At-sensor brightness temperature, h = Plank's constant, s = Boltzmann constant, c = velocity of light, w = wavelength of emitted radiance, e = LSE

Estimation of Rainfall, Relative Humidity, and Wind Speed

Phan and Nguyen (2023) and Wango *et al.* (2018) compared the average climatic data from NASA Earth Observatory and WorldClim databases with the climatic data from ground weather stations and recorded non-significant difference. Thus, the annual rainfall, relative humidity, and wind speed of 1986, 2004 and 2022 of the study area were obtained from the databases as previously done by other researchers (Akinbobola *et al.*, 2023; and Wang *et al.*, 2021).

Using daily data, the monthly mean and total yearly relative humidity and mean wind speed values were calculated for the research periods using the equation [8] for each location. Based on proximity, some local governments have same climatic features; hence, thirty-five-point locations from 35 local governments were purposely selected from the 42 local governments under study, as the representative sample. The annual relative humidity and mean wind speed were computed for each location using equations [9] and [10], respectively.

$$RH = \sum_{i=1}^{12} RH_i \quad \text{equation [9]}$$

$$Ws = \sum_{i=1}^{12} Ws_i \quad \text{equation [10]}$$

The high spatial resolution at 30s, 2.5 min, 5 min, and 10 min of WorldClim v2.1 in GEOTIFF format was used to map out the spatial distribution pattern, maximum and minimum rainfall for the years 1986, 2004 and 2022 of the study area in ARCGIS environment (Akinbobola *et al.*, 2023). Each grid cell in the raster denotes a distinct geographic area and carries a value that reflects the total amount of rainfall in that location. The minimum and maximum rainfall for each year was used to compute the mean annual rainfall.

Relationship between LU/LC Types and Climate Variables

Pearson correlation matrix was used to ascertain the relationship between LU/LC types (water, wetland, farmland/sparse vegetation, dense vegetation, built up) and climate variables (relative humidity, wind speed, rainfall, LST) in the study area. A perfect negative association is represented by a correlation coefficient of -1, no association is represented by a correlation coefficient of 0, and a perfect positive association is represented by a correlation coefficient of 1. Overlay analysis and spatial autocorrelation were further carried out between LST map and LU/LC map of same year to evaluate their spatial relationship.

RESULTS

Spatio-Temporal Distribution and Area Coverage of LU/LC of the NDR, Nigeria

The LU/LC map of the research area for the years: 1986, 2004 and 2022 are revealed in Figures 2, 3, and 4, respectively. Five (5) LULC types were identified and categorized as built-up, water body, wetland, farmland/sparse vegetation, and dense vegetation. Dense vegetation dominated the area throughout the study periods in decreasing trend of 6196.69km² (63.23%) in 1986, 5412.00km² (55.23%) in 2004, and 4259.11km² (43.46%) in 2022 (Table 3 and Figure 5) respectively. Similar trend was observed in wetland ecosystem, the spatial extent decreased from 1326.01km² (13.53%) in 1986, to 1029.86km² (10.51%) in 2004, and 861.92km² (8.80%) in 2022. Spatial extent

of built-up and farmland/sparse vegetation exhibited an upward trend within the study periods. Built-up increased from 834.28km² (8.51%) in 1986 to 1349.29km² (13.77%) in 2004, and extremely increased to 2258.03km² (23.04%) in 2022. Farmland/Sparse vegetation increased from 546.25km² (5.57%) in 1986, to 999.84km² (10.20%) in 2004, and 1688.45km² (17.23%) in 2022. Water body exhibited an irregular pattern of spatial extent. It increased from 896.25km² (9.15%) in 1986 to 1008.47km² (10.29%) in 2004 and reduced to 731.95km² (7.47%) in 2022.

These finding reveal the gains, losses, and the rate of changes in LU/LC of the study area (Table 4). Loss was recorded at varying rates under wetland (296.15km²) and dense vegetations (167.94km²). Wetland lost 296.15km² and 167.94km², at the varying rates of 16.45km²/yr and 9.33km²/yr between 1986 – 2004, and 2004 – 2022, respectively. Dense vegetation had a lost of 784.69km² and 1152.89km² at the rates of 43.59km²/yr and 64.05km²/yr between 1986 – 2004 and 2004 – 2022, respectively. In contrast, built-up gained 515.01km² and 908.74km² at the rates of 28.62km²/yr and 50.49km²/yr; farmland/sparse vegetation also gained 453.59km² and 688.61km² at the rates of 25.20km²/yr and 38.26km²/yr between 1986 – 2004 and 2004 – 2022, respectively. Water body gained 112.23km², at the rate of 6.23km²/yr between 1986 – 2004, lost 276.52km² at the rate of 15.36km²/yr between 2004 – 2022.

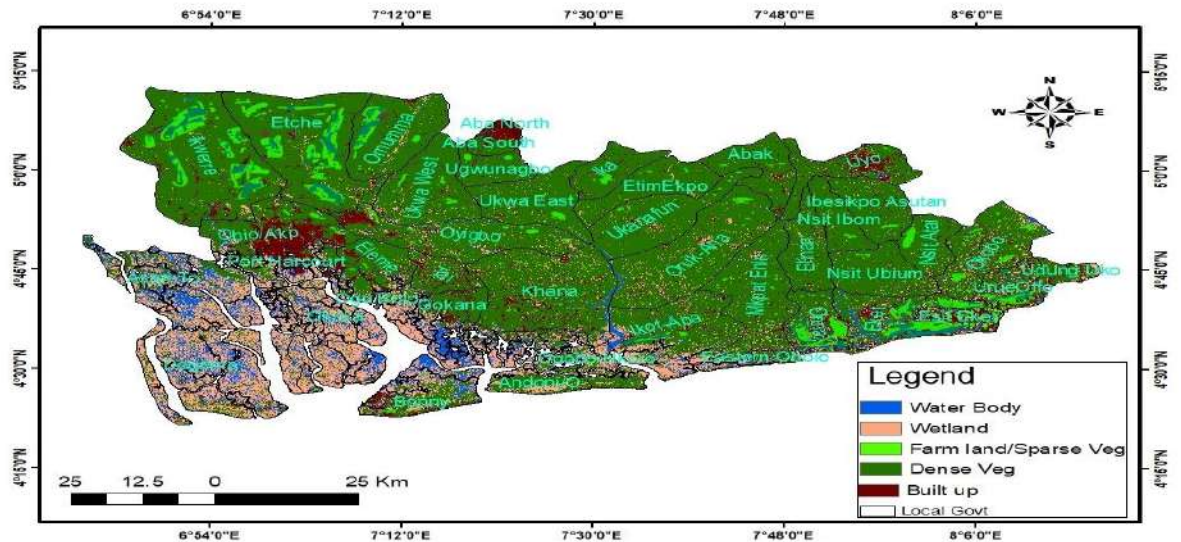


Figure 2: 1986 Land Use Land Cover (LU/LC) of Niger Delta Region, Nigeria

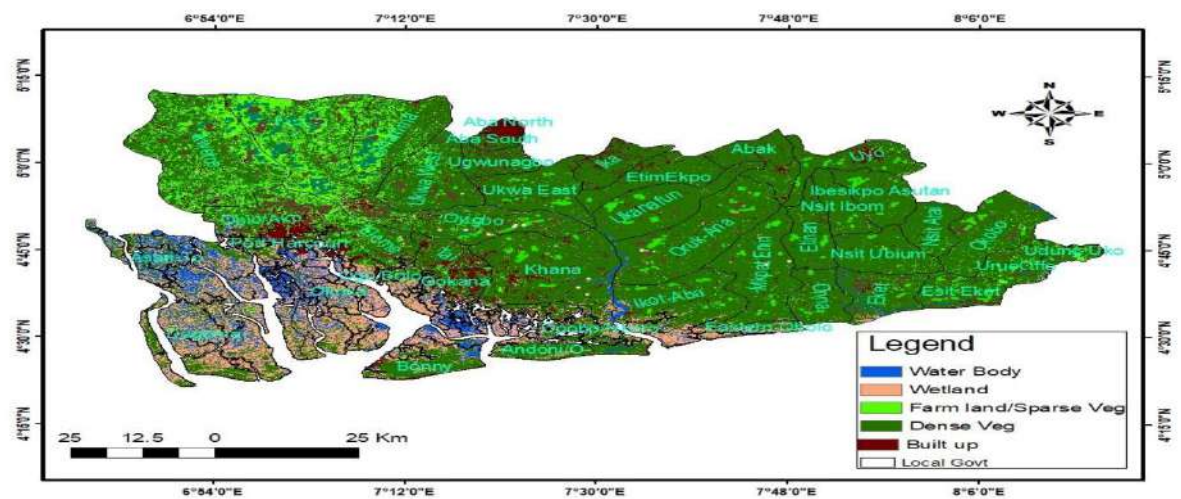


Figure 3: 2004 Land Use Land Cover (LU/LC) of Niger Delta Region, Nigeria

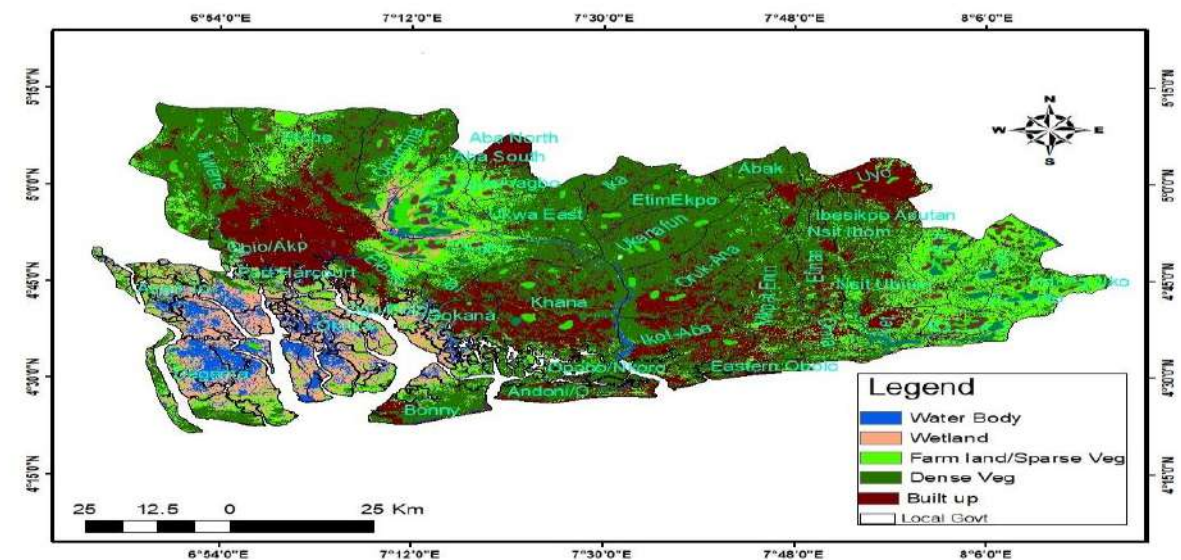


Figure 4: 2022 Land Use Land Cover (LU/LC) of Niger Delta Region, Nigeria

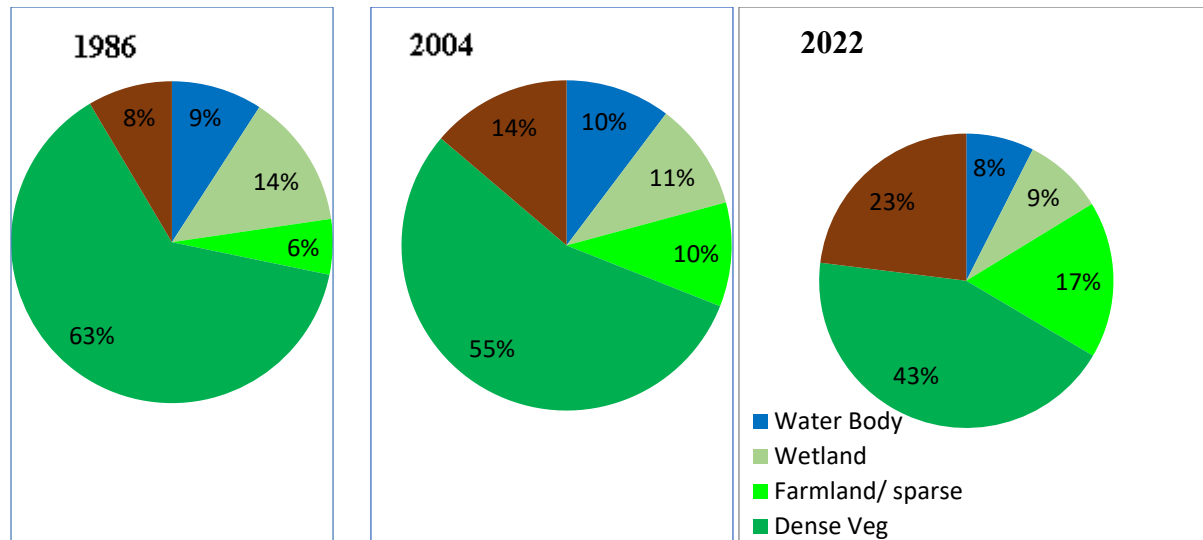


Figure 5: Percentage Fraction of Each Land Use Land Cover (LU/LC) Types in Niger Delta Region, Nigeria

Table 3: Variation in Land Use Land Cover (LU/LC) Types

Time series (year)	Water	Wetland	Farmland/sparse Vegetation	Dense Vegetation	Built up
1986	896.2±2.0 ^b	1326.0±10.0 ^a	546.3±10.0 ^d	6196.7±4.4 ^a	834.3±4.0 ^d
2004	1008.5±5.0 ^a	1029.9±9.0 ^b	999.84±4.0 ^c	5410.7±0.6 ^b	1349.3±7.8 ^c
2022	732.0±1.7 ^d	861.9±10.0 ^c	1688.45±9.2 ^b	4259.11±13.8 ^c	2258.0±2.0 ^b
<i>p</i> -value	0.000	0.000	0.000	0.000	0.000

Mean with dissimilar superscript on same column are statistically different at 0.05 levels.

Table 4: Observed Changes and Rate of Change of Land Use Land Cover (LU/LC) Types from 1986 – 2040

LULC	Observed Change (Km ²) 1986 - 2004	Change Rate (km ² /Yr)	Observed Change (Km ²) 2004 - 2022	ChangeRatekm ² /Yr)
Water body	112.23	6.23	-276.52	-15.36
Wetland	-296.15	-16.45	-167.94	-9.33
Farmland /Sparse	453.59	25.20	688.61	38.26
Dense Veg	-784.69	-43.59	-1152.89	-64.05
Built up	515.01	28.61	908.74	50.49

Spatio-Temporal Distribution of LST and Rainfall

The results on spatial distribution of LST (Figures 6 to 8) revealed areas of high, moderate to high values of LST. The maximum and minimum LST exhibited a

growing trend through the study years. In 1986, maximum and minimum LST was 27.25°C and 18.38°C, respectively. It increased to 30.28°C maximum and 19.12°C minimum in 2004; and increased to 34.61°C maximum and 21.68°C minimum

in 2022. The spatial rainfall distribution also showed areas of high, moderate to low rainfall in 1986, 2004 and 2022. The rainfall pattern (Figure 10) exhibited an irregular trend. The maximum and minimum annual rainfall in 1986 was 3073.12mm and 2158.25mm, respectively. The year 2004 experienced a moderate increase of maximum (3166.49mm) and minimum 2276.97mm, while a sharp decrease of maximum (2518.30mm) and

minimum (1872.61mm) was recorded in 2022.

Temporal trend of mean LST across LU/LC types within the study periods (Figure 9) followed a regular trend throughout the study periods. Water body had the least mean LST, followed by wetland, farmland/sparse vegetation, dense vegetation. However, built-up had the highest mean LST.

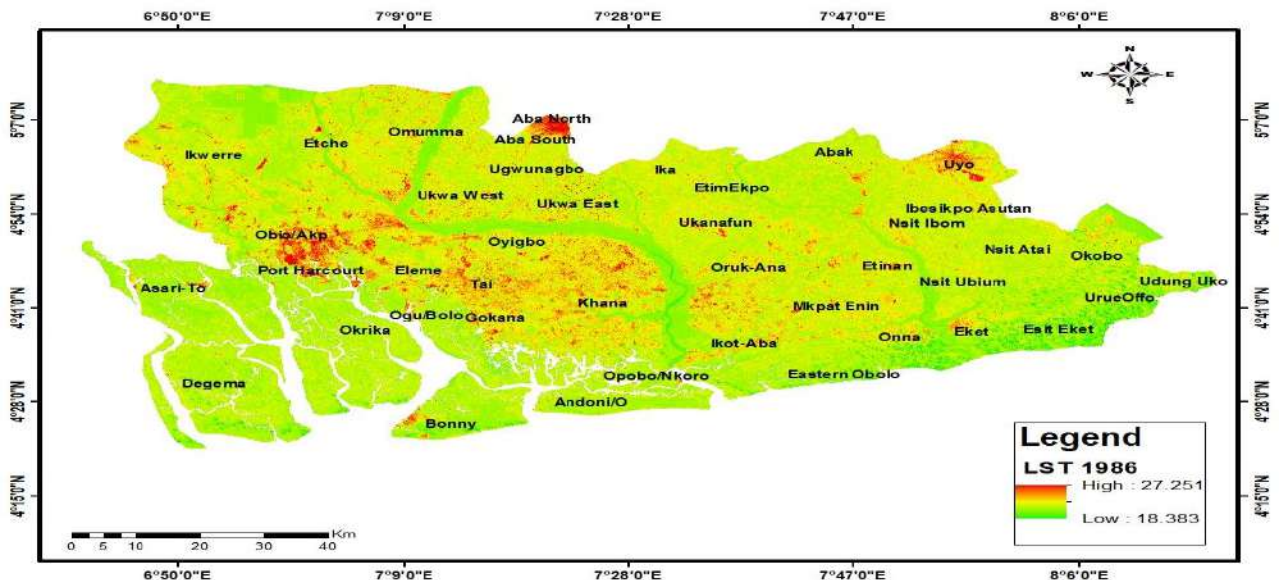


Figure 6: Spatio-Temporal Distribution of LST of Niger Delta Region in 1986

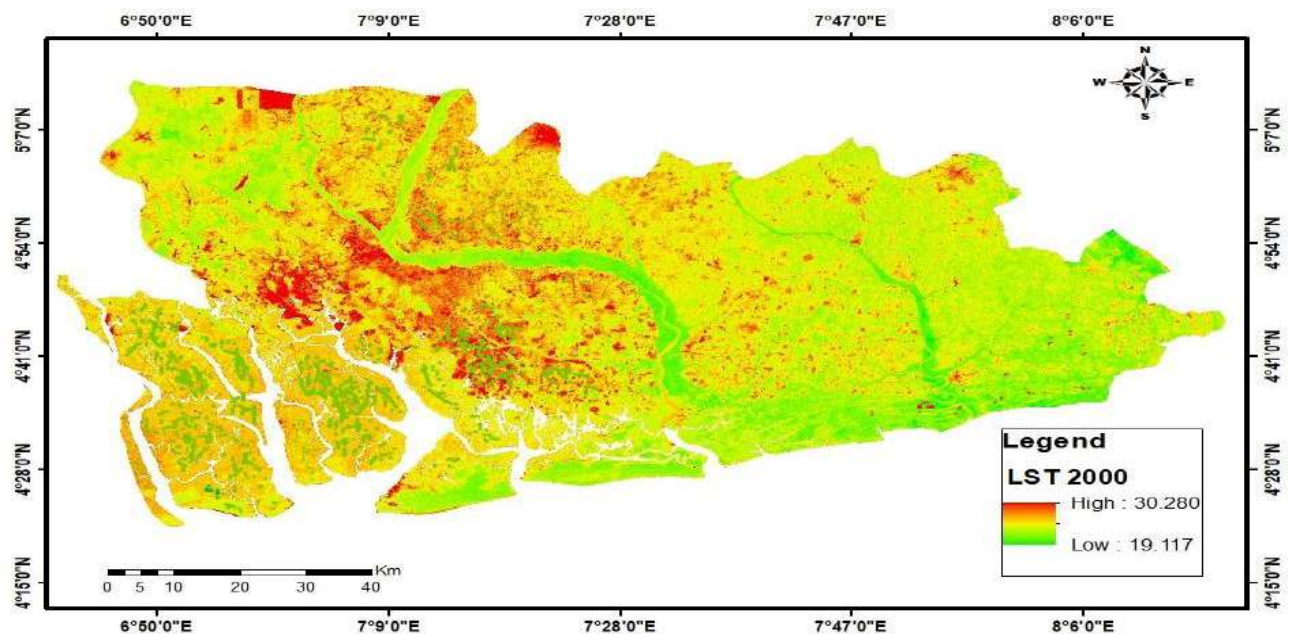


Figure 7: Spatio-Temporal Distribution of LST of Niger Delta Region in 2004

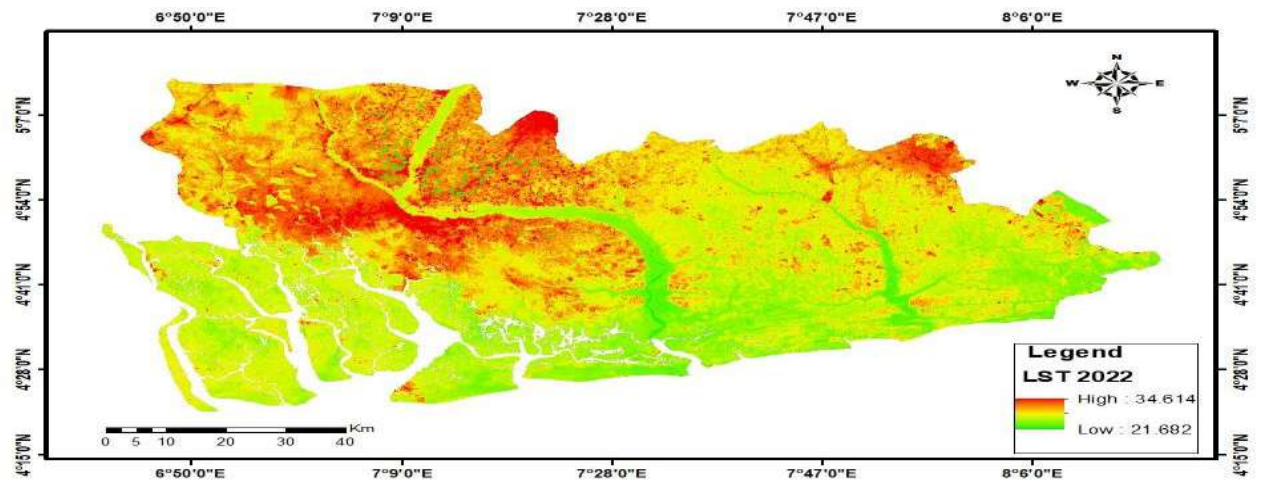


Figure 8: Spatio-Temporal Distribution of LST of Niger Delta Region in 2022

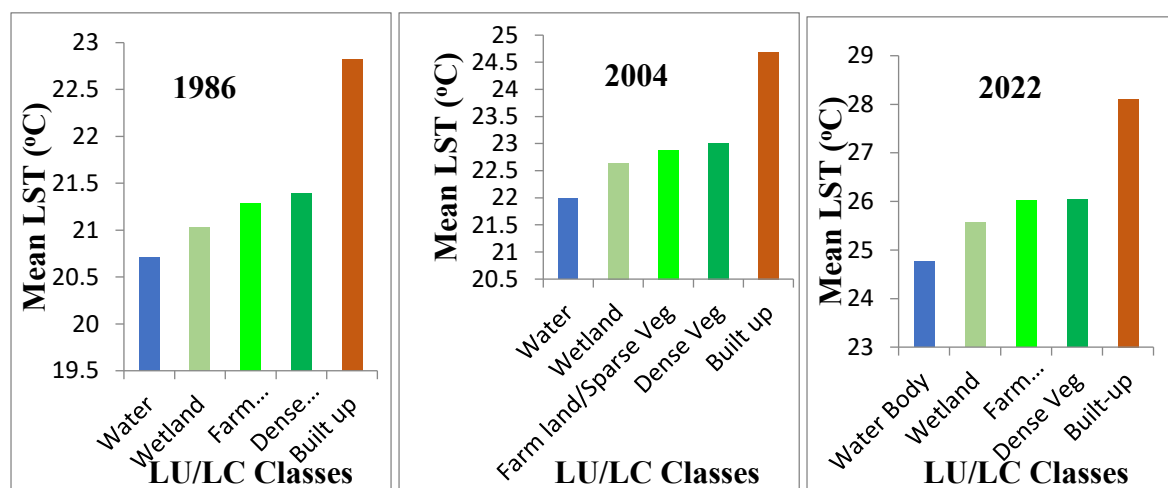


Fig. 9: Temporal Trends of Mean LST across LU/LU Types in 1986, 2004 and 2022

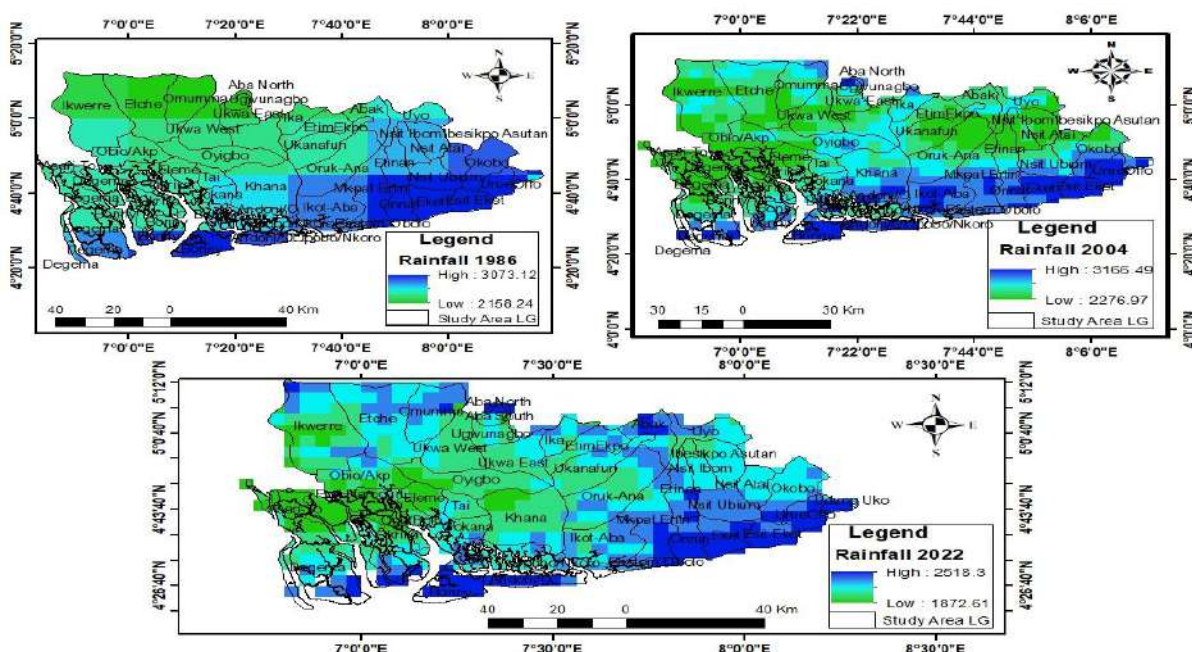


Figure 10: Spatio-Temporal Distribution of Rainfall of Niger Delta Region within the Study Periods

Changes in Climatic Variables of the Study Area within the Study Periods

There are notable changes in the climatic variables within the study periods. Mean relative humidity remained relatively stable; with slight fluctuations from $86.43 \pm 8.3\%$ in 1986 to $87.67 \pm 1.5\%$ in 2004 and $86.07 \pm 9.5\%$ in 2022 (Table 8). Mean wind speed was $2.45 \pm 1.0 \text{ m/s}$, $2.49 \pm 1.0 \text{ m/s}$ and $2.29 \pm 1.0 \text{ m/s}$ in 1986, 2004 and 2022, respectively. There was variability on mean rainfall across the (Table 5). Maximum mean rainfall was

recorded in 2004 ($2721.7 \pm 10.0 \text{ mm}$), followed by 1986 ($2615.7 \pm 15.0 \text{ mm}$) and least in 2022. Mean LST experienced a consistent increase over the years, from $22.8 \pm 1.7^\circ\text{C}$ in 1986, to $24.7 \pm 1.9^\circ\text{C}$ in 2004 and $28.2 \pm 11.1^\circ\text{C}$ in 2022. The results indicated changing climatic/environmental conditions in the study area. Average relative humidity and average wind speed exhibited significant differences ($p > 0.05$) while mean rainfall and mean LST showed significant difference over time ($p = 0.000$, 0.519)

Table 5: Variation in the Climatic Variables of Niger Delta Region (NDR) within the Study Periods

Time series (year)	Mean Relative Humidity (%)	Mean Wind speed (m/s)	Mean Rainfall (mm)	Mean LST ($^\circ\text{C}$)
1986	86.43 ± 8.3^a	2.45 ± 1.0^a	2615.7 ± 15.0^a	22.8 ± 1.7^a
2004	87.67 ± 1.5^a	2.49 ± 1.0^a	2721.7 ± 10.0^a	24.7 ± 1.9^a
2022	86.07 ± 9.5^a	2.29 ± 1.0^a	2195.5 ± 5.0^b	28.2 ± 11.1^b
p-value	0.413	0.968	0.000	0.519

Mean with dissimilar superscript (alphabet) on same column are statistically different at 0.05 levels.

Relationships between LU/LC Types and Climatic Variables

Pearson correlation matrix (Table 6) revealed the relationship between LU/LC types and climatic variables in the study area. Water body had a strong positive correlation with rainfall (0.98), wind speed (0.97), relative humidity (0.91). There was a strong negative correlation between water body and LST (-0.72) and built-up (-0.71). Also, there was moderate positive and negative correlation between water body and dense vegetation (0.68) and farmland/sparse vegetation (-0.68). Wetland had strong positive association with dense vegetation (0.96), average positive relationship with wind speed (0.64), rainfall (0.64) and strong negative association with LST (-0.95), built-up (-0.95) and farmland/sparse vegetation (-0.96).

Farmland/sparse vegetation had a perfect negative and positive correlation with dense vegetation (-1.00), built-up (1.00) and LST (1.00), and strong negative correlation with rainfall (-0.83) and wind speed (-0.83). Dense vegetation had a perfect negative correlation with built-up (-1.00) and LST (-1.00), and strong positive correlation with wind speed (0.82) and rainfall (0.82). Built-up, had a strong negative correlation with wind speed (-0.85) and rainfall (-0.85), and a perfect positive correlation with LST (1.00). Relative humidity had strong positive correlation with wind speed (0.80) and rainfall (0.80), and weak negative correlation with LST (-0.37). Wind speed had a perfect positive relationship with rainfall (1.00) and strong negative association with LST (-0.86), while rainfall had a strong negative association with LST (-0.85).

Table 6: Pearson Correlation Matrix on Land Use and Climatic Variables of the Study Area

	Water	Wetland	Farmland/ Sparse	Dense Veg	Built- up	Rel. Humidity	Wind speed	Rainfall	LST
Water	1.00	-	-	-	-	-	-	-	-
Wetland	0.46	1.00	-	-	-	-	-	-	-
Farmland/ Sparse Veg	-0.68	-0.96	1.00	-	-	-	-	-	-
Dense Veg	0.68	0.96	-1.00	1.00	-	-	-	-	-
Built up	-0.71	-0.95	1.00	-1.00	1.00	-	-	-	-
Rel. Humidity (%)	0.91	0.06	-0.33	0.32	-0.37	1.00	-	-	-
Wind speed (m/s)	0.97	0.64	-0.83	0.82	-0.85	0.80	1.00	-	-
Rainfall (mm)	0.98	0.64	-0.83	0.82	-0.85	0.80	1.00	1.00	-
LST (°C)	-0.72	-0.95	1.00	-1.00	1.00	-0.37	-0.86	-0.85	1.00

DISCUSSION

Spatio-Temporal Distribution and Area Coverage of LU/LC of the Region

The LU/LC of the research area were basically dense vegetation, water body, wetland, built-up and farmland/sparse vegetation. This result is similar with the report of Elekwachi *et al.* (2021) who worked on LU/LC types in the NDR of Nigeria. Generally, the entire study area is predominantly dense vegetation throughout the study periods. However, areas like Degema, Bonny, Ogu-Bola, Opobo/Nkoro and Asari-Toru were consistently dominated by wetland and water body; while Obio/Akpo, Port Harcourt, Aba North and Uyo were consistently dominated by built-up. Each of these LU/LC type has experienced changes, losses, and gains at varying rates due to many factors.

The decreasing trend in dense vegetation, wetland, and the increasing trend in built-up and farmland/sparse vegetation area were similar to the trend of LU/LCC reported by Elekwachi *et al.* (2021) in NDR, Wizer *et al.* (2020) in Obio/Akpo Local Government, Ubaekwe *et al.* (2022) in Finima Nature Park, Bonny Local Government Area. Elekwachi *et al.* (2021) attributed the decreasing trend of dense vegetation and wetland to human population increase and the associated demand for more agricultural land, settlement, and commercial activities. These invariably elevated the areas of built-up as well as the areas of farmland/sparse vegetation. Elekwachi *et al.* 2018 also reported a decrease in wetland area of Port Harcourt Local Government Area because of extreme urban slump and rapid conversion of wetland to housing development.

Tariku *et al.* (2020) recorded decrease in areas of Abaya-Chamo wetland because of

swift population growth, farm extension, overgrazing, and the damage of natural vegetation closest to the wetland. They also reported that the high rate of Abayo-Chamo wetland degradation was triggered by absence of strong regulations and legal actions on the exploitation, and poor protection of wetland resources. Obiefuna *et al.* (2013) also recorded rapid decline in Lagos wetland ecosystem and linked the loss to urban development. The inconsistent trend in the area coverage of water body was also observed by Elekwachi *et al.* (2018). Additionally, Collins and Elekwachi (2020) recorded a significant decline in area coverage of water body in Obio/Akpo Local Government Area within the study period of 2000 to 2018. Both studies linked the decline in water body to urban development and human population growth.

Spatio-Temporal Distribution of LST and Rainfall

LST is an important parameter that determines the energy exchange and surface radiation controlling the heat distribution between the surface and atmosphere; it changes as a result of many factors. In this study, the minimum and maximum LST were moderately low in 1986 and increased with the years within the study periods. Similar trend was recorded by Koko *et al.* (2021) in Abuja metropolis; and Eyoh and Okwuashi (2017) across the NDR. The latter recorded minimum and maximum LST of 19.40°C and 29.89°C in 1986; 19.8°C and 30.9 °C in 2002 and 19.9°C and 31.1°C in 2016.

The values were almost same with the values recorded in this study; however, the very slight differences could be attributed to the larger coverage of areas in NDR in their study. The former recorded minimum and maximum LST of 20.30°C and 37.11°C in 1990, and 20.58°C and 40.13°C in 2019. The mean LST in Abuja Metropolis were significantly higher when compared with the

mean LST in the NDR. The minimum and maximum LST recorded in the study area were also low when compared with minimum (23.86°C) and maximum (34.39°C) LST recorded by Traore, *et al.* (2021) in 1986; and compared favourably with the minimum (19.85°C) and maximum (29.22°C) LST in 1999; minimum (21.35°C) and maximum (35.23°C) LST in 2021 in the city of Bangui southern part of Central African Republic and in northern Oubangui river bank. The variations in the minimum and maximum LST over the years indicated traces of climate change in the region.

Different LU/LC types exhibited varying range of mean temperature in the study. Spatially, areas of water body exhibited the minimum mean LST, followed by wetland; farmland/sparse vegetation, dense vegetation, while built-up exhibited the highest mean LST. In other words, changes in any LU/LC types will directly and indirectly affects the mean LST. Eyoh and Okeke (2017) reported similar trend in a study on the relationship between LU/LC change and LST across the NDR of Nigeria. Their findings showed that water body, mangrove, forest, low density built-up and high density built-up had increasing mean LST of 21.59°C, 22.73°C, 22.94°C, 24.75°C, and 27.96°C respectively.

Bharath *et al.* (2013) and Traore *et al.* (2021) also reported elevated values of LST in plain regions and cities when compared with low LST recorded in dense vegetation. The authors concluded that the presence of impermeable objects, asphalt, low albedo materials have high capacity to absorb solar energy and convert into thermal energy thereby increasing the surface temperature; whereas dense vegetation, wetland, farmland, and water body have higher albedo, thus reflecting more sunlight and reducing the amount of solar radiation being absorbed. Liu *et al.* (2015) and Qijiao and Zhixiang, (2015) added that high rate of evapotranspiration in dense vegetation has a cooling effect on the

land surface which lowers the mean LST compared to built-up areas with little or no vegetation. These explain the spatial variations in LST distribution across different local governments in the study areas. The temperature in Aba North, Obior/Akpo, Uyo and Port Harcourt Local Government Areas were significantly higher than the LST in Ukwu East, Ukanafun, Degema, Andoni, etc. because of different surface materials and anthropogenic activities in the locations.

The range of annual rainfall recorded in the study area is extremely high when compared with the annual mean rainfall of 1033.95mm, 1098.85mm, 1079.61mm and 660.01mm in the years 1987, 1997, 2007 and 2017 respectively according to Mngube *et al.* (2020) in the Mara River Basin, Kenya; the mean annual rainfall of 2400mm, 1400mm and 2050mm reported by Wang *et al.* (2021) in the years 2001, 2011 and 2019 respectively in Guangdong–Hong Kong–Macao; and the mean annual range of 2,208mm and 1,662mm recorded by Akintuyi *et al.* (2021) in the derived savannah region of Nigeria between the years 1941 - 2019. However, the mean rainfall in the study area compared favourably with the report of Akinbobola *et al.* (2023). They recorded mean rainfall of 2350mm between the year 2000 – 2004; 2300mm between the years 2004 – 2009; 2250mm between the years 2009 – 2014; and 2550mm between the years 2015 – 2020 in the NDR. The high rainfall confirmed in the NDR could be traceable to the Atlantic Ocean situated within the region. Spatially, areas closest to the coast received consistent high rainfall throughout the study periods, while areas away from the ocean depicted an irregular pattern.

Akinbobola *et al.* (2023) reported that Atlantic Ocean offers maritime humid trade winds which bring forth moisture to the land; and that the region is characterised by highlands which enhances orographic processes that result to rain. Rosenfeld *et al.*

(2019) in agreement added that areas closest to the Atlantic Ocean experience more and frequent rainfall due to the combine effects of maritime, sea breezes, convergence zones and topographic effects. There were variations in the mean relative humidity and mean wind speed across the study years; however, the variations were not significantly difference. The variability both in spatial distribution and amount of rainfall and LST recorded in this study is an evidence of climate change. This assertion was supported by Akinbobola *et al.* (2023), Mngube *et al.* (2020) and Wang *et al.* (2019), they added that the climate change was exacerbated by rapid LU/LC changes.

Relationships between Land Use and Climatic Variables of the Research Area

Correlation matrix shows the relationship existing between land use/land cover types and the climatic variables. Among the LU/LC types, built-up area is the major factor of decrease in dense vegetation, wetland and water body, and had caused increase in farmland/sparse vegetation. This supports the assertion by Ubaekwe *et al.* (2023), Elekwachi *et al.* (2021), Ubaekwe *et al.* (2022), Wizer *et al.* (2020), Tariku *et al.* (2020) that human population growth, urbanization, industrialization and poor policy implementation are the major factors of forest loss, water and wetland encroachment. Farmland/sparse vegetation had perfect negative correlation with dense vegetation, and strong negative correlation with wetland and water body. However, increase in spatial extent of farmland/sparse vegetation decreases to a greater extent the area coverage of dense vegetation, wetland, and moderately water body. The observed strong positive correlation between dense vegetation and wetland in this study supported the studies by Smith *et al.* (2018) and Jones and Brown, (2015). This linear relationship highlights the intricate and mutually beneficial ecological interplay between the two natural landscapes.

According to Smith *et al.* (2018), Jones and Brown (2015), the wetland features such as water availability, rich soil nutrient, water flow control and high nutrient cycling processes provide favourable conditions for vigorous and rapid vegetation growth; while dense vegetation provides habitat and cover to wetland ecosystem, thus contributes to its resilience and stability against human disturbances and ecological pressures.

Changes in dense vegetation can lead to changes in the wetland ecosystem, and conversely, changes in the wetland can affect the dense vegetation. In addition, the observed moderate relationship among water body, dense vegetation and wetland also confirm the interdependency of the components. The strong positive correlation between water body, rainfall, wind speed and relative humidity reveals that increase in rainfall will directly increase the relative humidity, water body and wind speed. This explains why areas closest to the seacoast had highest amount of rainfall. Smith and Johnson (2015) supported the assertion and added that rainfall is one of the major factors that affect water body formation, water levels and sustainability. More so, high relative humidity enhances cloud formation, which can result to rainfall; while strong winds cause waves and currents in water bodies, which help in water movement (Johnson, 2019).

Considering the five-land use/land cover types and other climatic variables, increase in dense vegetation, water body, wetland, wind speeds and rainfall decreased LST, while increase in built-up increased LST and decreased wind speed and rainfall. This relationship is similar to the report of Eyoh and Okeke (2017), Koko *et al.* (2021). This explains why areas with high built-up densities such as Aba North, Obior/Akpo, Port Harcourt, and Uyo exhibited high temperature when compared with the areas of high vegetation densities like Ukwu west,

Ukanafun, Etche, a phenomenon often referred to as urban heat island. Ashwini and Sil (2022), explained that elevated wind speeds and rainfall cause decline in LST since heat from the surface which causes high temperature are being dissipated by wind, while rainfall through direct cooling effects of evaporation and increased moisture content in the air moderates land surface temperature.

CONCLUSION

This study revealed the major LU/LC patterns in the study area, and the changes occurring over time and their relationships with climate variables. Dense vegetation emerged as the dominant land cover type, while water bodies exhibited the least area coverage. However, each land use/land cover category experienced significant changes in spatial extent, with gains observed in built-up and farmland/sparse vegetation, and losses in dense vegetation, wetlands, and water bodies.

The analysis of land surface temperature (LST) revealed a moderate to low range, with an increasing trend observed from 1986 to 2022. Built-up areas consistently exhibited higher LST values compared to other land cover types. Additionally, the study observed high rainfall levels, particularly in areas close to the seacoast. Wind speed and relative humidity displayed similar spatial patterns with rainfall across the study periods.

Significant relationships were identified between land use/land cover types, climate variables, and their interactions. Negative correlations were observed between dense vegetation, water bodies, wetlands, and built-up areas, while farmland/sparse vegetation showed positive associations with built-up areas. Furthermore, inverse relationships were observed between dense vegetation, water bodies, wetlands, wind speeds, rainfall, and LST. Water bodies exhibited direct

relationships with relative humidity, rainfall, and wind speed.

The study has revealed the impact of changes in LU/LC on climate variables, indicating the importance of proper land management practices. To address environmental challenges, aggressive protection measures for wetland ecosystems, forest vegetation, and water bodies are recommended. Additionally, promoting urban greenery and implementing sustainable urbanization strategies, such as green roofs and permeable pavements, can mitigate adverse effects on the environment. Ultimately, effective land use and cover management are essential for mitigating climate change and preserving ecological balance in the NDR.

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DISTRIBUTION OF POTASSIUM FRACTIONS ON DIFFERENT FOREST PLANTATIONS IN OMO FOREST RESERVE OGUN STATE

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ABSTRACT

This study evaluates the distribution and forms of potassium in soils under different land-use types, specifically assessing the impact of these land uses and soil depths on soil physicochemical properties. The research was conducted in five different land-use areas: *Nauclea diderrichii* plantation, *Pinus caribea* plantation, *Gmelina arborea* plantation, *Tectona grandis* (Teak plantation), and natural forest, with sampling done at three different soil depths (0-30 cm, 30-60 cm, and 60-90 cm). Standard soil analytical procedures were followed in carrying out soil analysis for pH, Exchangeable bases (Na, K, Mg, Ca), Soil particle size, Organic carbon, Total nitrogen, Available phosphorus, and potassium fraction distribution. Data obtained from the laboratory analysis was subjected to 2-way analysis of variance (ANOVA) using statistical analytical software (SAS) version 9.2 (SAS, 2002). Means data obtained was separated using Duncan's Multiple range test (DMRT) at $p < 0.05$. Correlation analysis was used to evaluate the relationship between potassium forms and other soil properties within the selected forest plantations. The available potassium (K) was highest in the *Gmelina arborea* plantation at 0-30 cm (3.11 cmol/kg) and lowest in *Tectona grandis* (0.16 cmol/kg). Potassium in the form of water-soluble potassium ranged from 0.78 cmol/kg in some land uses to 0.0 cmol/kg in others, indicating variability across the different sites. Exchangeable potassium followed a similar trend, with values ranging from 2.34 cmol/kg to 0.16 cmol/kg. Soil properties, including total nitrogen (TN), organic carbon (OC), organic matter (OM), and cation exchange capacity (Ca, Mg, Na), correlated significantly with potassium fractions, with both positive and negative correlations. TN showed a negative significant correlation with available phosphorus ($r = -0.525$) and a positive correlation with available K, soluble K, and exchangeable K. OC had a positive correlation with available K ($r = 0.680$) and soluble K ($r = 0.733$). OM exhibited a negative correlation with available phosphorus and positive correlations with potassium forms such as available K, soluble K, and exchangeable K. Sandy soil content had negative correlations with potassium fractions, indicating soil texture's influence on potassium availability. Significantly positive relationship was observed between different forms of potassium, especially between available K, soluble K, and exchangeable K. Available K showed a very strong positive correlation with soluble K ($r = 0.906$) and exchangeable K ($r = 0.986$). Soluble K also had a strong positive correlation with exchangeable K ($r = 0.828$). Low potassium concentrations in these soils suggest that potassium availability is limited in the studied areas. In conclusion, the study highlights the significance of land use and soil depth in determining potassium distribution and the important relationships between potassium fractions and other soil properties. Effective soil management practices are essential for maintaining adequate potassium levels to support plant growth.

Keywords: Potassium, Forms, Depth, Forest, Plantations

INTRODUCTION

Potassium, a crucial nutrient and the richest element in soils, exhibits varying levels across different locations due to differences in the physicochemical properties of the soil (Lalitha and Dhakshinamoorthy, 2014). It is one of the vital elements required for plant growth and physiology and the most abundant inorganic cation in plant tissues. It is one of the most soluble elements, yet being present in the form of a simpler chemical complex in nature. It's classified as a macronutrient because plants uptake large quantities during their life cycle. Though the quantity of K absorbed by plants is as much as or higher than nitrogen (N) for most cultivated crops (SOPIB, 2001). The highest concentrations of K are found in young developing tissues and reproductive organs indicative of its high activity in cell metabolism and growth. In cells, K is needed in the maintenance of transmembrane voltage gradients for cytoplasmic pH homeostasis and in the transport of inorganic anions and metabolites (White and Karley, 2010). Uptake and accumulation of K by plant cells is the primary driving force for their osmotic expansion (Mengel and Kirkby, 2001). As a result, it absorbs quickly from solutions and soils and moves quickly through the plant and indeed essential in modern agriculture, horticulture, and vegetable crops as it makes plants tolerant to drought and frost and resistant to several diseases and pests besides its impact on yield and quality (Romheld and Kirkby, 2010). From the field crop nutrition, two of the most perceived roles of K are in photosynthesis and the maintenance of cell turgor in plants conditions where there is a deficiency in potassium (K). Under conditions of potassium deficiency, photosynthesis is hindered due to the accumulation of sucrose in the leaves, impacting gene expression (Hermans *et al.*, 2006).

Forest plantations are important for timber production and as a means of restoring degraded lands. However, the availability of critical elements such as potassium (K) may limit the growth and production of trees in these plantations. Potassium is one of the three primary macronutrients required by plants for growth, and its distribution in different forms can influence the overall health and productivity of forest plantations (Li *et al.*, 2019). The distribution of K fractions in forest soils can also vary depending on the tree species. Several studies have investigated the distribution of K fractions in forest plantations, and they have shown that the majority of K in forest soils is present in non-exchangeable forms, such as mineral-associated K and organic matter-bound K (Dhakal *et al.*, 2019; Laiho *et al.*, 2015). These forms of K are not readily available to plants and are slowly released through weathering and decomposition processes. In contrast, exchangeable K, which is more readily available to plants, accounts for a smaller fraction of total soil K (Dhakal *et al.*, 2019; Laiho *et al.*, 2015). Understanding the distribution of K fractions on different forest plantations is essential for effective nutrient management and sustainable forest productivity. The objective of this study is to understand the distribution of potassium fractions in different forest plantations in Omo Forest Reserve in Ijebu area, Ogun state, Nigeria. And this involves analyzing the various forms of K present in the soil and plant tissues, and identifying the factors that influence their availability and uptake by trees. The results of this study can inform the development of effective forest management strategies aimed at improving soil fertility and tree growth.

MATERIALS AND METHODS

Study Area

The study was carried out at Omo Forest Reserve, Ijebu region, Ogun state, Nigeria.

The Omo Forest Reserve is a protected section of tropical rainforest in the southwest of Nigeria, in the state of Ogun (Figure 1). The Omo Forest Reserve is situated in the southwest region of Nigeria, roughly 135 kilometers north-east of Lagos and 80 kilometers east of Ijebu-Ode, between latitudes $6^{\circ} 35'$ and $7^{\circ} 05'$ and longitudes $4^{\circ} 19'$ and $4^{\circ} 40'$. It is located in the nearby city of Ijebu-Ode, Ogun State, Nigeria, and spans an area of around 130,500 hectares (322,000 acres). The average rainfall is around 2,000 mm. The terrain is largely flat and well-drained, with some low rolling hills, and forms part of the Omo River watershed (Ojo, 2004). Omo Forest Reserve has a mixed, moist, semi-deciduous rainforest type of

vegetation. This can be divided into a wet evergreen forest in the south and a dry evergreen mixed deciduous forest in the north. The places' geographies vary greatly, ranging from virtually flat to hilly. The main river that runs through the sites, the River Omo, has a watershed that receives good drainage from about 80% of the sites. Numerous small hills dot the landscape, which is uneven and traversed by tributaries of the Omo, Shasha, and Oluwa Rivers. The soil types at the locations vary, but they all come from tertiary sediments. The majority of the oxidized soils are severely leached. Sand-loam topsoil and sandy clay subsurface make up the typical soil texture (Ojo, 2004).

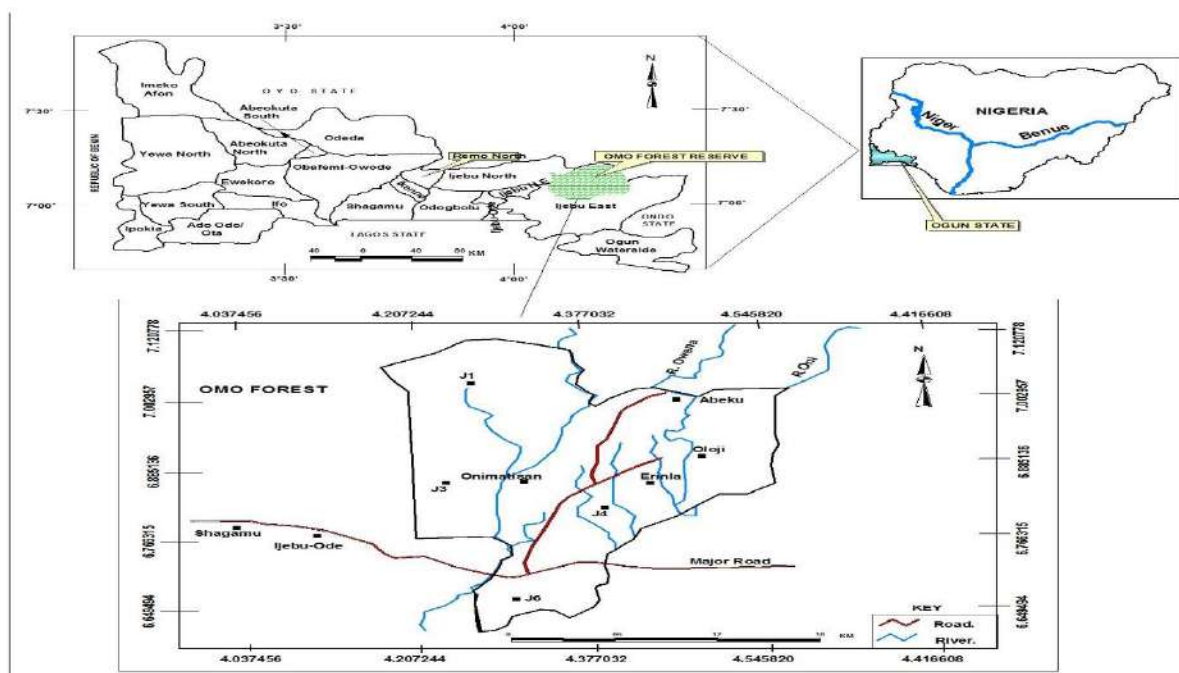


Figure 1: Omo Forest Reserve showing the study area

Site selection, Sampling Procedure and Plot Location

The coordinates of the study area and points where soil samples were collected was recorded with the aid by Global positioning system (GPS). The selection of site for the study was from five different forest

plantations: *Nauclea diderrichii* plantation, *Pinus caribaea* plantation, *Gmelina arborea* plantation, *Tectona grandis* (Teak plantation) and Natural Forest. Profile pits were dug to collect bulk soil samples from the center and the four corners of forest plantations at 0-30, 30-60 and 60-90 cm depths using a soil auger (5 cm inner diameter). The collected samples were bucked up and mix thoroughly and then

divided into three (3) replicates of 0.5kg and were poured into a well labeled sample bag. In each forest plantation, nine samples were collected. A total number of forty-five (45) soil samples were collected from all the study sites in all the locations. Collected samples were taken to laboratory where it was air-dried, ground (pulverized) and passed via a 2 mm mesh sieve sized to screen the debris and large particles. The sieved samples were

weighed and divided into portions for the analysis of parameters having different procedures and then properly packed.

Experimental Design

The experiment was laid out in 3×5 factorial design in a Randomized Complete Block Design (RCBD). The experimental layout for all the land use in the study is shown in Figure 2.

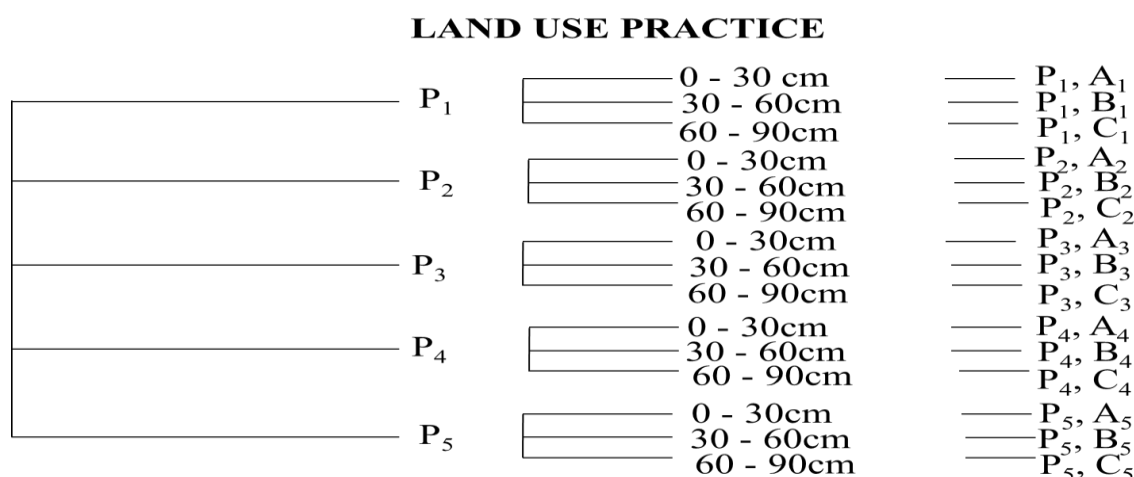


Figure 2: Experimental Layout for all the land use in the study

Statistical model for RCBD

The mathematical model of the three factor (3×5) factorial experiment is given as:

$$Y_{ijk} = \mu + (AB)_i + (AC)_j + (AD)_k + (AE)_f + (BC)_r + e_{ijk}$$

Where:

Y_{ijk} = Individual observation

μ = General mean of individual observation

A = Effect of factor A

B = Effect of factor B

C = Effect of factor C

D = Effect of factor D

E = Effect of factor E

AB = Interaction between factor A and B

AC = Interaction between factor A and C

AD = Interaction between factor A and D

AE = Interaction between factor A and E

BC = Interaction between factor B and C

e_{ijk} = experimental error

Analysis of Soil Samples

The soil samples were stored immediately in polyethylene plastic bags after collection in the field. All soil samples were air-dried for 3 days at room temperature to remove moisture in the soil, and were grounded using a mortar and pestle, and then sieved through a 2-mm sieve.

• Soil pH And Particle Size Distribution

A pH meter was used to measure the soil reactivity in a 1:2.5 soil to water suspension after 30 minutes of stirring (Jackson, 1973). After extracting the supernatant as stated by Jackson (1973) using a conductivity meter, it was evaluated in a suspension of 1:2.5 soil to water.

a) The pH of the soil samples was determined in water by means of Bechman's pH meter using a soil water ratio of 1:2.5 (Thomas, 1996).

b) The particle size distribution was determined by the hydrometer method (Bouyoucos, 1951).

- **Organic Carbon**

Organic carbon was determined by the procedure Walkley and Black's (1934) using the dichromate wet oxidation method (Nelson and Sommers, 1996) as described by Piper (1996).

- **Available Phosphorus**

Available P was extracted by (Bray and Kurtz, 1945) method, Phosphorus in the extracts was determined calorimetrically (Murphy and Riley, 1962).

- **Exchangeable Cations or bases**

Ammonium acetate (NH_4OAc), which has a pH of 8.1, was used as the extraction solution to conduct the ion exchange process technique to evaluate the exchangeable cations or bases. The extraction solution was created using the Suarez (1996) stated procedures. While Ca^{2+} and Mg^{2+} were examined using titration with the (EDTA) disodium salt, Na^+ and K^+ were examined using a flame photometer.

- **Available Potassium**

Available potassium (ppm) was determined by adding water soluble potassium and exchangeable potassium.

- **Water-Soluble Potassium**

Water-soluble K was determined by shaking the soil sample with deionized water. In this method, 5g of air-dried soil was placed in a conical flask and 25 ml of distilled water was added (1:5 ratio). This mixture was shaken in a mechanical shaker for an hour and filtered. Potassium was estimated from the filtrate on the flame photometer (Pratt, 1982).

- **Exchangeable Potassium**

Exchangeable K was obtained by flame photometer using 1N neutral ammonium acetate extraction (NH_4OAc). This method involved placing 5 g soil in a conical flask; 2 ml 1N NH_4OAc was added and shaken for 10 min. The supernatant liquid was decanted into a 100 ml volumetric flask. There would be three additional extractions made in the same manner. The combined extractions were diluted to 100 ml with 1N NH_4OAc and K was determined by flame photometer (Piper, 1966). To calculate the soil's exchangeable potassium concentration, the water-soluble K was deducted from the $\text{NH}_4\text{OAc-K}$.

Data analysis

The data obtained were subjected to 2-way analysis of variance (ANOVA) using statistical analytical software (SAS) version 9.2 (SAS, 2002). Means data obtained were separated using Duncan's Multiple range test at $p < 0.05$. Correlation Indices was used to determine the relationship between potassium forms and other soil properties within the selected forest plantations.

RESULTS

Effect of Depth on the Physiochemical properties, Forms and Distribution of Potassium in the Study Areas.

Table 1 revealed the means of the physiochemical properties, forms and distribution of Potassium in *Gmelina arborea*, *Tectona grandis*, *Nauclea diderrichii*, *Pinus caribaea* and Natural Forest at three depths;

0-30cm, 30-60cm and 60-90cm. The soil pH recorded at these depths were (5.75a), (5.66b) and (5.61c) respectively, with the highest pH recorded at 0-30cm depth (5.75a), and the least at 60-90cm depth (5.61c). There was no significant difference ($p > 0.05$) in the mean of the pH recorded at these three depths. The result of the total nitrogen percentage (TN%) recorded were (0.21a), (0.15b) and (0.16c) at 0-30cm, 30-60cm and 60-90cm depths respectively with the highest recorded at 0-30cm depth (0.21a) and the lowest recorded at 30-60cm depth (0.15b). There is significant difference ($p \leq 0.05$) in the percentage of total nitrogen at these three depths. The Organic carbon (OC%) result showed there was no significant difference ($p > 0.05$) in the percentage at three depths, the individual percentage organic carbon recorded at 0-30cm depth (2.32a), 30-60cm depth (2.93b) and 60-90cm (1.68b). The highest percentage was recorded in the second depth 30-60cm (2.93b) and the least at 60-90cm depth (1.68b). The organic matter (OM%) percentage recorded were (4.02a), (2.93b) and (3.00b) at 0-30cm, 30-60cm and 60-90cm respectively with the highest recorded at 0-30cm depth (4.02a). There was no significant difference ($p > 0.05$) in the percentage of the organic matter at three depths. The soil sand particles recorded at 0-30cm, 30-60cm and 60-90cm depths were (84.80a), (81.14b) and (80.10b). There was no significant difference ($p > 0.05$) in the sand particles among the three depths. The highest sand particles were recorded at 0-30cm depth (84.80a), (81.10b) was recorded at 30-60cm depth while the least was (80.10b) at 60-90cm depth. However, there is significant difference ($p \leq 0.05$) in the clay particles recorded at these three depths respectively; the values were (9.88a), (12.70b) and (16.60a) recorded at 0-30cm depth, 30-60cm depth and 60-90cm depth respectively.

The highest clay particles recorded at 0-30cm depth (16.60a) while the least at 30-

60cm depth (12.70b). The silt particles in the soil at 0-30cm, 30-60cm and 60-90cm depths were (5.27a), (3.33c) and (3.56b). The silt particles at 0-30cm depth (5.27a) had the highest silt particle and the least at 30-60cm depth (3.33c). Available phosphorus (mg/kg) result at the three depths were (7.18a), (7.03b) and (5.34c) at 0-30cm, 30-60cm and 60-90cm depths respectively, with the highest recorded at 0-30cm depth (7.18a) and the least at depth 60-90cm depth (5.34c). The result showed there is significant difference ($p \leq 0.05$) in Available phosphorus among the three depths. The result for available potassium (mg/kg) recorded were (1.00a), (0.47b) and (0.34c) at 0-30cm, 30-60cm and 60-90cm depths. There is significant difference ($p \leq 0.05$) between the depth at 30-60cm and 60-90cm depth. The highest available potassium was recorded at 0-30cm depth (1.00a) while the least at 30-60cm depth (0.34c). The result recorded for soluble k were (0.34a), (0.16b), and (0.11c) with the highest (0.34a) at depth 0-30cm and least at 60-90cm depth (0.11c). the result of exchangeable K revealed at the three depths were (0.69a), (0.35b) and (0.26c) at 0-30cm, 30-60cm and 60-90cm depths. There was significant difference ($p \leq 0.05$) among the three depths. The highest at 0-30cm depth (0.69a) while least at 0-60cm depth (0.26c). The result of Magnesium (Mg) content was (0.20a), (0.13c) and (0.17c) at 0-30cm, 30-60cm and 60-90cm depths respectively, with the highest was at the 0-30cm (0.20a). the result revealed that there was no significant difference ($p > 0.05$) in magnesium among the depths at 30-60cm (0.13c) and 60-90cm at depth (0.17c). The highest value was recorded at 0-30cm depth (0.20a), while the least at 30-60cm depth (0.13c). The result revealed that there was no significant difference ($p > 0.05$) in the available calcium at the three depths. 0-30cm depth recorded value was (3.81a), at

30-60cm depth (3.56b) and at 60-90cm depth (1.82c). The highest at 0-30cm depth (3.81a) while the least at 0-30cm depth (1.82c). The result of sodium revealed that there was no significant difference ($p > 0.05$) at the three depths with the highest at 30-60cm depth (0.28a) while least at 0-30cm depth (0.23c). The result of Kcmol/kg revealed that there was significant difference ($p \leq 0.05$) across the potassium (K) content at three depths 0-30cm,

30-60cm and 60-90cm depths. (0.03a), (0.01b) and (0.01b) were recorded for the Kcmol/kg at 0-30cm, 30-60cm and 60-90cm depths respectively. The highest value at 0-30cm depth (0.03a) while least at 30-60cm depth (0.01b).

Table 1: Effect of Depth on the Physiochemical, Forms and Distributions of potassium

Depth (cm)	0 – 30cm	30 – 60cm	60 – 90cm
PH (H ₂ O) 1:2	5.75a	5.66 b	5.61 c
TN %	0.21 a	0.15 b	0.16 c
OC %	2.32 a	2.93 b	1.68 b
OM %	4.02 a	2.93 b	3.00 b
SAND %	84.80a	81.14a	80.10 b
CLAY %	9.88 a	12.70 b	16.60 a
SILT %	5.27 a	3.33 c	3.56 b
Available-P (mg/kg)	7.18 a	7.03 b	5.34 c
Available- K(mg/kg)	1.00 a	0.47 b	0.34 c
Soluble K	0.34 a	0.16 b	0.11 c
Exchange K	0.69 a	0.35 b	0.26 c
Mg (Cmol/kg)	0.20 a	0.13 c	0.17 c
Ca (Cmol/kg)	3.812 a	3.56 b	1.82 c
Na (Cmol/kg)	0.23 c	0.28 b	0.27 b
Kc (Cmol/kg)	0.03 a	0.01 b	0.01 b

Mean with the same alphabet in rows are not significantly different at ($p \geq 0.05$)

Effects of Land Use Practices on the Physiochemical properties, Forms and Distribution of Potassium

Table 2 showed the effect of land use practices on the physicochemical properties, forms of potassium in the soils of the five locations *Tectona grandis* plantation, *Gmelina arborea* plantation, *Pinus caribaea* plantation *Nauclea diderrichii* plantation, and Natural Forest. The result of soil pH (H₂O) 1:2 values revealed that there was significance difference ($P \leq 0.05$) across the five locations. The highest pH value was recorded in *Nauclea diderrichii* plantation of (6.09^a) and the lowest in *Tectona grandis* plantation of (4.88^e). The result of total nitrogen (TN%) in the five locations were *Tectona grandis* plantation (0.19^c), *Gmelina arborea* (0.23^a), *Pinus caribaea* plantation (0.12 d), *Nauclea diderrichii* plantation (0.21^b) and Natural Forest (0.10^e). The result

showed that there was significance difference ($P \leq 0.05$) in the total nitrogen at the four plantations and the Natural Forest. The highest pH value was *Gmelina arborea* (0.23^a) while the least was Natural Forest (0.10^e). The result of organic carbon (OC%) revealed that there was significance difference ($P \leq 0.05$) in the organic carbon analyzed across the plantation, in the five locations. The highest value in *Nauclea diderrichii* plantation (2.66^a) while the lowest organic carbon was revealed in Natural Forest with percentage (1.17^e). The result of the total organic matter (OM%) recorded in the five locations were in *Tectona grandis* plantation (3.77^c), *Gmelina arborea* plantation (4.62^a), *Pinus caribaea* plantation (2.12^d) and *Nauclea diderrichii* plantation (4.07^b) and 2.02^d, and Natural Forest (2.02^d). However, the highest value was revealed in *Gmelina arborea* (4.62^a) while the lowest was in (2.02^d) in Natural Forest. There was

no significant difference ($P>0.05$) between the *Pinus caribaea* (2.12^d) and Natural Forest (2.02^d). The result of the sand particle analysis showed that there was significance difference ($P\leq 0.05$) across the five locations. However, *Pinus caribaea* plantation had the highest sand particle (91.52^a), followed by Natural Forest (88.38^b), *Nauclea diderrichii* plantation (80.00^c) while the lowest was observed in *Gmelina arborea* plantation (76.25^e). The result of clay particle % were *Tectona grandis* plantation (15.50^c), *Gmelina arborea* plantation (18.33^a), *Pinus caribaea* plantation (6.84^e), *Nauclea diderrichii* plantation (16.00^b) and Natural Forest (8.32^d). However, the result revealed there was significance difference ($P\leq 0.05$) between all the locations. Both *Gmelina arborea* and *Nauclea diderrichii* plantation had the highest clay percentage of (18.33^a) while the lowest was *Pinus caribaea* plantation (6.84^e). The results of the Silt particle percentage were *Tectona grandis* plantation (5.67^a), *Gmelina arborea* plantation (5.42^a), *Pinus caribaea* plantation (1.53^d), *Nauclea diderrichii* plantation (4.25^b) and Natural Forest (3.40^c). The highest was recorded in *Tectona grandis* plantation (5.67^a) while the lowest silt percentage was recorded in *Pinus caribaea* plantation (1.53^d). However, there was significance difference ($P\leq 0.05$) across the five locations. The Available phosphorus results revealed in the locations were in *Tectona grandis* plantation (7.33^c), *Gmelina arborea* plantation (5.45^d), *Pinus caribaea* plantation (8.40^a), *Nauclea diderrichii* plantation (3.56^e) and Natural Forest (7.83^b). The highest total phosphorus was recorded in *Pinus caribaea* plantation (8.40^a) while the lowest 3.56^e in *Nauclea diderrichii* plantation (3.56^e). There was significance difference ($P\leq 0.05$) in Available phosphorus across the five locations. The results of Available-K recorded were *Tectona grandis* plantation (0.31^c), *Gmelina arborea* plantation (1.45^a), *Pinus caribaea* plantation (0.31^c), *Nauclea*

diderrichii plantation (0.47^b) and Natural Forest (0.47^b). There was no significance difference ($P>0.05$) across the five locations. However, the highest was recorded in *Gmelina arborea* plantation (1.45^a), while the lowest in *Pinus caribaea* plantation (0.31^c). The result recorded for soluble K were in *Tectona grandis* plantation (0.10^c), *Gmelina arborea* plantation (0.45^a), *Pinus caribaea* plantation (0.11^c), *Nauclea diderrichii* plantation (0.21^b), and Natural Forest (0.12^c). However, the result revealed there was no significant difference ($P>0.05$) between *Tectona grandis* plantation, *Pinus caribaea* plantation and Natural Forest. *Gmelina arborea* plantation had the highest soluble K (0.45^a) while *Tectona grandis* plantation had the lowest soluble K (0.10^c). The result recorded for exchangeable K were in *Tectona grandis* plantation (0.21^d), *Gmelina arborea* plantation (0.21^d), *Pinus caribaea* plantation (1.04^a), *Nauclea diderrichii* plantation (0.26^c), and Natural Forest (0.37^b). *Gmelina arborea* had the highest exchangeable K (1.04^d) and while *Tectona grandis* had the lowest exchangeable K (0.21^d). However, the results revealed that there was not significant difference ($P>0.05$) between *Tectona grandis* plantation and *Pinus caribaea* plantation. The result of magnesium (Mg)cmol/kg revealed the highest in Natural Forest plantation (0.22^a) while lowest magnesium was revealed in *Pinus caribaea* (0.07^c). However, the result revealed that there was significance difference ($P\leq 0.05$) in the magnesium result across the five locations. The results revealed that there was significant difference ($P\leq 0.05$) in calcium (Ca)cmol/kg across four plantations and Natural Forest. The highest was recorded in *Gmelina arborea* (11.06^a), while the lowest was recorded in *Pinus caribaea* plantation (0.09^e). The result of sodium (Na)cmol/kg revealed that there is no significance difference in sodium concentration between *Nauclea diderrichii* (0.24^c) and *Pinus caribaea*

(0.23^c). However, *Tectona grandis* had the highest sodium content (0.32^a) and the lowest in Natural Forest (0.21^d). The Potassium (k)cmol/kg results revealed that there was no significant difference ($P>0.05$) in *Pinus*

caribaea plantation and Natural Forest. The highest was recorded in *Gmelina arborea* (0.05^a) while the lowest was recorded in Natural Forest (0.01^d)

Table 2: Effect of Land use Practices on the Physiochemical, Forms and Distributions of Phosphorus in the Study Areas

Soil properties	TG	GA	PC	ND	NF
PH (H2O) 1:2	4.88 ^e	5.84 ^c	6.00 ^b	6.09 ^a	5.56 ^d
TN %	0.19 ^c	0.23 ^a	0.12 ^d	0.21 ^b	0.10 ^e
OC %	2.19 ^c	2.66 ^a	1.22 ^d	2.28 ^b	1.17 ^a
OM %	3.77 ^c	4.62 ^a	2.12 ^d	4.07 ^b	2.02 ^d
SAND %	78.83 ^d	76.25 ^a	91.52 ^a	80.00 ^c	88.38 ^b
CLAY %	15.50 ^c	18.33 ^a	6.84 ^a	16.00 ^b	8.32 ^d
SILT %	5.67 ^a	5.42 ^a	1.53 ^d	4.25 ^b	3.40 ^c
Available -P (mg/kg)	7.33 ^c	5.45 ^d	8.40 ^a	3.56 ^a	7.83 ^b
Available -K (mg/kg)	0.31 ^c	1.45 ^a	0.31 ^c	0.47 ^b	0.47 ^b
Soluble K	0.10 ^c	0.45 ^a	0.11 ^c	0.21 ^b	0.12 ^c
Exchange K	0.21 ^d	1.04 ^a	0.21 ^d	0.26 ^c	0.37 ^b
Mg (Cmol/kg)	0.21 ^a	0.18 ^c	0.07 ^a	0.14 ^d	0.22 ^b
Ca (Cmol/kg)	0.78 ^c	11.06 ^a	0.09 ^a	3.27 ^b	0.12 ^d
Na (Cmol/kg)	0.32 ^a	0.28 ^b	0.24 ^c	0.23 ^c	0.21 ^d
Kc (Cmol/kg)	0.02 ^b	0.05 ^a	0.01 ^d	0.02 ^c	0.01 ^d

means with same superscript in rows are not significantly different at ($p\geq 0.05$)

Gmelina arborea (GA) *Tectona grandis* (TG) *Nauclea diderrichii* (ND) *Pinus caribaea* (PC) and Natural Forest (NF).

Interactive Effect of Depth and Land Use Practices on the Physiochemical properties, Forms and Distribution of potassium

Table 3 showed the result of Interactive Effect of Depth and Land Use Practices on the Physiochemical properties, Forms and Distribution of potassium across the five locations *Gmelina arborea*, *Tectona grandis*, *Nauclea diderrichii*, *Pinus caribaea* and Natural Forest at various depths 0-30cm, 30-60cm and 60-90cm. The result showed that there was a significance difference ($P\leq 0.05$) in the pH across the five plantations. However, there was not significance difference ($P>0.05$) in *Tectona grandis* (5.92^c) at depth 0-30cm depth, *Nauclea diderrichii* (5.89^c) at 0-30cm depth, *Pinus caribaea* (6.13^{ab}) at 0-30cm depth and Natural Forest (5.74^d) at 60-90cm depth. The highest pH was recorded *Nauclea diderrichii* (6.20^a) at 30-60cm depth while the least pH was recorded was in *Tectona grandis* (4.70ⁱ) at 30-60cm depth. The results of total nitrogen (TN%) showed that there was significant difference ($P\leq 0.05$) in the total nitrogen

percentage across the five location at various depths. The highest total nitrogen percentage was recorded in *Gmelina arborea* (0.34^a) at 0-30cm depth, while the lowest was recorded in Natural Forest (0.09^j) at 60-90cm depth. However, there was not significance difference ($P>0.05$) in *Gmelina arborea* (0.21^{de}) at 0-30cm depth, *Tectona grandis* (0.13^h) at 30-60cm depth, *Nauclea diderrichii* (0.19^{ef}) at 0-30cm depth. *Pinus caribaea* (0.11ⁱ) at 60-90cm depth, and Natural Forest (0.11ⁱ) at 30-60cm depth. Organic carbon (OC%) result showed there was significant difference ($P\leq 0.05$) across the five locations at various depths. *Gmelina arborea* plantation (3.78^a) had the highest value at 0-30cm depth while least percentage was recorded in *Pinus caribaea* (0.89^m) at 60-90cm depth. However, *Gmelina arborea* (2.02^f) at 60-90cm depth, *Nauclea diderrichii* (2.04^f) at 30-60cm depth, *Pinus caribaea* (1.20^{jk}) at 0-30cm depth and Natural Forest (1.14^{kl}) at 0-30cm depth were not significantly different ($P>0.05$) from each other. The result of Organic matter (OM%) showed that there was not significant

difference ($P>0.05$) across the organic matter in the five locations at various depths. However, *Gmelina arborea* plantation (6.60a) had the highest value at 0-30cm depth, while the least percentage was recorded in *Pinus caribaea* (1.54^k) at 0-30cm depth. However, *Gmelina arborea* (3.78e) at 30-60cm depth, *Tectona grandis* (4.61c) at 60-90cm depth, *Nauclea diderrichii* (5.30 b) at 0-30cm depth, and *Pinus caribaea* (2.74g) at 30-60cm depth were significantly different ($P>0.05$) from each other. The result of sand particles revealed that there was significance difference ($P\leq 0.05$) across the five locations at various depths. However, Natural Forest (92.50a) had the highest at 30-60cm depth, while the lowest at *Gmelina caribaea* (68.75j) at 60-90cm depth. *Gmelina arborea* (81.0 e) at 0-30cm depth and (78.50 g) at 60-90cm depth, *Tectona grandis* (80.50e) at 0-30cm depth, *Pinus caribaea* (91.94a) at 30-60cm depth, and Natural Forest (92.50a) at 30-60cm depth were not significantly different ($P>0.05$) from each other. The Result of clay particles% showed that there was significance difference ($P\leq 0.05$) in the percentage clay particle in the five location at various depths. However, *Gmelina arborea* plantation had the highest value (28.0a) at 60-90cm depth, while the least was recorded in Natural Forest (5.80h) at 30-60cm depth. *Gmelina arborea* (17.0c) at 30-60cm depth, *Tectona grandis* (16.50 c) at 30-60cm depth, *Nauclea diderrichii* (8.50 f) at 0-30cm depth, *Pinus caribaea* (6.83 g) at 30-60cm depth and Natural Forest (10.50e) at 0-30cm depth were not significantly different ($P>0.05$) from each other. The result of silt particles showed that, there was significant difference ($P\leq 0.05$) in the % of silt across the five locations at various depths. However, the highest silt particle was recorded in *Gmelina arborea* (8.50^a) at 0-30cm depths, while the lowest silt particle percentage was recorded *Pinus caribaea* plantation (0.82k) at 60-90cm depth. *Gmelina arborea* (4.50^{def}) at 30-60cm

depth, *Tectona grandis* (5.5 c) at 30-60cm depth, *Pinus caribaea* (4.25^{efg}) at 30-60cm depth and Natural Forest (4.50def) at 0-30cm depth were not significantly different ($P>0.05$) from each other. The result of Available phosphorus (cmol/kg) showed that there was significant difference ($P\leq 0.05$) across the five locations at various depths. The highest available phosphorus was recorded *Pinus caribaea* (9.78a), while the lowest was recorded in *Nauclea diderrichii* plantation (0.13j) at 60-90cm depth. *Tectona grandis* (9.53a) at 30-60cm depth, *Pinus caribaea* (9.78a) at 30-60cm depth and Natural Forest (9.61a) at 0-30cm depth were not significantly different ($P>0.05$) high from each other. The potassium fractions results showed that, there was no significance difference ($P>0.05$) across the Available-K in the five locations at various depths. However, the highest was recorded in *Gmelina arborea* plantation (3.11a) at 0-30cm depth while the lowest was recorded in *Tectona grandis* (0.16g) at 30-60cm depths. *Gmelina arborea* (0.31 f) at 60-90cm depth, *Tectona grandis*, (0.47e) at 0-30cm depth, (0.31 f) at 60-90cm depth, *Nauclea diderrichii*, (0.31 f) a t60-90cm depth, *Pinus caribaea* (0.31 f) at 60-90cm depth and Natural Forest (0.48 d) at 0-30cm depth, (0.47e) at 30-60cm depth and (0.47 d) at 60-90cm depth were not significantly different ($P>0.05$) from each other. The result of soluble-K showed that, there was no significance differences ($P>0.05$) across the five locations at various depth. However, the highest value was recorded in *Gmelina arborea* (0.78a) at 0-30cm depth while the lowest was recorded Natural Forest (0.0f) at 60-90 cm depth. However, *Tectona grandis* (0.16d) at 30-60cm depth and (0.16d) at 60-90cm depth, *Nauclea diderrichii* (0.16 d) at 30-60cm depth, (0.16d) at 60-90cm depth, *Pinus caribaea* (0.16 d) at 0-30cm depth and Natural Forest (0.17 d) at 0-30cm depth and (0.16d) at 30-60cm depth were not significantly different ($P>0.05$) from each

other. The result of Exchangeable-K showed that there was no significance different ($P>0.05$) across the five locations at various depths. *Gmelina arborea* plantation (2.34a) had the highest value at 0-30cm depth while the least exchangeable -K was recorded in *Tectona grandis* (0.16f) at 0-30cm depth. However, *Pinus caribaea* (0.19e) at 60-90cm depth was the only significant different ($P\leq 0.05$).

The result of Magnesium (cmol/kg) in the soil showed that there was no significance difference ($P>0.05$) across the five locations at various depths. Highest magnesium concentration was recorded in *Tectona grandis* plantation with a value of (0.35a) at 0-30cm depth while, the least concentration of magnesium was observed in *Pinus caribaea* (0.04^l) at 30-60cm depth. However, *Gmelina arborea* (0.11i) at 60-90cm depth, *Tectona grandis* (0.16 g) at 30-60cm depth, and Natural Forest (0.27b) at 60-90cm depth were significantly different ($P\leq 0.05$) from each other.

The result of the calcium (cmol/kg) in the soil showed that there was no significance

difference ($P>0.05$) in *Pinus caribaea* (0.06k) and Natural Forest (0.06k) depths. The highest calcium was recorded in *Gmelina arborea* (13.83) at depth 0-30cm. while the least was recorded in *Pinus caribaea* (0.06k) at 60-90cm depths. The result of Sodium concentration showed that there was no significance different ($P>0.05$) across the five location at various depths. The highest sodium concentration was recorded in *Tectona grandis* plantation (0.39a) at 60-90cm depth. while the lowest sodium concentration was recorded in *Nauclea diderrichii* plantation (0.18i) at 0-30cm depth. Lastly, the result of the potassium (cmol/kg) showed that there no significance different ($P>0.05$) across the five locations at various depths. the highest potassium concentration was recorded in *Gmelina arborea* (0.10a) at 0-30cm while the least potassium concentration was recorded in *Pinus caribaea* (0.01e) at 30-60cm depth

Table 3: Interactive Effect of Land use Practices and Depth on the Physiochemical, Forms and Distribution of potassium

Location/depth	TG 0- 30cm	TG 30- 60cm	TG 60- 90cm	GA 0- 30cm	GA 30- 60cm	GA 60- 90cm	PC 0-30cm	PC 30-60cm	PC 60- 90cm	ND 0- 30cm	ND 30-60cm	ND 60-90cm	NF 0- 30cm	NF 30- 60cm	NF 60-90cm
PH (H ₂ O) 1:2	5.01 #	4.70 ^a	4.92 ^b	5.92 ^c	6.10 ^b	5.50 ^a	6.18 ^{ab}	6.13 ^{ab}	5.73 ^d	5.89 ^c	6.20 ^a	6.18 ^{ab}	5.80 ^d	5.15 ^f	5.74 ^d
TN %	0.21 ^d	0.13 ^b	0.24 ^c	0.34 ^a	0.21 ^{de}	0.18 ^f	0.10 ^{ij}	0.14 ^h	0.11 ⁱ	0.27 ^b	0.187 ^{ef}	0.16 ^g	0.11 ⁱ	0.11 ⁱ	0.09 ^j
OC %	2.41 ^d	1.46 ⁱ	2.70 ^c	3.78 ^a	2.41 ^e	2.02 ^f	1.20 ^{jk}	1.59 ^h	0.89 ^m	3.08 ^b	2.04 ^f	1.74 ^g	1.14 ^{kl}	1.30 ^j	1.08 ⁱ
OM %	4.16 ^d	2.52 ^{gh}	4.61 ^c	6.60 ^a	3.78 ^e	3.48 ^{ef}	2.07 ^{ij}	2.74 ^g	1.54 ^k	5.30 ^b	3.41 ^f	3.49 ^{ef}	1.98 ^{ij}	2.24 ^{hi}	1.86 ^j
SAND %	80.50 ^e	77.50 ^h	78.50 ^g	81.0 ^a	79.0 ^e	68.75 ^j	90.25 ^b	91.94 ^a	92.36 ^a	87.25 ^c	79.75 ^f	73.0 ⁱ	85.0 ^d	92.50 ^a	87.67 ^c
CLAY %	13.0 ^d	17.0 ^c	16.50 ^c	10.50 ^a	16.50 ^c	28.0 ^a	6.90 ^g	6.83 ^g	6.81 ^g	8.50 ^f	16.75 ^c	22.75 ^b	10.50 ^a	5.80 ^h	8.67 ^f
SILT %	6.50 ^b	5.5 ^c	5.0 ^{cd}	8.50 ^a	4.50 ^{def}	3.25 ^h	2.60 ⁱ	1.18 ^{jk}	0.82 ^k	4.25 ^{efg}	3.75 ^{gh}	4.75 ^{de}	4.50 ^{def}	1.70 ^j	4.0 ^{fg}
Available-P (mg/kg)	7.46 ^c	9.53 ^a	4.99 ^b	3.56 ⁱ	5.34 ^{fg}	7.44 ^c	9.78 ^a	8.45 ^b	6.97 ^{de}	5.47 ^f	5.09 ^{gh}	0.13 ^j	9.61 ^a	6.73 ^e	7.14 ^d
Available-K (mg/kg)	0.47 ^a	0.16 ^g	0.31 ^f	3.11 ^a	0.94 ^b	0.31 ^f	0.31 ^f	0.31 ^f	0.31 ^f	0.62 ^c	0.47 ^{de}	0.31 ^f	0.48 ^d	0.47 ^e	0.47 ^{de}
Soluble K	0.16 ^d	0.0 ^f	0.16 ^d	0.78 ^a	0.47 ^b	0.10 ^e	0.16 ^d	0.04 ^f	0.13 ^{de}	0.31 ^c	0.16 ^d	0.16 ^d	0.17 ^d	0.16 ^d	0.0 ^f
Exchangeable K	0.31 ^c	0.16 ^f	0.16 ^f	2.34 ^a	0.47 ^b	0.31 ^f	0.16 ^f	0.27 ^d	0.19 ^e	0.31 ^c	0.32 ^c	0.16 ^f	0.31 ^c	0.31 ^c	0.47 ^b
Mg (Cmol/kg)	0.35 ^a	0.16 ^g	0.20 ^d	0.26 ^c	0.18 ^f	0.11 ⁱ	0.08 ^{jk}	0.04 ⁱ	0.09 ^j	0.15 ^h	0.07 ^k	0.19 ^{ef}	0.18 ^{ef}	0.19 ^{de}	0.27 ^b
Ca (Cmol/kg)	1.45 ^g	0.50 ^h	0.40 ⁱ	13.83 ^a	13.17 ^b	6.14 ^c	0.16 ^j	0.08 ^k	0.06 ^k	3.60 ^a	3.90 ^d	2.36 ^f	0.06 ^k	0.15 ^j	0.16 ^j
Na (Cmol/kg)	0.22 ^{gh}	0.35 ^b	0.39 ^a	0.28 ^d	0.33 ^c	0.24 ^{ef}	0.25 ^e	0.25 ^e	0.23 ^{fg}	0.18 ⁱ	0.27 ^d	0.25 ^e	0.21 ^h	0.21 ^h	0.21 ^h
Kc (Cmol/kg)	0.02 ^c	0.01 ^d	0.02 ^c	0.10 ^a	0.05 ^b	0.01 ^d	0.01 ^d	0.01 ^e	0.01 ^e	0.02 ^c	0.01 ^d	0.01 ^d	0.01 ^d	0.01 ^e	0.01 ^d

Mean with the same superscript in rows are not significantly different at ($p\geq 0.05$)

Gmelina arborea (GA) *Tectona grandis* (TG) *Nauclea diderrichii* (ND) *Pinus caribaea* (PC) and Natural Forest (NF).

Correlation between Potassium Fractions and Physicochemical Properties

The results of correlation studies of table 4 on the soils showed pH is negative with Organic

carbon ($r = -0.004$), clay ($r = -0.114$), silt ($r = -0.204$), total phosphorus ($r = -0.289$). However, there was a positive significant correlation with soluble K ($r = 0.299$), Na ($r = -0.313$), Ca ($r = 0.318$) at 5%. The exchangeable bases had a negative significant correlation with Mg ($r = -0.429$) at 1%.

The results of the correlation studies of total nitrogen (TN%) showed that, there was a positive significant with OC ($r = 0.998$), OM ($r = 0.984$), silt ($r = 0.682$), Available K ($r = 0.698$), Ca ($r = 0.678$) soluble K ($r = 0.764$), exchangeable K ($r = 0.646$) and Kcmol/kg ($r = 0.751$), Available phosphorus ($r = -0.525$) at 1%. However, there was a negative significant correlation with sand ($r = -0.362$), and Mg ($r = 0.299$) at 5%

The results of correlation studies of Organic carbon (OC%) showed a positive significant with OM ($r = 0.992$), Available K ($r = 0.680$), soluble K ($r = 0.733$), Ca ($r = 0.661$), silt ($r = 0.691$), Available phosphorus ($r = -0.493$) and Kcmol/kg ($r = 0.733$) at 1%. However, there was a negative significant with sandy ($r = -0.371$), and Mg ($r = 0.320$) at 5%

The results of correlation studies of (OM) showed a significant with sand ($r = -0.400$), with silt ($r = 0.705$) with Available K ($r = 0.608$), soluble K ($r = 0.735$), exchangeable k ($r = 0.632$) with Ca ($r = 0.661$) with Available p ($r = -0.551$), and Kcmol/kg ($r = 0.735$) at 1%, and a positive significant with Mg ($r = 0.334$) at 5%

The results of correlation studies of sand% showed there was a significant correlation with clay ($r = -0.964$), silt ($r = -0.535$), Available phosphorus ($r = 0.403$), Available K ($r = -0.058$), soluble K ($r = -0.108$), exchangeable K ($r = -0.063$), Mg ($r = -0.190$), Ca ($r = 0.408$), Na ($r = 0.419$), Kcmol/kg ($r = -0.201$) at 1%. The results of correlation studies of Clay percentage showed a significant correlation with Available

phosphorus ($r = -0.367$), Available K ($r = -0.129$), soluble K ($r = -0.062$), exchangeable K cmol/kg ($r = -0.120$), Ca ($r = 0.297$), and Na ($r = 0.371$) at 5%. The results of correlation studies of Silt percentage showed was a negative significant of 5% with Available Phosphorous ($r = -0.331$), Available K ($r = 0.618$), soluble K ($r = 0.574$) and exchangeable K ($r = 0.605$) at 5%. The exchangeable bases have a positive significant correlation with Mg ($r = 0.697$), Ca ($r = 0.513$), Na ($r = 0.316$), and Kcmol/kg ($r = 0.700$) at 1%.

The results of correlation studies of Available phosphorus showed that there was a negative significant correlation with Available K ($r = -0.358$), silt ($r = -0.445$), exchangeable K ($r = -0.306$), Mg ($r = -0.210$) and KC mol ($r = -0.377$) at 5%, a negative significant correlation with Ca ($r = -0.432$), and Na cmol/kg ($r = -0.132$) at 1%. The results of correlation studies of the Available K showed that there was a correlation n of positive significant correlation with soluble K ($r = 0.906$), exchangeable K ($r = 0.986$), Ca ($r = 0.767$) and Na ($r = 0.967$) at 1%. And a positive significant correlation with Mg ($r = 0.343$) at 5%. The results of correlation studies of soluble K showed that there was positive significant correlation with exchangeable K ($r = 0.828$), with Ca ($r = 0.854$), K cmol/kg ($r = 0.925$) at 1%.

The results of correlation studies of exchangeable K showed that there was a correlation of positive significant correlation with Mg ($r = 0.348$) at 5%, Ca ($r = 0.709$) and K Cmol/kg ($r = 0.936$) at 1%. The results of correlation studies of exchangeable bases of sodium showed that there was a negative correlation with Na ($r = -0.021$), KC mol ($r = 0.365$) at 5%, and Lastly, the exchangeable base result of calcium showed that there was a positive significant correlation with K cmol/kg ($r = 0.844$) at 1%.

Table 4: Correlation Coefficient between Physicochemical Properties and Potassium Fractions.

	pH (H ₂ O) 1:2	TN %	OC %	OM %	SAND %	CLAY %	SILT %	Available- P (mg/kg)	Available- K (mg/kg)	SOLUBLE K (mg/kg)	EXCHANGEABLE K (mg/kg)	Mg (Cmol/kg)	Ca (Cmol/kg)	Na (Cmol/kg)	K(Cmol/kg)
pH (H ₂ O) 1:2	1														
TN %	0.019	1													
OC %	-0.004	0.988*	1												
OM %	0.019	0.984*	0.992*	1											
SAND %	0.163	-0.362*	-0.371*	-0.400*	1										
CLAY %	-0.114	0.193	0.199	0.230	-0.964**	1									
SILT %	-0.204	0.682*	0.691*	0.705*	-0.535**	0.292	1								
Available - P (mg/kg)	-0.289	-0.525*	-0.493*	-0.551*	-0.403**	-0.367	-0.331*	1							
Available - K (mg/kg)	0.221	0.698*	0.680*	0.680*	-0.058	-0.129	0.618*	-0.358*	1						
Soluble K	0.299*	0.764*	0.733*	0.735*	-0.108	-0.062	0.574*	0.445*	0.906*	1					
Exchange K	0.179	0.646*	0.633*	0.632*	-0.063	-0.120	0.605*	-0.306*	0.986*	0.828**	1				
Mg (Cmol/kg)	-0.429*	0.299*	0.320*	0.334*	-0.190	0.003	0.697*	-0.210	0.343*	0.260	0.348*	1			
Ca (Cmol/kg)	0.318*	0.678*	0.661*	0.661*	-0.408**	0.297	0.513*	-0.432*	0.767*	0.854**	0.709*	0.158	1		
Na (Cmol/kg)	-0.313*	0.258	0.242	0.239	-0.419**	0.371	0.316*	-0.132	0.083	0.133	0.056	-0.021	0.251	1	
K(Cmol/kg)	0.182	0.751*	0.733*	0.735*	-0.201	0.004	0.700*	-0.377*	0.967*	0.925**	0.936*	0.365*	0.844*	0.263	1

*. Correlation is significant at the 0.05 level (2-tailed).
 **. Correlation is significant at the 0.01 level (2-tailed).

DISCUSSION

The soil texture of the study areas was within the depth of 0-30cm, 30-60cm and 60-90cm. However, these Mineral particles in soil are classified into three primary categories sand, silt, and clay based on their size. The unique blends of these particles at different ratios lead to diverse soil textures, ultimately impacting the physical and chemical attributes of the soil, including water retention, drainage, and nutrient. The results of the soil physical properties are in accordance with to Brady and Weil (2008), and Bouma (2014).

The result obtained from showed that the physicochemical properties and forms of potassium in the soil vary with depth and forest type. The soil pH, total nitrogen, organic carbon, total organic matter, sand, silt, clay, and available phosphorus decrease with depth, while the exchangeable potassium, soluble potassium, magnesium, calcium, sodium, and potassium increase with depth. The soil under *Gmelina arborea* has the highest values of most of the parameters,

followed by *Tectona grandis*, *Nauclea diderrichii*, *Pinus caribaea*, and Natural Forest.

These results are consistent with the findings of Weldmichael *et al.* (2020), who reported that soil depth had differential effects on chemical properties and microbial respiration in the upper soil horizons. They found that available nitrogen, cation exchange capacity, and magnesium were strongly influenced by soil depth, and that soil microbial respiration was higher in surface soils than in subsurface soils. They also observed that soil microbial respiration had a positive correlation with total nitrogen, available nitrogen, and soil organic matter.

Similarly, Ndukwu *et al.* (2018), evaluated the forms and distributions of potassium in soils derived from three lithological materials in southeastern Nigeria. They found that exchangeable potassium, and potassium supplying power were higher in shale than in lower coal measure and upper coal measure. They also reported that exchangeable potassium and non-exchangeable potassium had a positive relationship with potassium supplying power.

The result obtained from the studies showed that the physicochemical properties and forms of potassium in the soil are affected by land use practices and landscape position. The soil under different plantations has different values of pH, organic matter, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, soluble potassium, magnesium, calcium, sodium, and potassium. The soil under *Gmelina arborea* plantation has the highest values of most of the parameters, followed by *Nauclea diderrichii* plantation, Natural Forest, *Tectona grandis* plantation, and *Pinus caribaea* plantation.

These results are in agreement with the findings of Seifu *et al.* (2020), who reported that land use change from natural ecosystems to managed ecosystems had deleterious effects on soil structure and quality in a semiarid watershed in northern Ethiopia. They found that the conversion of Natural Forest or savanna to farmland reduced the silt content, moisture content, organic matter, organic carbon, total nitrogen, available phosphorus, pH, and exchangeable bases, but increased bulk density, exchangeable acidity, and sand content significantly. They also observed that soil quality was higher in Natural Forest and savanna than in farmland and grazing land.

Similarly, Alemu *et al.* (2017) evaluated the spatial variability of soil chemical properties under different land use types in the central highlands of Ethiopia. They found that soil pH, organic carbon, total nitrogen, available phosphorus, and exchangeable bases were higher in Natural Forest and grassland than in cultivated land and eucalyptus plantation. They also reported that soil chemical properties varied significantly with landscape position, with higher values in the valley bottom and lower values in the upper slope.

The result obtained from the studies showed that the interactive effect of depth and land

use practices on the physicochemical properties and forms of potassium in the soil is significant. The soil under different plantations and Natural Forest has different values of pH, organic matter, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, soluble potassium, magnesium, calcium, sodium, and potassium at different depths. The soil under *Gmelina arborea* plantation has the highest values of most of the parameters at 0-30 cm depth, followed by *Nauclea diderrichii* plantation, Natural Forest, *Tectona grandis* plantation, and *Pinus caribaea* plantation.

These results are similar to the findings of Seifu *et al.* (2020), who reported that soil depth had differential effects on chemical properties and microbial respiration in the upper soil horizons. They found that available nitrogen, and magnesium were strongly influenced by soil depth, and that soil microbial respiration was higher in surface soils than in subsurface soils. They also observed that soil microbial respiration had a positive correlation with total nitrogen, available nitrogen, and soil organic matter.

The result obtained from showed that the correlation between potassium fractions and physicochemical properties in the soil is complex and depends on various factors such as soil depth, land use practices, landscape position, and parent material. The soil under different plantations and Natural Forest has different values of pH, organic matter, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, soluble potassium, magnesium, calcium, sodium, and potassium, and these are correlated with each other in different ways. The soil under *Gmelina arborea* plantation has the highest values of most of the parameters, followed by *Nauclea diderrichii* plantation, Natural Forest, *Tectona grandis* plantation, and *Pinus caribaea* plantation.

These results are comparable to the findings of Ndukwu *et al.* (2018), who reported that the forms and distribution of potassium in soils derived from three lithological materials in southeastern Nigeria were influenced by soil depth, parent material, and clay mineralogy. They found that exchangeable potassium and potassium supplying power were higher in shale than in lower coal measure and upper coal measure. They also reported that exchangeable potassium had a positive relationship with potassium supplying power.

These studies suggest that soil depth, land use practices, landscape position, and parent material are important factors that influence the correlation between potassium fractions and physicochemical properties in the soil, and that these in turn affect the soil fertility and productivity. Therefore, soil management options should consider the effects of these factors on soil quality and adopt sustainable land management practices to enhance soil health and crop production.

CONCLUSION

The soils in different land use types exhibit variations in their properties, generally being coarse-textured, acidic, low in organic matter, and deficient in nutrients such as nitrogen, phosphorus, calcium, magnesium, and potassium. These soils are poorly aggregated and have low clay activity. This study focused on evaluating important physical and physicochemical properties as well as the distribution of different forms of potassium in soils under various plantations, including *Gmelina arborea*, *Tectona grandis*, *Nauclea diderrichii*, *Pinus caribaea*, and Natural Forest in the growing areas of Omo Forest Reserve. The findings of this research indicate that different forms of potassium were present in the soil in the following order at both surface and sub-surface depths: available potassium > water-soluble potassium > exchangeable potassium.

Specifically, *Gmelina arborea* plantation exhibited higher levels of available potassium, water-soluble potassium, and exchangeable potassium at a depth of 0-30 cm. Conversely, *Tectona grandis* and Natural Forest had lower levels of available potassium at a depth of 30-60 cm. The analysis of potassium distribution among these plantations revealed that *Tectona grandis*, *Nauclea diderrichii*, *Pinus caribaea*, and Natural Forest soils would benefit from increased fertilization with available potassium, water-soluble potassium, and exchangeable potassium to enhance their potassium fertility. This study emphasizes the importance of incorporating higher doses of potassium for maintaining plant survival under various conditions. Potassium is not only a component of the chemical structure of plants but also plays a crucial regulatory role in biochemical and physiological processes that contribute to plant growth and development. The results of this study highlight the interrelationships among these factors, which can enhance crop yield and sustain soil productivity.

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DISTRIBUTION OF POTASSIUM FRACTIONS ON DIFFERENT FOREST PLANTATIONS IN OMO FOREST RESERVE OGUN STATE

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ABSTRACT

Soil characterization and classification is vital to know the potential and limitations of the soil resources for agricultural production, and for devising relevant soil management strategies. The study was carried out to characterize and evaluates the physicochemical properties of the soils in Ijegba forest for sustainable agricultural practices. Three representative soil profiles were dug randomly within the study area and samples were collected at depths 0-30cm, 30-60cm and 60-90cm with a total of 15 replicates at varying altitude and slopes, representing different physiographic positions: upper slope, middle slope and lower slope. The profiles were described following the FAO guidelines (2006) and collected samples were analysed for physical and chemical analyses, The physical analysis were soil texture (sand, silt and clay) and bulk density, while the chemical analysis include pH, organic matter, total nitrogen, available phosphorus, exchangeable bases (Na, K, Ca and Mg) and available micronutrients (Zn, Cu, Fe and Mn). The data obtained from the laboratory analysis were subjected to one way ANOVA using SPSS version 26. Means were separated using DMRT at ($P < 0.05$). The results revealed significant variability in soil properties across the depth and profiles where the structure across the different depths varied from moderately medium subangular blocky to weakly coarse granular structures. The soils colour also varied from very dark brown (10YR2/2) to reddish yellow (5YR 6/6) in profile 1, while in profile 2, the colour varied from very dark brown (10YR2/2) to strong brown (7.5YR4/6) and then to yellow (10YR7/8) but red colour (2.5YR4/6) was observed at the deepest depth in profile 3. Bioactivities were common in all the profiles. Consistency varied from friable at the surface for all the profiles to loose at the subsurface and firm at the last horizon for profile 1. The soils exhibited a sandy loam to sandy clay loam texture with high sand content in the surface layer and decreasing with depth as clay content increased at the deeper layer of the profile. Bulk density values ranged from 0.96 g/cm³ at the 0-30cm depth in profile 1 and had the highest recorded values at 60–90cm depth 1.82 g/cm³ with corresponding porosity values indicating the surface area were less compacted and more conducive for plant growth. Soil pH remained slightly acidic to neutral (5.94, 6.60 and 6.08) at depth 0–30 cm, 30–60 cm and 60-90 cm. The highest concentration of total nitrogen (0.19%) and organic carbon (2.13%) were observed in the surface layer (0-30 cm) corresponding with high organic matter from the input of litter. Available phosphorus was low at depth 60–90cm (1.22 mg/kg) and was higher at depth of 30 60 cm (8.60 mg/kg). Micronutrients analysis indicated that Manganese (Mn) and Iron (Fe) were most concentrated at the upper horizon but decline sharply with depth. Correlation analysis indicated strong relationship between organic matter content, total nitrogen and organic carbon content ($r > 0.98$), emphasizing the role of organic input in maintaining soil fertility. A strong negative correlation was found between sand and clay content ($r = 0.85$) indicating water retention and nutrient dynamics. Based on the analysis of the soil properties, The soil was classified as Alfisols, characterized by high base saturations, distinct horizons, favorable physical structures making them suitable for agricultural and forestry uses. The study concludes that Ijegba forest soils are highly suitable fertile. However, the observed decline in nutrient concentration with depth emphasizes the need for depth-specific soil management practices.

Keywords: *characterization, physicochemical properties, depth and Ijegba forest.*

INTRODUCTION

Soil is a nonrenewable resource that is essential to the world's stock of natural capital, with a protracted formation process. A centimeter of soil forms over a period of 100 -1000 years and can erode quickly as a result of misuse, bad management and limited opportunities for regenerate. (Jonsson and Daviðsdottir, 2016; Santos-Francés, et al., 2022). Therefore, soil scientists have recommended that detail information about the soil we walk on, in order to take proper management practices of it and avoid destroying this vital component of our ecosystem and food security. Perhaps the most challenging, underappreciated, and poorly understood matrix is the soil. (Saljnikov, et al., 2022).

The main ecological functions of the soil contributed to the categorization of the soil into the following key categories: (i) supporting and regulatory function. (ii) Provision function. (iii) The functions of religion, culture, leisure, and information. (Devi, 2021).

Approximately 95% of humanity's food supply is derived from the soil, which also provides ecosystem services. However, the growing population, rising food prices, competition for land usage, extensive vegetation clearing, desertification, misuse, and poor management are all putting increasing strain on the soil. It surpasses its performance limit as a result of these. (Saljnikov, et al., 2022).

Determining the geographical distribution of soils and their characteristics can therefore enhance the management of soil natural resources and forecast the properties of soil in places that have not been studied. Given the significance of soil to the environment and to human survival, soil health must be evaluated.

Soil physical and chemical properties deteriorate to the change in land use especially from agriculture and forest. The change in physicochemical properties of soil leads to infertile soil and soil that does not support normal growth

Information on physical and chemical properties like structure, colour, consistency, texture and quantity of carbonates, rocks and roots are all contribute to the classification of

soil. Due to these characteristics, scientists are able to understand how the ecosystem works and prescribe soil use practices that will have the least negative effects on the ecosystem. Data on soil characteristics can assist scientists in forecasting the risk of flooding and drought. It can also be used to ascertain the soil types and qualities crucial for agricultural productions and other land use decisions. (Leenaars, et al., 2020). For the benefit of humanity, the combination of soil characterization and soil classification offers a potent resource, particularly in the area of environmental sustainability and food security.

Owing to the fact that no study has been carried out on the soils in the study area (Ijegba forest), characterization and classification will help to reveal essential information that could be useful in the management and use of the soil in a sustainable and environmentally friendly manner. Therefore, the objectives of this study were to characterize and document the variations in the physical and chemical properties of soil under different depths in Ijegba forest, Abeokuta, Ogun state, Nigeria.

MATERIALS AND METHODS

Study area: The study was carried out in Ijegba forest, Abeokuta, Ogun state, located in the deep outskirts of the ancient city of Abeokuta. The Ijegba Forest was a private property of Professor Wole Soyinka which has been a sort of tourist attraction for people especially the literary minded because of the old antiques present in the house and the serenity of the surrounding forest. The site is between latitude 7°14'682" N and longitude 3°38'75" E. The tree species in the site includes: *Delonix regia*, *Cauthium inspidum*, *Anacadim occidentale*, *Ficus exasperate*, *Lecanodiscus cupannoides*, *Leucena leucocephala*, *Antians toxicama*, *Bligha uniguculata*, *Monodora tennifolia*, *Millicia excela*, *Hildegiardia barteri*, *Alstonia bonei*, *Spondis monubin*, *Sterculia triagacanth*s. The undergrowth vegetation includes: *lcacine triagacantha*, *Lecanodiscus cupannoides*, *Trichilis monadelpha*, *Mallorus oppositifolia*, *Panlinia pinnata*,

Sphenocentrum jollyanum, *Deinbolia pinnata*, *Massularia accumulate*, *Ranvolfia vonnitoria*, *Albizia zygea*, *Chassalia kolly*, *Cola millenie*, *Deinbolia pinnata*, *Bliglia uniguculata*, *Sphenocentrum jollyanum*, *Hunteria umbrillatum*, *Smilae crussiana*, *Crutis fernginea*, *Newbouldia laevis*.

Profile Site Selection and Analytical Procedures

A reconnaissance survey was conducted in the study area to identify the topography and other parameters in order to identify the suitable to cite the profile pits. The identified places for

citing profiles were recorded in a handheld GPS for easy identification. Three profile pits (A, B, C) were dug, each at upper, middle and lower slope within the study area. The profiles were described following the standard guideline of FAO (2006), the morphology characteristics and other field observations were well recorded in a proforma sheet, both disturbed and undisturbed samples were collected at the 0-30 cm, 30-60 cm and 60-90 cm respectively. The undisturbed samples were collected using core samplers while disturbed samples were collected inside polythene bags. The collected samples were well labelled and properly packed and taken to the laboratory for further analysis.

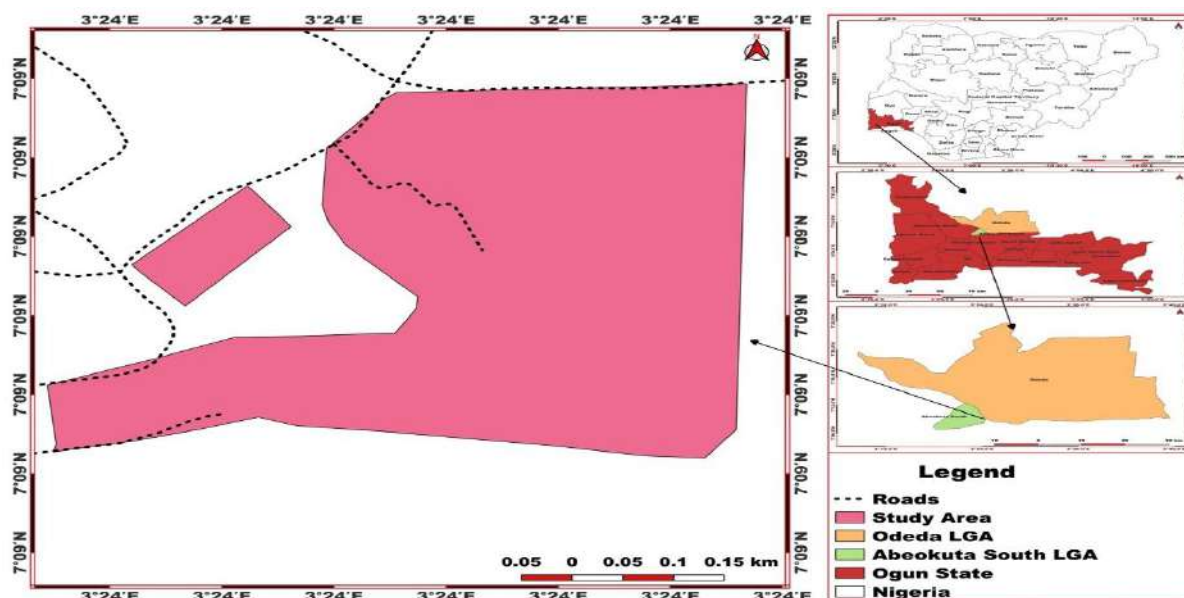


Fig 1: Map showing the study area.

Laboratory analysis: The collected samples were air dried, gently crushed with a wooden mortar and pestle and sieved through a 2mm mesh. Samples for organic matter were further crushed into finer particles. The particle size analysis was done using the hydrometer method (Bouyoucous, 1962) using sodium hexamataphosphate (calgon) as the dispersant. The soil pH was measured in (1:1) soil: water ratio. Organic matter was determined by Walkley Black wet oxidation method (Allison, 1965, Ojekunle et al., 2023) while Total nitrogen was determined by the Macro – Kjeldahl digestion and distillation procedures

as described by (Bremner, 1965; Oladoye, 2015). Available phosphorus was determined using the Bray No.1 method (Bray and Kurtz, 1945). Exchangeable cations (Ca, Mg, Na, K) were determined using Ammonium acetate as extractant and filtered through Whatman No 1 filter paper, Ca and Mg were read under Atomic absorption spectrophotometer while Na and K were read under flame photometer (Summer and Miller, 1996)

Manganese and copper in the soil were determined using the dilute and extraction method of EDTA. The suspension was filtered through Whatman No 1 filter paper. Cu and Mn

in the filtrate were determined through absorption spectrophotometry.

Data Analysis

The data obtained from the soil analysis were subjected to a one-way Analysis of Variance (complete randomized design) Each of the soil depth across the profile were the treatment. This is to detect whether the soil attributes studied differed significantly between the soil depth (treatments) and the land use. Descriptive statistics was carried out using SPSS (version 26). Data was also analyzed using Pearson correlation to show the relationship between the determined parameter.

RESULTS

The morphological properties of the three profiles representing soils in the three units as presented in table 1 and 2. The three profiles were dug in forest land use type at different points in the study site. The slope positioning were upper slope for profile 1, lower slope for profile 2 and middle slope for profile 3 as shown in table 1. The morphological features shows a range of hues of (10YR2/2), (7.5YR4/6), (10YR5/7) to (5YR7/8) which indicates the soils show variations of colour such as dark brown, strong brown, yellow brown to reddish yellow at the bottom of the profile. They were presence of mottle (5YR7/8) at 145cm depth of profile 2., morphologically the soils were either moderate medium subangular blocky at surface and bottom and weak coarse granular in the subsurface for profile 1 and 2 but moderately coarse subangular blocky at the bottom in profile 3. The boundaries between the horizons were from irregular, clear and wavy to wavy granular. Texturally the soils were either sandy loam or sandy clay loam as shown in table 2. Other morphological characteristics such as roots, manganese concretion was also identified in the soil.

Table 3 presents the results of the physical properties of the soil. The sand content in the profile 1 were high, it ranged from 78.5% to 90.5%, and decreased with the depth of the profile. The clay content ranged from 7% to 19%, it also fluctuated along the profile. The silt content ranged from 1.5% to 2.5%. Texturally, the studied soils in profile 1 were sand and sandy loam (Table 3). There was variation in the bulk density; it ranged from 0.96 – 1.55g/cm³. The bulk density varied inconsistently with depth in the profile. The soil porosity values also varied from 41.65 – 63.93% following the variation in bulk density.

In profile 2, the sand content was high but decreased down the horizon, it ranged from 70.5% - 90.5%, without following a regular pattern. The clay content ranged from 8 - 23%. It was low at the subsurface but became higher down the depth. The silt content fluctuated along the depth from 1.5% in the subsurface to 6.5% at the bottom. The textural class recorded for the profile 2 changed from loamy sand to sand and then sandy loam along the depth (Table 3). The bulk density was lower at the surface with 1.37g/cm³ and highest at the subsurface with 1.75% values. The porosity also followed the same variation in the bulk density. It ranged from 3.59 – 48.47%.

In the profile 3, the sand content was high but also decreased along the depth. It ranged from 74.5–92.5%. The clay content ranged from 7 – 23%. There was a significant increase along the depth. The silt content ranged from 0.5 – 2.5%, it also increased along the depth. Textually, the studied soils in profile 3 were sand, loamy sand and sandy loam (Table 3). The bulk density value ranged from 1.50 – 1.82g/cm³. The porosity values also varied from 31.50 – 43.22%.

TABLE 1: Selected Site Characteristics of Representative Soil Profile

Profile	Location		Altitude (m)	Slope %	Slope position	parent material	Surface characteristics	land use
	Latitude	Longitude						
1	7.15279° N	3.40091° E	162	0 - 0.2	Upper slope	Basement complex	Litters cover	Forest /shrub land
2	7.15205° N	3.40118° E	140	0.2 - 5	Lower slope	Basement complex	Litters cover with rock fragments	Forest land
3	7.15267° N	3.40235° E	142	0.2 - 5s	Middle slope	Basement complex	Litters and shrubs around /biological activities	Forest land

Source: field survey, 2024.

TABLE 2: MORPHOLOGICAL PROPERTIES OF THE SAMPLED SOIL

Horizon	Depth (cm)	Munsell colour (moist)	Soil colour description	Texture	Structure type/size /grade	Concentration name/size /shape	Consistence (moist)	Coarse material shape/nature/ size/amount	Root size/abundance	Pores size/abundance	Porosity	Bioactivity	Boundaries distinctiveness/ topography
Profile 1: Upper Slope.													
A1	0 – 21	10YR2/2	Very dark brown	SL	SB/ ME/ MO	Nil	Friable	Nil	Medium/ few	Coarse/ common	High	common	C/ W
A2	21 – 51	10YR5/4	Yellowish brown	SCL	GR/ CO/ WE	Nil	Loose	S/ QS/ C/ A	Very fine/ very low	Medium/ common	Medium	common	C/ W
B1	51 – 84	7.5YR6/6	Reddish yellow	SCL	GR/ CO/ WE	Nil	Loose	F/ QS/ F/ NO	Very fine/ none	Medium/ common	High	Few	C/ W
B2	84 -134	5YR6/6	Reddish yellow	SCL	SB/ ME/ MO	Nil	Firm	S/ QS/ F/ M	Very fine/ none	Very fine/ Few			-
Profile 2: Lower Slope													
A	0 – 28	10YR2/2	Very dark brown	SL	SB/ ME/ MO	Nil	Very friable	S/ QS/ C/ C	Coarse/ few	very fine/ very few	High	Common	G/ W
B	28 – 83	7.5YR4/6	Strong brown	SCL	GR/ CO/ WE	Nil	Very friable	S/ QS/ M/ C	Fine/ very low	very fine/ very few	Medium	Common	G/ W
C	83 – 145	5YR7/8	Reddish yellow	SCL	SB/ ME/ MO	Nil	Friable	S/ QS/ F/ V	Very fine/ none	very fine/ none	Low	Few	-
Mottie	10YR7/8	Yellow				Few							
Profile 3: Medium Slope													
A	0 – 18	10YR3/4	Dark yellowish brown	SL	SB/ ME/ MO	Nil	Friable	S/ QS/ F/ F	Medium/ few	Medium/ common	High	Common	G/ I
B	18 - 53	7.5YR4/6	Strong brown	SCL	SB/ CO/ WE	Mn/ M/ I	Loose	S/ QS/ C/ C	Fine/ very low	Medium/ few	Medium	Common	G/ W
C	53 - 98	2.5YR4/6	Red	SCL	SB/ CO/ MO	Mn/ F/ I	Friable	S/ QS/ M/ F	Very fine/ none	Very fine/ few	Low	Few	-

Source: field survey, 2024

According to FAO (2014), Texture: SL= Sandy loam; Sandy clay loam. Structure: SB= Subangular blocky; GR= granular; ME= medium; MO= moderate; WE= weak; CO= coarse.

Concentration: Mn= Manganese; M= many; I= Irregular; F= few. Coarse material: S= subangular; Qs= Quartz; C= coarse; F= fine gravel; M= medium gravel; C= common; F= few; V= very few. Boundary: C/W= Clear/ wavy; G/W= Gradual/ wavy; G/I= Gradual/ Irregular.

TABLE 3: Physical Properties of the Ijegba Forest Soils

Profile	(cm)	%			Si/Cl ratio	Textural Class	(g/cm ³)	%
	Soil Depth	Sand	Silt	Clay			BD	Porosity
1	0-30	90.5	1.5	8	0.19	Sand	0.96	63.93
	30-60	90.5	2.5	7	0.36	Sand	1.55	41.65
	60-90	78.5	2.5	19	0.13	Sandy loam	1.37	48.38
2	0-30	84.5	5.5	10	0.55	Loamy sand	1.37	48.47
	30-60	90.5	1.5	8	0.19	Sand	1.73	34.59
	60-90	70.5	6.5	23	0.28	Sandy loam	1.45	45.29
3	0-30	92.5	0.5	7	0.07	Sand	1.50	43.22
	30-60	82.5	0.5	17	0.03	Loamy sand	1.69	36.38
	60-90	74.5	2.5	23	0.11	Sandy loam	1.82	31.50

Source: field survey, 2024 Si = Silt, Cl= Clay, BD = Bulk density

The Chemical Properties of the Soils in Ijegba Forest:

The pH values across the different depths were (5.94^a), (6.06^a) and (6.08^a) at 0 – 30cm, 30 – 60cm and 60 – 90cm respectively as shown in (Table 4). The pH value at 0 – 30cm indicating that the pH moderately acidic across the depth. The pH range was slightly acidic at 30 – 60cm, but there was a slight increase in acidity at depth 60 – 90cm. The soil can be said to be slightly acidic to neutral and this provides the best growing condition and influences the uptake of nutrients by plants (Suleiman et al., 2017). The Soil pH across the different depth indicated no significant differences. The consistent pH level may suggest uniform soil formation processes across the depths (Table 4). The percentage of the total nitrogen (%TN) recorded were (0.192^a), (0.136^b) and (0.07^c) at 0–30cm, 30–60cm and 60 – 90cm depths respectively (Table 4). The total nitrogen content varied significantly with depth, the highest concentration occurred at the surface (0 - 30cm) and the lower value observed and reflecting reduced nitrogen available at the greater depth (Table 4). Organic Carbon also followed a similar pattern to TN. The organic carbon (%OC) showed significant different across the depth, with individual percentage of (2.13^a) at 0 -30cm which has the highest percentage (Table 4), (1.54^a) at 30 -60cm depth and (0.78^b) at 60–90cm depth which has the lowest percentage of organic carbon. This pattern is expected as decomposition of plant litters and root biomass occurs on the surface.

Organic matter percentage (%OM) also varied across the depth with the highest at 0-30cm depth (0.366^a), the percentage reduced to (2.65^a) at 30–60cm and then to (1.33^b) at 60–90cm depths. The result for the available phosphorus also fluctuated and showed significant differences (Table 4). The available phosphorus recorded were (7.79^a), (8.60^a) and (1.22^b) at 0-30cm, 30–60cm and 60– 90cm depths. The high values of total nitrogen (TN) and available phosphorus (AP) may be attributed to high content of organic matter in the soil (Jimoh, 2015; Aliyu et al., 2016).

The micronutrients in the studied soil as presented in Table 4 shows that the means of the elements varied across each depth. Manganese (Mn) content was significantly higher at the surface 0–30cm (334.40^a) but decreased drastically at depth 30–60cm (50.80^b) and 60–90cm (20.40^b) depths (Table 4). The surface layer had a higher mean value for Magnesium (Mg) but did not show significant variation across the depths. Zinc content did not vary significantly across the depths (Table 4). The recorded zinc was (7.22^a) at 0–30cm, (7.07^a) at 30–60cm and (6.76^a) at 60–90cm across each depth. This suggests that Zn is fairly uniformly distributed across the soil depths. Iron (Fe) content significantly decreased with depth and the highest concentration occurred in the upper layer, 0-30cm (9.40^a) followed by 30–60cm (7.50^b) and the lowest recorded was 60–90cm depth with mean of (5.30^c) (Table 4). Copper (Cu) as shown in the (Table 4) showed differences but not statistically significant although there is an increase in copper content with depth, it varied from (5.03^a), (8.36^{ab}) and to (7.36^b) at 0 -30cm, 30–60cm and 60–90cm respectively, but did not follow a regular pattern.

The exchangeable cations (Mg, Ca, Na and K) which are presented in (Table 4) shows that the soil was dominated by Ca followed by Mg, Na and K, which is suitable for plant growth and development. Exchangeable Calcium (Ca) content differed significantly across the three depths, the mean values ranging from (18.19^a) at 0–30cm, (4.31^b) at 30–60cm and to (4.45^b) at 60–90cm, although the highest value was recorded at the 0–30 cm depth (Table 4). The Sodium (Na) contents in the (table 4) showed no significant variation across the depth. It was relatively stable across all depths. Its mean values were (4.51^a), (4.60^a) and (4.47^a) at depths 0– 30cm, 30–60cm and 60–90cm respectively. Potassium was generally low in all the depths studied and showed no significant variation across depths. Potassium remains fairly consistent it had similar means values across all the depth (Table 4). Exchangeable potassium recorded were (0.31^a) at 0–30cm, (0.24^a) at 30–60cm and (0.31^a) at 60– 90cm depths respectively. Cations Exchangeable

Capacity (CEC) as recorded in (Table 4) showed that it varied significantly with depth. Its highest values were recorded at depth 0–30cm (29.90^a) but remained constant at depth 30–60cm (13.42^b) and 60–90cm (13.92^b). The wide range at the surface suggests proper management practices that influences nutrient retention. Sand content decreased down the depths. It showed variation but was more significant at depth 30 – 60cm (90.90^a) and depth 60 – 90cm (75.70^c) (Table 4). However, silt content across the depth were (3.60^a), (2.50^a) and (4.50^a) at depth 0–30cm, 30–60cm and 60–90cm. it remained constant and showed no significant variation as shown in (Table 4). Clay content shows a significant difference between the soil depths. The high F-value indicates variation in clay content across the different depth. Clay content increased down the depth in all the profile pits. It ranged from (9.40^b), (7.80^b) and (21.00^a) at depth 0–30cm, 30–60cm and 60–90cm respectively (Table 4).

The result as shown in (Table 5) shows that certain attributes of soil showed significant relationship with each other, whereas others did not show any significant form of relationship between themselves. Correlations coefficients whose values ranges between 0.9 and 1.00 can be said to be rated as very highly correlated, values between 0.7 and 0.9 as highly correlated, coefficients ranging from 0.5 to 0.7 as moderately correlated, 0.25 and 0.50 as low correlation as stated by Abdul (2017). From physical properties, there were highly negative correlation between sand and clay content ($r = 0.85$) which might be due to the movement of

fine particles and leaching of clay down the depth of the profile. The content of Total Nitrogen was significantly and highly correlated with Organic matter ($r = 0.98$) and Organic Carbon ($r = 0.99$) and also Iron ($r = 0.95$), however it showed a moderate correlation with sand ($r = 0.54$), Mg ($r = 0.51$), Mn ($r = 0.55$) (Table 5). Available phosphorus was significant and negatively correlated with clay ($r = -0.80$) and strongly correlated with sand ($r = 0.62$), Mn ($r = 0.58$), Ca ($r = 0.56$), CEC ($r = 0.53$) and Fe ($r = 0.56$). Clay shows a linear but negative relationship between TN ($r = -0.56$), OC ($r = -0.54$) and O.N ($r = -0.54$) but strongly significant with silt ($r = 0.60$). Exchangeable Ca was highly significant and positively correlated with Mg ($r = 0.88$), Mn ($r = 0.98$) while Mg also correlated strongly with Mn ($r = 0.85$) and CEC ($r = 0.92$). Mn with CEC ($r = 0.98$) Potassium was significant and positively correlated with silt ($r = 0.74$). Iron was significant and showed a highly correlation between Mg ($r = 0.63$), CEC ($r = 0.61$) whereas it was significantly negative with clay ($r = 0.60$) (Table 5). The weak and insignificant correlation was found between Zn and Mg ($r = 0.01$), between silt and TN ($r = 0.02$), OC ($r = 0.04$), ON ($r = 0.04$), Fe ($r = 0.01$), and also between pH and Zn ($r = 0.01$), available phosphorus and Cu ($r = 0.04$). However, a weak and low correlation was seen between Zn and Mn ($r = -0.25$), Ca ($r = -0.25$), CEC ($r = -0.21$), Fe (0.28) and Cu ($r = 0.32$) (Table 8). pH showed a low correlation with silt ($r = 0.40$) but a negative correlation with Na ($r = -0.41$), sand ($r = -0.17$), Fe ($r = -0.17$), TN ($r = -0.16$), OC ($r = -0.18$) and OM ($r = -0.18$).

Table: 4 Summary of variations between soil depths and the chemical properties studied

soil property	Soil depths (cm)			F>0.05	P>0.01
	0-30	30-60	60-90		
pH	5.94 ^a	6.06 ^a	6.08 ^a	0.067	0.935
%TN	0.19 ^a	0.13 ^b	0.07 ^c	16.521	-
%OC	2.13 ^a	1.54 ^a	0.78 ^b	11.661	0.002
%OM	3.66 ^a	2.65 ^a	1.33 ^b	11.487	0.002
AV. P (mg/kg)	7.79 ^a	8.60 ^a	1.22 ^b	12.592	0.001
Zn (mg/kg)	7.22 ^a	7.07 ^a	6.76 ^a	0.438	0.655
Fe(mg/kg)	9.40 ^a	7.50 ^b	5.30 ^c	16.84	-
Cu(mg/kg)	5.03 ^a	8.36 ^{ab}	7.36 ^b	2.973	0.089
Mn(mg/kg)	334.4 ^a	50.80 ^b	20.40 ^b	8.622	0.005
Mg (Cmol/kg)	6.88 ^a	4.28 ^b	4.68 ^{ab}	3.16	0.079
Ca (Cmol/kg)	18.19 ^a	4.312 ^b	4.45 ^b	6.158	0.014
Na (Cmol/kg)	4.51 ^a	4.60 ^a	4.47 ^a	0.654	0.537
K (Cmol/kg)	0.31 ^a	0.24 ^a	0.31 ^a	0.561	0.585
CEC	29.90 ^a	13.43 ^b	13.92 ^b	5.848	0.017
%Sand	88.60 ^a	90.90 ^a	75.70 ^c	23.253	-
%Silt	3.60 ^a	2.50 ^a	4.50 ^a	1.017	0.391
% Clay	9.40 ^b	7.80 ^b	21.00 ^a	50.219	-

Means with the same letter on the row are not significantly different ($F>0.05$ or $P>0.01$)

Table 3: Correlation coefficient for selected physicochemical properties of soil of the study area.

	pH	%TN	%OC	%OM	AV.P	Zn Mg/Kg	Fe Mg/Kg	Cu Mg/Kg	Mn Cmol/kg	Mg Cmol/kg	Ca Cmol/kg	Na Cmol/kg	K Cmol/kg	CEC	Sand%	Silt%	Clay%
pH	1																
%TN	-0.16	1.00															
%O. C	-0.18	0.99**	1.00														
%O.M	-0.18	0.98**	1.00	1.00													
AV. P	0.10	0.45	0.45	0.45	1.00												
Zn Mg/Kg	0.01	0.44	0.46	0.46	-0.11	1.00											
Fe Mg/Kg	-0.17	0.95**	0.95**	0.95**	0.56	0.28	1.00										
Cu Mg/Kg	0.27	-0.37	-0.34	-0.34	0.04	0.32	-0.42	1.00									
Mn Cmol/kg	0.15	0.55	0.51	0.51	0.58	-0.25	0.70	-0.47	1.00								
Mg Cmol/kg	0.27	0.51	0.50	0.50	0.36	0.01	0.63*	-0.13	0.85**	1.00							
Ca Cmol/kg	0.25	0.44	0.40	0.39	0.56	-0.25	0.59	-0.33	0.98**	0.88**	1.00						
Na Cmol/kg	-0.41	0.34	0.41	0.41	-0.13	0.11	0.33	-0.52	-0.21	-0.34	-0.39	1.00					
K Cmol/kg	0.22	0.33	0.38	0.38	-0.09	0.26	0.38	0.08	0.35	0.73	0.36	-0.06	1.00				
CEC	0.25	0.47	0.43	0.43	0.53	-0.21	0.61*	-0.31	0.98**	0.92**	1.00	-0.38	0.45	1.00			
Sand%	-0.17	0.54	0.53	0.53	0.62*	0.25	0.50	-0.18	0.10	-0.22	-0.01	0.40	-0.48	0.05	1.00		
Silt%	0.40	0.02	0.04	0.04	-0.18	0.25	0.01	0.21	0.13	0.44	0.20	-0.27	0.74**	0.25	-0.43	1.00	
Clay%	0.13	-0.56	-0.54	-0.54	-0.80*	-0.06	-0.60*	0.11	-0.36	-0.07	-0.28	-0.18	0.38	0.25	0.85**	0.60	1

Values with ** shows correlation is significant at 0.05 level, values with * shows correlation is significant at 0.01 level.

OC: Organic Carbon; OM: Organic matter; TN: Total nitrogen; AV.P: Available phosphorus ; Fe : Iron; Zn: Zinc; Cu: Copper; Mn: Manganese;

Mg: Magnesium; K: Potassium; Na: Sodium; CEC: Cations Exchangeable Cation

DISCUSSION

The results of the study indicates variation in soil properties studied across the soil depth. The soil horizon of profile 1 was deep but it was shallower than the depth of profile 2 and deeper than profile 3. The recognized genetic horizon had different thickness. In Profile 1, A1 horizon had around 21 thickness between A1 horizon about 30cm thickness subsoil was recognized, below A2 horizon 33cm thick subsoil was recognized, and the forth horizon B2 which had 50cm thick horizon. Profile 2 was opened at the lower slope of the study area. The total depth of the profile 2 was 145 and the thickness recorded were 28cm, 55cm and 62cm across the depth. Profile 3 was opened in the middle slope and the thickness recorded were 18cm, 35cm and 45cm across the different horizon. In general, the depth of the soil increased down the topographic position indicating soil movement. (Nahusenay et al., 2014).

Surface horizon of profile 1 had very dark brown colour in moist soil (Table 2), yellowish brown in the subsurface and reddish brown in the B2 horizon. In profile 2, the colour varied from very dark brown (10YR2/2) to strong brown and then to reddish yellow (5YR6/6). The profile 3 also had colour variation from yellowish brown to strong brown and then to red. The dark or very dark colour in the surface area shows the presence of high organic matter, while the reddish colour shows the presence of other minerals such as Fe in the subsurface. The structure of the horizon across the different depth varied from moderately medium subangular blocky to weak coarse granular structure in all the profiles studied plays a crucial role in soil aeration and water movement. In general, the variation in the soil structure of the horizon points to the presence of vertical variation in the formation of the soil profile (Mohammed et al., 2017). The consistency varied from friable at the surface to firm at the depth. The horizon for

each profile opened at different part of the forest had the same texture across the different depth. It varied from sandy loam in the upper layers (0-60 cm) and a shift to sandy clay loam at 60-90 cm for all the profiles. The general increase in clay content across each profile with depth might be due to the translocation of clay through the process of illuviation (Kebede et al., 2017). This textural variation has significant implications for water retention, drainage, and root penetration (Hillel, 2004). The high sand content, particularly in the 30-60 cm layer, suggests that the soil is well-drained, which is favorable for most forest species. Bulk density ratio ranged from (0.96 - 1.55g/cm³), (1.37 - 1.73 g/cm³) to (1.50 - 1.83g/cm³) in profile 1, 2 and 3 respectively. The increase with depth in the bulk density might be due to the overlaying soil and relatively low amount of organic matter in the subsurface horizon. (Kassa and Kibret, 2013). The observed variation in bulk density and porosity is crucial for water infiltration and root growth as noted by Lal and Stewart (2013) in their comprehensive review of soil physical properties.

The physicochemical properties of the soil varied significantly across the different depths, reflecting the dynamic nature of soil formation and nutrient cycling processes. The pH values across the soil profile were slightly acidic, ranging from 5.94 to 6.08. This slightly acidic nature is typical to many forest soils, particularly in tropical regions, where organic matter decomposition releases organic acids into the soil (Brady and Weil, 2017). The organic carbon (OC) and total nitrogen (TN) content were higher in the topsoil (0-30 cm) and decreased with depth. Ahn (1993), noted that organic matter is typically concentrated in the upper soil layers due to the accumulation of plant litter and root biomass. The decrease in organic carbon with depth indicates a reduction in organic matter, which is a critical source of nutrients

and a key factor in maintaining soil fertility (Lal, 2004). The cation exchange capacity (CEC) also decreased with depth, indicating that the nutrient retention capacity of the soil diminishes as depth increases, which could affect root growth and nutrient uptake for deep-rooted plants. The dominance of calcium, followed by magnesium and potassium aligns with the findings from soil fertility studies in similar forest soils (Suleiman et al., 2017). The micronutrient which includes (Zinc, Iron, Copper, and Manganese) showed varying distributions across the soil profile. Iron and Manganese concentrations were significantly higher in the topsoil and this is likely due to the association of these elements with organic matter. Zinc and Copper showed uniform distribution across the depth, this shows that these elements were stable in the soil. Based on the soil morphological, physicochemical properties and characteristics studied, the soils in Ijegba Forest has a high sand content, especially in the upper layers, with sandy loam to sandy clay texture, the soil profiles exhibits a distinct increase in clay content with depth, slightly acidic pH, moderately low fertility with a decline in nutrient at greater depth.

The soil's chemical analysis reveals a high base saturation, indicating that it is rich in essential cations such as calcium (Ca), magnesium (Mg), and potassium (K). The presence of trace elements like iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) further enhances the soil's fertility. This high nutrient status contributes to the soil's fertility and supports its classification as an Alfisol. Alfisols are typically well-drained soils with a high base saturation and clay-enriched subsoil (Bt horizon) due to clay illuviation. These soils are commonly found in temperate to tropical regions and are known for their moderate to high natural fertility, making them suitable for a variety of land uses, including agriculture and forestry.

The identification of a distinct Bt horizon, characterized by increased clay content with depth, is a key factor in classifying these soils as Alfisols. This is consistent with the USDA soil taxonomy and the FAO World Reference Base for soil Resources (IUSS Working Group WRB, 2015).

The high base saturation and nutrient availability in Alfisols make them inherently fertile soils, suitable for supporting a wide range of crops. The soil is slightly acidic to near-neutral pH levels further enhance nutrient availability, particularly for trace elements like iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn), which are essential for plant growth. The sandy loam to sandy clay loam texture observed in the soil profile provides good drainage while retaining sufficient moisture to support crop production.

5.2 CONCLUSION

The physicochemical properties of the soil across different depths in Ijegba forest reveals that the soil is slightly acidic, with a sandy loam texture in the upper layers and a transition to sandy clay loam at deeper levels. The organic matter content and nutrient levels are highest in the topsoil, which is typical of forest soils where nutrient cycling is driven by surface litter. The study showed that soil texture is one of the most important factors influencing the physical and chemical properties of the soil. The relationships of organic carbon (OC) and organic matter (OM) with other determined parameters in the studied soils indicated them as important soil nutrients.

The soil's cation exchange capacity and fertility decrease with depth, which may limit the growth of deep-rooted plants. The distribution of trace elements suggests that the soil is generally suitable for supporting forest vegetation, although the lower availability of Fe and Mn at depth could be a concern for certain species. The soils in

Ijegba Forest have the potential to support a wide range of land uses, provided that appropriate soil conservation and fertility management practices are implemented.

The classification of these soils as Alfisols is supported by their high fertility, as indicated by the presences of essential cations (Ca, Mg, K), favourable pH, and good structural stability.

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WETLANDS OF SOUTHWEST NIGERIA: IMPORTANCE, EMERGING CHALLENGES, TRENDS, AND FUTURE DIRECTIONS FOR SUSTAINABLE MANAGEMENT

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ABSTRACT

Wetlands are vital ecological zones that offer numerous supports that sustain the environment and local livelihoods. Wetlands in Southwestern Nigeria provide essential habitats for diverse plant and animal species, contribute notably to agriculture through initiatives such as the FADAMA projects, and support both fishing and ecotourism activities. Despite this importance, the ecosystem continues to face threats from urban expansion, unsustainable farming practices, pollution, and climate change. This paper synthesizes the ecological and socioeconomic significance of wetlands in Southwest Nigeria, reviews current trends in wetland degradation that are peculiar to Wetland in Southwestern Nigeria and identifies key challenges undermining their sustainability. It further emphasizes policy, and management gaps and discusses pathways to nature-based solutions, and the integration of wetland management into regional planning frameworks. The study highlights the need for preemptive strategies and collaborative governance to preserve the ecological integrity of wetlands and enhance their resilience in the face of increasing anthropogenic pressures.

Keywords: *Fadama management, Southwestern Nigeria, Wetland threats, Nature -based solutions, Conservation efforts*

Word Count: 152

INTRODUCTION

Wetlands are among the most productive ecosystems on earth, encompassing swamps, marshes, bogs, floodplains, and estuarine margins, all well-defined by their hydrological regimes and water-saturated soils. These unique landscapes are ecologically invaluable, offering critical ecosystem services such as water purification, flood attenuation, groundwater recharge, carbon storage, and climate regulation. Equally important, wetlands support a wide range of biodiversity, serving as habitats and breeding grounds for numerous species of

fish, amphibians, birds, and invertebrates. Wetlands are cultivated to ensure cultivation and food production in the time of water scarcity in the uplands, most especially at the peak of the dry seasons. However, in recent decades, there has been an increase in the agricultural use of wetlands, especially in developing countries (McCartney *et al.*, 2010; Commonwealth of Australia, 2016). In Southwestern Nigeria, wetlands such as the Eleyele Wetland in Ibadan, Lagos Lagoon, and the Eriti Wetland in Ogun State are not only ecological hotspots but also socio-economic lifelines (Odine *et al.*, 2011;

Adeleke, 2022). They provide essential resources for food production, crop farming, fishing, natural resource collection, and other livelihood activities for rural and peri-urban communities.

Despite their ecological and socio-economic significance, wetlands in this region face increasing threats from human-driven factors, particularly urbanization and climate change (Gasu, 2018). Rapid urban expansion, spurred by population growth and infrastructural development, has resulted in the conversion of wetland areas into residential, commercial, and agricultural lands. For instance, in Lagos State, large portions of wetlands have been encroached upon to meet the demands of the growing metropolis, leading to severe habitat degradation and biodiversity loss.

Concurrently, climate change is reshaping wetland dynamics by altering rainfall patterns, increasing temperatures, and disrupting hydrological cycles. These changes not only impact water availability and quality but also threaten the survival of flora and fauna that depend on the stability of wetland ecosystems.

As wetland degradation accelerates, it becomes imperative to assess current trends, understand the underlying drivers, and identify sustainable conservation pathways. This paper examines the importance of wetlands in Southwestern Nigeria, explores the trends and impacts of their degradation particularly due to urbanization and climate-related stressors as well as community-led solutions for the integrated and resilient management of these vital ecosystems.

Table 1: Some Selected Wetland in Southwest Nigeria

S/N	Wetland	Location
1	Eleyele Wetland	Ido Local Government Area, Ibadan, Oyo State
2	Eriti Wetland	Obafemi Owode Local Government Area, Ogun State
3	Akure wetland	Ondo State
4	Wetland of Ekiti	Ado-Ekiti, Ekiti State
5	Ilesa wetland	Osun State
6	Lagos Wetland	Spans Epe to Badagry Local Government Areas, Lagos State; fed by rivers including Yewa, Ogun, Ona/Ibu, Oshun, Shasha, and Oni

Source: Adapted from Odine *et al.*, (2011) and Adeleke, (2022)

IMPORTANCE OF WETLAND IN SOUTHWESTERN NIGERIA

Wetlands in Southwest Nigeria are vital ecosystems that support diverse and dynamic livelihood activities. They provide fertile land and water resources, making them ideal for crop farming, particularly the cultivation of leafy and fruity vegetables, rice, and cassava (Baba, 1993; Odine *et al.*, 2011). Wetland environment has been described as

a small-scale irrigation site developed through exploitation of shallow groundwater by private farmers, who take responsibility for the investment and management of the farms. It is an alternative to large-scale irrigation system, which failed to meet the food self-sufficiency and security of Nigeria (Baba, 1993). In other words, wetland cropping afforded people some opportunities utilizing the surplus labor during the dry

seasons unlike in the rainy seasons when there is labor constraint.

According to Odine *et al.*, (2011), in three southwestern states, farming is the most prominent livelihood activity, often practiced alongside fishing or natural resource collection such as sand, snails, or leaves in wetlands. In rural areas, proximity to natural wetlands encourages more resource gathering, while urban wetlands support service-based enterprises like trading, transport, and hospitality. Residents often diversify their livelihoods by combining multiple wetland-related activities farming with farming or fishing with resource collection based on seasonal changes in water availability. This flexibility reflects the critical role wetlands play in sustaining both the environment and local economies (Bikangaga, 2007; Odine *et al.*, 2011), which note that seasonal variations in wetlands influence livelihood strategies, requiring adaptability from the communities that depend on them.

Wetlands are home to diverse flora such as *Nymphaea lotus* (Egyptian lotus), *Raphia hookeri* (raffia palm), and *Pteridium aquilinum* (bracken fern), which contribute to ecological stability and habitat structure (Adeniyi *et al.*, 2016). Fauna diversity includes species such as the African jacana (*Actophilornis africanus*), West African crocodile (*Crocodylus suchus*), and amphibians like the African bullfrog (*Pyxicephalus edulis*). Economically important fish such as *Clarias gariepinus* (African catfish) and *Tilapia* spp. also thrive in these ecosystems (Akin-Oriola and Anetekhai, 2014).

The sharp decline in species that depend on wetlands, as well as the concurrent degradation of ecosystem services, has triggered a growing global focus on wetland conservation through protection, restoration, and creation efforts (MEA, 2005). Although

many wetlands are not specifically intended for wildlife conservation, they frequently attract fauna due to their resemblance to natural wetland environments or because they include key habitat characteristics that animals seek (Bendell-Young *et al.*, 2000; Thiere *et al.*, 2009; Scheffers and Paszkowski, 2013). These sites can thus function as valuable habitats, supporting ecological connectivity and contributing to the preservation of biodiversity and species survival (Thiere *et al.*, 2009).

TRENDS IN WETLAND DEGRADATION

Wetlands are among the Earth's most productive and threatened ecosystems combined (Ducks Unlimited Canada, 2008); accounting for only 6.2-7.6% of the Earth's land surface (Lehner and Deoll 2004; Cassidy, 2019). Wetland degradation in Southwestern Nigeria has become increasingly pronounced over the past few decades due to a combination of natural and human-induced factors. These wetlands, which include Eleyele (Oyo State), Eriti (Ogun State), and the Lagos Lagoon (Lagos State), are under significant threat despite their ecological, economic, and socio-cultural importance. Accordingly, an agricultural incursion into wetlands is the chief destroyer and modifier of wetlands, after which is the issue of urbanization (Orimoogunje, *et al.*, 2009).

One of the most significant trends in wetland degradation in the region is the continuous expansion of urban centers. Cities like Ibadan, Lagos, and Abeokuta have witnessed rapid population growth, leading to the encroachment of wetlands for residential, commercial, and industrial use. For example, the Eleyele wetland in Ibadan has been severely affected by the development of housing estates, markets, and roads, reducing the wetland area and altering its natural functions (Tijani *et al.*, 2011).

Conversion of wetlands to agricultural lands may cause the alteration of soil physicochemical properties, which in turn may influence the soil fertility status of a given area (Kassahun *et al.*, 2014). The fertile soil and water availability in wetlands attract intensive agricultural use, particularly for rice and vegetable farming. Over time, traditional farming practices have shifted toward more intensive, often unsustainable, land-use methods that contribute to the depletion of wetland vegetation, soil structure alteration, and pollution from fertilizers and pesticides. The Fadama farming scheme is one such example that, while economically beneficial, has inadvertently contributed to wetland stress in some locations (Adeleke, 2022).

Illegal and unregulated sand mining, especially in wetlands around Lagos and Ogun states, has emerged as a serious threat. Mining disturbs aquatic habitats, leads to bank erosion, and increases turbidity levels in the water. Communities around Eriti wetland in Ogun State rely on sand mining for livelihoods, which intensifies degradation in the absence of control measures.

Another emerging trend is the increasing pollution of wetland waters from domestic sewage, industrial effluent, and solid waste. The Lagos Lagoon, for instance, receives runoff from several urban centers, carrying with it plastics, oil residues, heavy metals, and untreated wastewater. This not only reduces water quality but also threatens aquatic biodiversity.

Changes in rainfall patterns and increasing temperatures due to climate change have altered the hydrological cycles of many wetlands. Inconsistent flooding and drying cycles have disrupted breeding grounds for fish and amphibians and affected vegetation regeneration (Okon *et al.*, 2021). This trend is compounded by poor water resource management.

IMPACT OF AGRICULTURAL AND URBAN EXPANSION ON WETLAND LOSS IN SOUTHWESTERN NIGERIA

Wetlands in Southwestern Nigeria have been significantly impacted, degraded, and lost, primarily due to agricultural development and urban expansion. While the loss of wetlands in rural areas is often linked to agriculture and tends to be temporary, those lost to urban development are permanent. The accelerating pace of urbanization, coupled with the intensifying impacts of climate change, poses unprecedented challenges to both the environment and human well-being (Das *et al.*, 2024). Aside these anthropogenic effect, Nigeria's water and wetland supplies have been impacted by climate fluctuations. Many large waterbodies are experiencing marked reductions in flow rate and network length in reaction to decreased rainfall and higher evapo transpiration (Obioha, 2008; Okon *et al.*, 2021). In Nigeria, available literature shows that about 27–53 million people in the coastal area have been displaced due to sea-level rise (USAID, 2012).

In Lagos, wetland areas decreased from 708.96 hectares (52.68%) in 1965 to just 7.10 hectares (0.53%) by 2005. In Oyo State, the Eleyele Wetland (riparian zone) saw a consistent reduction, shrinking from 1.25 km² in 1984 to 0.42 km² by 2014. Ogun State's Eriti forested wetlands experienced a loss of 45.32% between 1972 and 2015. In Ondo State, the Akure South Local Government Area's wetlands decreased from 98.90 km² (30.13%) in 1999 to 90.33 km² (27.52%) in 2009. Additionally, Ilesa wetlands in Osun State shrank from 258 hectares to 89 hectares between 1986 and 2002 (Odine *et al.*, 2011). These patterns indicate that soon, the wetlands in the region may be entirely lost, with uncontrolled

urbanization being a significant contributing factor.

SYNERGISTIC IMPACTS OF URBANIZATION AND CLIMATE CHANGE ON WETLAND FAUNA

Urbanization and climate change are not separate, isolated forces; they often interact in ways that amplify their individual impacts on wetland ecosystems. Urban development, for example, increases the vulnerability of wetlands to climate change through activities such as land reclamation, infrastructure expansion, and pollution (Gasu, 2018). In turn, climate change can further stress the already fragile wetland habitats that are being encroached upon by urban expansion (Akinro *et al.*, 2008; Adeoye *et al.*, 2009; Ede *et al.*, 2013; Ezeabasili and Okonkwo, 2013; Adegoke and Sojobi, 2015; Okon *et al.*, 2021).

One key interaction between urbanization and climate change is the alteration of the hydrological cycle in wetland areas. Urbanization leads to the creation of impermeable surfaces such as roads, buildings, and parking lots, which increase surface runoff and reduce the ability of wetlands to absorb and retain water (Carter *et al.*, 2012; Haase *et al.*, 2014; McPhearson *et al.*, 2014). This affects the way water would naturally flow into wetland areas, leaving them more vulnerable to the effects of climate change, such as prolonged droughts or excessive flooding. Moreover, as urban areas continue to expand, they often encroach on wetland ecosystems, leading to habitat loss and fragmentation, which reduces the capacity of wetlands to buffer the impacts of climate change.

Urbanization also leads to increased pollution, which in turn exacerbates the environmental stress caused by climate change (Das *et al.*, 2024). For instance, increased industrial activity and population growth in urban areas result in greater pollution runoff, including

chemicals, sewage, and solid waste, which can degrade water quality in wetlands. When combined with the rising temperatures and reduced water quality caused by climate change, this pollution can lead to eutrophication, toxic algal blooms, and the decline of aquatic life.

The synergistic effects of urbanization and climate change make wetland fauna even more vulnerable to population declines and extinctions. Species that are already facing the pressures of habitat loss due to urban encroachment are further threatened by the unpredictable changes in water levels, temperature, and food availability brought about by climate change.

For example, amphibians such as frogs, toads, and newts are particularly sensitive to changes in temperature and water availability. Urbanization can destroy or fragment their breeding habitats, while climate change can alter the timing of breeding events or cause drought conditions that dry up their ponds and streams. Together, these factors reduce the availability of suitable habitats for amphibians, leading to population declines.

Similarly, migratory birds that rely on wetland stopover sites are at risk from both urbanization and climate change. Urban development often leads to the destruction of critical wetland areas used by birds for feeding and resting during their migrations. At the same time, climate change may alter migration patterns, such as the timing of arrival or departure, and disrupt the availability of food at key stopover sites. The combined pressures of habitat loss and climate-induced changes in migration patterns can result in declines in bird populations.

Fish species that depend on wetlands for breeding and nursery grounds also face compounded risks. Urbanization leads to the loss of wetland areas through land reclamation and pollution, while climate

change increases water temperatures and alters the timing and frequency of seasonal flooding. These changes can disrupt fish migration and breeding cycles, and in some cases, may cause the disappearance of fish species from regions that were once their primary habitats.

POLICY, MANAGEMENT GAPS AND PATHWAYS TO NATURE-BASED SOLUTIONS

The conservation of wetlands in Southwestern Nigeria faces several critical challenges stemming from policy and management deficiencies (Olanrewaju *et al.*, 2012). Arising from the reported and wide degradation of Wetlands, O'Connell (2003) has noted that an essential tool for management action is the ability to detect, measure and then reverse changes in the 'ecological character' of a site. Ecological character according to Ramsar Convention Bureau (2000) is defined as the structure and inter relationships between the biological, chemical, and physical components of a Wetland, derived from the interactions between its processes, functions, attributes and values.

One of the foremost issues is the existence of outdated or weakly enforced environmental laws that fail to specifically address the unique nature of wetland ecosystems. Wetlands are often overlooked in land-use planning and development strategies, and the responsibilities for their management are scattered across multiple government agencies, leading to overlaps and inefficiencies. This lack of clear and coordinated policy direction significantly hampers effective conservation. For example, In Ogun state it was reported that no clear-cut mandate is given to any Ministry as it relates to Wetlands and their management (Olanrewaju *et al.*, 2012).

In terms of management, there are numerous limitations. For example, in Oyo State,

although fishing activities at the Eleyele Wetland are somewhat regulated to promote its sustainable use, other human activities in the area remain largely uncontrolled. Across southwestern Nigeria, existing wetland management efforts mainly focus on public awareness campaigns and solid waste control. However, there is a lack of specific legislation addressing harmful uses of wetlands, and even where such laws exist, there is little to no monitoring to ensure enforcement or hold violators accountable (Olanrewaju *et al.*, 2012). As a result, wetlands in the region are prone to degradation due to the absence of comprehensive and coordinated management strategies.

Although the Lagos State government has made commendable progress by establishing a dedicated ministry responsible for wetland management (Olanrewaju *et al.*, 2012). This initiative represents a significant step toward more structured and effective oversight of wetland resources. If other states in southwestern Nigeria adopt a similar approach and demonstrate genuine commitment to implementing sustainable wetland management programmes, the full potential of wetlands in supporting livelihoods and maintaining ecosystem balance can be more effectively realized.

Inadequate funding limited technical capacity, and poor coordination among stakeholders are common problems. Public awareness about the importance of wetlands remains low, and local communities, who rely heavily on wetland resources for their livelihoods, are rarely involved in decision-making processes. Environmental management practices such as the enforcement of Environmental Impact Assessments (EIAs) are frequently neglected or compromised during infrastructural developments, allowing for unchecked degradation.

To address these challenges, the adoption of nature-based solutions presents a promising pathway. These are approaches that leverage natural processes and ecosystems to address societal issues like climate change, biodiversity loss, and disaster risks. Restoring degraded wetlands, for instance, can help recover ecological functions such as water purification and flood control. Involving local communities in conservation efforts ensures that their knowledge and needs are integrated, fostering a sense of ownership and sustainability.

Moreover, developing integrated wetland management plans that align with broader sectors such as agriculture, urban development, and water resources is essential (Nwankwoala, 2012). Promoting eco-tourism and the use of wetlands in green infrastructure can also highlight their economic value and incentivize preservation. For these strategies to be effective, however, reforms are needed in the legal and institutional frameworks. Stronger enforcement, improved coordination among agencies, and increased budgetary support are necessary to translate conservation policies into tangible actions (Olanrewaju, 2012; Adeleke, 2022).

In essence, bridging the gap between policy and practice, while embracing nature-based solutions, offers a viable route to safeguard wetlands in Southwestern Nigeria and ensure their continued support for both biodiversity and human wellbeing.

CONCLUSION

Wetlands in Southwestern Nigeria play an indispensable role in sustaining biodiversity, supporting rural livelihoods, regulating water cycles, and mitigating the impacts of climate change. However, rapid urbanization, poor land use planning, Overlap in duty assignment for government parastatals. inadequate enforcement of environmental policies, and low public awareness continue

to threaten their ecological integrity. This paper emphasizes not only the ecological and economic significance of wetlands in the region but also the prevailing challenges and the emerging trends of degradation.

For wetlands to continue providing essential ecosystem services, there is a pressing need for coordinated, multi-level management approaches that prioritize sustainability. Integrating nature-based solutions, strengthening policy frameworks, and empowering local communities through inclusive, participatory conservation strategies offer viable pathways to reversing current degradation trends. Future efforts must also incorporate adaptive management practices and research-based interventions to build climate resilience and promote the long-term conservation of these critical ecosystems. Sustainable wetland management is not just an environmental necessity but a development imperative for the well-being of present and future generations.

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ECOLOGICAL ASSESSMENT OF WETLAND HABITAT SUPPORTING FRESHWATER TURTLE (*Pelusios castaneus* Schweigger 1812) IN ILAJE, ONDO STATE, NIGERIA

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ABSTRACT

Wetlands ecosystems constitute valuable natural resources for both humans and biodiversity. This study was conducted in 2024 at Eki River, Ilaje, Ondo State, Nigeria, to examine the ecological properties of sediment supporting the freshwater turtle (*Pelusios castaneus*). Sediment samples were collected in triplicates, digested, and analyzed for heavy metals using Proton Induced X-ray Emission (PIXE). The results shows that the mean pH, EC, OM, Cl, Sand, Clay, silt, Fe, Ca, Mg, K, Mn, Zn, Pb, Cu and Cd were 6.62 ± 0.68 , $165.00 \pm 4.60 \mu\text{SCm}^{-1}$, $1.89 \pm 0.09\%$, $819.83 \pm 10.20 \text{ ppm}$, $43.27 \pm 1.50\%$, $6.33 \pm 0.42\%$, $7.99 \pm 0.70\%$, $509.98 \pm 10.12 \text{ mgkg}^{-1}$, $763.25 \pm 13.45 \text{ mgkg}^{-1}$, $426.90 \pm 9.35 \text{ mgkg}^{-1}$, $183.35 \pm 4.56 \text{ mgkg}^{-1}$, $193.80 \pm 5.23 \text{ mgkg}^{-1}$, $119.57 \pm 4.20 \text{ mgkg}^{-1}$, $1203.85 \pm 26.50 \text{ mgkg}^{-1}$, $308.97 \pm 12.38 \text{ mgkg}^{-1}$ and $91.80 \pm 1.25 \text{ mgkg}^{-1}$, respectively. Except for pH, the obtained values for these parameters were higher than the recommended values for optimal aquatic animal productivity and safety. The primary pathway of pollution observed in this study was through the intensive use of agrochemicals around the river corridor. It is likely that freshwater turtle utilizing this wetland have ingested pollutants through their food. Therefore, there is a need for aggressive environmental education and awareness among all users of this wetland, particularly dry-season farmers, to combat potential health risk associated with consuming aquatic species from this wetland and to ensure its sustainability.

Keywords: *Freshwater turtle, ecosystem sustainability, contaminants, habitat, sediment*

INTRODUCTION

Wetland-level factors such as turbidity, pH, dissolved oxygen, and vegetative cover were mentioned to have direct impact on accumulations of biotic communities (Kaller *et al.*, 2013; De Szalay and Resh, 2000; Anderson *et al.*, 2013; Clipp and Anderson, 2014; McPherson *et al.*, 2020). For example, many wetland-associated organisms, such as aquatic turtles, require upland habitats for reproduction because female turtles undergo terrestrial nesting migrations. Consequently, aquatic turtles represent a taxonomic group

where a certain life stage (i.e. reproductively active females on terrestrial nesting migrations) is at disproportionate risk of mortality and would benefit from terrestrial habitat protections. Freshwater turtle require both terrestrial and aquatic habitat hence consideration to examine the soil in the study area is crucial. Unfortunately, a comprehensive examination of soil will be a rigorous and expensive exercise. In wetlands ecosystem, sediments serve as habitats for many organisms and it can be regarded as sink of heavy metals capable of providing information on pathway of environmental

pollutant or contaminants. The presence of toxic elements in sediments plays a significant role in its toxicity to aquatic organisms because of its persistence and ability to be activated at different stages of food chain (Baran *et al.*, 2019). Bottom sediments was mentioned to serves as a sink which absorb all pollutants introduced to the aquatic environment (Ekere *et al.*, 2017) and this ability to absorb and release dissolved substances makes the bottom sediments a significant factor in nutrient and metal circulation (Birch, 2017). Sediment dwelling organisms were directly affected by sediment associated contaminants (Ogbeibu *et al.*, 2014). Information on sediment quality is very important for evaluating the wetland ecosystems status. Ogunjobi (2022) observed the needs for further study on impact of environmental factors on the well-being of *Pelusios castaneus* in their natural habitat. This study was carried out to examine the physiochemical properties of sediment supporting freshwater turtles (*Pelusios castaneus*) in Eki Rivers in Ilaje, Ondo State, Nigeria with a view of given insight into the animal habitat and providing useful information on potential impact of eaten freshwater turtles (*Pelusios castaneus*) by human.

MATERIALS AND METHOD

Eki River (6° 20' 56.81"N, 4° .45' 31.27"E), a seasonal river known for hunting freshwater, Nile crocodile and other aquatic animal is about 2.4km to Igbokoda Ilaje,, Ondo State, Nigeria. The area supports a wide range of aquatic animals that are integral part of this wetland ecosystem and source of livelihood for many people in the area. The flora components of this wetland include mangrove forest, riparian vegetation, and freshwater vegetation while the fauna species are fish species, crustaceans,

mollusks, birds, reptiles (Nile crocodile, snake, freshwater turtle) and primate (monkeys), mammals (wild pig). Some communities around the sites includes Eki, Ago Ijebu, Ago Agbede, Lerinrin, Orere Ara, Aboto, Motiala, and Igbokoda (Ogunjobi, 2022). Ecological factors considered for analysis in this study was sediment. The samples were collected into polythene bag and transported to the laboratory. The polythene bags were cleaned and rinsed with water samples at the point of sediment collection. The sediments were air dried and further dried at 105°C in an oven. The Bouyoucos Hydrometer method was used for particle size distribution while the organic matter (OM) was determined by volumetric method as described by Muller (1981), elemental analysis were carried out using Proton-induced X-ray emission (PIXE), 1.7 MeV SSDH Pelletron Accelerator at the Obafemi Awolowo University (Ile-Ife) Central laboratory, Nigeria. The Certified reference material (IAEA Soil-7) was used for quality control. The conductivity and pH was measured using potable meter (Hanna 991300 model).

RESULTS

Ecological aspect of sediment supporting Freshwater turtles in Ilaje Rivers

The mean pH, EC, OM, Cl, Sand, Clay, silt, Fe, Ca, Mg, K, Mn, Zn, Pb, Cu and Cd were 28.93±0.11°C, 3.90± 0.03mg/L, 6.62±0.68, 165.00±4.60µSCm-1, 1.89±0.09%, 819.83±10.20 ppm, 43.27±1.50%, 6.33±0.42%, 7.99±0.70%, 509.98±10.12mgkg-1, 763.25±13.45 mgkg-1, 426.90±9.35 mgkg-1, 183.35±4.56 mgkg-1, 193.80±5.23 mgkg-1, 119.57±4.20 mgkg-1, 1203.85±26.50 mgkg-1, 308.97±12.38 mgkg-1 and 91.80±1.25 mgkg-1, respectively (Table 1).

Table 1: Physicochemical parameters and elemental concentration of soils/sediments in Eki River

Variables	Location 1	Location 2	Location 3	Mean
pH	5.10	7.25	7.50	6.62±0.68
EC (µSCm-1)	35.40	96.20	100.10	165.00±4.60
OM (%)	0.40	2.50	2.76	1.89±0.09
Cl (ppm)	98.60	1110.40	1250.50	819.83±10.20
Sand (%)	38.10	45.50	46.20	43.27±1.50
Clay (%)	3.50	7.10	8.40	6.33±0.42
Silt (%)	4.02	9.50	10.45	7.99±0.70
Fe (mgkg-1)	154.50	525.15	850.30	509.98±10.12
Ca (mgkg-1)	178.74	980.50	1130.50	763.25±13.45
Mg (mgkg-1)	80.90	99.40	1100.40	426.90±9.35
K (mgkg-1)	78.60	110.85	360.60	183.35±4.56
Mn (mgkg-1)	89.90	120.90	370.60	193.80±5.23
Zn (mgkg-1)	40.50	148.50	169.70	119.57±4.20
Pb (mgkg-1)	70.15	700.50	2840.90	1203.85±26.50
Cu (mgkg-1)	70.20	320.90	535.80	308.97±12.38
Cd (mgkg-1)	26.50	98.50	150.40	91.80±1.25
Cd (mgkg-1)	26.50	98.50	150.40	91.80±1.25

DISCUSSION

Quality of water depends on a large number of physico-chemical parameters, and monitoring of these parameters is essential for the determination of magnitude and source of pollution load among aquatic animals. The water parameters studied are presented in Table 1. The pH values (6.50 - 7.80) was within recommendation for optimal aquatic productivity while other parameters measured were higher. This may be as a result of gradual flow of saline enrichment from farmland as reported by Ayedun (2021). For example, the mean Fe concentration of 509.98mgkg-1 is much higher than values reported by Ayedun (2021) and Eddiagboya *et al.*, (2022) in Oluwa and Igbekebo rivers, respectively. High percentage of sand may be due to yearly eutrophication from the road side. Duan *et*

al., (2012) and Hedrick *et al.*, (2013) mentioned that surrounding landscape characteristics such as road density, agriculture, and other anthropogenic land uses can increase sediment and nutrient loading through runoff and this have the potential to lower abundances of taxa due to increased environmental stressors.

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ASSESSMENT OF HEAVY METAL TRANSFER TO VEGETABLES CULTIVATED ALONG THE KUBANNI WETLAND IN ZARIA, NIGERIA

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ABSTRACT

Wetland environment plays a vital role to our wellbeing as it provides support to agriculture particularly irrigation in most states within northern Nigeria. However, rapid population increase alongside urbanization alters the natural ecosystem through pollution from nearby communities and industries which are transferred to produce cultivated within the environment. This study assesses the transferability of some selected heavy metals to vegetables cultivated along the Kubanni wetland in Zaria, Nigeria. The selected vegetables include spinach, cabbage, lettuce, onion and tomatoes. The metals analyzed include Cr, Fe, Pb, and Cd. Findings from this study revealed that soil to plant transfer of Cr is more in tomatoes with a value of 0.239 mg/kg than all other vegetables. The transfer of Fe is highest in lettuce (0.240 mg/kg), Pb is accumulated most by spinach (0.539 mg/kg) while lettuce recorded highest transfer of 0.687 mg/kg for Cd. Overall, Cd had the highest transfer value of 2.8 mg/kg followed by Pb with 2.3 mg/kg, Cr with 1.0 mg/kg and the least is Fe with 0.93 mg/kg. ANOVA result shows that there is a significant difference in heavy metal transfer from soils to vegetables among different metals analyzed within the study area. The research recommends that farmers should be encouraged to implement simple and efficient agronomic techniques that can lower soil heavy metal pollutants in order to lessen the buildup of these metals in vegetables grown in the Kubanni wetland.

Keywords: Heavy Metal, Contamination, Transfer, Vegetables, Kubanni

INTRODUCTION

Wetland ecosystem provides important services such as habitat for many species of plants and animals, food production, water sanitation, tourism and so on (Xu *et al.*, 2023). In recent time, population growth, urbanization, evolution of modern technology coupled with increased demand for food has resulted to diverse human activities on the environment. Effluents from industries, human settlement and agro-chemicals from farmlands are released into water channels and their surrounding environment (Abdulkadir *et al.*, 2024). High rates of population growth, particularly in the

urban and peri-urban areas, have intensified competition for sanitary infrastructure. In the developing world, about two thirds of the population lack sanitary ways to dispose of excreta, and an even larger portion lack proper ways to dispose of wastewater. Approximately 2.4 billion people lack access to basic sanitation. Around 85% of the wastewater produced by urban areas globally is estimated to end up untreated in the environment. After passing through storm water, the majority of this water drains into streams. This results to the release of harmful metals into the environment which can be passed on to plants. According to Traore *et al.*

(2022), many African city dwellers dump waste and sewage into streams and rivers, which could potentially spread diseases to humans if the water is used to irrigate crops. Due to lack of clean water, urban and peri-urban irrigation farmers use this effluent for irrigation (Sulaiman *et al.*, 2021). Industrial pollutant emissions affect not only human health but also plants, animals, and their ecosystems, disrupting breeding cycles and biodiversity. Additionally, pollutants can accumulate on structures and monuments and erode crucial infrastructure, necessitating expensive repairs. The majority of industrial waste is discharged into surrounding streams and rivers, which can be used for irrigation in cities. If these contaminants are present in big enough quantities, they may negatively impact human health when they enter the food chain. One of the simplest ways for exposing humans to the risk of heavy metals is through food chain (Bayissa and Gebeyehu, 2021).

Significant level of metal pollutants in soil can be transferred to plants including vegetables and when consumed by human, it may result to severe health effect. Heavy metals are transported from the environment to plants during the bio-accumulation process. According to Tomno *et al.* (2020), bioaccumulation is a state in which metals are transferred to living components of the environment through the soil, water, and air. Because monitoring the environment is a continuous process, it is crucial to assess metal transfer to vegetables from soils within the study area due to the harmful effects they have on the environment and human health.

MATERIALS AND METHOD

The Study Area

Kubanni wetland is located at Longitude $7^{\circ}38'0''$ to $7^{\circ}44'0''$ East and Latitude and $11^{\circ}4'0''$ to $11^{\circ}10'0''$ North (see Figure 1).

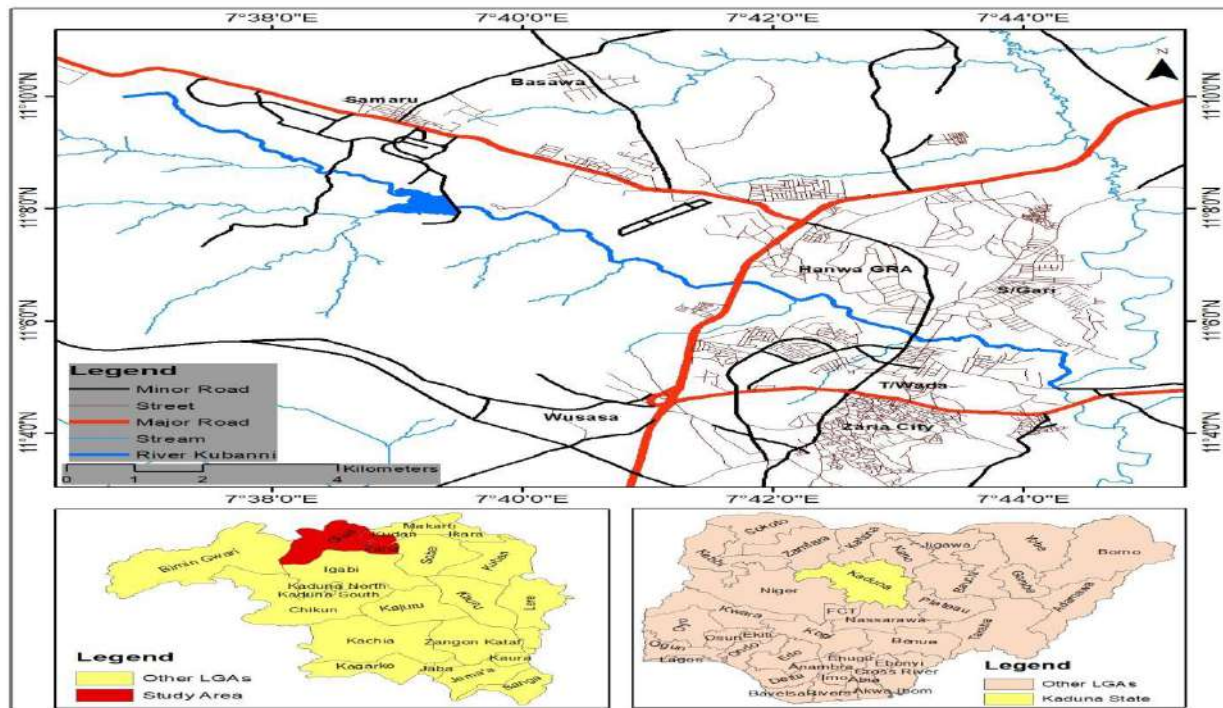


Figure 1: Map of the Study Area

Source: DIVA-GIS Software 7.5

Sampling Technique

Twenty-five farmlands in all were used as sampling locations. 125 vegetable samples were obtained using the random sampling approach. For this study, five vegetables which include spinach, lettuce, tomatoes, onions, and cabbage were taken into consideration. This is due to the fact that they are the most popular vegetable varieties in the research region. To obtain composite samples of soil in such a way that they are fully representative of the field; this was done using Randomized Complete Block Design (RCBD) method as used by Abdulkadir *et al.*, (2024). Chromium (Cr), iron (Fe), lead (Pb),

and cadmium (Cd) are among the metals that were examined using the Atomic Absorption Spectrophotometer (AAS) method. The metals were chosen according based on their health effects on consumers of vegetable. The samples were taken to Multi-User Laboratory at the Ahmadu Bello University Zaria for preparation, digestion and analysis using AAS machine.

RESULTS AND DISCUSSION

Soil to Plant Transfer of Heavy metals

The result for soil to plant transfer is contained in Figure 1, 2, 3, and 4.

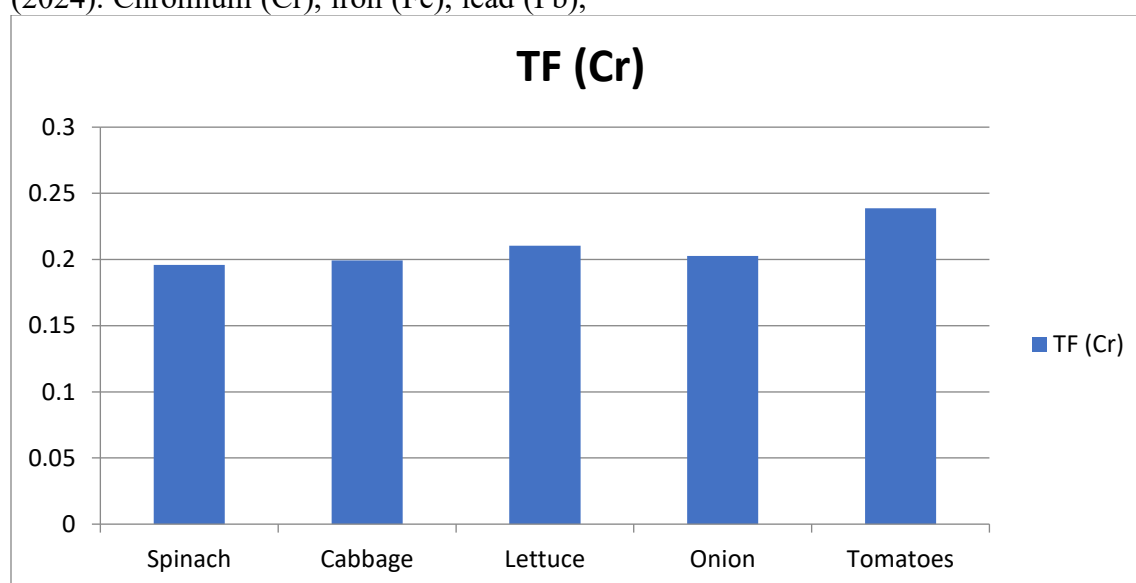


Figure 1: Transfer Factor for Cr

Figure 1 indicated that highest soil to plant transfer of Cr is seen in tomatoes with a value of 0.239 mg/kg, it is followed by spinach with 0.195 mg/kg, lettuce 0.210 mg/kg, onion 0.203 mg/kg, and cabbage 0.199 mg/kg. This implies that tomatoes accumulate Cr the most than other vegetables considered in this study. The result is similar with the findings of Adeoye *et al.* (2018), who reported that Cr had the highest transfer factor (TF) of 0.01mg/kg-1.47mg/kg in Minna Nigeria than all other metals analyzed in their study. Xu *et al.* (2023) stated that while Cr is naturally present in the environment, human activities

like mining as well as the use of agrochemicals may cause a rise in their level. The use of pesticides and other agrochemicals is a common practice for irrigation farmers within the study area (see Plate i). The extensive use of solid waste from municipal dumpsites also adds to Cr contents in soil which can be transferred to vegetables in the study area (see plate ii). Although there won't be too much risk, steps should be taken to lessen Cr contamination within the Kubanni irrigation area. Health related problems such as cancer, respiratory diseases, liver and kidney diseases are caused

by excessive Cr intake (Abdulkadir *et al.*, 2024). Cr in soil can be reduced through flushing of the soil with clean water or excavation of polluted soil and replacing it

with a clean one. The use of Cr contaminated fertilizer should also be avoided (Sule *et al.*, 2021).

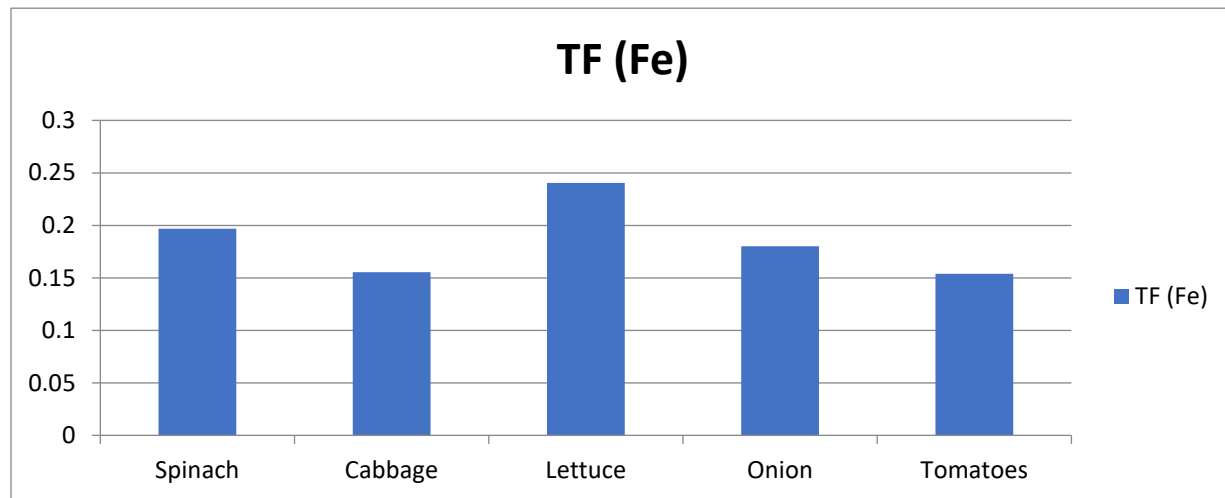


Figure 2: Iron Transfer

From Figure 2, it shows that the maximum Fe transfer is observed in lettuce with a transfer value of 0.240 mg/kg, it is followed by tomatoes (0.154 mg/kg), spinach (0.197 mg/kg), onions (0.180 mg/kg), and cabbage (0.155 mg/kg). This means that lettuce possesses more ability to accumulate Fe from soil among the chosen vegetables in this study. The transfer factor values observed are higher than what was reported in the study of Gebeyehu and Bayissa, (2020) in their analysis of metal transfer in the Mojo area,

Ethiopia who observed that Tomatoes had a TF value of 0.002 mg/kg, while cabbage had 0.012 mg/kg. Despite iron being useful to man, excess amount could be hazardous as many health challenges such as nausea, diarrhea and abdominal disorder are caused by high iron consumption mostly from contaminated food like vegetables (Samuel and Sani, 2019). To lower the high iron concentration in vegetables, irrigation farmers must adopt proper farming practices.

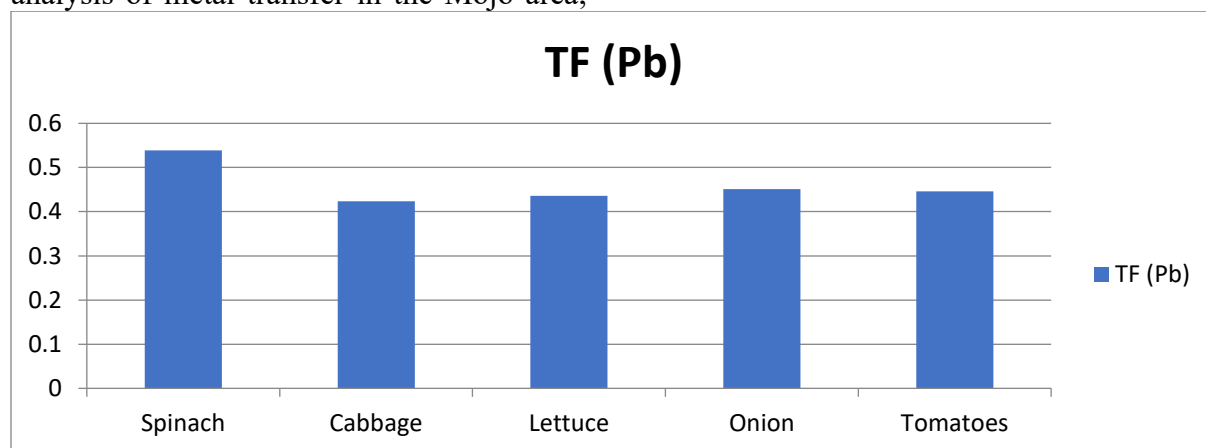


Figure 3: Pb Transfer

As seen in Figure 3, soil to plant transfer of Pb is more on spinach (0.539 mg/kg) followed by onion (0.451 mg/kg), tomatoes (0.446 mg/kg), lettuce (0.436 mg/kg), and cabbage with the lowest (0.424 mg/kg). It means that spinach is the highest accumulator of Pb among all the selected vegetables in this study. The values are less than what was observed by Mijinyawa *et al.*, (2022) in their assessment of metal transfer in Sabon-gari, Giwa and Hunkuyi LGA of Kaduna state who reported that Pb had transfer factor as high as 1.89 mg/kg for cabbage and a low value of 0.25 mg/kg for spinach. Also, Sulaiman *et al.*, (2021) studied soil to plant metal transfer in Bauchi, Nigeria and observed a value of

0.111 mg/kg for Pb in vegetables within area. Due to high Pb transfer to vegetables in the study area, consumption of vegetables especially spinach may result to higher risk of Pb related illness such as infection of the liver, kidney and lungs (Iyama *et al.*, 2022). Spray of agrochemicals on vegetables during cultivation alongside burning of old batteries in dumpsites may add Pb content and if used as manure may be passed on to vegetables. Pb levels in soil can be reduced through addition of lime, excavation of polluted soil and using safe agronomic practices like flushing contaminated soil with water (Ibrahim *et al.*, 2020).

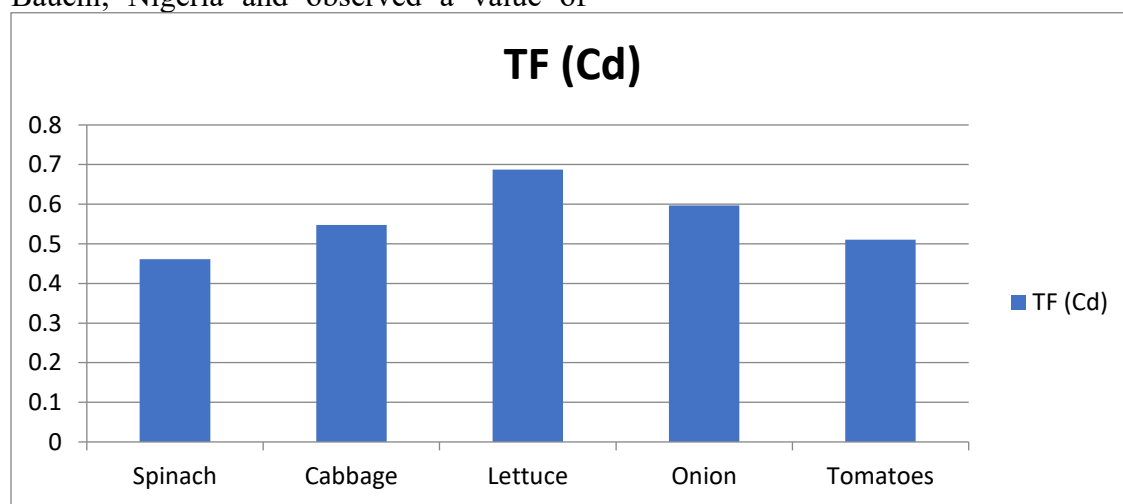


Figure 4: Cd Transfer

According to Figure 4, the largest Cd transfer factor was found in lettuce with a value of 0.687 mg/kg. This is followed by onion (0.597 mg/kg), cabbage (0.547 mg/kg), tomatoes (0.510 mg/kg), and spinach (0.461 mg/kg), which recorded the lowest TF value. Gebeyehu and Bayissa (2020) in their analysis of heavy metal transfer in tomatoes and cabbage from the Mojo region of Ethiopia, they found that the highest transfer factor for Cd was recorded in cabbage with TF of 0.129 mg/kg. This implies that Cd is mostly absorbed by lettuce than other vegetables considered in this study. This calls

for serious concern among consumers of vegetables within the Kubanni irrigation area due to risk associated with high Cd intake.

Cd may be naturally present in the environment but activities like burning of municipal solid waste may add Cd content in the soil which can be transferred to plants (Kumar *et al.* 2019). Pneumonia, bronchitis and gastrointestinal disorders are some of the few health challenges caused by excessive Cd intake (Abdullahi *et al.*, 2023). Some simple strategies to lower the amount of Cd in soil include selecting crops that are less likely to accumulate Cd, making sure

irrigation water is free of Cd, and avoiding the use of fertilizers contaminated with Cd.

Overall Soil to Plant Transfer of different Metals

The result for overall transfer of metals from soil to vegetables in this study is shown in Figure 5

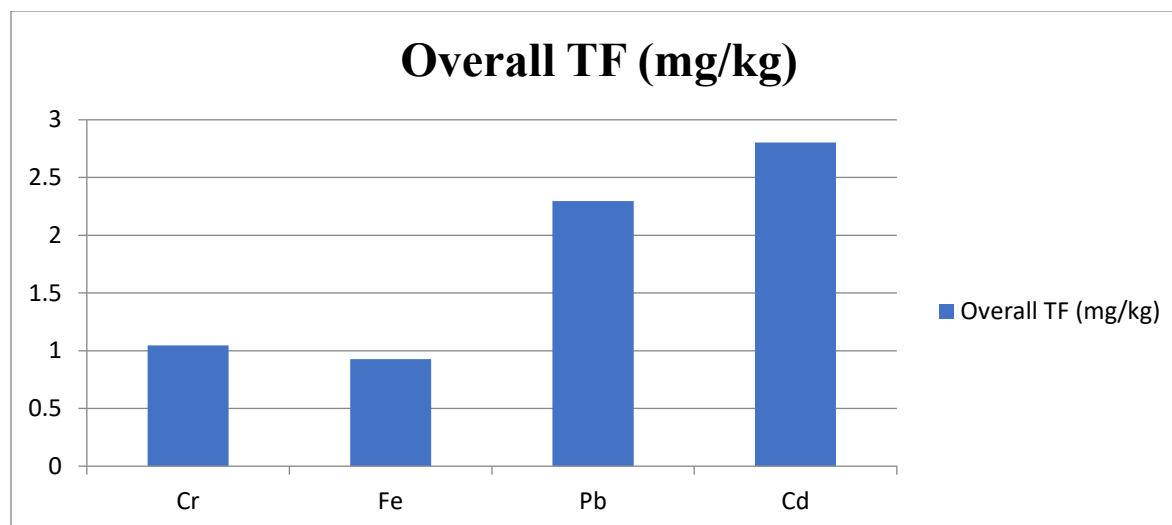


Figure 5: Transfer Levels for the Selected Metals

Cd had the highest TF of 2.8 mg/kg followed by Pb with 2.3 mg/kg, Cr with 1.0 mg/kg and the least is Fe with 0.93 mg/kg. This suggests that vegetables within the study area are likely to contain more Cd than other metals considered in this study. The result concurs with the findings of Lemessa *et al.* (2022) who they found that Cd had the highest soil to plant transfer with a maximum value of 19.39 mg/kg in vegetables cultivated at Lemi, Ethiopia. In another study by Ratul *et al.*, (2018) where they assessed metal accumulation in Narayanganj, Bangladesh reported that Cd had highest transfer factor (TF), it shows that Cd ranges from 0.0998-0.2266 mg/kg, Cr 0.0023-0.0492 mg/kg, Pb 0.0607-0.2222 mg/kg. Similarly, Edogbo *et al.*, (2020) in their analysis of soil to plant transfer of heavy metals in Challawa Kano reported that Cadmium accumulated the most with the transfer factor (TF) ranging from 6.52–2.88 mg/kg. Contrary to this, in Bauchi Nigeria, Sulaiman *et al.* (2021) in their analysis of soil-to-plant metal transfer recorded 0.00 transfer levels for Cd.

However, Iyama *et al.*, (2022) in their analysis of metal transfer to vegetables in Port Harcourt, Nigeria reported that Pb had the lowest metal transfer while Fe recorded the highest transfer factor followed by Cr, Cd, and Ni.

Owing to the increased ability of Cd to be transferred from soil to vegetables across the Kubanni area, there may be a greater chance of risk associated with excessive Cd consumption through vegetables in the research area. The kinds of plants, the state of the soil, and the type of metals all affect the rates of accumulation of metal pollutants in plants (Adeoye *et al.* 2018). Emurotu and Onianwa, (2017) state that plant leaves actively participate in photosynthesis which allows for increased transpiration rates. Because of this, the leafy sections of the plant need more water and other nutrients than other portions of the plant. This may result to a larger buildup of heavy metals. Because only the edible portions of vegetables were analyzed in this study. It means that a greater

concentration of metal is anticipated since majority of the chosen vegetables, such as spinach, cabbage, lettuce, and onions which have both leaves and stems as the edible portion except tomatoes where the fruit is the edible part.

Differences in the Transfer of Metals from Soil to Vegetables

Table 1: Analysis of Variance (ANOVA) for Metal Transfer

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	0.515204	3	0.171735	61.54496	5.26E-09	3.238872
Within Groups	0.044646	16	0.00279			
Total	0.55985	19				

Source: Authors' Analysis, 2024

Table 1, shows that F critical value is < F calculated value, this means that there is a significant difference in heavy metal transfer from soils to vegetables among different metals analyzed within the study area.

CONCLUSION

There is high level of soil to plant transfer (bio-accumulation) of heavy metals in all the selected vegetables.

RECOMMENDATIONS

The study recommends that farmers should adopt simple agronomic practices such as adding lime to lower soil levels of heavy metals, choosing crops that are less likely to accumulate heavy metals, avoiding fertilizers containing heavy metals, using irrigation water free of metal contaminants, excavating contaminated soil and replacing it with clean soil, and water flushing.

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APPENDIX



Plate I: A farmer spraying insecticide on Spinach



Plate II: Solid Dumpsite

PHYSIOLOGICAL EVALUATION OF FRESHWATER TURTLE (*Pelusios castaneus* Schweigger 1812) FOUND IN ILAJE, ONDO STATE, NIGERIA

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ABSTRACT

Irrespective of animal ecosystem, their blood profile reflects the attributes of their environment and the fitness of such animal for human consumption. In this study, blood biochemistry and oxidative stress on the livers and kidneys of male freshwater turtle averaging 280 ± 6.15 g captured from Eki River, Ilaje, Ondo State, Nigeria was evaluated. The values for the animal blood chemistry: total serum concentration (7.79 - 8.55 g/dl), blood glucose (87.16 - 176.15 g/dl), aspartate aminotransferase (63.5 - 80.5 μ l), alanine aminotransferase (9.82 - 30.18 μ l), alkaline phosphatase (0.321 - 0.324 μ l), lactate dehydrogenase (2.0635 - 6.905 μ l), urea (2.01 - 2.11 mg/dl), creatinine (0.33 - 0.83 mg/dl), triacylglycerol activities in blood plasma (190.91 - 204.55 mg/dl) and cholesterol (91.38 - 96.55 mg/dl) were obtained. Oxidative stress levels differed in kidneys and livers of experimental animals with higher values obtained in the experimental animal liver for all the parameters examined except for catalase and superoxide Dismutase. Further studies are recommended to investigate the pathway of likely environmental contaminants in *Pelusios castaneus* and the potential health risk of consuming such animal.

Keywords: Freshwater turtle, animal wellness, environmental resources, food safety, Ilaje

INTRODUCTION

Blood biochemistry reflects the metabolic condition of several biochemical processes and the health status of the organism (Ullah *et al.* 2019). For example, alanine aminotransferase has been used as a diagnostic tool to identify various tissues damage due to pollutant exposure (Lala and Minter, 2018). Health status of animals will positively or negatively affects man and other animals directly or indirectly at the higher food chain levels. There is paucity of information about environmental contaminants in freshwater turtle in Ilaje, southern Ondo State, Nigeria. Ogunjobi (2022) suggested further studies to investigate the impact of environmental

factors on the well-being of *Pelusios castaneus* in their natural habitat. Useful information on *Pelusios castaneus* well-being can only be obtained through physiological investigation. Oxidative stress is considered an important player in the pathophysiology of both acute kidney injury and chronic kidney diseases (Bellomo *et al.*, 2012) This study was carried out to examine the blood chemistry and organs (livers and kidneys) oxidative stress in freshwater turtles (*Pelusios castaneus*) captured in Eki River in Ilaje, Ondo State, Nigeria with a view of providing useful information on species well-being and potential impact of freshwater turtles (*Pelusios castaneus*) eaten by human being.

MATERIALS AND METHOD

Ilaje, covering a total area of 1,318 km² is situated within the southern part of Ondo State, South-western Nigeria (5.8333° – 6.2500° N; 4.5000° – 5.1667° E). Ilaje generally supports a wide range of aquatic animals (Ogunjobi and Surulere, 2020). The main types of vegetation are Mangrove forest and coastal, Freshwater swamp forest, Savanna, stunted rain forests of the sand ridges and mainland margin. These abundant aquatic resources in Eki River are integral part of the aquatic ecosystem and source of dry season farming for people in the area (Ogunjobi, 2022). The River which is about 2.4 km from Igbokoda is habitat for freshwater turtles, Nile crocodile and other aquatic animal. Experimental animals were 12 male *Pelusios castaneus* (280±6.15g) captured from Eki river (6° 20' 56.81"N, 4° 45' 31.27"E) seasonal River. Animal sex was identified through direct observations of the gonads in situ as suggested by Readell *et al.* (2008) and only the male animal was used in this study. Blood samples were collected via jugular puncture using 2 ml syringe and dispensed in 5 ml sample bottles. The blood samples were centrifuged at 3000 rpm for 10 min to obtain sera for blood chemistry and oxidative stress analyses. Tissue samples were rinsed, homogenized with cold physiological normal saline and centrifuged at 4000 rpm for 15 min to obtain lysate supernatant for oxidative stress assay which includes Alanine Aminotransferase (ALT), Aspartate Aminotransferase (AST), Alkaline Phosphatase (ALP). Urea (U), Creatinine (Cr), Total Protein Content (TPC), Catalase, Superoxide Dismutase (SOD) Activity, Reduced Glutathione (GSH), Lipid Peroxidation and Triacylglycerol activities in blood plasma, Cholesterol in Blood Plasma. Data collected were subjected to descriptive statistical analysis in form of tables, frequency, percentages.

RESULTS

Blood chemistry and organ oxidative stress in Freshwater Turtle found in Ilaje River

The result (Table 1) shown that the total serum concentration found in *Pelusios castaneus* was (7.79-8.55 g/dL), while the blood glucose range from 787.16-176.15 g/dL. It was discovered from the study that Aspartate Aminotransferase (AST) was 63.5-80.5 (μ/l), while Alanine Aminotransferase (ALT) was 9.82-30.18 (μ/l). Alkaline Phosphatase (ALP) ranged from 0.321-0.324 (μ/l), while Lactate Dehydrogenase (LDH) was 2.0635-6.905(μ/l). Urea present was 2.01-2.11 (mmol), Creatinine 0.33-0.83 (mg/dl), Triacylglycerol activities in Blood Plasma discovered as 190.91-204.55 (mg/dl) and Cholesterol as 91.38-96.55 (mg/dl). Oxidative Stress was higher for protein content (133.02(g/μ)), lipid peroxidation (26.225(μ/mmol) and glutathione (1.03425(μ/mmol) in the liver while higher values was obtained for catalase (3.7025(μ/g) and superoxide dismutase in the kidney as shown in Table 2.

Table 1: Blood Chemistry of Freshwater Turtle in Ilaje

VARIABLES	MIN	MAX
Total serum	7.79	8.55
Blood Glucose	87.16	176.15
Aspartate Aminotransferase (AST)	63.5(μ /l)	80.5(μ /l)
Alanine Aminotransferase (ALT)	9.82(μ /l)	30.18(μ /l)
Alkaline Phosphatase (ALP)	0.321(μ /l)	0.324(μ /l)
LactateDehydrogenase (LDH)	2.0635(μ /l)	6.905(μ /l)
Urea	2.01(<u>mmol</u>)	2.11(mg/dl)
Creatinine	0.33(mg/dl)	0.83(mg/dl)
Triacylglycerol	190.91(mg/dl)	204.55(mg/dl)
Cholesterol	91.38(mg/dl)	96.55(mg/dl)

Ac
Cg**Table 2: Oxidative Stress in Liver and Kidney of Freshwater turtle in Ilaje**

VARIABLES	LIVER	KIDNEY
Total Protein	133.02(g/ μ)	82.4675(g)
Catalase	1.19(μ /g)	3.7025(μ /g)
Lipid Peroxidation (LPO)	26.225(μ /mmol)	35.8975(μ /mm0l)
Glutathione (GSH)	1.03425(μ /mmol)	0.04615(μ mmol)
Superoxide Dismutase (SOD)	0.4125(μ /g)	0.9995(μ /g)

DISCUSSION

Higher protein content occurring in the liver (133.02(g/μ) of freshwater turtle (*Pelusios castaneus*) found in Ilaje was similar to the level of protein concentration for *P. expansa* from Araguaia River (Mundim *et al.*, 1999) and the ones farmed in Goia's State, Brazil (Santos *et al.*, 2005). Presence of catalase (3.7025(μ/g) in the kidney of freshwater turtle in the study area differs from the report by Kishore (1983) which exhibited significant reduction of catalase abundance in the kidney. It was discovered from the study that Lipid Peroxidation (LPO) is more in the kidney (35.8975μ/mm0l). Results of the lipid Peroxidation content in the kidney of the turtle (*Pelusios castaneus*) agrees with the study by Akhirevbulu and Okonji (2013). Similar results was reported by Akhirevbulu and Okonji (2013) who observed no difference in the lipid Peroxidation content in the liver and kidney of *Pelusios castaneus*. The present report shows that kidney has the high Glutathione (GSH) 1.03425(μ/mmol) compare to the kidney (0.04615μmmol). The serum concentration (7.79-8.55 g/dL) obtained in the study is similar to the range (2.3-4.4 g/dL) reported in the loggerhead sea turtles, *Caretta caretta* (Gicking *et al.*, 2004). Findings of this study present baseline data on the haematology and serum biochemical parameters for *in-situ* *Pelusios sinuatus* in Ilaje, Ondo State, Nigeria.

It was discovered from the study that Aspartate Aminotransferase (AST) was 63.5-80.5 (μ/l), while Alanine Aminotransferase (ALT) was 9.82-30.18 (μ/l). Alkaline Phosphatase (ALP) ranged from 0.321-0.324 (μ/l). This finding is in line with previous studies (Xu, 2020). The reason for the values obtained may be due to the fact that a sufficiently high concentration of phosphate was present in the serum of turtles fed the high-phosphorus diet, satisfying the needs for

skeleton mineralization; hence, the ALP activities in liver was lower.

CONCLUSION

AND

RECOMMENDATION

It can be concluded that the *Pelusios castaneus* found in Eki River in Ilaje, Ondo State, Nigeria is being stressed and exposed to unbearable environmental factors, probably from anthropogenic activities around the study area, most especially, from the unsustainable farming activities. Further study to determine the pathway of stressor in this animal and the potential health risk to the animal itself and the consumers of such animal are recommended.

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FOREST STRUCTURE ANALYSIS OF AKAGUAMA MANGROVE FOREST IN NEMBE, BAYELSA STATE, NIGERIA.

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ABSTRACT

The Akaguama mangrove forest in Nembe, Bayelsa State is among the complex wetland ecosystems undergoing degradation from anthropogenic activities in the Niger Delta of Nigeria. This study aims at generating and sustainable management of the wetland. Predetermined quadrant plots of 20m* 10m was established within the impacted and control basin forest, while 40m * 20m plots was established at the fringe forest, all in three replications respectively by tracking, using the GPS device. Mangrove species height and stem circumference at breast height were determined and used to analyze the forest structure. Findings showed that majority of the trees encountered in the fringe forest (66.7%) and control basin (64.8%) belong to the emergent stratum, while the upper story were distributed within the impacted basin (24.4%), fringe (21.6%) and control basin (19.7%). The impacted basin forest was a mixture of the middle stratum (39%) and emergent stratum (34.2%) and upper story (24.5%). Larger proportion of trees were in the lowest diameter at breast height (DBH) class < 5 (144), with reduction in proportion of trees based on DBH increase. The study further showed that *Rhizophora mangle* was the abundant species with an importance index of 98.86, while *Caesalpinia spp* indicated 2.58.

Keywords: Forest structure, Mangrove, Wetland, Sustainable management.

INTRODUCTION

Mangrove, an assemblage of classified heterogenous woody trees and shrubs inhabits the intertidal zones of tropical and subtropical coasts (Joshi and Ghose, 2014). Mangrove forest subsist on alluvia mud soils located at seaboard regions and estuaries that experience tides, with species in genus such as *Rhizophora*, *Avicennia*, *Nypa*, *Cerriops*, *Sonneralia*, *Bruguiera*, *Aegiceras*, *Excoeceria*, *Scyphyphora*, *Lumnizera* and *Xylocarpus* (Soerianegara, 1987). They frequently form thick forests that dominate

intertidal muddy coast often consist mainly of mono specific patches (Hogarth 2017).

Interspaced among mangroves are noticeable non-mangrove plants with or without few morphological mangrove adaptations do exist in the forests (Ong and Gong, 2013). Such plants are considered invasive species.

The spread of mangrove forest cuts across 123 countries globally, covering 15.2 million ha of land.

The continental distribution showed Asia with the largest coverage of 37%, followed by North and South America, with 27.2%,

Africa and Australia, new Zealand, South Pacific Island, New Guinea occupying 12.4% of global distribution (FAO, 2007, Sandilyan and kathiresan, 2012).

Structurally, there are variations in mangrove vegetation based on ecosystem location, disturbance and management (Sarno *et al.*, 2015). These differences in distribution are mainly controlled by climate, while soil properties, tidal fluctuation and topography are contributive factors (Abou Seedo *et al.*, 2017).

Mangrove serve as a hub for biodiversity of flora and fauna, providing suitable habitats for in terrestrial and aquatic organisms such as fish, crustacean, amphibian, reptilian, mammalian, insect and avian species (Thomas *et al.*, 2017). Beside supporting fisheries resources and biodiversity of marine organisms, it is pivotal to sustainable livelihood in the coastal communities (Kathiresan and Bingham, 2001; Garcia *et al.*, 2014; Hoque *et al.*, 2015a). Other contributions include coastal protection, ecological services, biomass production, with highly rated economic valuation (McLeod and Salm, 2006, Well *et al.*, 2006) when compared to other communities of plants (Rodriguez and Feller, 2004).

This all-important wetland forest has been predicted to record rapid decline of up to 25% in under-developing countries including Nigeria by this year 2025 (McLeod and Salm, 2006).

Anthropogenic activities such as illegal logging and conversion of land for local agriculture had been identified as causes of forest disturbance and fragmentation, whose trend is recurring in Nigeria (Bisong and

Mfon, 2006; Ogunjobi *et al.*, 2010). Other prevailing factors include exploration of seismic activities and production of petroleum hydrocarbon, with its associated pollution and environmental degradation.

For better sustainable management of natural resources productivity at coastal and marine ecosystem, the massive extension of mangrove ought to be managed and protected from destruction (Muarif *et al.*, 2016).

Sustained structural forest data generation and analysis such as measurement of tree height and diameter distribution which provide information on relative proportion of young and old trees in the ecosystem would serve as a data base for conservation and management (Saka *et al.*, 2012).

In the light of the obvious diversities of threats and degradation facing this invaluable wetland forest that is bestowed with useful ecosystem contributions and welfare of other organisms, and the foreseeable extinction threats, this study was designed to generate and analyze the mangrove forest structure of Akaguama in Nembe for sustainable management and development.

MATERIALS AND METHODS

Study Area

The site is located at Akaguama community in Nembe Local Government Area, Bayelsa State. It lies within coordinates 4°31.977'N and 6°15.509'E, which is more than 10km from Obama Flow Station. Transportation to the site was via boat. The administrative map of Bayelsa State showing the affected LGA is shown in Figure 1, while the aerial photo of the study location is shown in Plate 1.

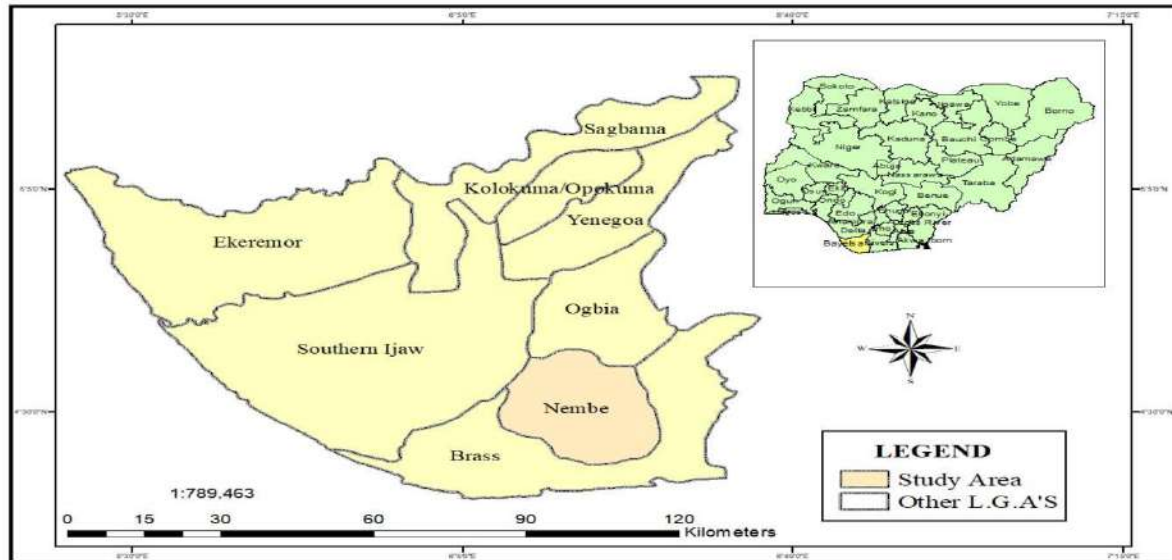


Figure 1: Bayelsa Map showing the affected Local Government Area



Plate 1: The Aerial photo showing the Assessment Area

Sampling Design

Forest structure samples were collected from pre-determined points as shown in table 1. Points were tracked with the aid of a GPS device. Plots within the forest basin and fringe forest were determined using 20m x 10m and 40m x 20m quadrants respectively in each sampling location.

Plant data for height, stem circumference at 1.30m (diameter at breast height (DBH),

total number of each species in each sampling plot were collected. Plant height was collected using measuring rod, while tall trees were measured laser pointer. Stem circumference was measure using 50m measuring tape.

Table 1: Sampling Plots

Point Label	Description	Coordinates
IB 1	Impacted basin forest with no evidence of deforestation.	4° 32.065 ¹ N/6° 15.529 ¹ E
IB 2	Impacted basin forest with no evidence of deforestation.	4° 32.131 ¹ N/6° 15.825 ¹ E
IB 3	Impacted basin forest with no evidence of deforestation.	4° 32.367 ¹ N/6° 15.827 ¹ E
IF 1	Impacted fringe forest with no evidence of severe deforestation.	4° 31.087 ¹ N/6° 15.905 ¹ E
IF 2	Impacted fringe forest with no evidence of severe deforestation.	4° 32.361 ¹ N/6° 15.531 ¹ E
IF 3	Impacted fringe forest with no evidence of severe deforestation.	4° 32.367 ¹ N/6° 15.827 ¹ E
CB 1	Control basin forest.	4° 32.389 ¹ N/6° 14.786 ¹ E
CB 2	Control basin forest.	4° 32.512 ¹ N/6° 15.111 ¹ E
CB 3	Control basin forest.	4° 32.628 ¹ N/6° 15.365 ¹ E

Data Analysis

Abundance: This was estimated using the formula:

$$\text{Abundance} = \frac{\text{Total number of individual of species}}{\text{Number of quadrat per unit in which they occur}} \times 100$$

$$\text{Relative Abundance} = \frac{\text{Total number of species}}{\text{Total number of individual of all species recorded}} \times 100$$

Density: This was estimated using the formula:

$$\text{Density} = \frac{\text{Total number of individual of species}}{\text{Number of quadrat per unit studies}}$$

Relative density: This was estimated using the formula:

$$\text{Related Density} = \frac{\text{Density of a given species}}{\text{Total density of all species}} \times 100$$

Frequency: Frequency was evaluated using the formula:

$$\text{Frequency} = \frac{\text{Number of unit in which the species occurred}}{\text{Total number of units studied}}$$

Relative Frequency = $\frac{f}{n}$ where f = frequency of the species, n = Total number of species

Stem diameter at breast height (DBH) was calculated using the formula

$$d = \frac{C}{\pi} \text{ where } d = \text{diameter, } C = \text{circumference and } \pi = \text{PI (3.142)}$$

Basal area of trees was enumerated using DBH. $BA = \pi D^2 / 4$, where BA = basal area(m²), D = diameter at breast height (cm), $\pi = 3.142$ (Husch *et al.*, 2003)

Importance value index (IVI) of tree species was enumerated according to Clinton and Novelli, (1984) as described by Schaffer – Novelli (1984) and Gonzalez-Zamarono *et al.*, (2011), by adding relative abundance, relative frequency and relative density.

Correlation coefficient of the study locations was estimated based on DBH (diameter at breast height), THT (total tree height), BA (Base Area), and NS (Number of stems).

t-test statistics was used to evaluate yield.

Rescaled distance cluster dendrogram using complete linkage was used to estimate similarity and dissimilarity of vegetation types.

All trees in the study area were grouped into five diameter classes namely 0-2m, 2-5m, 5-15m, 15-25m, and > 25m.

Tree Height Distribution

The distribution of trees into height classes based on stratum in the three forest types is shown in table 2.

The highest proportion of trees encountered in the study area was found in the control basin forest (54.93%), followed by the impacted basin forest (82.93%) belonging to the understory stratum (2-5m), while the fringe forest had 59.09% of under story stratum with stand errors of 4.73 ± 6.87 , 2.73 ± 2.82 and 3.40 ± 4.74 respectively (Table 3).

The highest canopy stratum (5-15m) was found in the control basin forest (45.07%) followed by the fringe forest (22.73%) while the impacted basin forest had very low proportion of canopy stratum (17.07%). The emergent stratum was sparsely observed in the fringe forest (18.18%) alone (Table 2).

RESULTS AND DISCURSION

Table 2: Height distribution (m) of trees per hectare in the study area.

	IB Impacted basin	IF Fringe forest	CB Control basin
0-2m	0(0.00%)	0(0.00%)	0(0.00%)
2 – 5m	34(82.93%)	26(59.09%)	39(54.93%)
5 – 15m	7(17.07%)	10(22.73%)	32(45.07%)
15 – 25m	0(0.00%)	8(18.18%)	0(0.00%)
>25m	0(0.00%)	0(0.00%)	0(0.00%)
Total	41(100%)	44(100%)	71(100%)

Table 3: Descriptive statistics of trees height (m) in the study area

Parameter	IB impacted basin	IF impacted fringe	CB control basin
Mean	2.73	3.40	4.73
Standard Errors	2.82	4.74	6.87
Minimum	0	0	0
Maximum	6.7	11.33	16.33
Skewness	0.54	1.75	0.80

Distribution of diameter at breast height (DBH) (cm)

The result of DBH distribution showed that the largest proportion of trees in the study areas were in the lowest DBH class < 5 (144). The result further showed a reduction in

proportion of trees with increasing DBH (Fig. 1). The descriptive statistics indicated a standard error of 1.25 ± 1.8 for the control basin, while the fringe and impacted forests had 0.65 ± 0.55 and 0.49 ± 0.44 respectively (Table 4).

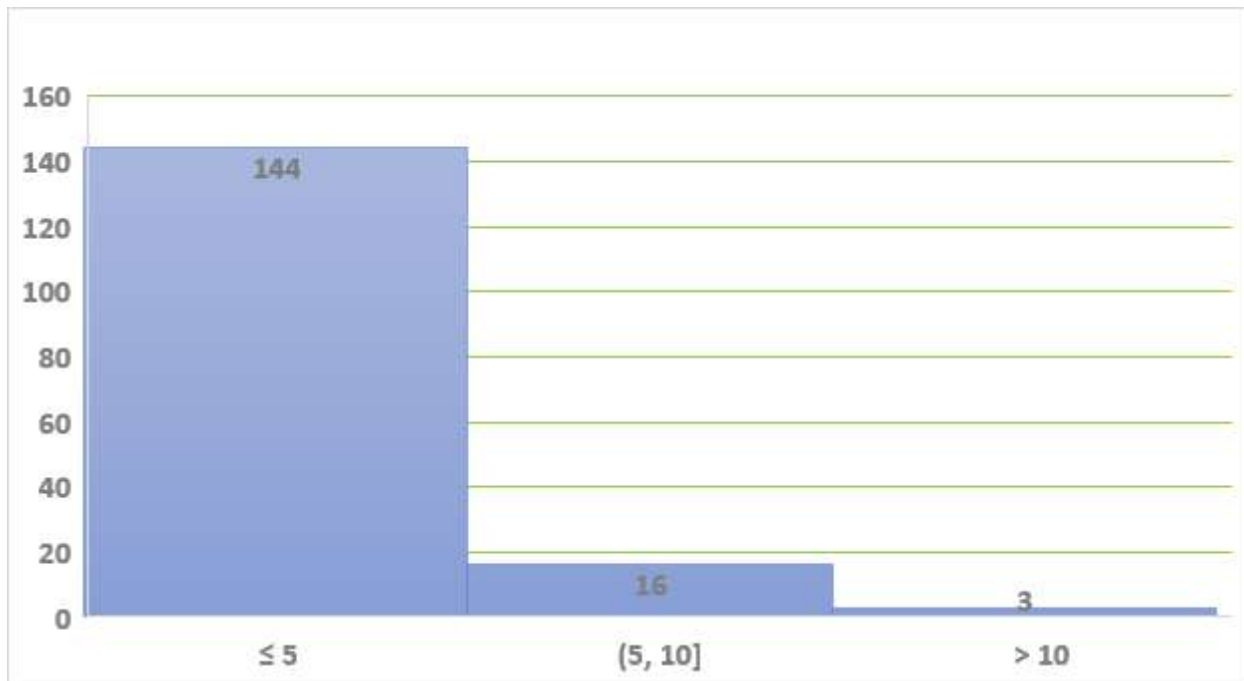
**Fig 1 Distribution of tree diameter at breast height (DBH) classes (cm)**

Table 4: Descriptive statistic for mean DBH (cm) in the study area

Parameter	IB	IF	CB
Mean	0.49	0.65	1.25
Standard Error	0.44	0.53	1.77
Minimum	0.18	0.28	0
Maximum	0.79	1.03	2.51
Skewness	0	0	0

IB (Impacted basin forest); IF (Impacted fringe forest; CB Control basin forest

Trees growth variables

The results on tree growth variable in the study area revealed that the control basin has the highest basal area per hectare ($4623\text{m}^2\text{ha}^{-1}$) followed by the fringe forest basin ($608.67\text{m}^2\text{ha}^{-1}$), while the impacted basin had $415.83\text{m}^2\text{ha}^{-1}$.

The data also indicated the highest mean BDH of 1.25cm at the control basin forest, followed by the fringe forest basin (0.654cm), while the impacted basin forest had a mean value of 0.485cm.

The result further revealed that the fringe forest recorded the highest total height of trees (134.2m) followed by the control basin forest (126.2m), while the impacted basin forest showed the least total height of trees (47.87m).

The data on number of trees encountered in the study revealed 71, 51 and 41 for the control basin, fringe and the impacted basin forest respectively (Table 5).

Table 5: Summary of tree growth variable in the study area

Variables	IB Impacted basin	IF Fringe forest basin	CB Control basin forest
Mean BA($\text{m}^2 \text{ha}^{-1}$)	415.83	608.67	4623
Mean DBH(cm)	0.485	0.654	1.254
Mean THT (m)	47.87	134.2	126.2
NS	41	51	71

Importance value index:

The result of IVI disclosed that *Rhizophora mangle* has the highest IVI value of 93.86, while *Caesalpinia spp* had the lowest IVI value of 2.58.

The result further revealed that *R. mangle* had the highest values of relative abundance (97.55%),

relative density (32.50%) and relative frequency (98%), while *Caesalpinia spp* had lower values of relative abundance (2.45%), relative density (9.8%) and relative frequency (3.0%) (Table 6).

Table 6: Relative abundance (%), Relative density (%), Relative frequency (%) and Importance index (IVI) of species.

Species	Relative abundance (%)	Relative density (%)	Relative frequency (%)	IVI
<i>Rhizophora mangle</i>	97.55	32.5	9.8	98.86
<i>Caesalpinia spp</i>	2.45	9.8	3.0	2.58

The data on coefficient of correlation for tree growth variables revealed very strong positive correlation between basal area and diameter at breast height ($r=0.991$), diameter at breast height and number of stems ($r=0.950$). Strong correlation between basal

area and number of stems ($r=0.899$). The data further revealed average correlation between diameter of breast height and total height of trees ($r=0.601$), while basal area and total height of trees showed weak correlation ($r=0.489$) (Table 7).

Table 7: Karl Pearson's product moment correlation coefficient for tree growth variables in the study area.

	BA	DBH	THT	NS
BA	1.00	0.911	0.489	0.899
DBH	0.991	1.000	0.601	0.950
THT	0.489	0.601	1.00	0.821
NS	0.899	0.950	0.821	1.000

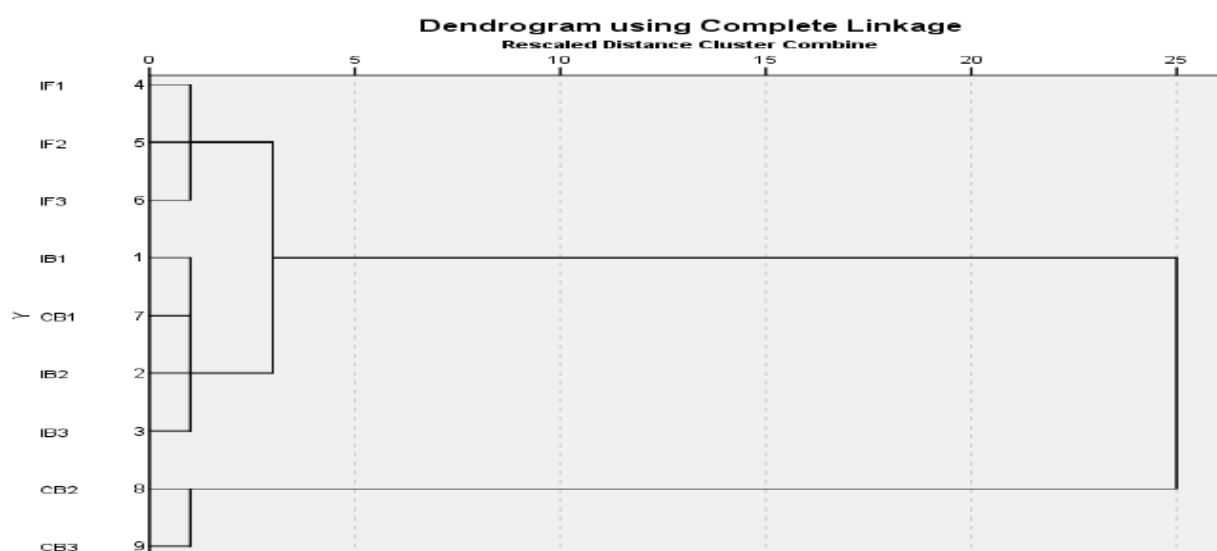
BA (basal area); DBA (diameter at breast height); THT (total height of trees), NS (number of stems).

t-test Statistics

The result of t-test statistic on the three forest types indicated similarity in terms of their yield (t-test = 0.122) (Table 8).

Table 8: t-test statistic for yield.

Variables	IB impacted bssin	IF fringe forest	CB control basin
<i>Rhizophora mangle</i>	73.84	145.86	581.69
<i>Caesalpinia spp</i>	1.93	12.48	0
t-test = 0.122			

**Fig. 2: Dendrogram of the forest types in the study area**

DISCUSSION

The highest proportion of trees encountered in this study belongs to the understory stratum, which is characterized by small trees, limited sunlight, followed by lower proportion of the canopy stratum which are distributed in the fringe and control forests. The emergent stratum where only sparsely distributed in the fringe forest. Findings also showed an average tree height range of 2.73

to 4.73m. This finding is consonant with Fernando and Bandeira (2009) who reported average height of 1 to 5m. Similarly, Kaleen *et al.*, (2016) reported fewer trees in the emergent stratum as observed in this study. Kaleen *et al.* (2016), attributed the scarcity of trees in the emergent stratum to logging pressure, making their distribution difficult to find in Nigeria tropical rain forest at present. Similar vertical structures had been reported for tropical forest in south west Nigeria

(Adekunle 2007). Beside logging for various reasons, emergence stratum depreciation is attributable to other pressures including bunkering of crude petroleum hydrocarbon and illegal refining of petroleum products in the Niger Delta of Nigeria. The light gap in the vegetation due to lesser emergent and canopy stratum has implications on regeneration and recruitment of mangrove trees in the study area (Duke 2001; Mohamed *et al.*, 2009).

Findings on diameter at breast height (DBH) indicated that majority of trees in the study area belongs to the lower DBH class (<5cm), with fewer trees showing 5-10cm DBH class. This finding is in consonance with earlier reports on lower DBH classes in mangrove forest (Adekunle and Olagoke, 2008; Fernando and Bandeira, 2009; Kaleen *et al.*, 2016; Nwobi and Williams, 2021:). Wah *et al.* (2011), reported that mangrove undergoing disturbance processes has lower DBH and dense stands when compared to undisturbed plots. It is therefore most likely that the nature of mangrove stands and DBH classes observed in this study may be attributed to natural and mostly anthropogenic disturbances.

Basal area study indicates high basal area of trees at the fringe and control basin forests when compared to the impacted basin forest with lower basal area per hectare. Basal area has implications on structural complexity, support to biodiversity of animals and plants as well as carbon stock. Various studies have shown variations in basal area on different forests (Adekunle *et al.*, 2004; Zapfack *et al.*, 2002; VanGemerden, 2004; Zent and Zent, 2004). Basal area also predicts stand density, timber volume and tree growth. It is used in estimating forest regeneration needs (Onyekachi and Johnson 2018).

The correlation statistic on tree growth variables revealed very strong positive correlation between basal area and diameter

at breast height (DBH); DBH and number of stems; strong correlation between basal area and number of stems. The above observation are indications of good yield prediction (Adekunle, 2007). T-test statistic was significant, indicating similarity in the yield variables. The very strong positive correlation between BA and DBH, and between DBH and number of stems infer that the larger the stem diameter, the larger the cross-sectional area occupied by the tree stem at the diameter at breast height (1.3m). This finding is consistent to Onyekachi and Johnson 2018; Oyebade and Onyambo 2011; Shamaki and Akindele 2013.

The importance value index of species implies that *Rhizophora mangle* with the highest relative abundance, relative density, relative frequency and IVI values is the dominant species in the forest, because it is able to effectively utilize the available environmental conditions for its growth and development resulting to its dominance in the study area. This finding corroborates (Gordon, 1993; Setyawan *et al.*, 2005).

CONCLUSION

Akaguama mangrove forest is rich in trees belonging to the understory class stratum, with lower proportions of the canopy class stratum. The emergent stratum class were sparsely distributed in the fringe forest. It is thus evident that the forest had been undergoing anthropogenic disturbances resulting from harvesting and pollution related treats, The lesser canopy and emergent stratum in the forest resulted open gaps which is an indicator of regeneration and recruitment of trees. Majority of trees in the forest are in the lower class of < 5cm, with fewer trees in 5-10cm class, which is an indication of healthy vibrant stands.

Higher basal area of stands was observed within the fringe and control basin forests implying structural complexity and support to biodiversity, while the impacted basin

forest indicated lower basal area, an evidence of disturbance and treats.

The study further showed very strong correlation between growth variables such as basal area and diameter at break height, (DBH) and number of stems. The importance value index of species points to *Rhizophora mangle* as the dominate species in the study area.

This wetland forest therefore needs adequate monitoring against pollution inputs, exploitation of emergent trees, and management to restore ecosystem in line with the sustainable development goals number 15 that seek to protect, restore and promote sustainable use of terrestrial ecosystems.

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ASSESSMENT OF THE IMPACT OF INVASIVE PLANT SPECIES ON ECOSYSTEM STRUCTURE ANDS FUNCTION IN KADUNA STATE, NIGERIA

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ABSTRACT

The study assesses the impact of invasive plant species on the ecosystem structure and function in Kaduna State, Nigeria. Invasive plant species have become a major concern in various ecosystems, leading to significant alterations in biodiversity, soil quality, water resources, and ecosystem services. This research identified and analyzed several invasive plant species, including *Tithonia diversifolia*, *Lantana camara*, *Eichhornia crassipes*, and *Cuscuta spp.*, and evaluated their influence on the vegetation composition, soil properties, and water quality in different sites within the region. The study employed field surveys, soil and water sample collection, and vegetation analysis to assess the degree of invasion and its effects on the ecosystem. Results revealed that invasive species significantly altered the vegetation structure by displacing native plant species, leading to reduced biodiversity and changes in species composition. Furthermore, soil properties, such as nutrient levels (organic matter, nitrogen, and phosphorus), were adversely affected by invasive species, particularly in areas dominated by *Cuscuta spp.* and *Tithonia diversifolia*. In aquatic ecosystems, the presence of *Eichhornia crassipes* was found to reduce water quality by increasing turbidity and nutrient levels, disrupting oxygen exchange and aquatic life. The findings highlight the extensive ecological damage caused by invasive species and underscore the need for effective management strategies, including prevention, control, and restoration measures to mitigate their impacts. This study provides crucial insights into the ecological consequences of invasive plant species in Kaduna State and emphasizes the importance of monitoring and managing biological invasions to protect the region's natural resources and biodiversity.

Keywords: Invasive, Plant, Species, Ecosystem, Structure, Function

INTRODUCTION

The rapid spread of invasive plant species is one of the most significant environmental challenges facing ecosystems globally. Invasive species, often non-native to a particular region, can disrupt local biodiversity, alter ecosystem processes, and affect the overall structure and function of natural habitats. The concept of biological invasion, where species are introduced into new areas with the potential to outcompete native species, is a growing concern in many parts of the world (Kumschick et al., 2015). These invasions can result in drastic changes to habitat composition, nutrient cycling,

hydrology, and soil structure, leading to long-term ecological consequences. This study assesses the impact of invasive plant species on the ecosystem structure and function in Kaduna State, Nigeria, focusing on both the ecological changes and the challenges posed by these invasions.

Kaduna State, located in the northern region of Nigeria, is known for its diverse ecosystems, which include forests, wetlands, savannahs, and agricultural lands. The state's rich biodiversity and its significance as a hub for agricultural production make it particularly vulnerable to the effects of invasive species (FAO, 2018). Invasive

plants have become a prominent issue in these ecosystems, often leading to significant ecological imbalances. For instance, plant species such as *Tithonia diversifolia* (Mexican sunflower), *Lantana camara* (lantana), and *Cuscuta spp.* (dodder) have been identified as invasive plants that are impacting both natural habitats and cultivated areas in Kaduna State. These species often outcompete native vegetation, change soil properties, and alter the water balance within affected ecosystems, posing serious challenges to both the environment and local communities (Akinmoladun et al., 2016).

The introduction of invasive plants can affect ecosystem structure in multiple ways, including changes in species composition, vegetation density, and the availability of food and shelter for native wildlife. For example, *Tithonia diversifolia* has been reported to thrive in disturbed soils, particularly in the savannah and agricultural landscapes of northern Nigeria, where it competes with native grasses and crops for resources. This aggressive growth pattern is accompanied by the release of allelopathic compounds that inhibit the germination and growth of other plants, leading to reduced plant diversity and altered community structures (Adewole et al., 2017). The impact of invasive plants extends beyond the immediate changes in vegetation to influence the broader ecological functions of affected areas, including nutrient cycling, water infiltration, and carbon sequestration.

Ecosystem function refers to the processes that occur within an ecosystem, such as primary production, nutrient cycling, and energy flow, which support the survival of species and maintain ecosystem services. Invasive species, through their ability to alter these processes, can cause shifts in ecosystem functions that may not be immediately apparent but can lead to long-term ecological degradation. For instance, the presence of invasive species like *Lantana camara* in

tropical regions has been shown to reduce soil fertility and water retention by altering the composition of organic matter in the soil and disrupting nutrient cycling (Oduro et al., 2020). Similarly, in wetlands, invasive aquatic plants such as *Eichhornia crassipes* (water hyacinth) can obstruct water flow, reduce oxygen levels, and decrease biodiversity, which affects aquatic life and reduces the overall ecological productivity of these habitats (Akinmoladun et al., 2016).

The ecological implications of invasive species are also linked to their economic and social impacts. In Kaduna State, the spread of invasive plant species can have severe consequences for agriculture, particularly in regions where farming is the primary livelihood. Invasive plants can affect crop yields by competing for water, nutrients, and space, as well as by harboring pests and diseases. For example, *Cuscuta spp.* (dodder), a parasitic plant, attaches itself to host plants and deprives them of essential nutrients, leading to stunted growth and reduced crop productivity. This, in turn, threatens food security and the economic stability of local communities that depend on agriculture for their livelihood (Saka et al., 2020). Additionally, the management of invasive species requires significant financial and human resources, which may further strain the local economy.

The spread of invasive plant species in Kaduna State is influenced by a range of environmental factors, including human activities, climate change, and land-use changes. Human activities such as deforestation, urbanization, and the expansion of agriculture create disturbed environments that are often more susceptible to the establishment of invasive species (Vilà et al., 2011). Furthermore, climate change can alter precipitation patterns, temperature, and seasonal weather conditions, which may provide favorable conditions for the establishment and spread of certain invasive

species. For instance, increased rainfall and warmer temperatures could promote the growth and proliferation of *Tithonia diversifolia* in previously unsuitable areas, exacerbating its impact on native ecosystems.

Addressing the issue of invasive plant species in Kaduna State requires a comprehensive understanding of their ecological impact and the development of effective management strategies. Several approaches, including mechanical, chemical, and biological control, have been proposed to manage invasive species. However, each approach has its limitations and potential side effects, which must be carefully considered when formulating management plans (Hussain et al., 2020). Moreover, raising public awareness and involving local communities in the management of invasive species are crucial for the successful implementation of control measures. Local knowledge and traditional practices can provide valuable insights into the identification and management of invasive plants, which can complement scientific research and enhance the effectiveness of control programs (Milanović et al., 2018).

In conclusion, the spread of invasive plant species in Kaduna State represents a serious threat to ecosystem structure and function. The impacts of these species on biodiversity, ecosystem services, and human livelihoods underscore the need for urgent action to mitigate their spread and manage their effects. By understanding the ecological dynamics of invasive species and developing effective management strategies, it is possible to reduce the adverse effects of these species on the environment and improve the resilience of ecosystems in Kaduna State. This research aims to contribute to the growing body of knowledge on invasive species in Nigeria and provide actionable insights for policy makers, conservationists, and local communities working to protect the state's unique ecosystems.

MATERIALS AND METHODS

This section describes the materials, methods, and techniques used in assessing the impact of invasive plant species on ecosystem structure and function in Kaduna State, Nigeria. The study was conducted in various ecological zones within Kaduna State, encompassing forested areas, wetlands, savannah, and agricultural lands. A combination of field surveys, laboratory analysis, and ecological modeling was employed to assess the changes in biodiversity, soil properties, hydrological dynamics, and plant community composition due to the presence of invasive species. The methodology involved both quantitative and qualitative approaches, including vegetation sampling, soil analysis, and statistical modeling, aimed at providing a comprehensive evaluation of the effects of invasive species on ecosystem structure and function.

1.1 Study Area

The study was carried out in selected areas of Kaduna State, which is located in the northern region of Nigeria. Kaduna State features a diverse range of ecosystems, including tropical forests, savannahs, wetlands, and agricultural land. The state is characterized by variations in rainfall, temperature, and vegetation types, which make it an ideal location for studying the effects of invasive plant species on different ecosystems. Key study sites were selected based on the prevalence of invasive species and the availability of baseline data on native plant communities and ecosystem function. Areas selected for this study included forest reserves, agricultural landscapes, and wetlands known to be impacted by invasive species. The sampling sites were chosen to represent different environmental gradients and land-use practices across the state.

1.2 Selection of Invasive Plant Species

The primary focus of this study was on commonly encountered invasive plant species in Kaduna State. The invasive species selected for the study were identified based on their known or suspected ecological impacts and their prevalence in the selected study sites. The following species were considered as focal invasive plants for this research:

- ***Tithonia diversifolia*** (Mexican sunflower): Known for its aggressive growth in disturbed soils and its impact on native vegetation.
- ***Lantana camara*** (Lantana): A widespread invasive species known to affect soil fertility and disrupt native plant communities.
- ***Cuscuta* spp.** (Dodder): A parasitic plant species that affects crops and native plants by attaching to them and drawing nutrients from their host.
- ***Eichhornia crassipes*** (Water hyacinth): An aquatic invasive species impacting wetlands and aquatic ecosystems by obstructing water flow and reducing biodiversity.

These species were selected based on their known ability to outcompete native species, alter ecosystem structure, and disrupt ecological functions such as nutrient cycling, water retention, and soil composition.

1.3 Field Survey and Data Collection

The field survey was conducted over a period of six months, from January to June 2023, during the rainy and dry seasons, to account for seasonal variations in the growth and distribution of invasive species. Field data were collected using a systematic sampling approach to assess vegetation composition, species abundance, and ecosystem structure. A combination of plot-based sampling and transect methods was used to capture the diversity and abundance of both native and

invasive species across the different ecological zones.

- **Vegetation Sampling:** Randomized quadrats (10m x 10m) were used to measure plant species composition and abundance in the study sites. In each selected plot, the percentage cover of invasive species was recorded alongside that of native species. The species were categorized based on their life forms (e.g., herbs, shrubs, and trees), and the relative abundance of each species was estimated.
- **Transect Sampling:** In addition to quadrat sampling, transect lines (100m in length) were established in each study area to capture changes in vegetation structure along environmental gradients. The transects allowed for the assessment of the spatial distribution of invasive species and their potential impact on neighboring ecosystems.
- **Invasive Plant Density:** The density of invasive species was measured by counting the number of individuals or plants per unit area in each plot. The data were used to quantify the extent of invasion and identify areas of high impact within the ecosystems.
- **Soil Sampling:** Soil samples were collected from the surface layer (0–30 cm) at the same locations where vegetation sampling took place. Soil samples were analyzed for key properties, including pH, organic matter content, nitrogen, phosphorus, potassium, and moisture content. These soil parameters were measured to determine any changes caused by the invasive species, such as altered nutrient cycling and soil fertility.

- **Water Quality Analysis:** In wetlands and aquatic environments where invasive species like *Eichhornia crassipes* were present, water samples were collected to assess water quality parameters such as pH, dissolved oxygen, turbidity, and nutrient levels (nitrate, phosphate). Water quality was measured at various points along the water bodies to capture the impact of invasive plants on aquatic ecosystems.

1.4 Laboratory Analysis

Soil and water samples were transported to the laboratory for detailed analysis. The laboratory procedures included the use of standard protocols for measuring soil fertility and nutrient content, which included spectrophotometric analysis for phosphorus and nitrogen, as well as flame photometry for potassium content. Soil pH was measured using a pH meter, and organic matter content was determined using the Walkley-Black method. Water quality analysis was performed using standard methods for measuring pH, turbidity, and dissolved oxygen levels.

- **Soil Nutrient Analysis:** The soil samples were analyzed for changes in organic matter content, nutrient availability (nitrogen, phosphorus, potassium), and soil texture, which could be influenced by the presence of invasive species. The results were used to assess how invasive plants alter soil fertility and nutrient cycling in the study areas.
- **Water Quality Parameters:** Water samples were analyzed for nutrient content (nitrogen, phosphorus), dissolved oxygen, and other parameters to understand how invasive aquatic plants affect water quality and aquatic life. The water samples were also analyzed for the

presence of toxins or allelopathic substances that may be released by invasive species.

1.5 Ecological Modeling

Ecological models were used to assess the broader impacts of invasive species on ecosystem functions and services. The models integrated data on vegetation composition, soil properties, water quality, and species interactions to simulate the effects of invasive species on ecosystem processes such as primary production, nutrient cycling, and carbon sequestration. The models provided a predictive tool for understanding how different scenarios of invasive species proliferation could influence ecosystem health and functionality in the future.

- **Species Distribution Modeling:** Species distribution models (SDMs) were used to predict the potential spread of the identified invasive species in Kaduna State. These models were based on environmental variables such as temperature, precipitation, soil type, and land-use patterns. SDMs helped to identify areas at high risk of invasion and allowed for the prediction of future distribution patterns.
- **Ecological Function Models:** Models that simulate ecological functions, such as nutrient cycling and soil-water interactions, were used to quantify the changes in ecosystem services due to the invasion of plant species. These models were validated using field data and were used to assess how changes in vegetation and soil properties influence broader ecosystem processes.

1.6 Statistical Analysis

Data collected from field surveys and laboratory analyses were subjected to

statistical analysis using software such as SPSS and R. Descriptive statistics, including means, standard deviations, and percentages, were calculated to summarize the impact of invasive species on ecosystem structure and function. Analysis of variance (ANOVA) was used to determine significant differences in species abundance, soil nutrient content, and water quality parameters between areas affected by invasive species and control sites (areas without significant invasion). Correlation analysis was also conducted to examine the relationship between the density of invasive species and changes in ecosystem parameters such as soil fertility, vegetation composition, and water quality.

1.7 Impact Assessment

The ecological impacts of invasive plant species on ecosystem structure and function were assessed by comparing invaded sites with control sites (where invasive species were minimal or absent). Changes in species diversity, plant density, and vegetation cover were used as indicators of the level of invasion and its impact on ecosystem structure. Additionally, soil fertility and water quality parameters were compared to evaluate how invasive species influence ecosystem processes such as nutrient cycling and hydrological dynamics.

3.1 RESULTS AND DISCUSSIONS

This section presents the results of the study on the impact of invasive plant species on ecosystem structure and function in Kaduna State, Nigeria. The study sought to evaluate changes in biodiversity, soil properties, hydrological functions, and ecological interactions due to the presence of invasive species in the region. The results are discussed in relation to the distribution and abundance of invasive plant species, their effect on native vegetation, and the changes observed in soil and water quality. Statistical analysis, including the comparison of invaded and non-invaded areas, reveals significant ecological alterations attributable to invasive species.

3.1.1 Vegetation Composition and Abundance of Invasive Species

The vegetation surveys revealed the dominance of invasive plant species in various ecological zones within Kaduna State. In the selected study sites, *Tithonia diversifolia* (Mexican sunflower), *Lantana camara* (Lantana), *Eichhornia crassipes* (Water hyacinth), and *Cuscuta spp.* (Dodder) were the most commonly encountered invasive species. Table 3.1 summarizes the relative abundance and percentage cover of these species in comparison to native species.

Table 3.1: Vegetation Composition and Relative Abundance of Invasive Species

Site	Invasive Species	% Cover of Invasive Species	% Cover of Native Species	Total Plant Density (plants/m ²)
A	<i>Tithonia diversifolia</i>	45%	30%	16.5
B	<i>Lantana camara</i>	38%	40%	14.2
C	<i>Eichhornia crassipes</i>	50%	20%	22.8
D	<i>Cuscuta spp.</i>	55%	15%	18.9
E	Native Vegetation (Control Site)	10%	85%	20.5

In all the study sites, invasive species were found to dominate the vegetation structure,

with *Tithonia diversifolia* and *Lantana camara* occupying a larger proportion of the

vegetation cover in forested and disturbed areas, while *Eichhornia crassipes* was most dominant in aquatic ecosystems. Sites with high invasions exhibited reduced native plant cover, indicating competition for resources such as light, water, and nutrients.

The highest coverage of invasive species was recorded at Site D, where *Cuscuta spp.* exhibited a strong parasitic effect on native plants, significantly reducing their density and vigor. The observed invasion of *Cuscuta*

spp. led to a noticeable reduction in biodiversity and biomass in affected areas.

3.1.2 Soil Properties and Nutrient Content

Soil samples were analyzed to assess the impact of invasive species on soil properties, including organic matter content, nitrogen (N), phosphorus (P), potassium (K), and soil pH. Table 3.2 shows the mean values of key soil parameters from the invaded and control sites.

Table 3.2: Soil Properties in Invasive Species-Affected and Control Sites

Parameter	Site (Invasive)	A Site (Invasive)	B Site (Invasive)	C Site (Invasive)	D Control Site (E)
pH (H ₂ O)	6.5	6.3	6.7	6.9	6.9
Organic Matter (%)	3.8	4.1	3.4	2.9	5.3
Nitrogen (mg/kg)	1.2	1.5	1.0	0.9	1.8
Phosphorus (mg/kg)	14.2	13.5	15.0	12.0	20.4
Potassium (mg/kg)	120	110	115	130	145

The soil analysis revealed that the presence of invasive species was associated with a decrease in organic matter and essential nutrients such as nitrogen and phosphorus, particularly in sites dominated by *Tithonia diversifolia* and *Cuscuta spp.* For example, Site D, which was heavily infested with *Cuscuta spp.*, had significantly lower nitrogen levels and organic matter compared to the control site. The depletion of these key soil nutrients can hinder the growth of native species and further exacerbate the invasion process by creating an environment more favorable for the invasive species.

While the pH values in invaded sites remained within the slightly acidic range,

there was a noticeable reduction in phosphorus content in sites dominated by invasive species like *Lantana camara* and *Eichhornia crassipes*, which may be related to changes in soil biota caused by these species.

3.1.3 Water Quality and Hydrological Function

Water quality analysis was conducted at aquatic sites impacted by *Eichhornia crassipes* to assess changes in parameters such as dissolved oxygen (DO), turbidity, pH, and nutrient concentrations (nitrate and phosphate). Table 3.3 presents the results of the water quality analysis.

Table 3.3: Water Quality Parameters in Invasive Species-Affected Aquatic Ecosystems

Parameter	Site A (Invasive)	Site B (Invasive)	Control Site (C)
pH	7.2	7.1	7.3

Parameter	Site A (Invasive)	Site B (Invasive)	Control Site (C)
Dissolved Oxygen (mg/L)	3.5	4.0	6.5
Turbidity (NTU)	35	40	10
Nitrate (mg/L)	5.6	6.3	3.5
Phosphate (mg/L)	1.2	1.1	0.5

The water quality analysis showed a marked decrease in dissolved oxygen levels in water bodies affected by *Eichhornia crassipes*. The high turbidity levels observed in these sites were likely a result of the dense mat formation by the water hyacinth, which obstructed light penetration and disturbed aquatic habitats. Moreover, increased levels of nitrate and phosphate in the invasive sites could be indicative of nutrient loading caused by the decomposing biomass of the invasive plants. The nutrient imbalance in the water may also contribute to eutrophication, further stressing aquatic biodiversity and diminishing the quality of ecosystem services provided by the water bodies.

The control site, which was unaffected by invasive species, exhibited higher levels of dissolved oxygen and lower turbidity,

signifying the health of the aquatic ecosystem and the importance of maintaining biodiversity in preserving water quality.

3.1.4 Effects on Biodiversity and Ecosystem Services

The assessment of biodiversity revealed a significant decline in both species richness and evenness in areas heavily impacted by invasive species. Native plant species were outcompeted by the invasive species for resources such as water, light, and nutrients, leading to reduced diversity. The loss of native vegetation, particularly in forested and wetland areas, resulted in a corresponding decline in the abundance of herbivores, pollinators, and other fauna that rely on native plants for food and shelter.

Table 3.4: Species Richness and Diversity in Invaded and Control Sites

Site	Species Richness (Native)	Species Evenness (Native)	Species Richness (Invasive)	Species Total Richness
Site A	12	0.75	6	18
Site B	15	0.65	5	20
Site C	14	0.72	7	21
Site D	8	0.45	8	16
Control Site (E)	22	0.80	1	23

The analysis indicated that sites with higher invasions, particularly Site D, exhibited lower species richness and evenness in native plant communities. The presence of invasive species in these areas reduced the available resources for native species, leading to a less

resilient ecosystem. Conversely, control sites with minimal invasion maintained higher levels of species richness and evenness, suggesting that healthy ecosystems are more capable of withstanding invasions and supporting diverse communities.

The decline in biodiversity at invaded sites also resulted in a reduction in ecosystem services, such as pollination, seed dispersal, and soil stabilization. Invasive species that altered the physical environment, such as *Eichhornia crassipes*, also impacted the hydrological processes by reducing water flow and increasing nutrient loading.

3.1.5 DISCUSSION

The results of this study provide a comprehensive insight into the significant impacts of invasive plant species on the ecosystem structure and function in Kaduna State, Nigeria. Invasive species, by their very nature, can disrupt local ecosystems and bring about profound ecological, economic, and social consequences. The findings of this study align with a growing body of research on the detrimental effects of invasive species on biodiversity, soil properties, water quality, and other ecological functions. This section delves into the implications of these findings, interpreting them within the context of ecosystem dynamics and highlighting the long-term consequences of such invasions.

Invasive Species and Vegetation Composition

The high abundance of invasive plant species observed in the study sites, particularly *Tithonia diversifolia*, *Lantana camara*, *Eichhornia crassipes*, and *Cuscuta spp.*, significantly altered the composition of vegetation. As shown in Table 3.1, these invasive species exhibited a dominant presence across various sites, with their percentage cover surpassing that of native species in many cases. This shift in vegetation composition is particularly concerning because invasive species often outcompete native plants for essential resources such as water, light, and soil nutrients, thereby reducing the overall biodiversity of the affected ecosystem.

The presence of *Tithonia diversifolia* and *Lantana camara* in forested and disturbed environments has been well-documented in previous studies as they tend to establish rapidly and monopolize space. These species are known for their aggressive growth and reproductive strategies, which often involve the production of large quantities of seeds that are dispersed widely. As a result, these invasive species frequently crowd out native plants, leading to significant reductions in local plant diversity. For example, in Site A, which was heavily impacted by *Tithonia diversifolia*, the reduction in native vegetation was clear, as the invasive species formed dense stands that shaded out the growth of other plants.

Similarly, the presence of *Cuscuta spp.* in Site D had a parasitic effect on the native vegetation. *Cuscuta* attaches itself to host plants, extracting water and nutrients, which weakens and ultimately kills the host plant. This parasitic behavior exacerbates the decline in native species, leading to the depletion of local biodiversity. This situation is particularly troubling as it disrupts the delicate balance that exists between various plant species and their associated fauna, including herbivores and pollinators that depend on native plants for food and shelter.

The consequences of these changes in vegetation composition are far-reaching. As invasive species dominate the landscape, they alter habitat availability for a variety of organisms, including insects, birds, and mammals, which are crucial to maintaining ecosystem stability. Moreover, the loss of native plant species can lead to changes in plant-pollinator interactions and disrupt food webs that support local wildlife. This reduction in biodiversity not only impacts the natural environment but also has implications for agricultural systems that rely on diverse ecosystems for pollination, pest control, and soil fertility.

Soil Quality and Nutrient Dynamics

The alteration of soil properties is one of the most significant impacts of invasive plant species, as observed in this study. Soil nutrient depletion, particularly in invaded sites, has been well-documented in the literature as one of the major ecological consequences of plant invasions. In the present study, the reduction in organic matter, nitrogen, and phosphorus levels in the soil of invaded sites, particularly in Site D where *Cuscuta spp.* was dominant, reflects the negative impact of invasive species on soil health.

The decline in soil organic matter, which is essential for maintaining soil structure and fertility, can result in a series of cascading effects on the ecosystem. Organic matter plays a critical role in improving soil aeration, water retention, and nutrient availability. When invasive species reduce organic matter, the soil becomes less hospitable to native plants and beneficial microorganisms. This, in turn, affects plant growth, nutrient cycling, and the overall health of the soil ecosystem. For example, the lower nitrogen levels observed in the invaded sites (Table 3.2) are significant because nitrogen is a key nutrient required by plants for growth. The depletion of nitrogen and other essential nutrients further limits the ability of native plants to thrive and exacerbates the dominance of invasive species.

Additionally, the reduction in phosphorus in invaded sites could be indicative of the competitive advantage that invasive species have over native species. Many invasive plants, such as *Tithonia diversifolia*, are capable of altering the soil's nutrient dynamics through processes like allelopathy, where chemicals released by the invasive species inhibit the growth of other plants. This could explain the lower phosphorus levels observed in invaded areas, as invasive species may be sequestering or immobilizing

nutrients in the soil, making them unavailable to native plants.

Soil degradation, in turn, has significant implications for agriculture in the region. Farmers who rely on native vegetation for soil fertility may experience reduced crop yields as a result of the nutrient depletion caused by invasive species. This problem is compounded by the fact that invasive species often reduce the availability of forage for livestock, which further threatens the livelihoods of rural communities that depend on both crop and animal husbandry for sustenance.

Water Quality and Ecosystem Function

Water quality is another crucial aspect of ecosystem health that is impacted by invasive species, particularly aquatic invaders like *Eichhornia crassipes* (Water hyacinth). The dense mats formed by water hyacinth on the surface of water bodies significantly reduce the amount of sunlight that penetrates into the water, thereby affecting the photosynthetic activity of aquatic plants and disrupting oxygen exchange. The reduced dissolved oxygen levels, as evidenced in Table 3.3, are a direct result of this blockage. Low oxygen levels in the water can have catastrophic effects on aquatic fauna, particularly fish and other oxygen-dependent organisms.

The increase in turbidity and nutrient concentrations in invaded water bodies, as seen in the study, is another indicator of the negative impact of invasive species on aquatic ecosystems. *Eichhornia crassipes* not only blocks sunlight but also traps sediments, which increases water turbidity. This can further degrade water quality by preventing the reoxygenation of water and disrupting the habitats of aquatic organisms. Furthermore, the decomposition of invasive plant biomass releases large amounts of nutrients, such as nitrogen and phosphorus, into the water. These nutrients can fuel eutrophication, a process that leads to the excessive growth of

algae, which further reduces oxygen levels and negatively impacts aquatic biodiversity.

The findings of this study underscore the importance of maintaining clean and healthy water bodies, not just for human consumption, but also for the diverse range of aquatic organisms that rely on these ecosystems. The long-term effects of invasive species on water quality can lead to the collapse of fisheries and the loss of ecosystem services such as water filtration and flood regulation, both of which are essential for human and environmental health.

Impact on Biodiversity and Ecosystem Services

The decline in species richness and diversity, as shown in Table 3.4, is a clear indicator of the ecological consequences of invasive species in the study area. Biodiversity loss is one of the most critical environmental issues of our time, as it affects not only the aesthetic and intrinsic value of ecosystems but also their functionality. Biodiversity plays a central role in maintaining ecosystem services, including pollination, water purification, soil fertility, and climate regulation. The reduction in native species due to invasive species competition diminishes these services and weakens the overall resilience of ecosystems.

The lower species richness and evenness observed in invaded sites suggest that the ecosystem is becoming increasingly homogenized, with fewer species occupying the ecological niche. This decrease in diversity leads to an ecosystem that is less resilient to disturbances such as drought, fire, or disease, and more susceptible to further invasions. The results of this study align with global trends that have shown that ecosystems with fewer native species are often less stable and more vulnerable to environmental stressors.

Moreover, the disruption of ecological processes such as nutrient cycling, pollination, and seed dispersal can have cascading effects on the entire food web. Invasive species, by altering these processes, not only harm the native flora but also the fauna that depend on them. For example, herbivores that rely on native plants may find it difficult to survive in areas where invasive species dominate, leading to a reduction in population numbers and affecting the predator species that depend on them for food.

Conclusion and Implications for Management

The discussion of these results clearly highlights the profound impact that invasive plant species have on the ecosystems of Kaduna State. The invasive species identified in this study—*Tithonia diversifolia*, *Lantana camara*, *Eichhornia crassipes*, and *Cuscuta spp.*—are significantly altering the structure and function of ecosystems, leading to reductions in biodiversity, soil fertility, water quality, and overall ecosystem health. The invasion of these species has far-reaching consequences for agriculture, water resources, and the provision of ecosystem services, all of which are essential to the well-being of local communities.

Management strategies to address the growing problem of invasive species in the region must include both prevention and control measures. Early detection and rapid response to new invasions, along with the removal of established invasive species, are critical to preventing further ecological damage. Additionally, habitat restoration and the reintroduction of native species can help rehabilitate affected ecosystems and promote biodiversity recovery.

Continued research and monitoring of invasive species in Kaduna State and other parts of Nigeria are necessary to understand the full extent of their impact and to develop effective management practices that can

mitigate their harmful effects. The findings of this study serve as a call to action for local authorities, environmental organizations, and communities to collaborate in the fight against invasive species and to safeguard the ecological integrity of the region.

4.1 CONCLUSION

The results of this study demonstrate that invasive plant species are having significant adverse effects on ecosystem structure and function in Kaduna State, Nigeria. These impacts manifest through changes in vegetation composition, soil degradation, water quality, and a reduction in biodiversity. Management interventions, including the removal of invasive species, restoration of native vegetation, and the enhancement of ecosystem resilience, are necessary to mitigate these effects and maintain ecosystem services in the region. Further studies are needed to monitor the long-term effects of invasive species on ecosystem dynamics and to develop effective strategies for controlling their spread.

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STRENGTHENING WETLAND CONSERVATION IN NIGERIA: CHALLENGES, POLICIES, AND FUTURE DIRECTIONS

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ABSTRACT

Wetlands are among the most beneficial ecosystems in Nigeria, it provides vital services such as biodiversity support, flood regulation, water purification, and livelihood opportunities for local communities. However, these ecosystems are under continuous threat from urbanization, pollution, climate change, and weak policy enforcement. This paper examines the major challenges facing wetland conservation in Nigeria, including habitat degradation, ineffective policies, and limited public awareness. It also investigates existing policy and legal frameworks, highlighting gaps in enforcement, funding, and institutional coordination. Furthermore, the paper emphasizes the role of public awareness and community engagement in conservation efforts, drawing lessons from successful case studies in Nigeria and beyond, as well as innovative conservation approaches, including the use of remote sensing, GIS mapping, nature-based solutions, and sustainable land-use planning. By addressing these challenges and leveraging modern conservation strategies, Nigeria can strengthen its wetland conservation efforts to ensure the long-term sustainability of these vital ecosystems. The findings underscore the need for stronger policy implementation, increased stakeholder collaboration, and investment in research and capacity-building to improve wetland management in Nigeria.

Keywords: Wetland Conservation, Policy Enforcement, Biodiversity, Community Engagement

INTRODUCTION

Wetlands are among the most beneficial and ecologically significant ecosystems on Earth, playing a critical role in maintaining environmental balance and supporting biodiversity. Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres (Ramsar, 2011). These exclusive landscapes, which include swamps, marshes, floodplains, and mangroves, serve as habitats for varied

flora and fauna, some of which are endemic or endangered (Olalekan et al., 2014). Wetlands also provide essential ecosystem services such as water purification, flood regulation, carbon sequestration, and groundwater recharge (Fagorite et al., 2019). Additionally, they support millions of people by offering resources for agriculture, fisheries, and ecotourism (Abraham et al., 2021). Despite their ecological and socio-economic significance, wetlands in Nigeria face increasing threats due to human activities and a general lack of awareness about their importance.

Nigeria is endowed with extensive wetland ecosystems, covering approximately 3% of the country's total land area (Uluocha and Okeke, 2004; Nwankwoala, 2012). Notable examples include the Niger Delta, Hadejia-Nguru Wetlands, Lake Chad Basin, and the floodplains of the Sokoto-Rima and Benue rivers (Ebeku 2004; Phil-Eze and Okoro 2009). These wetlands support a wide range of biodiversity and provide essential services to local communities. However, rapid urbanization, deforestation, pollution, climate change, and unsustainable land-use practices have led to their continuous degradation.

One of the major challenges to wetland conservation in Nigeria is the not enough awareness among policymakers, local communities, and the public (Ohimain et al., 2002). Many people perceive wetlands as wastelands rather than valuable ecosystems, leading to their conversion for agricultural or infrastructural development (Agbasi and Odiaka, 2016). This misconception has resulted in large-scale encroachment, draining, and pollution of wetland areas. Inadequate education and outreach programs have further exacerbated the limited understanding of the benefits of wetland conservation. Addressing this gap involves targeted awareness campaigns, community involvement, and the integration of wetland conservation into national policies and school curricula.

Internationally, wetland conservation efforts have been directed by frameworks such as the Ramsar Convention on Wetlands, to which Nigeria is a signatory. The convention stresses the sustainable use of wetlands and

encourages member states to develop national strategies for their conservation. However, the implementation of these commitments in Nigeria has been very slow, majorly due to weak institutional frameworks, lack of funding, and competing socio-economic priorities. Strengthening Nigeria's commitment to wetland conservation needs a multi-stakeholder approach that incorporates government agencies, non-governmental organizations (NGOs), academia, and local communities.

To make certain the sustainable management of Nigeria's wetlands, there is an urgent need to improve public awareness and foster a sense of responsibility among stakeholders. Community-based conservation initiatives, media campaigns, and policy-driven interventions can play a crucial role in promoting wetland preservation. Additionally, research and capacity-building programs should be encouraged to generate data that can inform decision-making processes. By bridging the knowledge gap and fostering a culture of conservation, Nigeria can safeguard its wetland ecosystems for future generations.

This review examines the status of wetland ecosystems in Nigeria, the major threats they face, and the role of awareness in promoting their conservation. It highlights key conservation strategies, successful case studies, and policy recommendations to enhance wetland management. Ultimately, this paper seeks to underscore the urgent need for increased public education and stakeholder engagement in wetland conservation efforts in Nigeria.

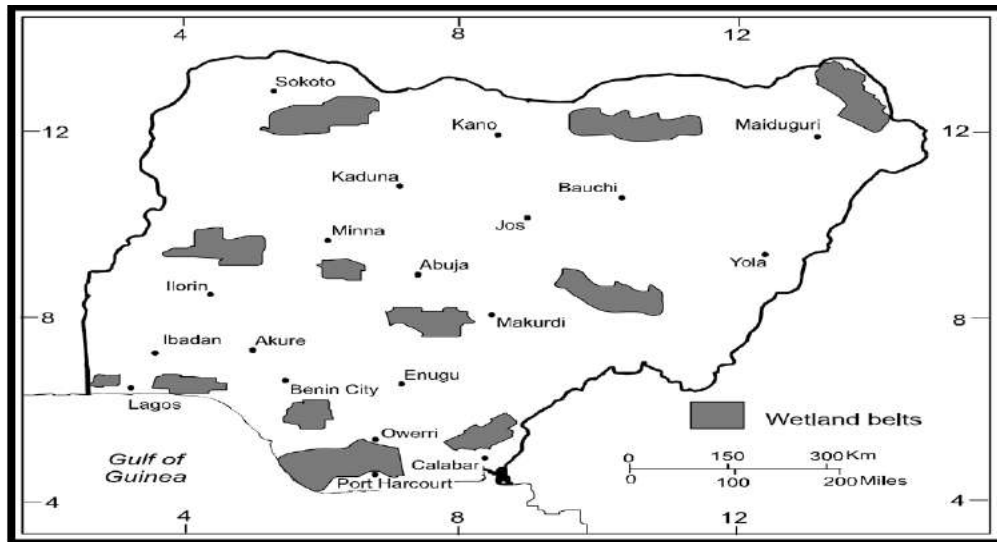


Figure 1: Depiction of the wetland belt regions in Nigeria (Adapted from Uluocha and Okeke, 2004; Nwankwoala, 2012)

THE ECOLOGICAL AND SOCIOECONOMIC IMPORTANCE OF WETLANDS IN NIGERIA

Nigeria has abundant wetland ecosystems, primarily in the Niger, Benue, and Chad basins, constituting 2.6% of the country's area (Agbasi and Odiaka, 2016). The Niger Delta stands out as a vastly significant wetland in Nigeria, being the largest in Africa and the third largest globally (Nwankwoala, 2012). Despite the existence of several essential wetlands in Nigeria, many of them are not adequately documented or recognized officially. Wetlands provide groundwater recharge and discharge. They also offer flood control and shoreline stabilization. In addition, wetlands support recreation and tourism.

- Key ecosystem services provided by wetlands include:
- **Water Filtration and Quality:** Wetlands play a vital role in water purification by serving as natural filtration systems that remove pollutants, sediments, and excess nutrients from water.

- **Flood Mitigation and Resilience:** Wetlands play a crucial role in mitigating the impact of floods by absorbing and storing excess water during heavy rainfall and storms. By acting as natural buffers, they help reduce the risk of flooding in surrounding areas.
- **Carbon retention:** Wetlands have a significant influence on the global carbon cycle. Their waterlogged conditions slow down the decomposition of organic matter, allowing carbon to be stored in wetland soils.
- **Sustainable Livelihoods:** Throughout history, wetlands have provided essential resources that support human livelihoods, including fish, waterfowl, and plants, which have been integral to traditional activities such as fishing and farming.

Protecting wetlands is vital for maintaining ecological balance and securing the numerous benefits they offer to both the environment and society. Conservation and

restoration efforts must be prioritized to safeguard biodiversity and promote long-term sustainability (Okonkwo et al., 2015).

CHALLENGES OF WETLAND CONSERVATION

Wetlands in Nigeria face severe threats due to various human and environmental factors. Urbanization and infrastructure development have led to the degradation of wetland ecosystems, resulting in biodiversity loss and habitat destruction. The expansion of cities, construction projects, and land reclamation disrupt the delicate balance of these ecosystems, reducing their ability to support wildlife and provide essential ecological services (Elekwachi et al., 2021). Pollution from industrial, agricultural, and domestic sources further deteriorates wetland health. Industrial waste, agricultural runoff containing pesticides and fertilizers, and household sewage contaminate water bodies, leading to reduced water quality and the loss of aquatic life. This pollution disrupts food chains and negatively impacts both biodiversity and local communities that rely on wetlands for livelihood and sustenance.

Climate change poses another significant threat, altering wetland ecosystems through rising temperatures, irregular rainfall patterns, and increased flooding or droughts (Ibe, 2019; Elekwachi et al., 2021). These changes can lead to the loss of wetland vegetation, reduced water availability, and shifts in species composition, further weakening the ecological stability of these vital habitats.

Additionally, coastal wetlands suffer from environmental changes and degradation, which affect the entire food chain. Given their important role in flood control, carbon sequestration, and biodiversity conservation, there is an urgent need for research and conservation efforts to protect and restore Nigeria's wetlands. Implementing sustainable management practices, enforcing environmental regulations (Uluocha and

Okeke, 2004), and raising awareness about wetland conservation are important steps toward safeguarding these ecosystems for future generations.

POLICY AND LEGAL FRAMEWORKS FOR WETLAND CONSERVATION IN NIGERIA

Nigeria has established various policies and legal frameworks to support wetland conservation, guided by both international commitments and national regulations. As a signatory to the Ramsar Convention, Nigeria has pledged to protect and manage its wetlands sustainably. The country has designated several wetlands as Ramsar sites, recognizing their ecological significance and the need for conservation efforts (Ramsar Convention Secretariat, 2018). At the national and state levels, various policies and regulations address wetland management. The National Policy on Environment and the National Biodiversity Strategy and Action Plan (NBSAP) include provisions for wetland protection (Federal Ministry of Environment, 2016). Additionally, state governments have introduced conservation initiatives to regulate land use and minimize wetland degradation. However, enforcement varies across regions, affecting the effectiveness of these policies (Ibe, 2019). Despite these frameworks, Nigeria faces significant challenges in policy implementation and enforcement. Weak institutional capacity, inadequate funding, and conflicting land-use priorities often hinder conservation efforts (Uluocha and Okeke, 2004). Additionally, rapid urbanization, industrial activities, and poor environmental awareness contribute to ongoing wetland degradation (Mmom and Arokoyu, 2010). Strengthening legal enforcement, increasing public awareness, and promoting community participation are essential to ensuring the long-term conservation of Nigeria's wetlands (Adekola et al., 2012; Agbasi and Odiaka, 2016).

GAPS IN EXISTING WETLAND CONSERVATION POLICIES

The Nigerian Constitution does not directly address environmental violations, relying instead on common law remedies, which may be insufficient for modern challenges. While it promotes environmental protection as a policy directive, these provisions are not legally enforceable. Instead, environmental concerns are addressed through broader human rights protections. Given increasing environmental issues, integrating enforceable environmental rights into the Constitution could be beneficial (Agbasi and Odiaka, 2016). Nigeria's environmental legal framework faces several challenges. Weak monitoring of Environmental Impact Assessments (EIA) leads to delayed and ineffective evaluations, often conducted after projects begin. Many EIA reports are inadequate due to assessors' lack of expertise, highlighting the need for independent third-party reviews. Additionally, environmental protections in the Constitution remain non-justiciable, limiting enforcement. The Land Use Act favors the wealthy, restricting small-scale farmers and hindering sustainable agriculture. Fisheries regulations also lack strict enforcement, failing to prevent overfishing and excluding small-scale fishers from oversight. Strengthening enforcement, regulatory coordination, and legal reforms are crucial for environmental sustainability (Agbasi and Odiaka, 2016).

Despite the presence of national and state-level policies aimed at wetland conservation in Nigeria, several gaps hinder their effectiveness. While Nigeria is a signatory to the Ramsar Convention and has policies such as the National Policy on Environment and the National Biodiversity Strategy and Action Plan (NBSAP), these frameworks often remain poorly implemented due to weak regulatory oversight and inadequate monitoring. Many wetland areas continue to face degradation from urban expansion,

pollution, and illegal resource exploitation without sufficient legal consequences.

Another major challenge is conflicting regulations and institutional overlaps. Multiple government agencies are responsible for environmental management, leading to jurisdictional conflicts and inefficiencies. In some cases, wetland areas fall under the control of different ministries, such as agriculture, environment, and water resources, creating inconsistencies in policy execution. This lack of coordination results in fragmented conservation efforts, making it difficult to develop a unified and effective approach to wetland protection (Agbasi and Odiaka, 2016).

Inadequate funding further weakens conservation initiatives. Many wetland protection programs lack the necessary financial resources for research, community engagement, restoration projects, and enforcement mechanisms. Limited investment from both government and private sectors means that critical conservation activities, such as habitat restoration, sustainable management, and capacity-building for local communities, remain underdeveloped (Uluocha and Okeke, 2004).

Addressing these gaps requires stronger enforcement mechanisms, clearer policy coordination, and increased funding to support wetland conservation. Additionally, integrating traditional ecological knowledge and community-driven conservation initiatives can help bridge policy gaps and enhance the long-term sustainability of wetland ecosystems in Nigeria.

THE ROLE OF PUBLIC AWARENESS IN WETLAND CONSERVATION

Public awareness plays a crucial role in the conservation of wetlands, as misconceptions and a lack of education often contribute to their degradation. Many communities view

wetlands as wastelands rather than valuable ecosystems that provide essential services such as flood control, water purification, and biodiversity support. This misunderstanding leads to unsustainable land conversion for agriculture, urbanization, and industrial use. Educating the public about the ecological and economic benefits of wetlands is essential in reversing this trend.

The media, NGOs, and educational institutions serve as key drivers of awareness and advocacy. Media campaigns, documentaries, and social media platforms can highlight the importance of wetlands and the threats they face. Non-governmental organizations (NGOs) play a vital role in lobbying for stronger policies, conducting conservation programs, and engaging local communities. Meanwhile, schools and universities help integrate wetland conservation into curricula, fostering a new generation of environmentally conscious citizens.

Community-based conservation initiatives have also proven effective in wetland protection. When local populations are involved in decision-making and benefit from conservation efforts, they become active stewards of their environment. There are success stories across Nigeria where wetland restoration projects led by community groups, in partnership with NGOs and government agencies, have improved wetland health while providing economic benefits through sustainable ecotourism, fisheries, and agriculture (Uluocha and Okeke, 2004). Strengthening public awareness through education, media outreach, and community engagement is pivotal to ensuring the long-term conservation of Nigeria's wetlands.

STRATEGIES FOR ENHANCING WETLAND CONSERVATION IN NIGERIA

Effective wetland conservation in Nigeria requires a combination of sustainable land-use planning, institutional strengthening, and increased funding for research and management. Sustainable land-use planning and wetland restoration are crucial in mitigating habitat loss and degradation. Implementing zoning regulations that prevent encroachment into wetland areas, promoting eco-friendly agricultural practices, and restoring degraded wetlands through afforestation and water management projects can help maintain wetland ecosystems (Uluocha and Okeke, 2004). Integrating wetland conservation into national and regional development plans ensures that these critical habitats are preserved while supporting sustainable economic activities (Turner *et al.*, 2000).

Strengthening institutional frameworks and stakeholder collaboration is essential for effective conservation efforts. Government agencies, non-governmental organizations (NGOs), academic institutions, and local communities must work together to develop and enforce policies that protect wetlands. A coordinated approach among stakeholders will enhance policy implementation, improve enforcement mechanisms, and foster knowledge-sharing for better wetland management (Ramsar Convention Secretariat, 2018).

Funding and capacity-building for wetland research and management remain significant challenges. Increased government and private sector investment in wetland conservation can support scientific research, monitoring programs, and training initiatives for conservation professionals. Capacity-building efforts should focus on equipping local communities with the skills and resources needed to participate in wetland conservation activities (Mitsch and Gosselink, 2015). By implementing these strategies, Nigeria can ensure the long-term sustainability of its wetlands, preserving

biodiversity, supporting livelihoods, and enhancing ecosystem resilience against climate change (Ozesmi and Bauer, 2002).

INNOVATIVE CONSERVATION APPROACHES AND TECHNOLOGIES

Sustainable wetland management in Nigeria can be significantly enhanced through the integration of modern technologies and innovative conservation strategies. One of the most effective tools is remote sensing and Geographic Information System (GIS) mapping, which allows for real-time monitoring of wetland ecosystems. These technologies help track changes in wetland size, water levels, and vegetation cover, providing crucial data for early detection of degradation and guiding conservation efforts (Ozesmi and Bauer, 2002). By using satellite imagery and drone surveillance, conservationists can assess threats such as encroachment, pollution, and climate-induced changes with greater accuracy (Klemas, 2013).

Another promising approach is the implementation of nature-based solutions to restore and protect wetlands. This includes wetland restoration projects, such as reintroducing native vegetation, rehabilitating degraded water bodies, and creating buffer zones to reduce pollution runoff (Zedler, 2003). Additionally, the construction of artificial wetlands can serve as an alternative method to improve water quality, manage stormwater, and support biodiversity, particularly in urban areas where natural wetlands have been lost (Mitsch and Gosselink, 2015).

Sustainable land-use planning also plays a critical role in wetland conservation. By incorporating wetland areas into regional development plans and promoting eco-friendly practices, such as sustainable agriculture and responsible tourism, wetlands can be preserved while still supporting economic activities (Turner et al., 2000).

Furthermore, community-led conservation initiatives, combined with digital platforms for awareness and education, can enhance public participation in wetland protection (Ramsar Convention Secretariat, 2018).

By embracing these innovative technologies and conservation approaches, Nigeria can improve the long-term sustainability of its wetlands, ensuring they continue to provide ecological, economic, and social benefits for future generations.

CASE STUDIES: LESSONS FROM SUCCESSFUL WETLAND CONSERVATION EFFORTS

Successful wetland conservation projects in Nigeria and other parts of the world provide valuable insights into effective strategies for protecting these critical ecosystems. One notable example in Nigeria is the Hadejia-Nguru Wetlands Conservation Project, which focuses on restoring wetland functions while supporting local livelihoods. This project has demonstrated the importance of integrating community participation, sustainable resource management, and policy support in conservation efforts (Hollis et al., 1993). Similarly, the Niger Delta Biodiversity Conservation Programme has worked to mitigate the impact of oil exploration on wetlands, highlighting the need for strong environmental regulations and corporate accountability in protecting wetland ecosystems (World Bank, 2015).

Internationally, the Everglades Restoration Project in the United States and the Ramsar-designated Okavango Delta in Botswana showcase the benefits of long-term policy commitment, stakeholder collaboration, and scientific research in wetland management. The Everglades project emphasizes government support and ecosystem restoration through extensive hydrological modifications (Davis and Ogden, 1994), while conservation efforts in the Okavango Delta highlight the importance of adaptive

management and community engagement in sustainable wetland protection (Ramberg et al., 2006). These projects emphasize the necessity of strong policy frameworks, sustainable funding, and collaborative approaches to ensure wetland conservation success.

CONCLUSION

Successful wetland conservation includes the active involvement of local communities, making sure that they derive economic benefits while contributing to ecosystem protection. Effective policies and enforcement mechanisms play a critical role in preventing wetland degradation, striking a balance between environmental preservation and sustainable livelihoods. Additionally, data-driven approaches are essential for assessing wetland health and guiding conservation strategies.

To reinforce wetland conservation in Nigeria, increased funding and investment in research, monitoring, and restoration projects are required. Stronger policy implementation is required to regulate land use and prevent further degradation, while public awareness campaigns through education and media can foster a culture of conservation. Moreover, enhanced collaboration among government agencies, NGOs, researchers, and local communities is key to ensuring coordinated and effective conservation efforts. By learning from successful models, Nigeria can develop inclusive, sustainable strategies that safeguard wetlands, preserving their ecological and economic benefits for future generations.

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POPULATION ECOLOGY OF PLANTS OF FOOD AND MEDICINAL PRODUCTS IN A COMMUNITY-MANAGED MOIST RAINFOREST IN AKWA IBOM STATE, NIGERIA

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ABSTRACT

Considering the socio-economic importance of many edible and medicinal plant species which are found in the forests, there is insufficient data to help conservation. Thus, Ikot Efre Itak Community-owned rainforest in Ikono Local Government Area, Akwa Ibom State, Nigeria was assessed for diversity and abundance of plant species of edible and medicinal products using combination of systematic and random sampling techniques. The data collected were subjected to non-parametric and descriptive analyses. A total of eighty-four plant species were encountered in the forest with distribution as trees (34), Shrubs (23), Herbs (16) and Climbers (11). In the tree life-form, *Macaranga barteri* had the highest population density of 62 per/ha while *Brachystegia eurycoma*, *Coelocaryon preusii* and *Dacryodes edulis* had the least population of 2 per/ha apiece. In shrub category, the population density varied from 300 to 1,750 per/ha with *Bambusa vulgaris* having the highest of 1,750 per/ha, while *Heinsia crinata* had the least of 300 per/ ha. In herb life-form, the population density varied from 75 to 5,400 per/ha, with *Nephtylis constanta* having the highest population density of 5,400 per/ha, while *Costus afer* had the least of 75 per/ha. That of climber life-form varied from 150 to 1,250 per/ ha, with *Selaginella myosurus* having the highest population density of 1,250 per/ha and *Gloriosa superba* had the least of 150 per/ha. The species richness of 1.625, 0.803, 0.468, and 0.713 were computed for the trees, shrubs, herbs and climbers respectively. With most tree species having low population density, it is therefore proffered that the forest should be primarily managed for production of non-timber products of food and medicine, rather than timber or wood alone management that often leads to deforestation, and eventual loss of biodiversity.

Keywords: Tropical rainforest, plants, food, medicine, conservation, sustainable management

INTRODUCTION

The Nigerian rainforest is an integral of the world tropical rainforest which has been adjudged the most biological diverse ecosystem on earth (Gillespies *et al.*, 2004, ITTO, 2011). The tropical rainforest ecosystem is a huge source of basic needs of man for food, medicine, energy and shelter. The rainforest has been viewed and managed over the years as an ecosystem of crop of merchantable timber trees, rather than a composite of interdependent biodiversity of

multiple value. Consequently, the Nigerian rainforest has been widely indiscriminately exploited for timber, thereby culminating in degradation, denudation and rife destruction. The rainforest now generally occurred in isolated small patches (Olajide, 2018). The estimated total coverage of rainforest is 95,372 km² of the country's landmass of 983,213 km² (Akpan-Ebe, 2021). The rainforest is stocked with diversity of plant species that produce edible and medicinal products in the forms of fruits, seeds, leaves,

twigs, nut, barks, floral and roots. The edible plant materials from the rainforest ecosystem are mostly available at the seasons of the year when the cultivated crops are not yet mature (Oni and Gbadamosi 1998, Olajide, 2018). The edible forest products constitute important and cheap sources of vitamins, minerals, protein, carbohydrate, fat and oil of the diet of the rural people.

The World Health Organisation (WHO) estimated that 80% of the population of sub-Sahara Africa relies on plant based medicine for everyday health-care needs (Bannerman, 1993 and Ande, 2006). Many plant species have been identified by the local people to contain therapeutic ingredients. The people have for ages been depending on these plant materials for their health-care needs. Natural forests generally provide the only medicine available to the largest proportion of the world's population of which 90 – 95% is in the developing world, and the high concentration of different chemicals in some plants serve as raw materials for the production of modern drugs (FAO, 1985 and Ande, 2006). With the

seemingly unabated high rate of destruction and conversion of rainforest ecosystem to different ecosystems in Nigeria, a lot of plant species, which are sources of food and medicine are disappearing.

Thus, this paper is a report of a study on the diversity and stock density of plant species that produce food and medicinal products in a community-managed rainforest in Akwa Ibom State, Nigeria. It is hoped that the information gathered would help conservation and sustainable management of the forest and other similar tracts of rainforest.

MATERIALS AND METHODS

Study Area

The study was carried out in Ikot Efre Itak community owned rainforest in Ikono Local Government Area, Akwa Ibom State, Nigeria (Figs. 1 and 2). The forest covers an area of 29.57ha (IWADU, 2000). The area has mean annual rainfall of 2400 mm, mean minimum and maximum temperatures of 25°C and 30°C respectively. The mean relative humidity is about 83%. The soil is predominantly silt-loam.

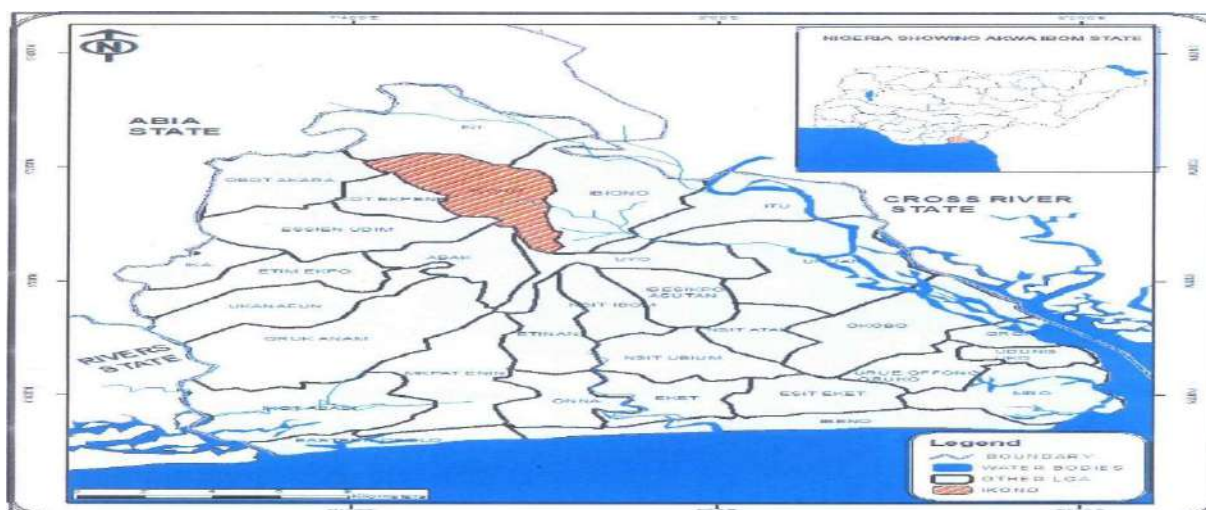


Fig. 1: Map of Akwa Ibom State showing Study area in Ikono Local Government Area

Source: Department of Geography and Regional Planning, Uniuyo (2019).

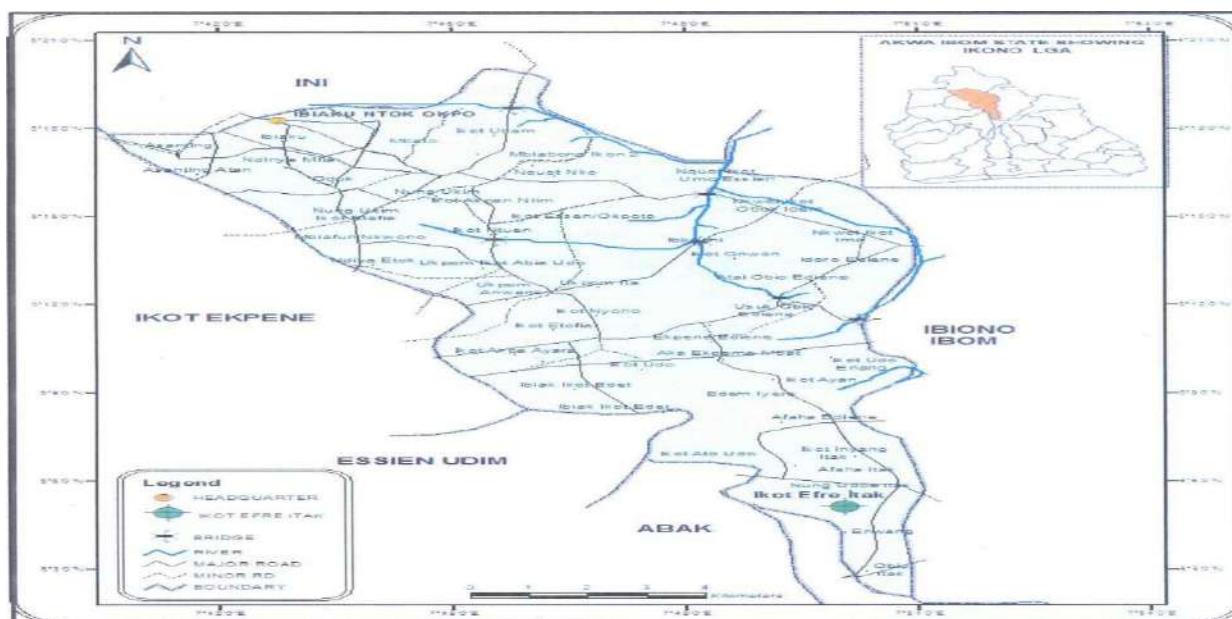


Fig. 2: Map of Ikono Local Government Area showing Ikot Efre Itak Village.

Source: Department of Geography and Regional Planning, UniUyo (2019).

Reconnaissance Survey

Reconnaissance Survey was carried out to familiarize with the terrain of the forest. Some of the natives of the area were consulted and interviewed on the edible and medicinal product they usually collected from the forest. The most apparent signs of disturbances in the forests were timber harvesting poles cutting for firewood, part of the forest cleared and burnt for farming activities and tree-bark removal for medicines.

Data Collection

A combination of systematic and random sampling techniques was employed in the course of collecting data. Five meters away from the main access routes into the forest, four 200m line transects were laid at 50m away from one another and perpendicular to the main access routes into the forest. Along each transect, four 20m by 20m quadrats were randomly laid in an alternate order on each transect for the enumeration of tree species of edible and medicinal products. One 5m x5m sub-

quadrat was laid at the centre of each 20m x 20m quadrat for enumeration of shrubs, herbs and climbers. The total number of quadrats and sub-quadrat was sixteen (16) apiece. It implied that a total area of 6,400m² (0.64ha) were enumerated for trees and 400m² (0.04ha) for the shrubs, herbs and climbers. Data collections were made both in the rain and dry seasons to ensure adequate data collection on both perennial, biennial and annual plant species. In the course of data collection, three native men whose ages ranges between 50- 60 years were involved in the plant identification and to ascertain different parts of the plant used as food and medicine. Specimens were collected from the plants that could not be scientifically identified on the field, and were thereafter identified at the Herbarium Laboratory of the Department of Botany and Ecological Studies of University of Uyo, Nigeria.

Data Analysis

Plant species were classified into four life-forms, viz; tree, shrub, herb and climber. The population density of each species per hectare was determined from its population

in the total areas of quadrats assessed using the relationship stated as follows:

$$D = \frac{x}{A} \times 1 \text{ ha}$$

Where,

D = Population density per/ha

x = number of individual species (i)

A = Total area of all the quadrats (0.64ha for trees and 0.04ha for shrubs, herbs and climbers)

The species richness index was calculated for each life-form using Menchinick's index formula given below (Menchinicks, 1964; Ogbebu, 2005; Etigale *et al*, 2017).

$$R = \frac{s}{\sqrt{N}}$$

Where,

R = species richness index

s = number of species enumerated and

N = total number of individuals enumerated

RESULTS

A total of 34 species of edible and medicinal products were encountered in the

tree life-form. The study showed that, the population density of the tree life-form varied from 2 to 62 per/ha with *Macaranga barteri* had the highest estimated population density of 62 per/ha, while *Brachystegia eurycoma*, *Coelocaryon preusii* and *Dacryodes edulis* had the least population density of 2 per/ha apiece (Table 1). In the shrub life-form, 24 species were encountered. The population density varied from 300 to 1,750 per/ha. *Bambusa vulgaris* with the frequency of (70) had the highest population density of 1,750 per/ha, while *Heinsia crinata* with the frequency of (12) had the least population density of 300 per/ha (Table 2). In the herb life-form, a total of 16 species were enumerated. The population density varied from 400 to 5,000 per/ha. *Nephthylis constanta* had the highest estimated population density of 5,000 per/ha while *Aspelia africana* and *Combratum racemosum* had the least of 400 each per/ha (Table 3). Also, a total of 11 species were encountered under climber life-form. The population density varied from 150 to 1,250 per/ha. *Selaginella myosurus* had the highest of 1,250 per/ha while *Gloriossa superba* had the least of 150 per/ha (Table 4).

It was observed that the parts of the plants used as food and medicine varied from leaf, stem, root, seed, bark, fruit, tuber and latex (Table 5a - d).

⊕ **Table 1: Population density of individual plant species of tree life-form**

S/N	Species	Family	Population density (per ha)
1	<i>Albizia ferruginea</i>	Fabaceae	25
2	<i>Alstonia boonei</i>	Apocynaceae	17
3	<i>Anthocleista djalonesis</i>	Loganiaceae	19
4	<i>Antiaris Africana</i>	Moraceae	42
5	<i>Baphia nitida</i>	Papilionaceae	3
6	<i>Bombax buonopzense</i>	Bombaceae	6
7	<i>Bosquiea angolensis</i>	Moraceae	47
8	<i>Brachystegia eurycoma</i>	Fabaceae	2
9	<i>Canarium schwenfurthii</i>	Burseraceae	42
10	<i>Coelocaryon preusii</i>	Myristicaceae	2
11	<i>Coula edulis</i>	Olaceae	27
12	<i>Gossypium hirsutum</i>	Malvaceae	6
13	<i>Dacryodes edulis</i>	Burseraceae	2
14	<i>Dacryodes klaineana</i>	Burseraceae	36
15	<i>Daniella ogea</i>	Fabaceae	5
16	<i>Dracaena arborea</i>	Dracaenaceae	44
17	<i>Elaeis guineensis</i>	Arecaceae	47
18	<i>Ficus exasperate</i>	Moraceae	22
19	<i>Irvingia gabonensis</i>	Irvingiaceae	3
20	<i>Macaranga barteri</i>	Euphorbiaceae	62
21	<i>Musanga cecropiodes</i>	Cecropiaceae	36
22	<i>Newbouldia laevis</i>	Bignoniaceae	9
23	<i>Pentaclethra macrophylla</i>	Papilionaceae	22
24	<i>Pterocarpus mildbraedii</i>	Papilionaceae	5
25	<i>Pterocarpus osun</i>	Fabaceae	6
26	<i>Piptadeniastrum africana</i>	Leguminosae	14
27	<i>Ruthmania hispida</i>	Rubiaceae	3
28	<i>Sterculia tragacantha</i>	Sterculiaceae	36
29	<i>Strombosia postulate</i>	Olaceae	3
30	<i>Spondias mombin</i>	Anacardiaceae	53
31	<i>Syncepalum dulsificum</i>	Sapotaceae	23
32	<i>Terminalia superba</i>	Combretaceae	9
33	<i>Uapaca guinensis</i>	Euphorbiaceae	3
34	<i>Xylocarpus gethionica</i>	Annonaceae	3

Table 2: Population density of individual plant species of shrub life-form

S/N	Species	Family	Population Density (per ha)
1	<i>Alchornea cordifolia</i>	Euphorbiaceae	1,125
2	<i>Anthonatha macrophylla</i>	Fabaceae	1,125
3	<i>Araliopsis soyauxii</i>	Rutaceae	750
4	<i>Bambusa vulgaris</i>	Poaceae	1,750
5	<i>Barteria nigritiana</i>	Passifloraceae	450
6	<i>Carpolobia lutea</i>	Polygaceae	1,050
7	<i>Cola millenii</i>	Sterculiaceae	700
8	<i>Cnestis ferruginea</i>	Clnnaraceae	975
9	<i>Garcinia manii</i>	Clusiaceae	1,000
10	<i>Hannoa klaineana</i>	Simaroubaceae	350
11	<i>Harungana madagascariensis</i>	Hypericaceae	700
12	<i>Heinsia crinata</i>	Rubiaceae	300
13	<i>Icacinia trichantha</i>	Icacinaceae	625
14	<i>Laccosperma secundiflorum</i>	Arecaceae	1,375
15	<i>Lansianthera Africana</i>	Bignoniaceae	1,250
16	<i>Longacarpus griffonianus</i>		450
17	<i>Maesobotrya barteri</i>	Euphorbiaceae	1,575
18	<i>Mallotus oppositifolius</i>	Euphorbiaceae	400
19	<i>Melastomastrum capitatum</i>	Melastomataceae	975
20	<i>Microdesmis pubarula</i>	Pandaceae	1,500
21	<i>Milleffia thoningii</i>	Leguminosae	500
22	<i>Sorindela mildbriedii</i>	Anacardiaceae	700
23	<i>Voacanya Africana</i>	Apocynaceae	875

Table 3: Population density of individual plant species of herb life-form

S/N	Species	Family	Population density (per ha)
1	<i>Aframomum sceptrum</i>	Zingiberaceae	3,500
2	<i>Anchomanes difformis</i>	Araceae	1,375
3	<i>Argemone Mexicana</i>	Papaveraceae	2,500
4	<i>Aspelia Africana</i>	Asteraceae	400
5	<i>Asystasia gangetica</i>	Acanthaceae	2,025
6	<i>Chromolanaena odorata</i>	Asteraceae	1,525
7	<i>Combratum racemosum</i>	Combretaceae	400
8	<i>Costus afer</i>	Costaceae	3,025
9	<i>Hibiscus surattensis</i>	Malvaceae	500
10	<i>Justicia schimperiana</i>	Acanthaceae	2,975
11	<i>Laportea aestuans</i>	Urticaceae	8,75
12	<i>Nephthylis constanta</i>		5,000
13	<i>Palisota hirsute</i>	Commelinaceae	3,000
14	<i>Piper umbellacum</i>	Piperaceae	450
15	<i>Thaumatococcus daniellii</i>	Marantaceae	857
16	<i>Urena lobate</i>	Malvaceae	750

Table 4: Population density of individual plant species of climber life-form

S/N	Species	Family	Population density (per ha)
1	<i>Adenopus breviflorus</i>	Vitaceae	450
2	<i>Cissus quadrangularis</i>	Vitaceae	300
3	<i>Combretum mfucronalum</i>	Combretaceae	500
4	<i>Gloriossa superba</i>	Colchicaceae	150
5	<i>Gnetum africanum</i>	Gnetaceae	250
6	<i>Gongronema latifolium</i>	Asclepiadaceae	300
7	<i>Ipomoea involucrate</i>	Convolvulaceae	700
8	<i>Loranthus apyllus</i>	Cactaceae	300
9	<i>Physalis angulate</i>	Solanaceae	1,000
10	<i>Selaginella myosurus</i>	Selaginellaceae	1,250
11	<i>Smilax ancepts</i>	Smilacaceae	750

Thespecie richness indices of 1.625, 0.803, 0.468 and 0.713 were computed for trees, shrubs, herbs and climbers respectively.

Table 5a: Plants of tree life-form producing edible and medicinal products

S/N	Plant Species	Family	Ibibio Name	Common/English Name	Uses	Parts Used
1	<i>Albizia ferruginea</i> (Gill and Perr) Benth.	Fabaceae	Ubam	Albizia	Medicinal	Bark, Root
2	<i>Alstonia boonei</i> De Wild.	Apocynaceae	Ukpo	Stool Wood	Medicinal	Latex, Root
3	<i>Anthocleista djalonesis</i> A. Chev.	Loganiaceae	Ibu	Cabbage tree	Medicinal	Bark
4	<i>Antiaris africana</i> Engl.	Moraceae	Afia Ofriyo		Medicinal	Bark, Root
5	<i>Baphia nitida</i> Lodd.	Fabaceae	Ofuo	Camwood	Medicinal	Stem/Root
6	<i>Bombax buonopzense</i> P.Beauv.	Bombaceae	Ukim	Red flowered silk Cotton tree	Medicinal	Bark
7	<i>Bosquiea angolensis</i> Ficalho	Moraceae	Uyie	Akee apple	Medicinal	Leaf, Bark and Root
8	<i>Brachystegia eurycoma</i> Harms	Fabaceae	Odukpa	Okwen	Medicinal	Bark, Root
9	<i>Canarium schwenfurthii</i> Engl.	Burseraceae	Ebenetidong	African Canarium	Edible	Fruit
10	<i>Coelocaryon preusii</i> Ward.	Myristicaceae	Uno Idim		Edible/Medicinal	Fruit Bark, Root
11	<i>Coula edulis</i> Baill	Olaceae	Ekom	Walnut	Edible/Medicinal	Seed, Bark
12	<i>Gossypium hirsutum</i> . L.	Malvaceae	Ofo	Cotton	Medicinal	Bark, Root
13	<i>Dacryodes edulis</i> (G. Don) H.J. Lam.	Burseraceae	Eben		Edible	Fruit
14	<i>Dacryodes klaineana</i> (Pierre) H.J.Lam.	Burseraceae	Eben Ikot		Medicinal	Leaf, Bark and Root
15	<i>Daniella ogea</i> (Harms) Rolfe ex Holl.	Fabaceae	Enang eto		Medicinal	Bark, Root
16	<i>Dracaena arborea</i> (Wild). Link Enum Hort	Dracaenaceae	Okono		Medicinal	Bark, Root
17	<i>Elaeis guineensis</i> Jacq.	Arecaceae	Eyop	Oil palm tree	Edible	Fruit
18	<i>Ficus exasperate</i> Vahl.	Moraceae	Ukwok	Sand paper tree	Medicinal	Leaf, Bark
19	<i>Irvingia gabonensis</i> (Aubry-Lecomte ex O. Rorke)Baill	Irvingiaceae	Uyo	Bush mango	Edible	Fruit, Stem
20	<i>Macaranga barteri</i> Mull. A.rg.	Euphorbiaceae	Akpa		Medicinal	Leaf, Root
21	<i>Musanga cecropioides</i> R. Br	Cercropiaceae	Uno	Cork wood	Medicinal	Bark, Root
22	<i>Newbouldia laevis</i> (P.Beauv) Seemann ex Bureau	Bignoniaceae	Itumo		Medicinal	Bark, Root
23	<i>Pentaclethra macrophylla</i> Benth	Fabaceae	Ukana	African oil beans	Edible/Medicinal	Seed, Bark
24	<i>Pterocarpus mildbraedii</i> Harms	Leguminosae	Mkpafere		Edible	Leaf
25	<i>Pterocarpus osun</i> Craib	Fabaceae	Ukpa	Cam wood	Medicinal	Bark, Root
26	<i>Piptadeniastrum africana</i> Hook Brenan	Leguminosae	Ukong		Medicinal	Bark, Root
27	<i>Ruthmania hispida</i> (K. Schum) Fanger lind	Rubiaceae	Okukin		Medicinal	Fruit, Leaf, Bark, Root
28	<i>Sterculia tragacantha</i> Lindl.	Steculiaceae			Edible/Medicinal	Leaf, Bark

29	<i>Strombosia postulate</i> Oliv.	Olaceae	Ekombak		Medicinal	Root, Bark
30	<i>Spondias mombin</i> L.	Anacardiaceae	Nsukakara	Hog plum	Medicinal	Leaf, Bark, Root
31	<i>Synsepalum dulcificum</i> (Schum. and Thonn) Daniel	Sapotaceae	Mkpantuk		Edible/Medicinal	Fruit
32	<i>Terminalia superba</i> Engl and Diels	Combretaceae	Afia eto	Whit afara	Medicinal	Bark, Root
33	<i>Uapaca guineensis</i> Mull.-Arg	Euphorbiaceae	Nkpenek	Red-cedar	Medicinal	Bark, Root
34	<i>Xylopia aethiopica</i> (Dunal) A. Rich	Annonaceae	Ata	African pepper	Edible/Medicinal	Root, Stem, Bark, Root

Table 5b: Plants of shrub life-form producing edible and medicinal products

S/N	Plant Species	Family	Ibibio Name	Common/English Name	Uses	Parts Used
1	<i>Alchornea cordifolia</i> (Schum. Thonn) Mull. Arg	Euphorbiaceae	Mbom	Christmas bush	Medicinal	Leaf, Root
2	<i>Anthonatha macrophylla</i> P. Beauv.	Fabaceae	Nya		Medicinal	Leaf, Root
3	<i>Araliopsis soyauxii</i> Engl.	Rutaceae	Editan eto		Medicinal	Leaf, Stem, Root
4	<i>Bambusa vulgaris</i> Schrad ex Wend.	Poaceae	Nyanyaha inyang	Bamboo	Medicinal	Leaf
5	<i>Barteria nigritiana</i> Hook	Passifloraceae	Ekpanekpang	Ant tree	Medicinal	Leaf, Root
6	<i>Carpolobia lutea</i> G. Don	Polygaceae	Ikpa fum	Cattie stick	Edible/Medicinal	Fruit, Root
7	<i>Cola millenii</i> K. Schum	Steculiaceae	Ekpa okpo	Monkey kola	Edible/Medicinal	Leaf, Fruit, Root
8	<i>Cnestis ferruginea</i> Dc	Clusiaceae	Utinewa	Velvet sunfruit	Edible/Medicinal	Fruit, Leaf, Root
9	<i>Garcinia manii</i> Oliv	Clusiaceae	Okok edi	Chewing stick	Medicinal	Leaf, Stem, Root
10	<i>Hannoa klaineana</i> Pierre and Engl	Simaroubaceae	Eto ibit		Medicinal	Leaf
11	<i>Harungana madagascariensis</i> Lam. ex Poir	Hypericaceae	Oton		Medicinal	Leaf, Root
12	<i>Heinsia crinata</i> (Afzel) G. Tayl	Rubiaceae	Atama		Edible/Medicinal	Leaf, Root
13	<i>Ipocasia trichantha</i> Oliv.	Ipocasiaceae	Efikisong	Earth ball	Edible/Medicinal	Tuber, Leaf
14	<i>Laccosperma secundiflorum</i> (P. Beauv) O. Kize	Arecaceae	Nkara	Rattan palm	Medicinal	Leaf
15	<i>Lansianthera africana</i> P. Beauv.	Bignoniaceae	Editan		Edible/Medicinal	Leaf, Stem
16	<i>Longocarpus griffonianus</i> (Baill) Dum		Ududu		Medicinal	Leaf, Bark, Root

17	<i>Maesobotrya barteri</i> (Baill) Hutch	Euphorbiaceae	Nyanyated		Edible/Medicinal	Fruit, Leaf
18	<i>Mallotus oppositifolium</i> (Geiseler) Mull.Arg	Euphorbiaceae	Nwariwa	Fruiting branch	Medicinal	Leaf
19	<i>Melastomastrum capitatum</i> Vahl A.andR. Fernandes	Melastomataceae	Eyop inuen		Edible/Medicinal	Fruit, Leaf
20	<i>Microdesmis pubarula</i> Hook. F. ex Planch	Pandaceae	Ntabit		Edible/Medicinal	Leaf, Root
21	<i>Milleffia thoningii</i> (Schum and Thom) Bak	Leguminosae	Isara		Medicinal	Leaf, Root
22	<i>Sorindela mildbrieadii</i>	Anacardiaceae	Adiahaidang		Edible/Medicinal	Fruit, Root
23	<i>Voacanya africana</i> Stapf	Apocynaceae			Medicinal	Leaf, Bark, Root

Table 5c: Plants of herb life- form producing edible and medicinal products

S/N	Plant Species	Family	Ibibio Name	Common/ English Name	Uses	Parts Used
1	<i>Aframomum sceptrum</i> K. Schum	Zingiberaceae	Ikpod		Edible/Medicinal	Fruit, Leaf, Root
2	<i>Anchomanes difformis</i> (Bl.) Eng.	Araceae	Nkokot	Spiny arum	Medicinal	Bark, Root
3	<i>Argemone mexicana</i> L.	Papaveraceae	Mbaraekpe	Devil's fig	Medicinal	Leaf, Stem, Root
4	<i>Aspelia africana</i> Oliv.andHiern	Asteraceae	Ndinuene	Compost weed	Medicinal	Leaf, Stem
5	<i>Asystasia gangetica</i> (L) T,Anderson	Acanthaceae	Eka meme	Chinese violet	Edible/Medicinal	Leaf, Stem
6	<i>Chromolanaena odorata</i> (L) R M.King andH.Robinson	Asteraceae		Siam weed	Medicinal	Leaf, Stem
7	<i>Combratum racemosum</i> P. Beauv.	Combretaceae	Asaka		Medicinal	Leaf
8	<i>Costus afer</i> Ker-Gawl	Costaceae	Mbrirem	Bush cane	Medicinal	Leaf, Stem
9	<i>Hibiscus surattensis</i> L.	Malvaceae	Ifod ebot		Medicinal	Leaf, Stem, Root
10	<i>Justicia schimperiana</i> (Hochst) Danby	Acanthaceae	Meme	Hunter weed	Edible/Medicinal	Leaf, Root
11	<i>Laportea aestuans</i> (L.) Chew.	Urticaceae	Ntan	African stinging nettle	Edible/Medicinal	Leaf, Root
12	<i>Nephthylis constanta</i>		Nyaratong		Medicinal	Leaf, Root
13	<i>Palisota hirsuta</i> (Thumb) K. Schum	Commelinaceae	Edongebot	Goat knee	Medicinal	Leaf, Root
14	<i>Piper umbellacum</i> L.	Piperaceae		Wild pepper	Medicinal	Leaf, Stem
15	<i>Thaumatococcus daniellii</i> Benth	Marantaceae	Mfang aya	Moi-moi leaf	Medicinal	Leaf, Stem, Root
16	<i>Urena lobata</i> L.	Malvaceae	Ndidi	African jut fibre	medicinal	Leaf, Root

Table 5d: Plants of climber life- form producing edible and medicinal products

S/N	Plant Species	Family	Ibibio Names	Common/ English name	Uses	Parts Used
1	<i>Adenopus breviflorus</i> Benth	Vitaceae	Ndise ekpo	Wild colocynth	Medicinal	Leaf, Stem
2	<i>Cissus quadrangularis</i> L.	Vitaceae	Oboro	Stem vine	Medicinal	Fruit, Leaf
3	<i>Combretum micranthum</i> G.Don	Combretaceae	Asaka		Medicinal	Leaf, Root
4	<i>Gloriosa superba</i> L.	Colchicaceae		Flame lily	Medicinal	Leaf, Fruit
5	<i>Gnetum africanum</i> Welw.	Gnetaceae	Afang	African salad	Edible/Medicinal	Fruit, Leaf
6	<i>Gongronema latifolium</i> Benth	Asclepiadaceae	Utasi		Edible/Medicinal	Leaf, Stem, Root
7	<i>Ipomoea involucre</i> P. Beauv.	Convolvulaceae	Mkpaefiang	Morning glory	Medicinal	Leaf, Root
8	<i>Loranthus apyllus</i> L.	Cactaceae	Ndot enyong	African mistieto	Medicinal	Leaf, Root
9	<i>Physalis angulate</i> L.	Solanaceae	Flower ikot	Wild tomato	Medicinal	Leaf, Stem
10	<i>Selaginella myosurus</i> (Sw.) Alston	Selaginellaceae	Mkpatatat	Spike mosses	Medicinal	Leaf, Stem
11	<i>Smilax ancepts</i> Willd.	Smilacaceae	Odufat	West African sarsaparilla	Edible/Medicinal	Tuber, Leaf

0.713

DISCUSSION

The existence and preponderance of a plant species in a rainforest ecosystem is a function of availability of its seeds or propagules and microclimate for germination and growth. Also, the abundance or rarity of a plant species of known socio-economic importance is a function of the intensity and pattern of exploitation the species is subject to in particular and the forest as a whole. The high population densities of most individual herb and shrub in the study forest can be ascribed to the favourable microclimate, which included adequate sunlight through the canopy-gaps created by felled trees, for their prolific regeneration and growth. Previous studies on disturbed tropical rainforests at different locations had reported similar results of higher population of undergrowth species of herb, shrub and climber as

compared with tree species (Udo *et al.*, 2009, Olajide and Udofia, 2008, Umoh, 2020; Sidabukke *et al.*, 2021). The fewer population of most tree species producing food and medicinal products observed in this study is indicative of their over-exploitation for either poles or timber or firewood. A number of earlier studies has reported very low stand population of timber trees producing economically valuable non-timber products in various tracts of rainforest subjected to timber exploitation (Olajide and Udofia, 2000, Olajide and Etigale, 2017; Okwokei and Ndakara, 2022; Osabiya *et al.* 2022). In summary, the higher population densities of undergrowth species of food and medicinal products over that of tree species express the floristic pattern of a typical severely disturbed rainforest, where undergrowth is the most predominant plants.

CONCLUSION

The study rainforest is a disturbed rainforest that contains many species of plant of food and medicinal products. The food and medicinal products enhance sustainable living of the adjoining communities. With most tree species having low population density, it is therefore proffered that the forest should be primarily managed for production of non-timber products of food and medicine, rather than timber or wood alone management that often leads to deforestation, and eventual loss of biodiversity.

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DIVERSITY VS. ABUNDANCE: IMPACT OF URBANISATION ON BIRD NUMBERS AND BEHAVIOURS

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ABSTRACT

Urbanisation is a key driver of ecological change, significantly altering bird diversity, abundance, and behaviour. As cities expand, natural habitats are transformed, leading to changes in species richness and community structure. While some birds adapt well to urban environments, others experience population declines due to habitat fragmentation, pollution, and human disturbances. Urban areas often provide new food sources and nesting sites, enabling certain species to thrive, whereas others struggle with increased competition and reduced green spaces. The behavioural adaptations of birds in urban settings, such as shifts in vocalisation patterns and modified foraging strategies, further demonstrate the complex interactions between avian species and urban landscapes. This paper examines the impact of urbanisation on bird populations, synthesising findings from multiple studies to highlight key ecological trends and conservation concerns. As the understanding of these patterns is crucial for developing effective urban biodiversity strategies that balance development with ecological sustainability.

Keywords: Urbanisation, Diversity, Abundance, Adaptations, Habitat Fragmentation.

INTRODUCTION

Urbanisation, is characterized by the rapid conversion of natural ecosystems into built areas for human benefits (Efenakpo *et al.*, 2019; Thompson *et al.*, 2022) and it is recognized as one of the most significant drivers of biodiversity and ecosystems change globally (Morelli *et al.*, 2016; Thompson *et al.*, 2022). With urban areas expanding globally, it is projected that by 2050, approximately 68% of the world's human population will reside in cities (UN DESA, 2018) this will further increase the current conversion rate of natural ecosystem to urban areas. However, despite these challenges, urban areas with green spaces still support diverse wildlife populations including birds (Ives *et al.*, 2016; Liordos *et al.*, 2021).

Birds, as highly mobile and ecologically diverse organisms, are particularly sensitive

to urbanisation orchestrated changes (Thompson *et al.*, 2022). Thus, they are important for assessing the impacts of urbanisation on wildlife species diversity, richness, evenness, and relative abundance. With the current accelerating pace of urban expansion, which is often proportional to biodiversity loss, it becomes imperative to understand how urban environments influence biodiversity to enhance conservation strategies and efforts, including niche sectors like avitourism that leverage bird diversity for economic and ecological benefits (Aronson *et al.* 2014; Awoyemi *et al.*, 2024; Efenakpo and Jacob, 2025). This review was therefore aimed at examining the concept and relationship between diversity and relative abundance of birds in urban environments, mechanisms through which urbanisation affects bird numbers and

behaviours and the implications for conservation and urban area planning.

2.0 The Concept of Diversity and Abundance in Ecology

Diversity and abundance are two important indicators used in ecology—the study of ecosystems, to evaluate the composition and health of wildlife populations in biodiversity studies. Abundance refers to the number of individuals of a particular species in a given area or sample, which aids in assessing species dominance and population trends over time, whereas diversity refers to the variety of species within a given community or ecosystem.

Diversity measurement tools includes species richness (s)—the total number of species in a given area—species evenness—the relative abundance of different species, indicating how evenly individuals are distributed among species, and species diversity indices—statistical measures that incorporate both species richness and evenness to quantify biodiversity. Understanding species relationships, ecological structure, and conservation goals requires knowledge of both diversity and abundance. While abundance metrics provide information on species dominance and population health, diversity indices aid in comparing biodiversity across regions. Common diversity indices used to measure diversity include;

Shannon-Wiener Index (H'): This index tool measures both species richness and evenness and it is mathematically expressed as follows:

$$H' = -\sum p_i \ln p_i \quad \text{.....i}$$

H' = Shannon index

$$p_i = \frac{\text{Number of individual of species}}{\text{Total number of species}}$$

ln = natural log

Simpson's Diversity Index (D): Measures the probability that two randomly selected individuals belong to different species and it is mathematically expressed as follows:

Calculation of Simpson Index (1-D)

$$D = \frac{1}{\frac{\sum n(n-1)}{N(N-1)}} \quad \text{.....ii}$$

D = Dominance index

N = total number of entities in the dataset

Margalef's Index (d): A richness-based index calculated as:

$$d = \frac{(S - 1)}{\ln(N)} \quad \text{.....iii}$$

Where:

d = Margalef's index

S = the total number of species in the sample

N = the total number of individuals in the sample

ln = the natural logarithm

While for measuring abundance include;

Evenness Index (E): which refers to how close in numbers each species in an environment is and calculated as:

$$E = \frac{H'}{\ln(S)} \quad \text{.....iv}$$

E = evenness index

H' = Shannon Weiner index

ln(S) = the natural logarithm of the species richness

Sorensen's coefficient index: calculates community similarity

$$\text{Sorensen's Coefficient (SC)} = \frac{2C}{S_1 + S_2} \dots\dots\dots \text{v}$$

Where: C = the number of species of two communities have in common

S1 = the total number of species found in community 1.

S2 = the total number of species found in community 2.

Relative Abundance: Calculation of Relative abundance

$$\frac{\text{Species relative abundance}}{\text{Species abundance} \times 100} = \dots\dots\dots \text{vi}$$

Density (D): The number of individuals per unit area or volume and it is expressed as:

Frequency: This is the proportion of sampling units in which a species occurs, showing distribution patterns.

Biomass: Total mass of organisms, often used in plant and aquatic ecology.

3.0 Bird Community Composition in Urban Areas

Globally, there are approximately 11,000 species of birds, exhibiting a vast range of ecological adaptations (Birdlife International, 2022). Urban bird communities vary widely across the globe, with cities in tropical regions often supporting higher species richness than those in temperate zones (Aronson *et al.*, 2014), although they face unique conservation challenges. In Nigeria alone, around 966 bird species (3 endemic and 33 globally threatened) have been recorded, representing diverse families and ecological niches (Lepage, 2025), offering untapped potential for avitourism as a conservation catalyst amid urbanization

pressures (Efenakpo and Jacob, 2025). However, as urbanisation expands, bird communities experience shifts in their composition and distribution due to habitat alterations, resource availability, and human activities (Marzluff *et al.*, 2016; Efenakpo *et al.*, 2019).

The composition of bird communities in urban areas is usually shaped by factors such as habitat availability, food sources, competition, and level of human disturbances (Ukpong *et al.*, 2023). While some bird species flourish in urban environment, others may struggle to adapt and face population declines (Petrenko *et al.*, 2024). Based on bird tolerance and adaptability to urbanisation, bird species found in urban environments can be broadly be classified into three categories; urban exploiter, adapters and avoiders (Blair, 1996; Humphrey *et al.*, 2023). These urban bird categories are explained as follows:

3.1 Urban Exploiters

Urban exploiters are also known as 'synanthropes', 'urban dwellers', 'commensals', 'anthrophilic species'. These are bird species that thrive in human-modified environments and can take advantage of the urban habitat and human activities for food and shelter (McKinney, 2002; Kark *et al.*, 2007). These categories of birds are usually highly adaptable, generalist diets, and are not affected much by changes and conversion of natural areas to urban. They utilize artificial structures such as poles and mast for housing support in the absence of and also use a range of anthropogenic resources, such as residential gardens, cavities in buildings and novel food sources (McKinney, 2002; Conole and Kirkpatrick, 2011; Callaghan *et al.*, 2019). These categories of birds tend to have high reproductive rates and can outcompete other species in densely populated areas. They include introduced species and native species

that have successfully colonized the urban environment (Humphrey *et al.*, 2023).

3.2 Urban Adapters

These are bird species are sometimes referred to as ‘urban utilizers’, ‘suburban adapters’, ‘edge species’ (Humphrey *et al.*, 2023). These bird species can tolerate and survive moderate urbanisation and rely on green spaces such as parks, tree avenues water bodies found within these urban areas. Urban adapters can thrive in residential areas by using a combination of native and non-native vegetation (Reichard *et al.*, 2001). Thus, they are often found in suburban or peri-urban areas with some level of natural habitat. These categories of birds often adjust their feeding and nesting behaviours to accommodate anthropogenic activities. They may include omnivores, granivores, nectarivores and aerial sweepers that favour open or edge habitats (McKinney, 2002; Minor and Urban, 2010; Conole and Kirkpatrick, 2011). The populations of urban adapters are often influenced by the availability of green spaces and human

disturbance levels as much of anthropogenic activities such as noises can force them to migrate from the area.

1.3.3 Urban Avoiders

These categories of urban birds are often termed as ‘urban-sensitive species’ or ‘forest interior species’, and these species are highly sensitive and struggle to survive in urban ecosystems. Consequently, causing their decline or disappearance as natural habitats are lost. They usually prefer undisturbed natural habitats, urban forest and green spaces within urban areas and are rarely recorded during urban surveys (McKinney, 2006; Kark *et al.*, 2007). They are often specialists with specific habitat or dietary requirements, making them vulnerable to habitat fragmentation. Conservation efforts are crucial for maintaining their populations in rapidly urbanizing landscapes.

Table 1 shows some major urban bird species and their families found in Nigeria and their urban classification category.

Table 1: Some Major Urban Birds Found in Nigeria

S/N	Family Name	Common Name	Scientific Name	Category
1	Accipitridae	Shikra	<i>Accipiter badius</i>	Urban Avoiders
2	”	Palm-nut Vulture	<i>Gypohierax angolensis</i>	Urban Adapters
3	”	Lizard Buzzard	<i>Kaupifalco monogrammicus</i>	Urban Adapters
4	”	Yellow-billed Kite	<i>Milvus migrans</i>	Urban Exploiters
5	”	African Harrier Hawk	<i>Polyboroides typus</i>	Urban Adapters
6	”	Hooded Vulture	<i>Necrosyrtes monachus</i>	Urban Exploiters
7	Alcedinidae	African Pygmy Kingfisher	<i>Ceyx pictus</i>	Urban Avoiders
8	”	Woodland Kingfisher	<i>Halcyon senegalensis</i>	Urban Adapters
9	Anatidae	White-faced Whistling Duck	<i>Dendrocygna viduata</i>	Urban Avoiders
10	Apodidae	Common Swift	<i>Apus apus</i>	Urban Adapters

11	”	Little Swift	<i>Apus affinis</i>	Urban Exploiters
12	”	Ethiopian Swallow	<i>Apus niansae</i>	Urban Adapters
13	”	Barn Swallow	<i>Hirundo rustica</i>	Urban Adapters
14	Ardeidae	Black-headed Heron	<i>Ardea melanocephala</i>	Urban Avoiders
15	”	Western Cattle Egret	<i>Bubulcus ibis</i>	Urban Exploiters
16	”	Grey Heron	<i>Ardea cinereal</i>	Urban Avoiders
17	”	Green-backed Heron	<i>Butorides virescens</i>	Urban Adapters
18	Bucerotidae	Piping Hornbill	<i>Bycanistes fistulator</i>	Urban Adapters
19	”	African Pied Hornbill	<i>Tockus fasciatus</i>	Urban Avoiders
20	Burhinidae	Senegal Thick-knee	<i>Burhinus senegalensis</i>	Urban Adapters
21	”	Water Thick-knee	<i>Burhinus vermiculatus</i>	Urban Avoiders
22	Capitonidae	Yellow-throated Tinkerbird	<i>Pogoniulus subsulphureus</i>	Urban Adapters
23	Caprimulgidae	Nightjar	<i>Caprimulgus sp</i>	Urban Avoiders
24	Cisticolidae	Grey-backed Camaroptera	<i>Camaroptera brachyura</i>	Urban Adapters
25	”	Chattering Cisticola	<i>Cisticola anonymus</i>	Urban Adapters
26	”	Winding Cisticola	<i>Cisticola galactotis</i>	Urban Avoiders
27	”	Tawny-flanked Prinia	<i>Prinia subflava</i>	Urban Adapters
28	”	Whinchat	<i>Saxicola rubetra</i>	Urban Avoiders
29	Columbidae	Laughing Dove	<i>Spilopelia senegalensis</i>	Urban Exploiters
30	”	Red-eyed Dove	<i>Streptopelia semitorquata</i>	Urban Adapters
31	”	Blue-spotted Wood Dove	<i>Turtur afer</i>	Urban Avoiders
32	”	Tambourine Dove	<i>Turtur tympanistria</i>	Urban Avoiders
33	”	Speckled Pigeon	<i>Columba guinea</i>	Urban Exploiters
34	”	Rock Dove/Feral Pigeon	<i>Columba livia</i>	Urban Exploiters
35	Corvidae	Pied Crow	<i>Corvus albus</i>	Urban Exploiters
36	Cuculidae	Senegal Coucal	<i>Centropus senegalensis</i>	Urban Avoiders
37	”	Didric Cuckoo	<i>Chrysococcyx caprius</i>	Urban Avoiders
38	”	Klaas’s Cuckoo	<i>Chrysococcyx klaas</i>	Urban Avoiders
39	Estrildidae	Orange-cheeked Waxbill	<i>Estrilda melpoda</i>	Urban Avoiders
40	”	Red-bellied Firefinch	<i>Lagonosticta senegala</i>	Urban Adapters
41	”	Grey-headed Nigrita	<i>Nigrita canicapillus</i>	Urban Avoiders

42	”	Bronze Mannikin	<i>Spermestes cucullatus</i>	Urban Adapters
43	”	Black-and-White Mannikin	<i>Lonchura bicolor</i>	Urban Adapters
44	”	Grey-headed Negrofinch	<i>Nigrita canicapillus</i>	Urban Avoiders
45	Falconidae	Common Kestrel	<i>Falco tinnunculus</i>	Urban Adapters
46	Halcyonidae	Woodland Kingfisher	<i>Halcyon senegalensis</i>	Urban Adapters
47	Hirundinidae	Common House Martin	<i>Delichon urbicum</i>	Urban Adapters
48	”	Ethiopian Swallow	<i>Hirundo aethiopica</i>	Urban Adapters
49	”	Common Sand Martin	<i>Riparia riparia</i>	Urban Adapters
50	Laniidae	Southern Common Fiscal	<i>Lanius collaris</i>	Urban Adapters
51	Meropidae	Rosy Bee-eater	<i>Merops malimbicus</i>	Urban Avoiders
52	”	Little Bee-eater	<i>Merops pusillus</i>	Urban Avoiders
53	Motacillidae	Plain-backed Pipit	<i>Anthus leucophrys</i>	Urban Avoiders
54	”	Yellow-throated Longclaw	<i>Macronyx croceus</i>	Urban Avoiders
55	”	Plain-backed Pipit	<i>Anthus leucophrys</i>	Urban Avoiders
56	Muscicapidae	White-crowned Robin-chat	<i>Cossypha albicapilla</i>	Urban Avoiders
57	Nectariniidae	Olive Sunbird	<i>Cyanomitra olivacea</i>	Urban Adapters
58	Numididae	Helmeted Guineafowl	<i>Numida meleagris</i>	Urban Avoiders
59	Passeridae	North.Grey-headed Sparrow	<i>Passer griseus</i>	Urban Exploiters
60	Phasianidae	Double-spurred Francolin	<i>Francolinus bicalcaratus</i>	Urban Avoiders
61	Ploceidae	Yellow-mantled Widowbird	<i>Euplectes macroura</i>	Urban Adapters
62	”	Village Weaver	<i>Ploceus cucullatus</i>	Urban Exploiters
63	”	Vieillot’s Black Weaver	<i>Ploceus nigerrimus</i>	Urban Exploiters
64	”	Western Grey Plantain-eater	<i>Crinifer piscator</i>	Urban Adapters
65	”	Northern Red Bishop	<i>Euplectes franciscanus</i>	Urban Adapters
66	Pycnonotidae	Common Bulbul	<i>Pycnonotus barbatus</i>	Urban Exploiters
67	”	Purple Glossy Starling	<i>Lamprotornis purpureus</i>	Urban Adapters
68	Turdidae	African Thrush	<i>Turdus pelios</i>	Urban Exploiters
69	Tytonidae	Barn Owl	<i>Tyto alba</i>	Urban Avoiders
70	Viduidae	Pin-tailed Whydah	<i>Vidua macroura</i>	Urban Adapters

Source: Adapted from Efenakpo *et al.* (2019)

Factors Influencing Bird Abundance and Diversity in Urban Areas

There are several factors such as food supplies, habitat availability, predation pressure, mate, and level of human activity,

that can affect bird species numbers and composition in urban and semi-urban areas. Some of the major factors, descriptions and their impact, influencing bird abundance in urban areas are shown in Table 2 below:

Table 2: Major Factors that Influence Bird Abundance and Diversity in Urban Areas

Factors	Description	Impact
Availability of food sources	Birds in urban environments utilize both natural food sources (fruits, seeds, insects) and artificial ones (bird feeders, food waste, garbage). Some species adapt by shifting their diets toward human-provided food sources.	Urban exploiters thrive on anthropogenic food sources and increase in abundance (Shochat <i>et al.</i> , 2006). However, a reduction in insect populations in urban areas can negatively impact insectivorous species there by reducing their abundance and diversity (Raupp <i>et al.</i> , 2010).
Level of human disturbance	Urban development, deforestation, and pollution (noise, light, and air) disrupt natural bird behaviours such as feeding, nesting, and migration. High human activity levels may also cause stress or displacement of sensitive species.	Noise pollution alters bird vocalization and communication (Halfwerk and Slabbekoorn, 2009). Light pollution disrupts circadian rhythms and migratory patterns (Hölker <i>et al.</i> , 2010). Direct habitat destruction reduces available nesting and foraging sites.
Availability of Green Spaces and Vegetation	Most urban birds rely on gardens, parks and avenue trees as essential habitats. Indigenous plant species support higher bird diversity by providing food and nesting sites compare to exotic plants species. The presence of trees, shrubs, and wetlands contributes to ecosystem complexity.	Higher vegetation cover generally supports greater species richness and abundance (Marzluff, 2017), and the loss of green areas often lead to fewer food sources, nesting sites. Hence, reduction in bird populations and diversity. Also, exotic plant species may alter food availability and reduce habitat quality for native birds (Reichard <i>et al.</i> , 2001).
Land Use Type	The degree of urbanization; impervious surfaces, road networks, and building density, influences bird populations. Areas with mixed land use, such as suburban or peri-urban zones, often support greater avian diversity compared to dense urban centers.	High-density urban areas tend to support fewer species, favoring urban exploiters (Awoyemi <i>et al.</i> , 2024). While suburban areas with green spaces provide habitats for a mix of generalist and specialist species.

Climate and Microclimate Effects	Urban climatic condition, temperatures, humidity, and precipitation patterns often affects habitat suitability for different bird species. Cities generally experience warmer conditions than surrounding rural areas.	Heat-tolerant species may become more abundant in cities, while heat-sensitive species decline (Oke, 1982). Changes in seasonal temperature patterns can influence migration timing and breeding cycles.
Predation and Competition	Urban areas host a range of predators, including raptors, domestic cats, and rodents, which can affect bird survival. Competition for food, nesting sites, and space among different bird species also influences abundance.	Increased predation pressure can reduce populations of small birds (Loss <i>et al.</i> , 2013). Competition for nesting sites such as mast, cavities, and rooftops may lead to the exclusion of less adaptable species.
Habitat Loss and Fragmentation	The conversion of forests, wetlands, and other natural habitats into urban infrastructure reduces the availability of nesting and foraging areas for birds. Fragmentation isolates populations, limiting movement and genetic diversity.	Leads to population declines, especially for habitat specialists (Fahrig, 2003). Reduced connectivity between green spaces affects migration, dispersal, and breeding success.
Homogenization of Habitats	Urban environments often have fewer habitat types, favoring generalist species that can adapt to artificial structures and human-modified landscapes. Urban sprawl leads to biotic homogenization, where the same species dominate across large areas.	Biodiversity declines as urban exploiters outcompete specialists (McKinney, 2006). Loss of unique local species and reduction in ecological functions provided by diverse bird communities.
Pollution	Noise, light, and chemical pollution alter bird behaviour, disrupt breeding cycles, and affect survival. Noise pollution interferes with bird communication, while artificial lighting disrupts sleep cycles and migration cues. Chemical pollutants (e.g., pesticides, heavy metals) impact bird health.	Reduced reproductive success due to disrupted mating calls and nesting behaviours. Increased stress and mortality from exposure to toxic substances. Altered migration patterns due to artificial lighting (Halfwerk and Slabbekoorn, 2009; Hölker <i>et al.</i> , 2010).

Bird Behavioral Adaptations to Urbanisation

Urban environments bring about arrays of unique selective pressures, prompting birds to modify their behaviours for survival and reproductive success. Birds in urban areas

adapt to the constant changes in urban areas through the following ways:

Foraging Behaviour

Urban bird species particularly urban exploiters exhibit remarkable dietary flexibility, and adapt to man-made food sources such as human leftovers, agricultural

produce, bird feeders, and ornamental plants as food (Pollock *et al.*, 2022). This opportunistic foraging enables these bird species to thrive in resource-rich urban areas, often leading to shifts in dietary composition and feeding strategies.

Nesting Strategies

In response to habitat modification, many urban-dwelling birds utilize artificial structures such as buildings, telecommunication mast, bridges, and streetlights for nesting support while also using artificial materials such as hair-attachment plastic strips, cellophane, and aluminum foil for nest making (Efenakpo *et al.*, 2017). These adaptations compensate for the scarcity of natural sites like tree cavities and shrubs, though they may also expose birds to new environmental hazards such as increased human disturbances and predation by invasive species.

Anti-Predator Responses

As a result of altered predator communities in urban environment, some bird species often exhibit reduced wariness and altered or lower vigilance levels. The relative scarcity of natural predators, combined with frequent human presence, leads some to develop increased tolerance toward human activity and less concern for predators such as snakes. However, certain birds may also adopt new defensive behaviours, such as aggressive mobbing of potential threats (Cooper *et al.*, 2020).

Acoustic Communication

Urban noise pollution poses a significant challenge for bird communication. To counteract auditory interference from traffic and industrial noise, birds adjust their vocalizations by increasing pitch, modifying song structure, or amplifying volume (Halfwerk and Slabbekoorn, 2009). For example, the Grey-headed Nigrita often modifies its call structure when it is in the

urban area compared to when in the natural or rural area. These adaptations enhance signal transmission and ensure effective communication for territory defense and mate attraction.

Migration Patterns

Urbanisation influences migratory behaviours in different bird species. The availability of stable food sources and milder microclimates encourages some bird species to shorten their migration routes or adopt sedentary lifestyles (Marra *et al.*, 2005). As a result, partial migration, a situation where only a portion of a population migrates while others remain year-round has become increasingly common in urban bird populations.

Human habituation

Urban birds often exhibit increased boldness and reduced flight initiation distances in response to frequent human interactions (Kitchen *et al.*, 2021). For example, species the Western cattle egrets following mowers and tractors operating in the field for food often feel less concerned about the human presence operating these machines. This habituation allows some species to exploit urban resources more effectively, though it may also increase risks of human-wildlife conflicts, such as dependency on artificial feeding and greater vulnerability to urban hazards.

Impacts of Urbanisation on Bird Numbers and Diversity

Urbanisation often comes with loss of natural habitat, pollution, anthropogenic disturbance (Jacob *et al.*, 2012; 2024a,b,c) and despite these challenges, healthy urban areas also support moderate diversity in certain contexts, particularly in green spaces like parks, gardens, and urban forests (Humphrey *et al.*, 2023). Although, urbanisation decreases overall diversity of avian species especially specialist and sensitive species, including

cavity nesters, insectivores, and large raptors, which are particularly vulnerable to urban expansion (Efenakpo *et al.*, 2019), it often increases the relative abundance of the few species (urban exploiters) that are highly adaptable to the urban conditions which thrive in urban landscapes due to their generalist diets and nesting habits (Efenakpo *et al.*, 2019). This pattern is often most pronounced in the urban core, while suburban areas may retain a higher diversity of bird species due to the presence of more green spaces and habitat heterogeneity, where avitourism can incentivize the preservation of such areas for both conservation and economic gain (Marzluff, 2017; Efenakpo and Jacob, 2025). Also, Species capable of thriving in human modified habitats often experience population booms.

Most often the species greatly affected by urbanisation include ground-nesting and specialist species such as urban avoiders which are due to lack of suitable habitats and increased predation pressures (McKinney, 2002; Minor and Urban, 2010; Conole and Kirkpatrick, 2011). Furthermore, urbanisation often results in community simplification and biotic homogenization, where communities are dominated by a few adaptable species, leading to lower functional diversity (McKinney, 2006).

Conservation Implications and Management Strategies

While urbanisation poses serious threat and challenges to avian diversity, well-planned urban areas can support thriving bird communities. However, through the implementation of sustainable conservation strategies, urban areas can become important refuges for birds and other wildlife species, striking a balance between urban development and biodiversity conservation. In order to enhance bird diversity and maintain balanced relative abundance in urban environments, the following

conservation and management strategies can be employed:

Biodiversity Conservation Strategies

The creation, preservation, restoration, and maintenance of urban green spaces such as parks, urban forests, gardens, and wetlands are crucial for sustaining bird diversity and habitats in cities (Goddard *et al.*, 2010; Jacob and Owolabi, 2010; Udoakpan *et al.*, 2012). This can involve not only increasing the total area of green space but also improving its quality by, for instance, restoring native plant communities, creating diverse habitat structure, and reducing disturbance from human activities and domestic pets (Marzluff, 2017). Also, encouraging the planting of indigenous trees and incorporating bird-friendly landscaping can provide suitable nesting sites, shelter, and food resources. Additionally, reducing habitat fragmentation by establishing ecological corridors that connect green spaces can facilitate movement and gene flow among bird populations, with avitourism serving as a catalyst for funding and community-driven green space initiatives (Bennett, 2003; Efenakpo and Jacob, 2025).

Reducing Pollution

Minimizing noise, light, and chemical pollution is crucial for creating a more hospitable environment for urban birds. Excessive noise can disrupt bird communication and breeding behaviours (Halfwerk and Slabbekoorn, 2009), while artificial lighting can interfere with migratory patterns and nocturnal species (Hölker *et al.*, 2010). Also, reducing pesticide and chemical use in urban landscaping can also prevent contamination of food sources and water bodies, safeguarding bird health.

Urban Planning and Design Considerations

Integrating bird-friendly features into urban design can significantly mitigate the negative

impacts of urbanisation on avian species. Key measures through which urban planning design and planning can be done effectively include:

- i. Reducing window collisions by using bird-safe glass and minimizing reflective surfaces on buildings (Klem, 2009).
- ii. Managing artificial lighting to prevent disruptions to nocturnal and migratory bird species.
- iii. Incorporating bird-friendly infrastructure, such as green roofs, nesting boxes, and urban wetlands, to provide additional habitats and resources for urban bird populations (Jacob *et al.*, 2024b).

Public Awareness Policies and Community Engagement

Public participation is vital for successful bird conservation in urban environment and several strategies can be used to achieve this goal which include:

- i. Policy implementation to regulate urban expansion in ecologically sensitive areas (Jacob *et al.*, 2012).
- ii. Educational initiatives to promote responsible pet ownership, particularly in reducing predation by free-ranging domestic dogs and cats.
- iii. Community involvement through citizen science programmes and conservation initiatives, encouraging urban residents to participate in bird monitoring and habitat restoration (Eniang *et al.*, 2019; Lepczyk *et al.*, 2017).
- iv. Promotion of sustainable practices, such as native plant gardening, reducing pesticide use, and creating bird-friendly yards and balconies, including avitourism programmes that promote education, festivals, and community-led bird monitoring (Jacob *et al.*, 2024d;

Emelue *et al.*, 2014; Efenakpo and Jacob, 2025).

Long-term Monitoring and Assessment

Establishing long-term bird assessment and monitoring programmes is essential for tracking changes in species diversity and abundance in urban environments (Jacob *et al.*, 2024c). Citizen science initiatives, in collaboration with academic institutions and nature conservation organizations, can provide valuable data on urban bird populations (Sullivan *et al.*, 2014). These continuous research on avian responses to urbanisation can inform adaptive management strategies, bolstered by avitourism-driven citizen science and research on Nigeria's avian hotspots

while also informing evidence-based policymaking for sustainable urban biodiversity conservation.

Conclusion and Recommendation

Urbanisation profoundly impacts bird diversity, relative abundance, and behaviours, often favouring generalist and adaptable species while threatening specialists. Mitigating these effects requires a multifaceted approach, including habitat preservation, urban planning, and public engagement and enlightenment. As urban areas continue to expand, understanding and addressing the impacts of urbanisation on bird populations will be critical for global biodiversity conservation. In light of this, it becomes inexorable to recommend; areas of research studies gaps and future directions such as global comparisons of temperate regions, tropical and subtropical cities, longitudinal studies tracks on the long-term impacts of urbanisation on bird populations, more research to understand the underlying mechanisms driving behavioural changes in urban birds and the role of the synergistically interaction of urbanisation and climate

change to understand the combined effects on avian populations.

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SPATIO-TEMPORAL ANALYSIS OF WETLAND DEGRADATION HOTSPOTS IN RIVERS STATE, NIGERIA

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ABSTRACT

The importance of wetlands in supporting ecological balance, maintaining biodiversity and provision of various ecosystem services cannot be overstated. These valuable ecosystems are becoming threatened due to human activities. Hence, this paper assessed the spatio-temporal extent of wetland degradation hotspots in River's state for a period of 40 years (1984 – 2024). Landsat images from United States Geological Survey were utilised to perform supervised land use and land cover (LU/LC) classification using Random Forest algorithm. Kappa coefficient, postclassification techniques and Kernel Density Estimation were used to evaluate the classification accuracy, spatial extent and hotspot analysis respectively. Results showed that seven LU/LC types - dense vegetation, sparse/grass land, wetland, built-up, water body, farmland and bare land were identified for the periods- 1984, 2004 and 2024. The predominant land covers were dense vegetation and wetland while prevalent land uses were farm land and built-up. Each of the LU/LC types experienced change within the study periods. Wetland experienced a declining trend of 3068.49Km² in 1984 to 2795.45Km² and 2553.30Km² in 2004 and 2024 respectively. A total of 2514.03Km² of wetlands remained stable, 515.19Km² of wetlands had been changed to other forms of LU/LC types, while 39.27Km² of wetlands had been recovered between 1984 and 2024. The hotspot analysis highlighted areas of very low/no degradation zones, low degradation, moderate, high and very high degradation. Degema, Bonny, Andoni, Opobo and Okirika were areas that had very high degradation hotspot, while Abua, Ahoada West, Port Harcourt and Khana exhibited high degradation hotspots. This research has identified the areas where urgent interventions and conservation efforts are needed towards curbing the present wetland degradation in River's state.

Keywords: Wetland degradation; Land use; Land cover; Hotspot analysis; remote sensing

INTRODUCTION

Wetland is an area of land covered by water, either temporarily or permanently, with vegetation adapted to saturated soil. They are characterized by different forms such as marshes, fens, and peatland, and are considered as among the most valuable ecosystems on the Earth. Wetlands are important at the national and international levels. They cover about 6 per cent of the

world landmass, and they are a significant part of global climate regulation and biodiversity conservation. Globally, wetlands are essential in the management and control of floods and coastal erosion, store carbon, and are significant abode to migratory birds and other animals; this makes wetlands relevant in the conservation efforts across borders (Bhowmik, 2022). Besides being ecologically

significant, wetlands help sustain the livelihoods of humans through agriculture, fishing, and tourism activities that aid in environmental sustainability and socioeconomic status (Xu *et al.*, 2019; and Reis *et al.*, 2017). In Nigeria, saline and freshwater wetlands such as marshes, swamps, bogs, fens, floodplains and mangrove forests predominate; and it cut across various regions of Nigeria such as the Niger Delta, Lake Chad, Hedejia Nguru, Benin-Owena, Okomu, Lagos-Lagoon and Lekki-Peninsula. Coastal and estuarine wetlands, which are mostly situated in Niger Delta region are important in enhancing environmental sustainability through preservation of biodiversity, regulation of waters and reducing effects of climate change. They also play an important role in the development of the economy through sustaining fisheries, crop production and other economic activities (Xu *et al.*, 2019). However, despite their ecological and socioeconomic functions, these wetlands have been experiencing series of pressures in recent years because of high rates of rural urban migration, unplanned infrastructural growth, agricultural encroachment, and industrial activities as well as oil-related pollution (Zabbey *et al.*, 2017).

Consequently, significant portions of natural wetlands have been destroyed or degraded to an alarming extent putting at risk the environmental sustainability and livelihood of the local populations. Profound effects of this degradation include loss of biodiversity, local communities' disruption, and susceptibility to climate-related disasters (Bariweni and Amukali, (2017). To effectively address these problems, Reis *et al.* (2017) opined that it is necessary to evaluate in detail the spatial and temporal patterns, intensity and triggering agents of wetland

degradation. This approach will aid in identifying degradation hotspots, advance scientific knowledge on landscape transformations, and provide empirical foundation to develop evidence-based policies and area-specific conservation actions to enhance the wetland ecosystem functions and service. Ubaekwe *et al.* (2022); Parsa *et al.* (2016) and Wang *et al.* (2010) have highlighted remote sensing and Geographic information system (GIS) as an effective tool capable of detecting land cover variations, wetland degradation hotspots, as well as measuring human encroachment over time.

Hence, this paper employs remote sensing and GIS to assess the spatio-temporal dynamics of wetland degradation in Rivers State, for the period of 40 years with the view of highlighting the areas of critical degradation hotspots as well as evaluating the underlying drivers of the wetland degradation. The study will provide support towards sustainable policy interventions that will enhance the conservation, restoration and long-term resilience of the wetland landscapes within the region.

MATERIALS AND METHODS

Study Area

This study was carried out in River's state, southern Nigeria, located within the latitude of 4°30'N to 5°30'N and Longitude of 6°30'E to 7°30'E (Figure 1). It covers the total area of about 11,077km² that spread across 23 local governments. The state is the centre for major economic activities especially the oil and gas industry, and it is characterized by diverse landscapes such as mangrove ecosystems, freshwater swamps and estuaries. The area experiences high rainfall above 3000mm and temperature range of 24°C to 32°C (Nwilo and Badejo, 2006).

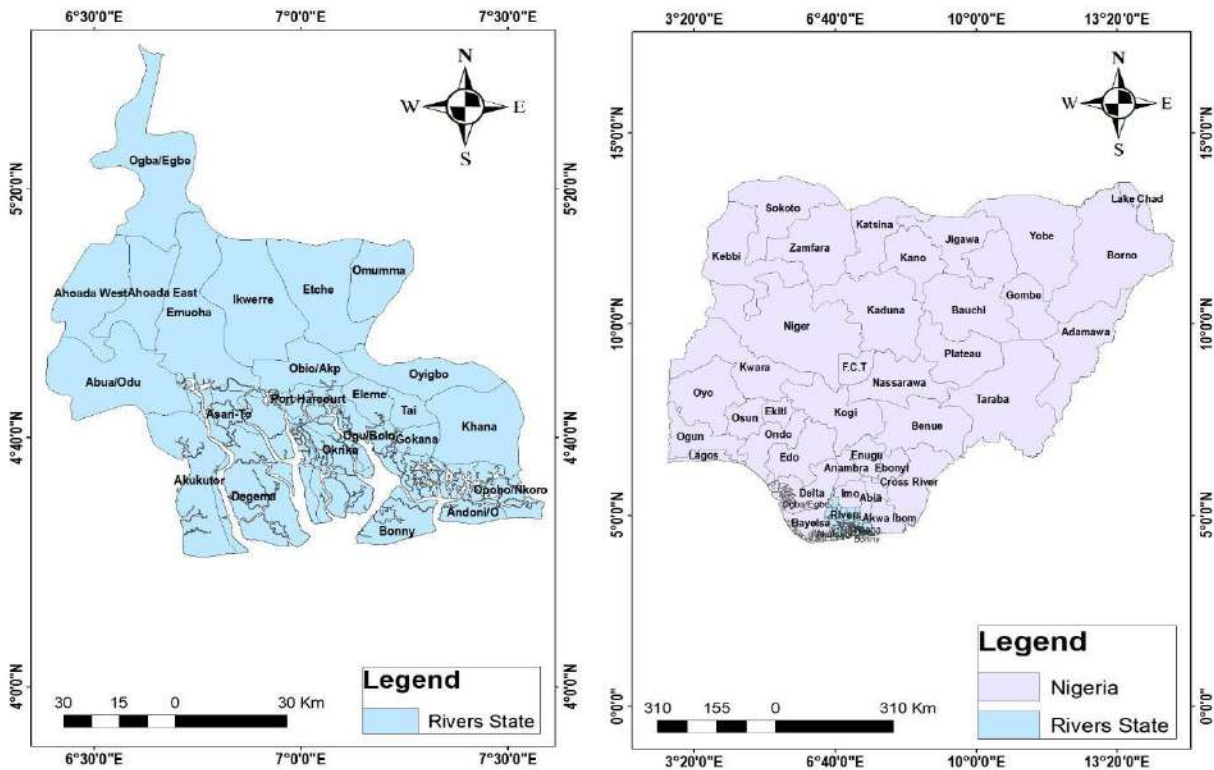


Figure 1: Map of the Study Area, Data Collection and Pre-processing

Primary and secondary data were employed to map out the spatial extent of wetland and wetland degradation hotspots. Multitemporal Landsat imageries of 1984, 2004 and 2024 were obtained from the United States Geological Survey (USGS) platform. The state boundary shapefile was obtained from the National Space Research and Development Agency (NASRDA). These databases have been used by many researchers including (Ubaekwe *et al.*, 2022;

Ukaegbu *et al.*, 2017 and Li *et al.*, 2013). The attributes of the datasets used are presented in Table 1 below. Ground truth points were collected randomly from the diverse land use and land cover types of the area with the aid of a Garmin Geographical Positioning System (GPS). The points were used for validation and accuracy assessment of the classifications. Data collected were pre-processed, pan shaped and geo-referenced using the Ground Control Points (GCP).

Table 1: Attributes of the Datasets Used

	1984	2004	2024
Scene ID	LT05_L1TP_188056_1984042_02_T1	LE07_L1TP_188056_20040108_02_T1	LC08_L1TP_1880240111_02_T1
Sensor ID	"TM"	"L7_ETM"	"L8_OLI_TIRS"
Spatial Resolution	30m	30m	30m
Acquisition Date	1984-04-20	2004-01-08	2024-01-07
Datum	"WGS84"	"WGS84"	"WGS84"
UTM	32N	32N	32N

DATA ANALYSIS

Supervised classification approach was used to classify different land use and land cover classes employing Random Forest Algorithm (RFA) classifier as used by (Hayes *et al.*, 2014). Confusion matrix was used to appraise the accuracy of the classifications. Percentage Kappa coefficient above 70% shows a high classification accuracy, less than 70% shows moderate to weak classification accuracy. This method has been widely used in related studies by (Suratman and Surayahana 2012; Ubaekwe and Engwoh 2020 and Lambin *et al.*, 2001). Post classification technique was carried out in ArcMap to determine the spatial extent of each LU/LC type. The wetland transition, including the areas of wetland gain, losses, and stable areas were estimated in Arcmap as adopted by several researchers including (Ubaekwe *et al.*, 2022; Kindu *et al.*, 2013; Demissie *et al.*, 2017).

Kernel Density Estimation method was used to carry out spatial hotspot analysis to determine the clusters of wetland degradation. Data analysis was done in R, while results are presented in maps, tables and figures.

RESULT AND DISCUSSION

The LU/LC types of the study area within the study periods (1984, 2004 and 2024) are presented in Figure 2. Seven LU/LC types were identified including – dense vegetation, sparse vegetation/grass land, wetland, built-up, water body, farm land and bare surface. The accuracy of the land use and land cover classifications is shown in Table 2. Percentage accuracy was 96.05, 90.0 and 99.2 for 1984, 2004 and 2024, respectively.

The spatial extent of each land use and land cover types for the years 1984, 2004 and 2024 are presented in Figure 3. Dense vegetation and wetland were the dominant land cover across the study periods while farm land and built-up were the dominant land use. The least land use and land cover types were bare land and water body. Each LU/LC types has undergone change over the study periods. Dense vegetation and wetland consistently showed a downward trend throughout the study periods. On the other hand, sparse/grass land, built-up, water body and bare land showed declining trends. Figure 4 shows the net changes in LU/LC types between 1984 and 2004; 2004 and 2024.

Within the first study period, dense vegetation and wetland lost -1147.28Km² and -273.04Km²;

and then -536.1Km² and -242.15Km² in the second period respectively. Sparse/grass land, built-up, water body, farm land and bare land gained 863.01Km², 241.42Km², 136.68Km², 169.94Km² and 9.27Km² between 1984 and 2004. The same trend was also observed between 2004 and 2024, except for farm land that exhibited a slight decrease. Figure 6 present the spatial dynamics of the wetland transition and the degree of Wetland transition over time between 1984 and 2024. It was recorded that larger areas of the wetland (2514.03Km²) remained stable within the periods, compared to the areas of

wetland loss (515.19Km²), and the relatively small areas of wetland gain (39.27Km²). Figure 7 describes the wetland degradation hotspots in the study area. It's categorized as very low/no degradation, low degradation, moderate, high and very high areas of degradation. Some local governments including Degema, Bonny, Andoni, Opobo, and Okirika were mostly the areas of very high degradation hotspot, while some other LGs including Abua, Ahoada West, Port Harcourt and Khana had some areas of high degradation hotspot.

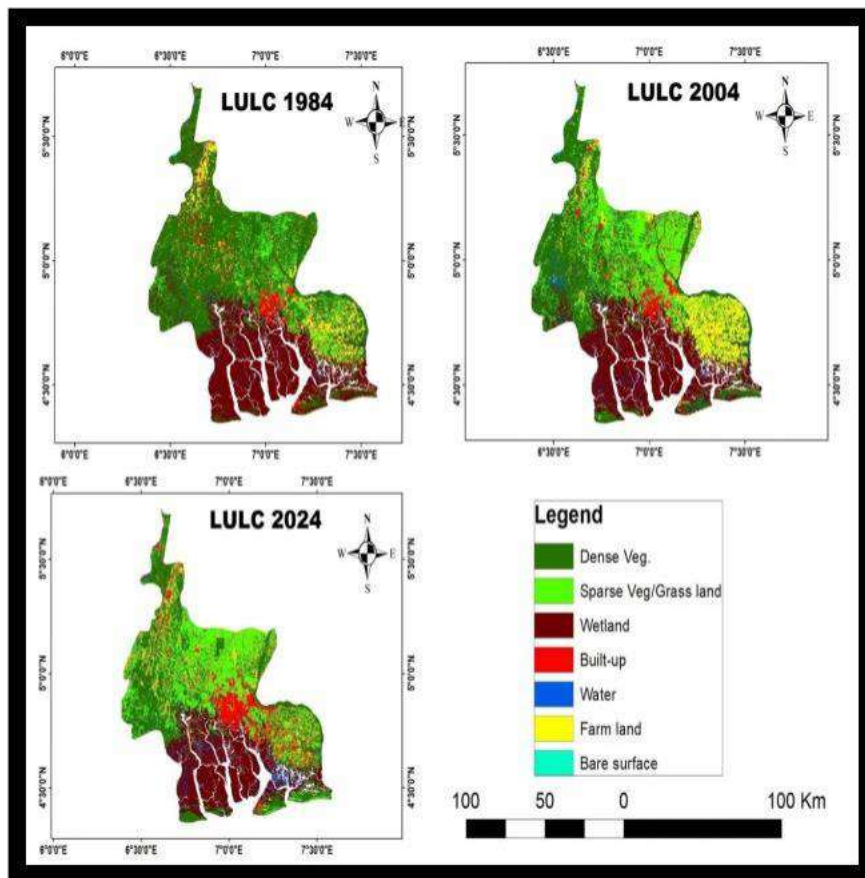
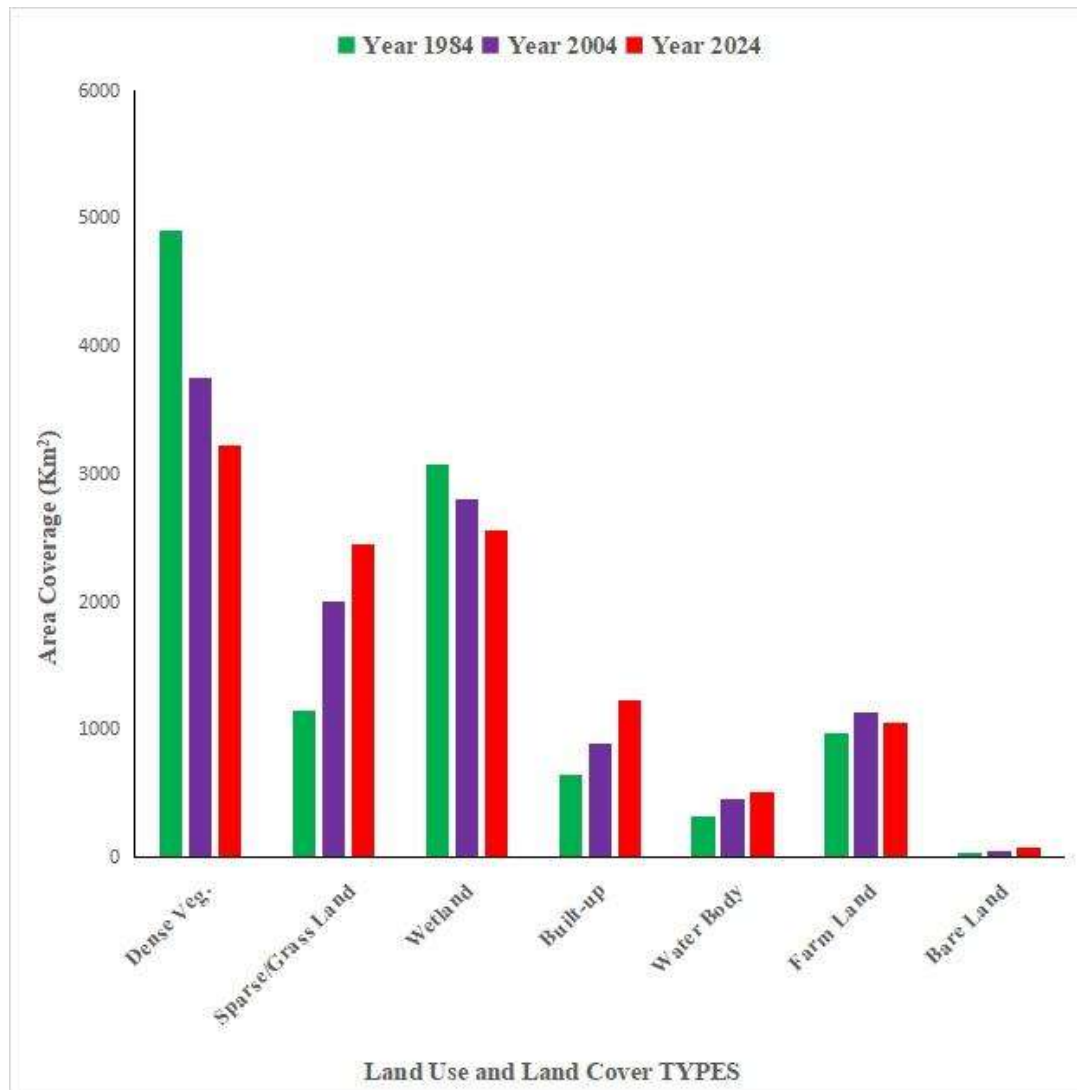


Figure 2: Land Use and Land Cover of Rivers State for 1984, 2004 and 2024

Table 2: Summary of the Accuracy Assessments of the LU/LC Classifications

Study Area	Overall Accuracy	P(r)	Kappa Coefficient	% Accuracy
1984	0.97	0.19	0.96	96.05
2004	0.92	0.20	0.904	90.0
2024	0.99	0.20	0.99	99.2

**Figure 3: Area Coverage of Each LU/LC Types within the Study Periods**

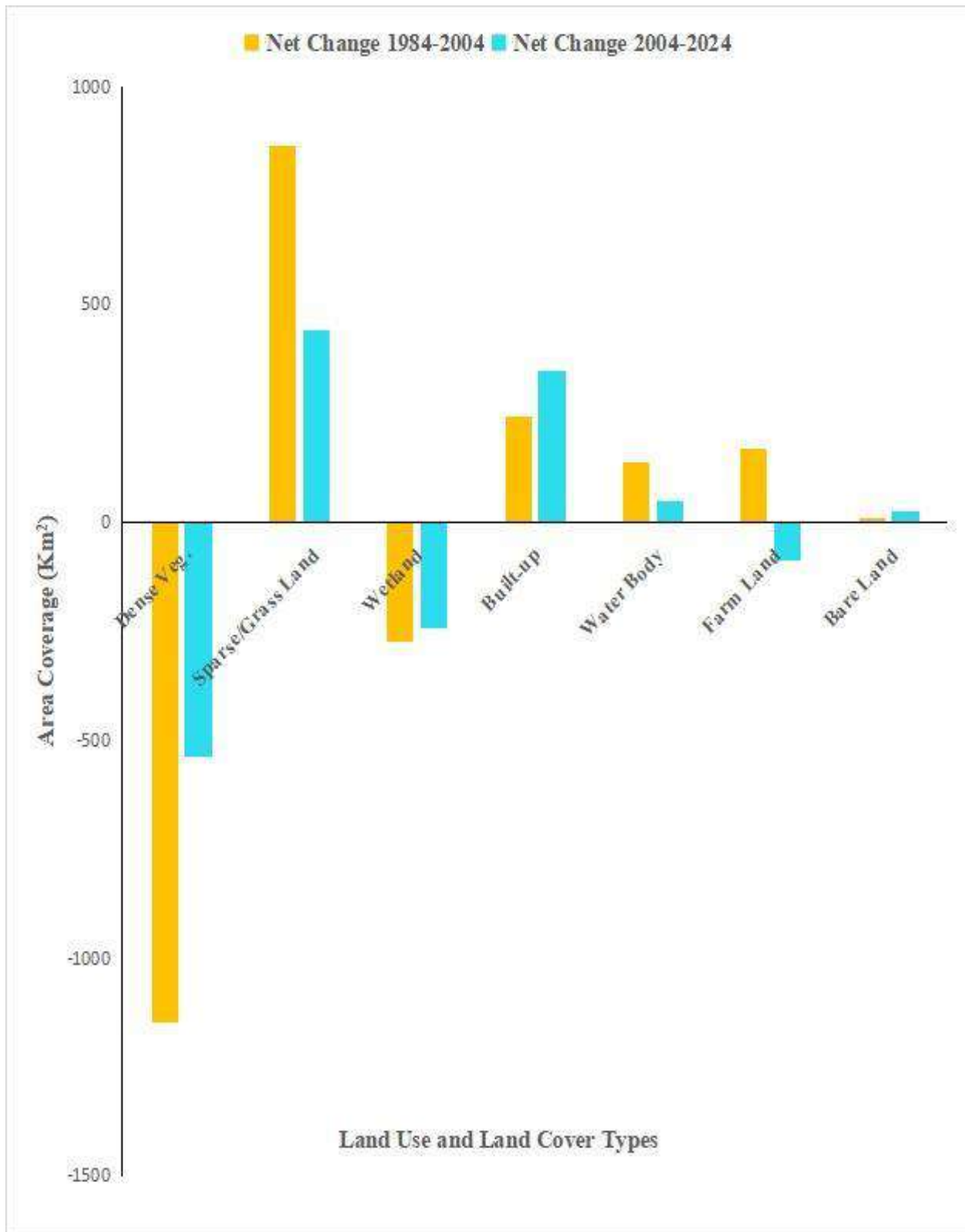


Figure 4: Net Changes in Land Use/Land Cover Types from 1984–2004 and 2004–2024

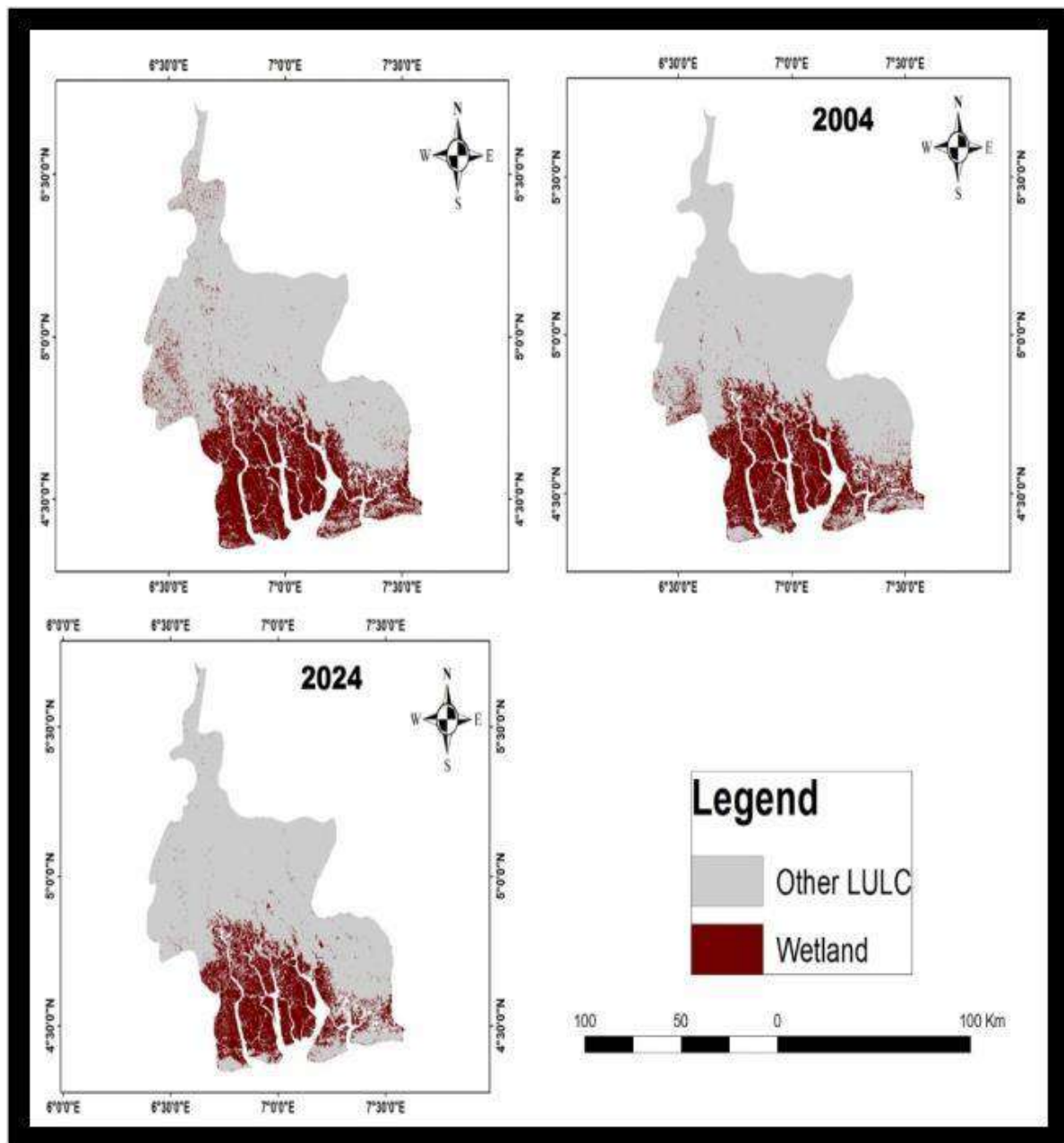


Figure 5: Spatial Extent and Dynamics of Wetland Cover

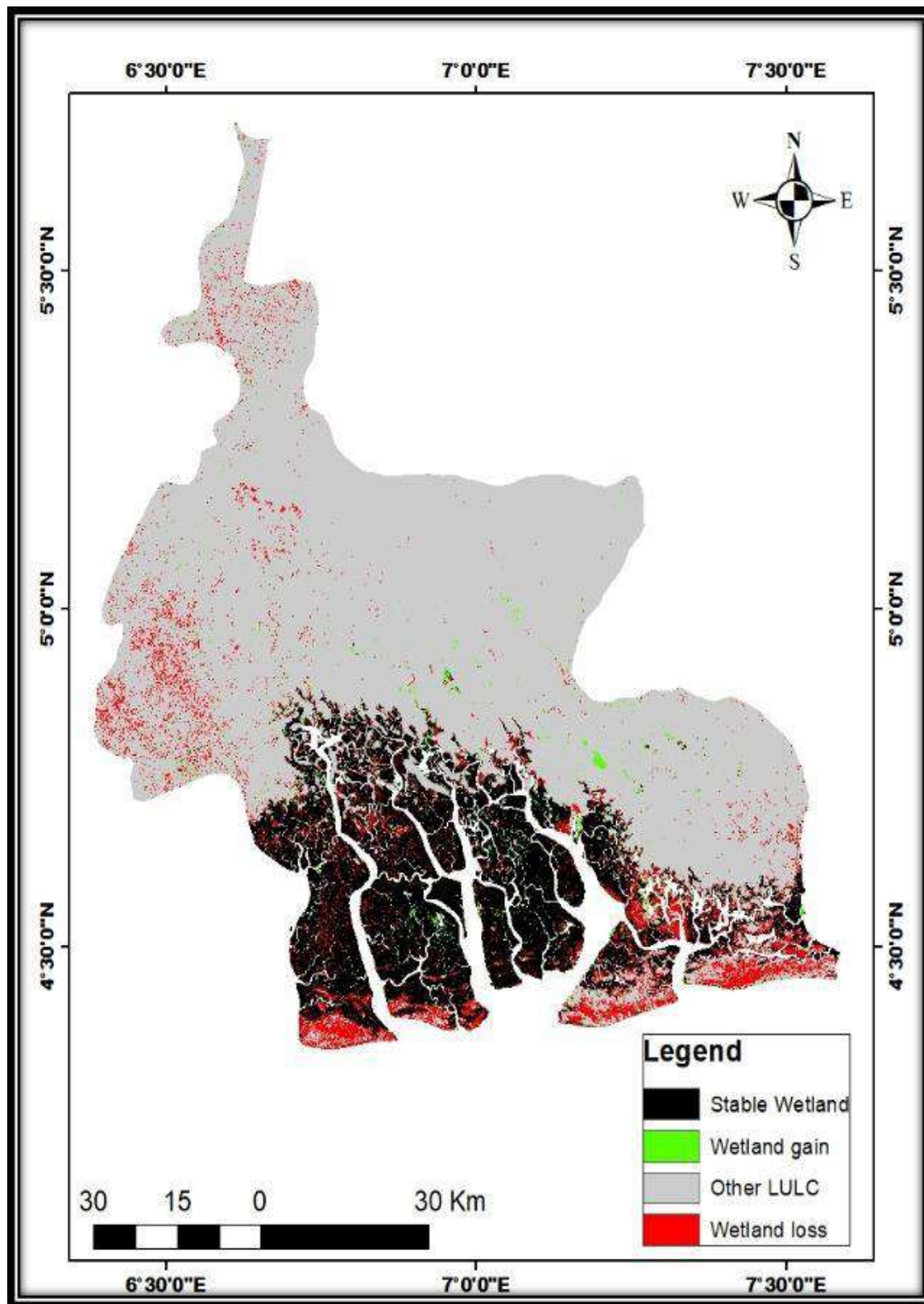


Figure 6: Spatial Patterns of Wetland Transitions from 1984 and 2024



DISCUSSION

The major land use and land cover types (dense vegetation, sparse/grass land, wetland, built-up, water body, farm land and bare land) consistently recorded in the study area within the study periods -1984, 2004 and 2024 were similar to the LU/LC types recorded in Bayelsa by Bariweni and Amukali, (2017), and other Niger Delta regions according to Ubaekwe *et al.* (2024) and Elekwachi *et al.* (2021). However, there was a slight difference in the LU/LC types of Northern Nigeria according to Sedano *et al.* (2020), and Owerri zone, according to Ubaekwe *et al.* (2021). The differences in the major LU/LC types could be linked to so many factors including the geographical location, topography, climatic condition, hydrology and soil type. Wetlands naturally form in low-lying areas where water accumulation is high and their soils are mostly characterized by water-retaining soils (Lambin *et al.*, 2001). Hence, the above factors play critical roles in determining the natural land cover patterns of an area (Verburg *et al.*, 2004). Furthermore, socioeconomic activities and urbanization could also contribute to the major LU/LC types of an area. The changes observed in all the LU/LC types support the fact that land is in a continuous state of transformation (Lambin *et al.*, 2003). The decreasing trend in dense vegetation and wetland; and the increasing trend in built-up, and water body are consistent with the findings of Iwalaiye *et al.* (2024); Ubaekwe *et al.* (2024) and Elekwachi *et al.* (2021). This trend could be linked to human population increase, high rate of urbanization, infrastructural development, industrialization and poor land management policies. According to Seto *et al.* (2012), urbanization is one of the key significant drivers of LU/LC change particularly in developing countries due to poor land use management system. Verburg *et al.* (2004), opined that human population growth is the chief driver of LU/LC change.

The more the population, the more the demand for housing, social amenities, food, and industrial development, resulting to increase in anthropogenic activities that vehemently alters the natural ecosystems. Furthermore, weak land management policy, and enforcement were also part of the problem (Sam and Zibimar 2024). Forest and wetland ecosystems provide vital services ranging from carbon sequestration, rich biodiversity, flood regulation, etc. However, due to no direct and fast economic incentives in maintaining the ecosystems, they are perceived as an option for the high yielding economic activities that have immediate returns such as the case of converting Nekede zoological garden established in 1976 to a residential estate by the then Imo state government in 2023. Kimario *et al.* (2023) also linked decreasing trend of vegetation and wetland in Wami-Ruvu River Basin, Tanzania to weak policy and implementation. Seto *et al.* (2012) mentioned that land use planning without adequate environmental considerations could lead to habitat loss, land degradation and environmental crisis. The increasing trend in water body could be attributed to natural and anthropogenic activities such as sand mining, dredging, climate variability and rise in sea level. IPCC (1996) predicted rise in sea level up to 1.0m; Arokoyu and Ogoro (2014) added that rise in sea level will cause expansion of water bodies and submergence of settlements especially within the coastal region. Giadom and Akpokodje (2016) reported that incessant sand mining in Eyaa River, Onne, Rivers State, have resulted to the expansion of the river channel to more than double its original width. The increasing rate of wetland degradation in Niger Delta Region has risen to a critical level that demands urgent and targeted interventions. Elekwachi *et al.* (2021); Efiog *et al.* (2018); Anule and Ujoh, (2017); Bariweni and Amukali, (2017); and Obiefuna *et al.* (2013) have reported high

wetland degradation in Niger Delta, Calabar, Markurdi, Bayelsa and Lagos respectively. They added that oil industry activities are the architecture of environmental pollution including wetland degradation in the Niger Delta Region; and the degradation threatens biodiversity, diminishes wetland ecosystem services, and affects the livelihoods of local communities. Kimario *et al.* (2023) recorded high wetland degradation in Tanzania and attributed the drivers to rapid economic development. The very high to high wetland degradation hotspots observed in Degema, Bonny, Andoni, Opobo, Okirika, Abua, Ahoada West, Port Harcourt, Khana and Obio/Akpor reveals that wetland degradation is still persistence in the Niger Delta and could be linked to many factors including oil and gas exploration, oil spillage, infrastructural development and urban expansion mentioned by the authors above. One of the biggest problems concerning wetland degradation is oil spillage. It deposits poisonous hydrocarbon like polycyclic aromatic hydrocarbons (PAHs) into the wetland soil and water. According to Badom *et al.* (2024); Ayanlade and Proske (2016); and Anule and Ujoh (2017), the toxic effects of these substances often lead to death of aquatic organisms and even vegetation resulting to ecological imbalance. More so, oil spill usually covers the surface of the water which decreases the oxygen transfer within the ecosystem hence suffocating the aquatic life. According to Kingston (2002), the after effect of oil spill remain in wetlands for decades, making recovery slow and challenging. Several mitigation measures have been initiated by the Nigeria government to curb series of environmental pollution and wetland degradation especially in the Niger Delta Region. This includes establishment of the Hydrocarbon Pollution Remediation Project (HYPREP) in 2012. Since its inception, HYPREP has been challenged with implementation of United

Nations Environment Program's (UNEP) on soil and ground water remediation, mangrove restoration and sustainable livelihoods of the affected communities (Sam and Zibima, 2024). Federal government also launched a clean-up exercise in Ogoni land with the sole aim of remediating the contaminated sites. In addition, environmental protection laws to prevent further land degradation were also enacted by the federal government. Nevertheless, Sam and Zibima (2024) disclosed that although laws and environmental policies were enacted, but they are not consistently applied, and environmental pollution and wetland degradation have continued to flourish. Nwaichi and Osuoha (2022) added that the region has recorded over 550 oil spills since 2014 despite the environmental policies. They added that law enforcement is the major challenge due to the indisposition of the government. However, many other agencies and NGOs including Nigeria Conservation Foundation (NCF) have contributed positively to wetland restoration projects in the region. Zabbey *et al.* (2017) have highlighted several success stories of remediation and restoration project by HYPREP in Niger Delta Region. Their efforts could be linked to the traces of wetland recovering recorded in this study.

Conclusion

The study classified varying land use and land cover types of Rivers state for some periods; and also determined the spatial extent of wetland degradation and hotspots. Dense vegetation and wetland were the dominant land covers across the study periods while farm land and built-up were the dominant land uses, other LU/LC types of the area includes sparse/grass land, water body and bare land. Dense vegetation and wetland consistently exhibited a decreasing trend while sparse/grass land, built-up, water body and bare land showed a decreasing trend throughout the study periods. High wetland

degradation hotspots were found in some local governments. Oil spillage, urbanization and poor policy enforcement were implicated as the major drivers of wetland degradation in the area. Hence, it is recommended that oil and gas activities should be checked, and efforts on policy enforcement should be strengthened.

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ASSESSMENT OF SPATIAL AND TEMPORAL PHYSICOCHEMICAL PARAMETERS IN THE SELECETED PORTION OF THE HADEJIA-NGURU WETLAND IN JIGAWA-YOBE, NIGERIA.

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ABSTRACT

This study assessed water quality of riparian portions of Hadejia-Nguru wetland through bacteriological and Physico-chemical analyses. Field studies were conducted in three communities during early and late dry seasons. Spatial concentrations of Physico-chemical parameters (Temperature, Turbidity, EC, pH, TDS, BOD, DO, Na⁺, Ca²⁺, K⁺, NO₃⁻, PO₄³⁻) were determined using standard analytical methods, The results revealed that there were no significant ($p > 0.05$) variations in the concentrations of the physicochemical parameters (temperature, EC, TDS, BOD, Na⁺, Ca²⁺, K⁺, NO₃⁻, and PO₄²⁻) and were within the WHO and NSDWQ recommended standards across the study sites - Adiyani, Ngurodi, Ngarbi and groundwater. Also, turbidity and DO mean concentrations were beyond the recommended standards by WHO and NSDWQ in all the sampling sites. Moreover, water samples collected during the late dry season exhibited significant variation ($p < 0.05$) in the physicochemical parameters mean concentrations compared to those collected during the early dry season. The study concludes that there is urgent need for prior treatment of the water before consumption and an effective management of the wetland and conservation measures to safeguard the wetland's water quality and overall ecological health.

Keywords: Wetland, Spatial, Temporal, water quality and physicochemical parameters.

INTRODUCTION

Nigeria is a country richly endowed with both coastal and inland wetlands and these wetlands are of ecological, economic, socio-cultural, scientific and recreational significance. Nigeria is also a home to one of the first wetlands to be listed as a (Ramsar site) which is a type of wetland that is internationally recognized (Tijani *et al.*, 2011). In Nigeria, wetlands cover about 28,000 km² (about 3%) of the 923,768 km of the country's land area. One of these is the HNWs named after two major towns

(Hadejia and Nguru wetlands) in the area and are surrounded by many villages. They are extensive floodplain wetlands in the dry lands of northeastern Nigeria. In 2000, the Nguru Lake and Marma Channel Complex Wetlands (located within the HNWs) were designated the first Nigerian wetlands of international importance under the Ramsar Convention (Ayeni *et al.*, 2019). Physicochemical analyses are important tools for assessing the environmental health of wetlands. These analyses provide valuable information about the health and

functioning of wetland ecosystems. Figure 1 showed the study's designated sampling points in the wetland where water samples were taken for physicochemical analysis.

MATERIALS AND METHODS

Study Area

The Hadejia-Nguru Wetland is located at a point where Rivers Hadejia and Jama're flow through a fossil dune field before converging and draining into Lake Chad and lie between longitude 10°15'E and 11°30'E, and latitude 12°13'N and 12°55'N. The wetlands extend for approximately 120 km from West to East within Jigawa State and for a further 60–70 km downstream in adjacent Yobe State, (Ayeni *et al.*, 2019). The climate of the Hadejia-Nguru wetland has been experiencing changes and variability over the years. These changes include fluctuations in climatic variables such as temperature, precipitation, wind. (Alkali *et al.*, 2023). The hydrological changes in the wetlands including changes in rainfall patterns, river flow regime, and river channel capacity have contributed to increased incidences of flooding in the surrounding communities speed, relative humidity and solar intensity, (Bukar *et al.*, 2021). The vegetation of the Hadejia-Nguru wetland consist of various plants species, including indigenous savannah trees such as *Anogeissus leiocarpus*, *faidherbia albida*, *parkia*

biglobasa, and *vitellaria paradoxa*. The wetlands are also affected by the proliferation of Typha grass, which has negative impact on Biodiversity and human socio-economic activities (Ayeni *et al.*, 2019). The Hadejia-Nguru wetlands are characterized by a complex subsurface structure with various rock units including sand stones, shales and limestone (Eshimiakhe *et al.*, 2023) the wetlands play major role in recharge of ground water in the komadugu-yobe basin. The diverse geology of the Hadejia-Nguru wetlands contributes to the unique and varied habitats found within the ecosystem.

Sampling Stations

The study was conducted in three purposively selected communities (Ngarbi, Ngurodi, and Adiyani) within the wetlands. These communities were selected because they are the major communities around the Ramsar site and located close to Marma channel that in turn receives large amount of water flowing into the Hadejia river. In addition, the selected communities are characterized by permanent saturation of water and each of the three communities have a major channel that contributes to the major channel of the Hadejia-Nguru wetlands, the selected communities also represented a unique environment with different socioeconomic activities around the wetland water, more so, people in the communities largely depend on the wetland

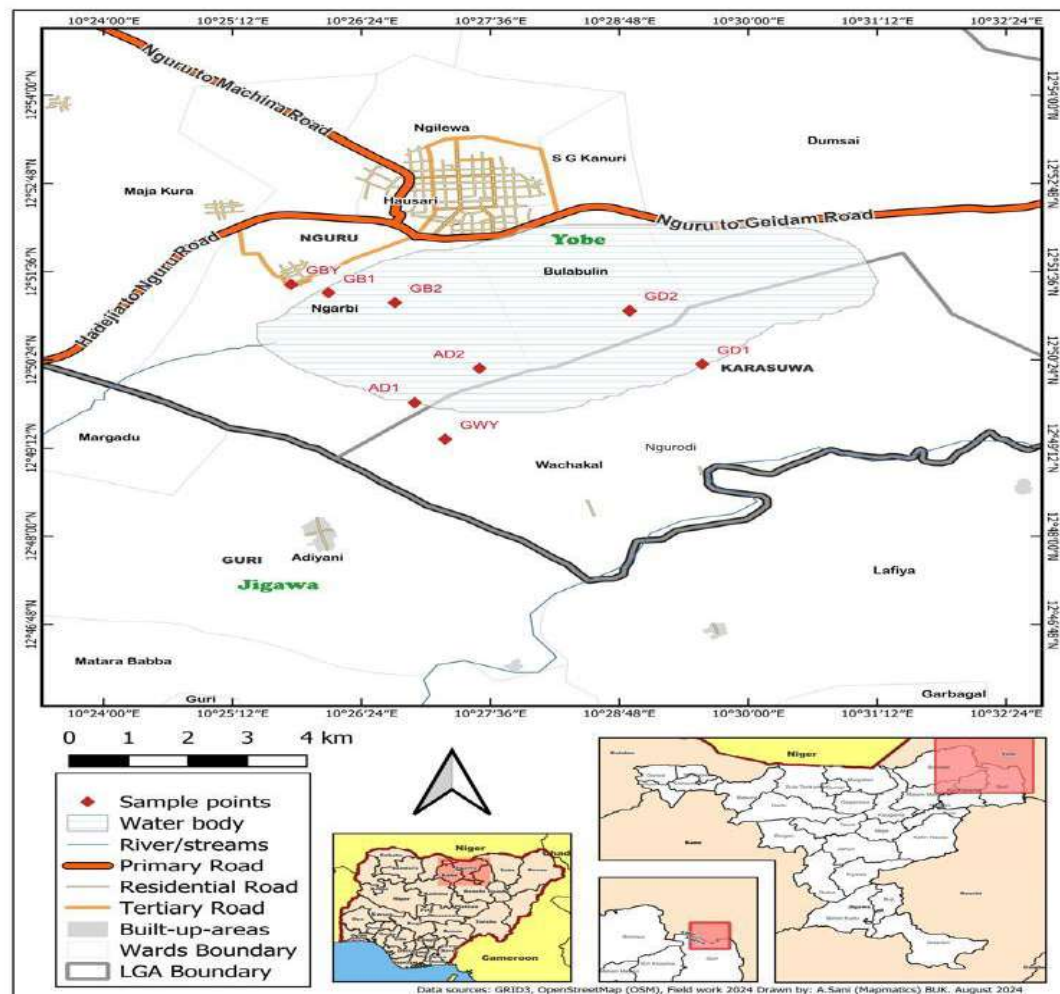


Figure 1: Study Area Showing Selected Portions of the Wetland and Groundwater Resource

around the wetland water, more so, people in the communities largely depend on the wetland water for socio-economic livelihood. Two sampling points were identified comprising of shallow zone which represented the near shore environment, typically with lower water depth and potentially greater influence from local activities. Also, offshore zone

was selected and this site was located further from the shoreline, typically in deeper water, and expected to exhibit less influence from immediate land-based sources. Additionally, two groundwater samples were collected as control from both Yobe and Jigawa parts of the wetland. The sampling stations description is presented in Table 1.

Table 1: Description of Water Sampling Stations in Hadejia-Nguru Wetland Study Area

Sample Code	Sampling area	Coordinates	
		Latitude(Y)	Longitude(X)
AD1	Adiyani shallow zone	12°83'03.76"N	10°44'82.86"E
AD2	Adiyani offshore zone	12°83'80.55"N	10°45'83.15"E
GWJ	Groundwater Jigawa	12°82'20.24"N	10°45'29.93"E
GB1	Ngarbi shallow zone	12°85'51.64"N	10°43'48.85"E
GB2	Ngarbi offshore zone	12°85'29.03"N	10°44'52.05"E
GWY	Groundwater Yobe	12°85'71.20"N	10°42'91.21"E
GD1	Ngurodi shallow zone	12°83'90.06"N	10°49'28.73"E
GD2	Ngurodi offshore zone	12°85'11.25"N	10°48'16.12"E

Sample Collection

A total of Thirty-two (32) samples of selected portion of the wetland water and groundwater were collected for the Physicochemical analyses between the hours of 6.00am to 10.00am during early dry season (December, 2023) and late dry season (April, 2024) Sample labels were used to clearly mark each sample container with date, location, zone (shallow/offshore). This meticulous approach ensured each sample were clearly traced throughout the analysis process, leaving no room for confusion. The storage and treatment of samples were done according to APHA 2005.

Determination of Physicochemical Parameters

Water temperature was determined in situ at all sampling points by suspending a thermometer

about 10 cm below water surface for at least 2 minutes before taking the readings. Turbidity analysis was done using turbid meter and measured in Nephelometric turbidity units (NTU). The pH was analyzed using pH meter by inserting its probe in standard buffer solutions with pH 4.0 and 7.0 then being rinsed with distilled water and inserted in water samples for 2 minutes before taking the readings. Electric conductivity was determined using electrometric method. The conductivity meter was calibrated according to maker's standards. 75ml of the water sample was inserted into a 100ml glass beaker, clean and dried conductivity probe was put into the glass beaker and stabilized reading was measured in micro-Siemens per centimeter. The dissolved oxygen was determined in situ by use of dissolved oxygen (DO) meter. During determination, pre- rinsed probe was immersed approximately 1.25 cm into water samples and stabilized reading was

taken and this was repeated. Biological oxygen demand (BOD) was calculated by the use of values obtained from dissolved oxygen according to Obed (2012) Total dissolved solid was determined by electrometric method using TDS meter (Hanna HI255) model. The meter was calibrated initially using standard potassium chloride solution and then the electrode of the meter was immersed in the sample. It was allowed to stabilize and the reading on the meter was recorded in milligram per liter (mg/l). Nitrate analysis was carried out according to the procedure described by the manual of soil, plant and water analysis by Udo *et al.*, 2009. This was carried out as previously described by Ouma, (2015). Phosphates (PO_4^{2-}) was analyzed by adopting the standard methods and procedures established by Golterman *et al.* (1978), Ademoroti (1996), and APHA (2005).

RESULTS AND DISCUSSIONS

Spatial and Temporal Concentrations of Physicochemical Parameters

Temperature ranged from a minimum of 15.00°C to a maximum of 26.00°C , with a mean value of $20.51 \pm 2.99^\circ\text{C}$ (Table 2). Specifically, the temperatures recorded were $20.00 \pm 2.94^\circ\text{C}$ at Adiyani shallow zone, $19.48 \pm 4.06^\circ\text{C}$ at Adiyani offshore, $19.00 \pm 3.16^\circ\text{C}$ at Ngurodi shallow zone, $19.38 \pm 2.98^\circ\text{C}$ at Ngurodi offshore, $21.38 \pm 4.19^\circ\text{C}$ at Ngarbi shallow zone, and $22.18 \pm 3.76^\circ\text{C}$ at Ngarbi offshore. Groundwater sites in Yobe and Jigawa had temperatures of $21.55 \pm 1.32^\circ\text{C}$ and $21.15 \pm 1.22^\circ\text{C}$, respectively. The p-value for temperature indicated no significant variation in temperature among the sites ($P > 0.05$) (Table 3). Temperature was significantly higher in the late dry season $22.99 \pm 1.51^\circ\text{C}$ than in the early dry season

$18.04 \pm 1.76^\circ\text{C}$, with a p-value of 0.000 (Table 4). Temperature values for this study aligned with findings from Ayeni *et al.* (2011); Yusuf and Audu (2017) and Haruna *et al.* (2020) who studied the Hadejia-Nguru wetlands and reported similar seasonal variations.

Turbidity ranged between a minimum of 21.00 NTU to a maximum of 53.40 NTU, with a mean value of 37.80 ± 1.80 NTU (Table 2). Turbidity concentration was 29.60 ± 8.85 NTU at Adiyani shallow zone, 30.75 ± 7.47 NTU at Adiyani offshore, 43.38 ± 5.51 NTU at Ngurodi shallow zone, 43.13 ± 3.87 NTU at Ngurodi offshore, 50.13 ± 2.72 NTU at Ngarbi shallow zone, and 49.58 ± 2.09 NTU at Ngarbi offshore. The turbidity at groundwater sites Yobe and Jigawa was 28.20 ± 0.73 NTU and 27.65 ± 0.60 NTU, respectively. There was significant variation ($p < 0.05$) in turbidity across the selected sites (Table 3). Turbidity was slightly higher in the early dry season (36.13 ± 10.44 NTU) than in the late dry season (39.48 ± 9.99 NTU), but this change was not statistically significant ($P > 0.05$) (Table 4). These concentrations are consistent with other studies showing turbidity in wetlands can range from 10 NTU to 100 NTU, depending on anthropogenic activities and natural events (Jones and McKay, 2019). These values are consistent with findings by Liu *et al.* (2019), who reported turbidity concentration ranging from 20 NTU to 60 NTU in various wetlands.

Table 2: Overall Descriptive Statistics of the Physico-Chemical Parameters in the Selected Portion of the Hadejia-Nguru Wetland

Statistics	Temp. (°C)	Turbidity (NTU)	pH	EC (µS/cm)	DO (mg/L)	TDS (mg/L)	BOD (mg/L)	Na ⁺ (mg/L)	Ca ²⁺ (mg/L)	K ⁺ (mg/L)	NO ₃ ⁻ (mg/L)	PO ₄ ²⁻ (mg/L)
N	32	32	32	32	32	32	32	32	32	32	32	32
Sum	656.40	1209.60	250.74	597.48	1278.63	4121.10	405.94	50.62	10.68	244.98	1393.57	746.08
Mean	20.51	37.80	7.84	18.67	39.96	128.78	12.69	1.58	0.33	7.66	43.55	23.32
Min	15.00	21.00	6.50	6.00	2.30	50.70	0.10	0.66	0.17	3.00	12.61	19.87
Max	26.00	53.40	8.98	46.20	80.00	318.00	40.06	2.55	0.52	12.70	96.67	28.10
Median	21.05	37.95	8.05	12.00	39.00	98.65	8.65	1.53	0.33	7.75	39.65	22.00
S.E.M	0.53	1.80	0.13	2.41	4.29	13.65	2.18	0.10	0.02	0.39	3.66	0.49
S. D	2.99	10.20	0.75	13.63	24.28	77.24	12.32	0.57	0.11	2.21	20.71	2.78
Variance	8.92	104.01	0.56	185.88	589.37	5965.98	151.72	0.32	0.01	4.89	428.80	7.75

Parameters	AD		GD		GB		GW		F	P
	1	2	1	2	1	2	Y	J		
Temp. (°C)	20.00 ±2.94	19.48 ±4.06	19.00 ±3.16	19.38 ±2.98	21.38±4.19	22.18 ±3.76	21.55 ±1.32	21.15 ±1.22	0.574	0.770
Turbidity (NTU)	29.60 ±8.85	30.75 ±7.47	43.38 ±5.51	43.13 ±3.87	50.13 ±2.72	49.58 ±2.09	28.20 ±0.73	27.65 ±0.60	15.767	0.000
pH	8.04±0.91	7.73±0.49	8.61±0.44	8.23±0.25	8.19±0.37	8.21±0.30	6.88±0.27	6.81±0.31	8.042	0.000
EC (µS/cm)	25.95 ±19.48	21.35 ±13.69	23.50 ±14.94	23.08 ±14.29	21.52 ±13.68	21.38 ±13.17	6.35±0.26	6.25±0.21	1.432	0.239
DO (mg/L)	13.08 ±13.40	13.23 ±12.62	52.68 ±12.54	54.50 ±13.46	34.50 ±21.92	34.80 ±21.54	59.05 ±23.16	57.83 ±23.03	4.337	0.003
TDS (mg/L)	127.70 ±127.27	126.15 ±122.68	73.43 ±9.58	72.33 ±8.80	138.08 ±49.11	136.80 ±46.11	177.25 ±73.62	178.55 ±72.75	1.101	0.394
BOD (mg/L)	6.81±5.77	7.43±6.12	17.82 ±16.74	17.58 ±16.60	21.39 ±14.42	20.95 ±13.85	4.84±4.06	4.68±3.90	1.652	0.169
Na ⁺ (mg/L)	1.01±0.31	0.96±0.29	1.48±0.60	1.48±0.62	2.06±0.55	2.10±0.55	1.77±0.11	1.80±0.10	3.801	0.006
Ca ²⁺ (mg/L)	0.22±0.08	0.25±0.06	0.35±0.10	0.35±0.09	0.30±0.09	0.30±0.08	0.45±0.07	0.46±0.05	4.914	0.001
K ⁺ (mg/L)	6.75±2.99	7.05±2.65	6.11±0.94	6.43±1.16	9.81±2.88	9.55±2.50	7.80±0.07	7.75±0.12	1.868	0.120

NO ₃ ⁻ (mg/L)	58.49 ±28.4	52.24 ±30.16	37.83 ±23.80	37.54 ±24.32	46.93±19.6	46.33 ±18.08	34.61 ±7.76	34.43 ±7.22	0.68	0.687
PO ₄ ³⁻ (mg/L)	22.30±1.95	22.02 ±2.50	25.51 ±2.61	25.19 ±3.01	24.32±3.62	24.60 ±3.34	21.37 ±0.68	21.23 ±0.62	1.958	0.104

Table 3: Spatial Variation in Physicochemical Parameters Concentrations Across Selected Sites in Hadejia-Nguru Wetland Water Resource

Key: AD = Adiyani, GD = Ngurodi, GB = Ngarbi, GW = Groundwater, Temp = temperature; EC = electric conductivity; DO = dissolved oxygen; TDS = total dissolved solids; BOD = biological oxygen demand; Na⁺ = sodium; Ca⁺ = calcium; K⁺ = potassium; NO₃⁻ = nitrate; PO₄³⁻ = phosphate, 1 = waterfront, 2 = offshore, * = P < 0.05.

Table 4: Temporal Variation in Physicochemical Parameters Concentrations in the Selected Portion of Hadejia-Nguru Wetland Water Resource

Parameter	Sampling Seasons		F	P
	Early Dry	Late Dry		
Temp. (°C)	18.04±1.76	22.99±1.51	72.965	0.000*
Turbidity (NTU)	36.13±10.44	39.48±9.99	0.859	0.361
pH	7.97±0.61	7.71±0.86	0.969	0.333
EC (µS/cm)	28.13±13.62	9.22±2.83	29.561	0.000*
DO (mg/L)	43.98±15.97	35.94±30.47	0.873	0.358
TDS (mg/L)	90.29±28.28	167.28±91.48	10.346	0.003*
BOD (mg/L)	21.10±12.10	4.27±3.99	27.916	0.000*
Na ⁺ (mg/L)	1.48±0.57	1.68±0.56	1.041	0.316
Ca ²⁺ (mg/L)	0.31±0.08	0.36±0.13	1.758	0.195
K ⁺ (mg/L)	8.26±1.47	7.05±2.67	2.545	0.121
NO ₃ ⁻ (mg/L)	35.23±10.89	51.87±24.89	6.006	0.020*
PO ₄ ³⁻ (mg/L)	22.93±2.97	23.71±2.62	0.620	0.437

Key: Temp = temperature; EC = electric conductivity; DO = dissolved oxygen; TDS = total dissolved solids; BOD = biological oxygen demand; Na⁺ = sodium; Ca²⁺ = calcium; K⁺ = potassium; NO₃⁻ = nitrate; PO₄³⁻ = phosphate, * = P < 0.05

The pH values ranged from 6.50 to 8.98, with a mean value of 7.84±0.75 (Table 2). The pH concentration across the different sites differed, with Ngurodi shallow zone recording the highest mean pH of 8.61±0.44, while groundwater Jigawa had the lowest mean pH of 6.81±0.31. Other sites recorded mean pH values of 8.04±0.91 at Adiyani shallow zone, 7.73±0.49 at Adiyani offshore, 8.23±0.25 at Ngurodi offshore zone, 8.19±0.37 at Ngarbi shallow zone, 8.21±0.30 at Ngarbi offshore, while groundwater Yobe had 6.88±0.27. The p-

value for pH was 0.000, indicating a significant variation in pH concentration among the sites (Table 3). pH was slightly higher (7.97±0.61) in the early dry season than in the Late Dry Season 7.71±0.86, with no significant difference observed (p>0.05) (Table 4). This study's pH values aligned with the findings by Barde and Uwem (2021) who reported pH range of 6.63±0.41 and 5.08 ± 0.76 in water from Hadejia–Nguru Wetlands in Jigawa and Yobe States, Nigeria. Result also aligned with the findings of Haruna *et al* (2020) from the

same wetland were pH values ranged from 7.6 to 8.0.

Electrical Conductivity (EC) had a mean value of 18.67 ± 2.41 $\mu\text{S/cm}$, with a wide range from 6.00 $\mu\text{S/cm}$ to 46.20 $\mu\text{S/cm}$ (Table 3.1). Specific EC values were 25.95 ± 19.48 $\mu\text{S/cm}$ at Adiyani shallow zone, 21.35 ± 13.69 $\mu\text{S/cm}$ at Adiyani offshore, 23.50 ± 14.94 $\mu\text{S/cm}$ at Ngurodi shallow zone, 23.08 ± 14.29 $\mu\text{S/cm}$ at Ngurodi offshore, 21.52 ± 13.68 $\mu\text{S/cm}$ at Ngarbi shallow zone, 21.38 ± 13.17 $\mu\text{S/cm}$ at Ngarbi offshore, 6.35 ± 0.26 $\mu\text{S/cm}$ at groundwater Yobe, and 6.25 ± 0.21 $\mu\text{S/cm}$ at groundwater Jigawa. There was no significant variation ($P > 0.05$) in EC concentration among the sites (Table 3). Electrical conductivity (EC) was higher (28.13 ± 13.62 $\mu\text{S/cm}$) in the early dry season than (9.22 ± 2.83 $\mu\text{S/cm}$) in the late dry season showing a statistically significant change with a p-value of 0.000 (Table 4). Jones *et al.* (2018) and Thompson and Samson (2020) reported in their study reported a decrease in pH during the dry season indicated higher decomposition rates and increased CO_2 concentration in the water, potentially impacting the solubility of metals and nutrient availability.

Dissolved Oxygen (DO) ranged from a minimum of 2.30 mg/L to a maximum of 80.00 mg/L, with a mean value of 39.96 ± 4.29 mg/L (Table 2). The dissolved oxygen (DO) concentration differed significantly across the different sites. Adiyani shallow zone had a mean DO concentration of 13.08 ± 13.40 mg/L, Adiyani offshore zone had 13.23 ± 2.62 , Ngurodi Shallow zone had 52.68 ± 12.52 while Ngurodi offshore recorded 54.50 ± 13.46 mg/L. Ngarbi shallow zone had DO concentration of 34.50 ± 21.92

mg/L, and Ngarbi offshore had a mean of 34.80 ± 21.54 mg/L. The groundwater sites Yobe and Jigawa exhibited the highest DO concentration, with values of 59.05 ± 23.16 mg/L and 57.83 ± 23.03 mg/L, respectively. There was significant ($P < 0.001$) variation in DO concentrations among the sites (Table 3). Dissolved Oxygen (DO) was higher in the early dry season 43.98 ± 15.97 mg/L than in the Late Dry Season 35.94 ± 30.47 mg/L, but this difference was not statistically significant ($p > 0.05$) (Table 4). Dissolved oxygen (DO) concentrations decreased from 44.26 ± 17.45 mg/L to 29.75 ± 28.54 mg/L, typical in the dry season. These values are significantly above those found by Hassan *et al.* (2014) in the Hadejia-Nguru wetlands, who noted DO concentrations closer to the WHO and NSDWQ thresholds. According to Ramachandra *et al.* (2018) and Wetzel (2019), this indicated that such declines are typical in the dry season due to reduced water mixing and higher biological oxygen demand.

Total Dissolved Solids (TDS) concentration had a mean value of 128.78 ± 13.65 mg/L, with values ranging from a minimum of 50.70 mg/L to a maximum of 318.00 mg/L (Table 2). The specific TDS values recorded were 127.70 ± 127.27 mg/L at Adiyani shallow zone, 126.15 ± 122.68 mg/L at Adiyani offshore, 73.43 ± 9.58 mg/L at Ngurodi shallow zone, 72.33 ± 8.80 mg/L at Ngurodi offshore, 138.08 ± 49.11 mg/L at Ngarbi shallow zone, 136.80 ± 46.11 mg/L at Ngarbi offshore, 177.25 ± 73.62 mg/L at groundwater Yobe, and 178.55 ± 72.75 mg/L at groundwater Jigawa. There was no significant ($p > 0.05$) variation in TDS concentration among the sites (Table 3). In addition, TDS concentration was significantly higher in the late dry season

with mean of 167.28 ± 91.48 mg/L compared to 90.29 ± 28.28 mg/L in the early dry season, with a p-value of 0.003 (Table 4). TDS values for this study is consistent with the findings of Zhang *et al.* (2017), who noted that increased TDS concentrations in the dry season result from evaporation and concentration of dissolved materials. High TDS concentration can affect water quality by altering the taste, increasing corrosivity, and potentially impacting aquatic organisms' health.

Biological Oxygen Demand (BOD_5) had a mean value of 12.69 ± 2.18 mg/L, with a range from 0.10 mg/L to 40.06 mg/L (Table 2). Regarding spatial variation, Adiyani shallow zone recorded a mean BOD of 6.81 ± 5.77 mg/L, while Adiyani offshore had 7.43 ± 6.12 mg/L. Ngurodi shallow zone and offshore sites showed higher BOD concentration at 17.82 ± 16.74 mg/L and 17.58 ± 16.60 mg/L, respectively. Ngarbi shallow zone and offshore had BOD_5 values of 21.39 ± 14.42 mg/L and 20.95 ± 13.85 mg/L. Groundwater sites Yobe and Jigawa had lower BOD concentration, with mean of 4.84 ± 4.06 mg/L and 4.68 ± 3.90 mg/L. The p-value for BOD was ($p > 0.05$), indicating no significant variation in BOD concentration among the sites (Table 3). Furthermore, BOD was higher in the early dry season 21.10 ± 12.10 mg/L than in the late dry season 4.27 ± 3.99 mg/L, with a p-value of 0.000 (Table 4). The variation in BOD across sites in the current study suggested different concentrations of organic pollution, potentially from various sources such as agricultural runoff or domestic wastewater. High BOD values at Ngarbi could indicate areas with higher organic matter input, which could lead to oxygen depletion and stress for aerobic organisms.

Sodium ion (Na^+) had a mean concentration of 1.58 ± 0.10 mg/L, ranging from 0.66 mg/L to 2.55 mg/L (Table 2). Na^+ concentration differed significantly ($p = 0.006$) across the sites. Adiyani shallow zone had a mean Na^+ concentration of 1.01 ± 0.31 mg/L, while Adiyani offshore recorded a slightly lower mean of 0.96 ± 0.29 mg/L. Both Ngurodi shallow zone and offshore had higher Na^+ concentration at 1.48 ± 0.60 mg/L and 1.48 ± 0.62 mg/L, respectively. The highest Na^+ concentration was observed at the Ngarbi offshore site with 2.06 ± 0.55 mg/L and 2.10 ± 0.55 mg/L. Groundwater sites Yobe and Jigawa had Na^+ concentrations of 1.77 ± 0.11 mg/L and 1.80 ± 0.10 mg/L, respectively (Table 3). Furthermore, Na^+ concentration was higher (1.48 ± 0.57 mg/L) in the early dry season to 1.68 ± 0.56 mg/L in the late dry season; however, this increase was not statistically significant ($P > 0.05$) (Table 4). The slightly higher Na^+ values recorded in this study aligned with Gupta and Sharma (2019) and Hashem and Baharuddin (2018), who observed that Na^+ ion concentrations often fluctuate seasonally due to varying water inputs and evaporation rates.

Calcium ion (Ca^{2+}) had a mean value of 0.33 ± 0.02 mg/L, with values between 0.17 mg/L and 0.52 mg/L (Table 2). There was significant ($p = 0.001$) variation in Ca^{2+} concentrations among the sites. Adiyani shallow zone had a mean Ca^{2+} concentration of 0.22 ± 0.08 mg/L, and Ngurodi offshore recorded 0.25 ± 0.06 mg/L. Both Ngarbi shallow zone and offshore sites had Ca^{2+} concentration of 0.35 ± 0.10 mg/L and 0.35 ± 0.09 mg/L, respectively. The highest Ca^{2+} concentration was observed at the groundwater sites, with 0.46 ± 0.05 mg/L at Jigawa and 0.45 ± 0.07 mg/L at Yobe (Table 3). Furthermore, Ca^{2+}

concentration was higher 0.36 ± 0.13 mg/L in the late dry season than 0.31 ± 0.08 mg/L in the early dry season, but the change was not statistically significant ($P > 0.05$) (Table 4). The spatial variation in calcium concentrations suggested differences in the input of calcium from surrounding areas, likely influenced by geological and hydrological factors. These slight changes in Ca^{2+} aligned with Gupta and Sharma (2019) and Hashem and Baharuddin (2018), who observed that ion concentrations often fluctuate seasonally due to varying water inputs and evaporation rates.

Potassium ion (K^+) had a mean value of 7.66 ± 0.39 mg/L, with a range from 3.00 mg/L to 12.70 mg/L (Table 2). There was no significant variation ($p > 0.05$) in K^+ concentration among the sites. Adiyani shallow zone had a K^+ concentration of 6.75 ± 2.99 mg/L, and Adiyani offshore had 7.05 ± 2.65 mg/L. Ngurodi shallow zone and offshore sites had 6.11 ± 0.94 mg/L and 6.43 ± 1.16 mg/L, respectively. Higher K^+ concentration was found at the Ngarbi offshore site with 9.81 ± 2.88 mg/L and 9.55 ± 2.50 mg/L. The groundwater sites Yobe and Jigawa had K^+ concentrations of 7.80 ± 0.07 mg/L and 7.75 ± 0.12 mg/L (Table 3). In addition, K^+ concentration was higher 8.26 ± 1.47 mg/L in the early dry season to 7.05 ± 2.67 mg/L in the late dry season, with no significant difference observed ($p > 0.05$) (Table 4). Potassium concentration recorded in this study were slightly higher than those reported by Carter *et al.* (2017), who found potassium concentrations ranging from 2 mg/L to 7 mg/L in wetlands. These values are consistent with findings by Chen *et al.* (2018), who reported potassium concentrations ranging from 5 mg/L to 10 mg/L in wetlands.

Nitrate (NO_3^-) had a mean concentration of 43.55 ± 3.66 mg/L, with values ranging from 12.61 mg/L to 96.67 mg/L (Table 2). Nitrate (NO_3^-) concentration differed less significantly ($p > 0.05$) among the sites, with Adiyani shallow zone showing 58.49 ± 28.4 mg/L and Ngurodi offshore showing 52.24 ± 30.16 mg/L. Both Ngarbi shallow zone and offshore had similar NO_3^- concentration of 37.83 ± 23.80 mg/L and 37.54 ± 24.32 mg/L. The groundwater sites at both Jigawa and Yobe had NO_3^- concentration of 34.61 ± 7.76 mg/L and 34.43 ± 7.22 mg/L (Table 3). In addition, NO_3^- concentration was higher mg/L 51.87 ± 24.89 mg/L in the late dry season than 35.23 ± 10.89 in the early dry season with a p-value of 0.020 (Table 4). Elevated nitrate concentrations in the dry season are consistent with findings by Zhang *et al.* (2019) and Zhao *et al.* (2018), who reported that lower water volumes and increased agricultural runoff contribute to higher nitrate concentrations.

Phosphate (PO_4^{3-}) had a mean concentration of 23.32 ± 0.49 mg/L, ranging from 19.87 mg/L to 28.10 mg/L (Table 2). Regarding the spatial variability, PO_4^{3-} , Adiyani shallow and offshore zones had a mean concentration of 22.30 ± 1.95 mg/L, and 22.02 ± 2.50 mg/L. Ngarbi shallow zone and offshore sites had PO_4^{3-} concentrations of 25.51 ± 2.61 mg/L and 25.19 ± 3.01 mg/L, respectively, Ngurodi shallow zones had a mean concentration of 25.512 ± 0.61 , Ngurodi offshore had 25.193 ± 3.01 , The groundwater sites showed similar concentration with 21.37 ± 0.68 mg/L at Yobe and 21.23 ± 0.62 mg/L at Jigawa. The p-value for PO_4^{3-} indicated no significant variation in PO_4^{3-} concentration among the sites ($p > 0.05$), (Table 3). Furthermore, PO_4^{3-} concentration was slightly higher 23.71 ± 2.62 mg/L in the late dry season than

in the early dry season 22.93 ± 2.97 mg/L, however, this change was not statistically significant ($p > 0.05$) (Table 4). Elevated nitrate concentrations in the dry season are consistent with findings by Zhang *et al.* (2019) and Zhao *et al.* (2018), who reported that lower water volumes and increased agricultural runoff contribute to higher nitrate concentrations.

Comparison of the Mean Physicochemical Concentrations and the Regulatory Standards

The comparison of physicochemical concentrations at different sampling locations, including shallow zones and offshore zones, against regulatory standards is showed in Table 5. The temperature ranged from $19.00 \pm 3.16^\circ\text{C}$ at Ngurodi shallow zone to $22.18 \pm 3.76^\circ\text{C}$ at Ngarbi offshore, all within the ambient temperature range set by standards. pH concentrations varied from 7.73 ± 0.49 at Ngurodi offshore to 8.61 ± 0.44 at Ngarbi shallow zone, all within the WHO and NSDWQ range of 6.5-8.5. Electrical conductivity (EC) was well below the 1000 $\mu\text{S}/\text{cm}$ standard at all sites, with the lowest values observed at Ngurodi offshore (21.35 ± 13.69 $\mu\text{S}/\text{cm}$) and Adiyani shallow zone (25.95 ± 19.48 $\mu\text{S}/\text{cm}$). Dissolved oxygen (DO) concentrations were highest at the groundwater site with 59.05 ± 23.16 mg/L, significantly exceeding the WHO and NSDWQ standards of 5 mg/L, while shallow zones and offshore values varied between 13.08 ± 13.40 mg/L at Adiyani shallow zone and 54.50 ± 13.46 mg/L at Ngarbi offshore. Total dissolved solids (TDS) were highest at the groundwater site with 178.55 ± 72.75 mg/L, but still below the WHO standard of 1000 mg/L, with values at shallow zone and offshore sites ranging from 72.33 ± 8.80 mg/L at Ngarbi

shallow zones to 167.28 ± 91.48 mg/L at Adiyani Offshore. Biological oxygen demand (BOD) was notably high at Ngarbi (21.39 ± 14.42 mg/L), surpassing the WHO standard of 3 mg/L, with values at shallow zone and offshore sites ranging from 4.68 ± 3.90 mg/L at Jigawa Offshore to 17.82 ± 16.74 mg/L at Ngarbi Offshore. Sodium (Na^+) concentrations ranged from 0.96 ± 0.29

mg/L at Ngurodi Offshore to 2.10 ± 0.55 mg/L at Ngarbi

Table 5: Comparison of the Mean of Physicochemical Concentrations and the Regulatory Standards

Parameter	AD		GD		GB		GW		Standards		
	1	2	1	2	1	2	Y	J	WHO	NSDWQ	Remark
Temp. (°C)	20.00 ±2.94	19.48 ±4.06	19.00 ±3.16	19.38 ±2.98	21.38±4.19	22.18 ±3.76	21.55 ±1.32	21.15 ±1.22	Ambient	Ambient	Good
Turbidity (NTU)	29.60 ±8.85	30.75 ±7.47	43.38 ±5.51	43.13 ±3.87	50.13 ±2.72	49.58 ±2.09	28.20 ±0.73	27.65 ±0.60	5	5.0	Above
pH	8.04±0.91	7.73±0.49	8.61±0.44	8.23±0.25	8.19±0.37	8.21±0.30	6.88±0.27	6.81±0.31	6.5- 8.5	6.5-8.5	Within
EC (µS/cm)	25.95 ±19.48	21.35 ±13.69	23.50 ±14.94	23.08 ±14.29	21.52 ±13.68	21.38 ±13.17	6.35±0.26	6.25±0.21	1000	1000	Below
DO (mg/L)	13.08 ±13.40	13.23 ±12.62	52.68 ±12.54	54.50 ±13.46	34.50 ±21.92	34.80 ±21.54	59.05 ±23.16	57.83 ±23.03	5	5.0	Above
TDS (mg/L)	127.70 ±127.27	126.15 ±122.68	73.43 ±9.58	72.33 ±8.80	138.08 ±49.11	136.80 ±46.11	177.25 ±73.62	178.55 ±72.75	1000	500	Below
BOD (mg/L)	6.81±5.77	7.43±6.12	17.82 ±16.74	17.58 ±16.60	21.39 ±14.42	20.95 ±13.85	4.84±4.06	4.68±3.90	3	3-5	Above
Na ⁺ (mg/L)	1.01±0.31	0.96±0.29	1.48±0.60	1.48±0.62	2.06±0.55	2.10±0.55	1.77±0.11	1.80±0.10	200	200	Below
Ca ²⁺ (mg/L)	0.22±0.08	0.25±0.06	0.35±0.10	0.35±0.09	0.30±0.09	0.30±0.08	0.45±0.07	0.46±0.05	75	75	Below
K ⁺ (mg/L)	6.75±2.99	7.05±2.65	6.11±0.94	6.43±1.16	9.81±2.88	9.55±2.50	7.80±0.07	7.75±0.12	1 - 2	55	Above

NO ₃ ⁻ (mg/L)	58.49 ±28.4	52.24 ±30.16	37.83 ±23.80	37.54 ±24.32	46.93±19.6	46.33 ±18.08	34.61 ±7.76	34.43 ±7.22	50	50	Within
PO ₄ ³⁻ (mg/L)	22.30±1.95	22.02 ±2.50	25.51 ±2.61	25.19 ±3.01	24.32±3.62	24.60 ±3.34	21.37 ±0.68	21.23 ±0.62	4	12	Above

Keys: NSDWQ = National standard for drinking water quality, WHO = World Health Organisation, AD = Adiyani, GD =Ngurodi, GB = Ngarbi, GW = Groundwater, Y=Yobe, J=Jigawa, 1= shallow zone, 2 = offshore. WHO (2022), NSDWQ (2022).

Offshore, all within the acceptable limit of 200 mg/L. Calcium (Ca^{2+}) concentrations ranged from 0.22 ± 0.08 mg/L at Adiyani shallow zone to 0.46 ± 0.05 mg/L at Jigawa, all within the standard of 75 mg/L. Potassium (K^+) concentrations exceeded the standard of 1-2 mg/L at all sites, with the highest value recorded at Ngarbi shallow zone (9.81 ± 2.88 mg/L). Nitrate (NO_3^-) concentrations ranged from 34.43 ± 7.22 mg/L at Jigawa to 58.49 ± 28.40 mg/L at Adiyani, with all values within the standard of 50 mg/L. Phosphate (PO_4^{3-}) concentrations were high at all sites, exceeding the WHO and NSDWQ standards of 4 mg/L and 12 mg/L, respectively, with the highest recorded at Ngurodi shallow zone (25.51 ± 2.61 mg/L). Turbidity was above the standard of 5 NTU at all sites, with the highest value observed at Ngarbi offshore (50.13 ± 2.72 NTU).

CONCLUSION

This study provided valuable insights into the Physicochemical characteristics of the Hadejia-Nguru wetland, the findings indicated significant variations in some Physicochemical parameters across different sites and seasons. Furthermore, the study highlights the temporal effects on temperature, EC, and BOD, with notable increases in concentration during the late dry season indicated severe contamination. The study concludes that there is urgent need for effective management and conservation measures to safeguard the wetland's water quality and overall ecological health.

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WETLAND DEGRADATION THROUGH POOR PLASTIC WASTE MANAGEMENT IN THE YENAGOA URBAN AREA

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Abstract

Wetlands are vital ecosystems that provide essential environmental services such as flood control, carbon sequestration, and biodiversity conservation. However, rapid urbanization in Yenagoa Metropolis, Bayelsa State, has led to significant wetland degradation, driven by land reclamation, pollution, and poor waste management practices. The study examines the impact of plastic waste mismanagement on wetland degradation in the Yenagoa municipal area. A survey research design was employed with 276 structured copies of the questionnaire administered to households across different zones. Findings revealed that plastic waste constitutes 35.8% of total municipal waste, with plastic bottles (21.0%) and plastic bags (22.2%) as dominant components. Most households (42.8%) generate 1–5 kg of plastic waste weekly, accounting for 42.4% overall plastic waste generation. Poor disposal practices, including open dumping and burning, exacerbate environmental risks, leading to drainage blockages that alter wetland hydrology, water contamination that degrades aquatic ecosystems, and biodiversity loss due to habitat disruption. All collected waste ends up at the waste dumpsites on the outskirts of Yenagoa wetland ecosystems. These wetlands are lost while their capacity to provide flood regulation and water filtration services are weakened. Low public awareness, the lack of proper waste collection and management facilities, and the absence of recycling facilities are contributory to the poor practice. The study identifies opportunities for improving plastic waste management through reuse, structured recycling programs, increased public awareness, and policy interventions. More importantly, relocation of the waste dumpsites is long overdue to avoid further loss and degradation of the wetland ecosystems.

Keywords: Wetland degradation, plastic waste management, urbanization, Disposal Methods, environmental sustainability, Yenagoa Metropolis.

1. INTRODCUTION

Wetlands are earth's most important and productive ecosystems (Kuchara et al. 2023). They are land that has areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six meters (Wali et al. 2018; Elemuwa et al. 2021). Wetlands also include a wide variety of inland habitats such as marshes, peat lands, floodplains, rivers and lakes, and coastal areas such as salt marshes, mangroves, intertidal mudflats and sea grass beds, and also coral reefs and other marine areas not deeper than six meters at low tide, as well as man-made wetlands such as dams, reservoirs, rice paddies and wastewater treatment ponds and lagoons (Bariweni and Amukali, 2018; Wali et al. 2018; Elemuwa et al. 2021). Wetlands provide many essential services such as flood control, groundwater recharge, carbon sequestration, and habitat for diverse flora and fauna (Ornes et al. 2014; Bariweni and Amukali, 2018), making them indispensable in human survival.

Despite their importance, wetlands are rapidly disappearing across the globe. The key drivers of this loss include agriculture, road construction, impoundments, resource extraction, waste accumulation, drainage, and land reclamation for residential and commercial use. Other contributing factors include conversion to croplands, mining, energy projects, water development schemes, and chemical pollution (Bariweni and Amukali, 2018; Elemuwa et al., 2021; Kuchara et al., 2023).

Yenagoa Metropolis became the capital city of Bayelsa State in 1996. Since then, urbanization has significantly influenced the population dynamics, driving notable infrastructural development across different parts of the metropolis (Ohwo and Abotutu,

2015; Bariweni and Amukali, 2018). However, this rapid development has come at a cost, particularly to the region's wetlands. Massive land reclamation and sand filling have led to the loss of over 8,687 hectares of wetlands between 1996 and 2021, mainly due to unchecked infrastructural expansion (Bariweni and Amukali, 2018; Odubo et al. 2023). Beyond physical destruction, pollution and poor waste management further compounds this issue, threatening the remaining wetlands. Ebuete et al. (2022) discovered that the total waste disposed in Yenagoa metropolis in 2021 was 546.830 tonnes, however, not up to 10% of all its solid waste component (which includes plastics) was recovered for reuse, recycling, or energy recovery by scavengers. Plastics form a great portion of the waste generated and disposed. The increasing consumption of plastic products has intensified waste accumulation, with plastics and nylons making up 20.38% of Yenagoa's waste stream (Simon and Opololaoluwa, 2022). With the ever-growing population, this figure is expected to rise with a negative environmental turnover.

Plastics, being non-biodegradable, are known to persist in the environment for decades, clogging drainage systems and leaching toxic chemicals into soil and water (Govind and Nishitha, 2023). Their accumulation disrupts wetland ecosystems, contributing to biodiversity loss, water contamination, and air pollution (Li et al. 2022). As plastics degrade, they release methane and other greenhouse gases, exacerbating climate change and posing serious public health risks (Govind and Nishitha, 2023; Abdullayeveaand Yaqubov, 2024). The combined impacts of wetland destruction and pollution highlight the urgent need for sustainable urban planning and better waste management strategies in Yenagoa Metropolis. Therefore, this study investigates the extent to which poor plastic waste management contributes to

wetland degradation and proposes mitigation measures.

AIM AND OBJECTIVES

The primary aim of this study is to examine the impact of poor plastic waste management on wetland degradation in the Yenagoa urban area. The specific objectives include;

- i. To determine the volume of plastic waste generated in Yenagoa Metropolis.
- ii. To assess the composition of plastic waste in Yenagoa Metropolis.
- iii. To evaluate the level of awareness regarding the environmental impacts of plastic waste mismanagement.
- iv. To assess the current methods of plastic waste disposal in Yenagoa Metropolis.
- v. To explore opportunities for reuse and recycling as a strategy for reducing impact on wetlands.

MATERIALS AND METHODS

The study area is Yenagoa Metropolis in Yenagoa LGA of Bayelsa State. It lies along

latitudes between 4° 48' 00" North and 5° 24' 10" East; and longitudes between 6° 12' 00"E and 6° 39' 30"E (Figure 1.1); bounded by Rivers State on the North East, North West by Delta State; South East by Ogbia LGA; and Southern Ijaw on the South west (Eludoyin et al., 2017). Yenagoa LGA is located within the lower delta plain believed to have been formed during the Holocene of the Quaternary period by the accumulation of sedimentary deposits. The climate of Yenagoa LGA is an equatorial type of climate (Iyorakpo, 2015); with a mean monthly temperature range from 25°C to 30°C; and a diurnal temperature range of about 30°C to 50°C (Arokoyu et al., 2016). Yenagoa LGA is drained with many rivers and creeks among which are Epie Creek, Nun River, Orashi River, and Ekole Creek (Eludoyin et al., 2017); with an estimated population of 50,000 persons (National Population Commission 2006; Ojile, 2019) in 1991 to about 350,000 in 2019" (National Population Commission 2006; Ojile, 2019). The population of the communities in the study area is 71,187 based on the projected figure for 2023.

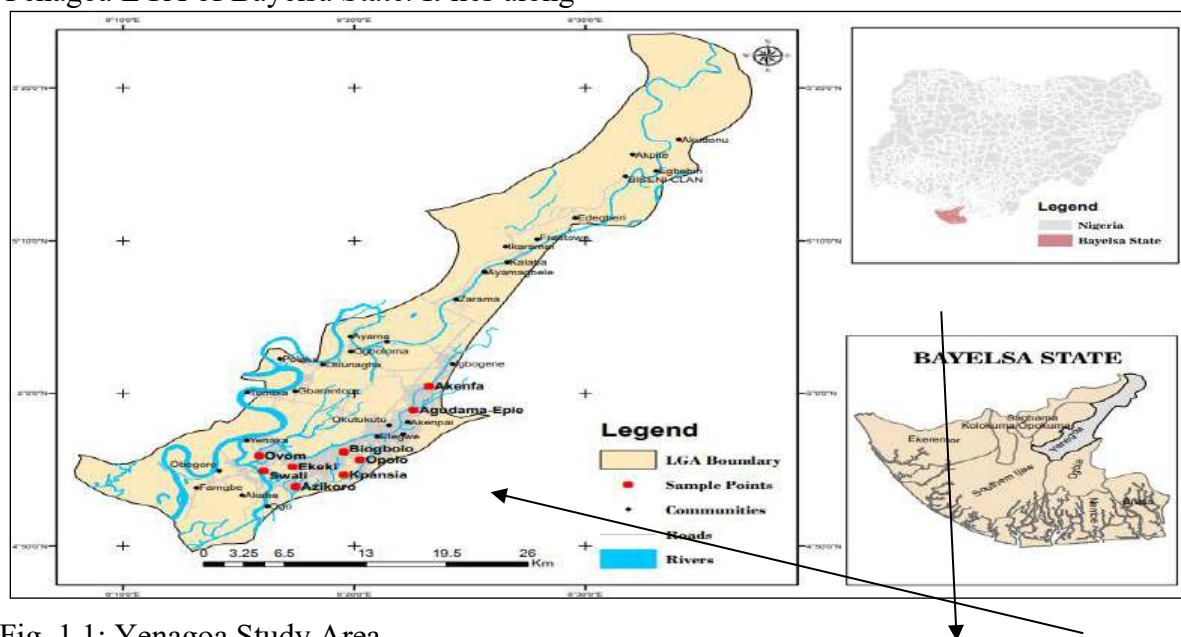


Fig. 1.1: Yenagoa Study Area.

Source: Researcher, (2024). Department of Environmental Management.

The study employed descriptive survey research design, using hard copies of 276 structured questionnaires administered to households in the various zones in the study area. A multi-stage sampling approach was further utilized in this study, consisting of three stages. Firstly, stratified sampling was used to divide, to narrow the study area into four distinct zones (A, B, C, and D). In the second stage, purposive sampling was used to select nine (9) communities within the metropolis. Finally, the third stage involved the use of random sampling to ensure an unbiased distribution of questionnaires across various households. The data collected was analyzed using both descriptive (frequencies and percentages) and inferential statistical tools. The data were analyzed using Microsoft Excel, and the Statistical Package for the Social Sciences (SPSS) software, (version 26.0).

RESULTS AND DISCUSSION

Volume of plastic waste generated in Yenagoa Metropolis

The study found that (42.8%) of households generates an estimated amount between 1–5 kg of plastic waste weekly (Chart 1), accounting for 42.4% of the overall plastic waste generation, with communities such as Agudama (60.0%), Biogbolo (41.4%), and Opolo (42.9%) showing the highest contributors to this figure. This aligns with findings from other urban centers, where moderate waste volumes are linked to average household sizes and increasing reliance on packaged goods (Akindele et al., 2023; Agunbiade and Oyebanji, 2020). Conversely, 23.6% of households generate

less than 1 kg weekly, with notable contributions from Akenfa (37.5%), Opolo (42.9%), and Swali (40.6). Additionally, 18.9% of households produce over 11 kg weekly, which is most significant in Ekeki (50.0%), followed by Akenfa (37.5%) and Ovom (24.1%) (Fig. 1) similarly reported by Mongtoeun, et al., (2019). This variation revealed that households in predominantly commercial areas like Opolo, Kpansia, Ekeki, and Swali generate more plastic waste per week than those in predominantly residential areas such as Agudama, Akenfa, Ovom, Azikoro and Biogbolo. Also 28.7% households in commercial areas generate less than 1 kg of plastic waste per week, compared to 19.6% in residential areas; While 17.2% in residential areas generated 6–10 kg, compared to 11.4% in commercial areas. Similarly, 19.6% of households in residential areas generated 11 kg and above, compared to 18.0% in commercial areas (Chart 1).

All these trickled down to the purchasing power of the individuals. The frequency of purchasing plastic-packaged items were 57.5% of respondents engage in daily purchasing habits. Communities such as Kpansia (87.5%), Biogbolo (72.4%), and Ovom (72.4%) (Chart 2), show a very high inclination to such habits. 30.8% engage weekly purchases, with prominent figures from Agudama (33.3%), Ekeki (64.5%), and Azikoro (31.3%). Monthly purchases are rare (5.0%), seen only in Agudama (13.3%) and Swali (25.0%). Similarly, Kibria et.al. (2023) and Lange et.al. (2022) detail the challenges involving waste management in a larger household

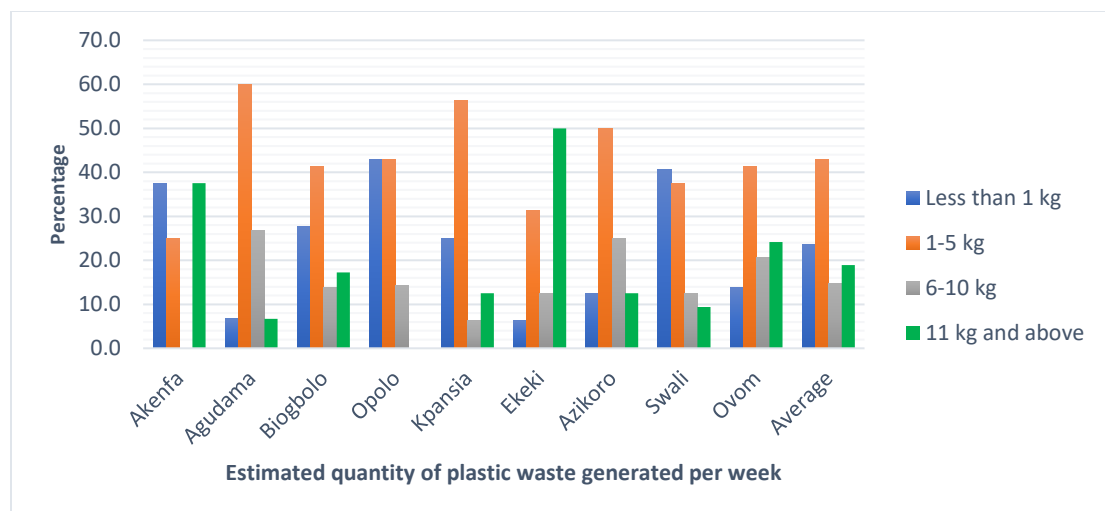


Fig. 1: Estimated quantity of plastic waste generated per week

Source: Author's fieldwork, 2024.

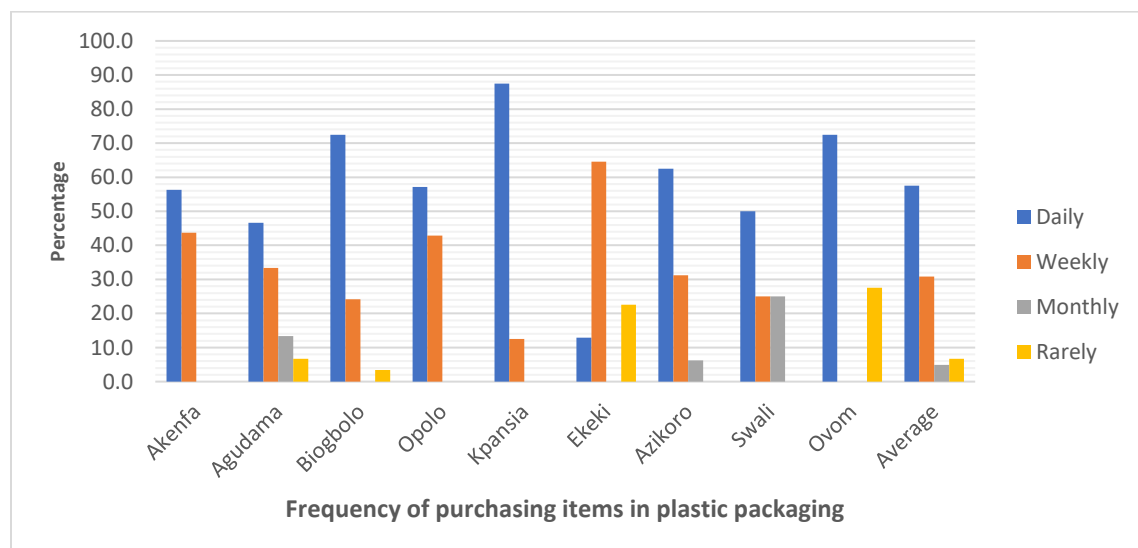


Fig. 2: Frequency of purchasing items in plastic packaging

Source: Author's fieldwork, 2024.

Composition of plastic waste in Yenagoa Metropolis

This study revealed that plastic waste accounted for 35.8% of total waste in the study area; similar with the proportion of organic waste (33.5%) (Chart 3) which is a complementary trend of developing urban centers. This report is considerably higher than the values reported by Angaye et al.

(2019) of 19%, and Simon and Opololaoluwa (2022) of 20.38% for Yenagoa Metropolis, explaining the rapid increase with increasing populations in the consumption of plastics products over the years.

Interestingly, among the most common types of plastic waste in Yenagoa (Chart 4), plastic bottles (21.0%) and plastic bags (22.2%) constituted larger proportion of the plastic

waste stream; a common feature among urban centers, where plastic bottles and bags dominate waste streams due to their widespread use in packaging beverages and carrying items (Winton et al., 2022; Lawal et al., 2021, Alteneiji et al., 2024). Aside from the plastic bottles and bags, sachet water

packaging occupied the third major contributor to plastic waste, accounting for 20.2%; reflecting the community's reliance on sachet water as an affordable and accessible drinking water source, a trend common across Nigerian cities.

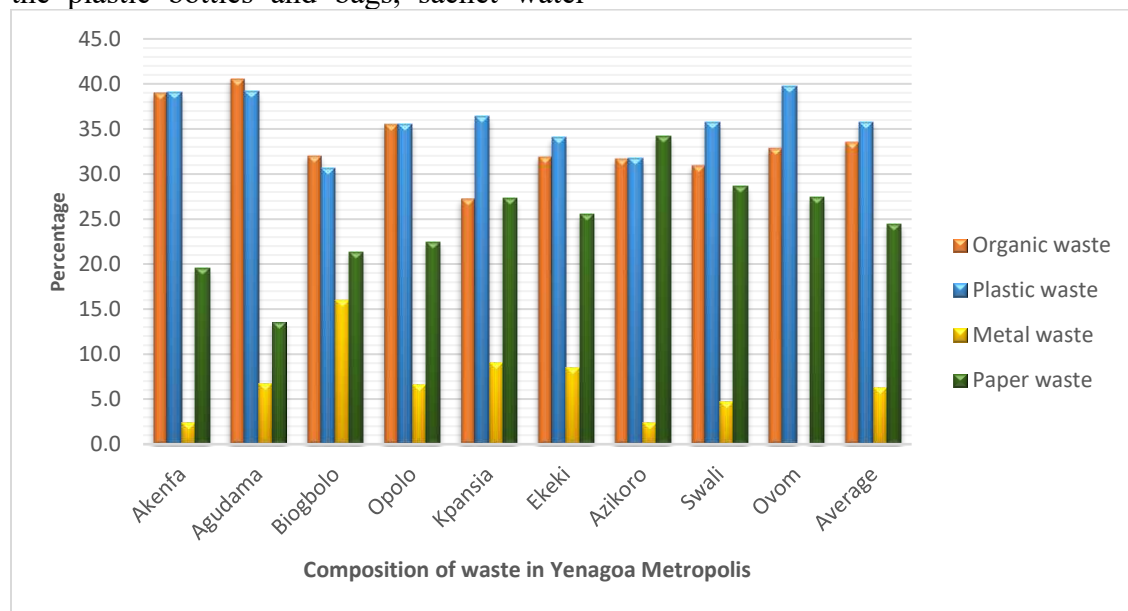


Fig. 3: Composition of waste in Yenagoa Metropolis

Source: Author's fieldwork, 2024.

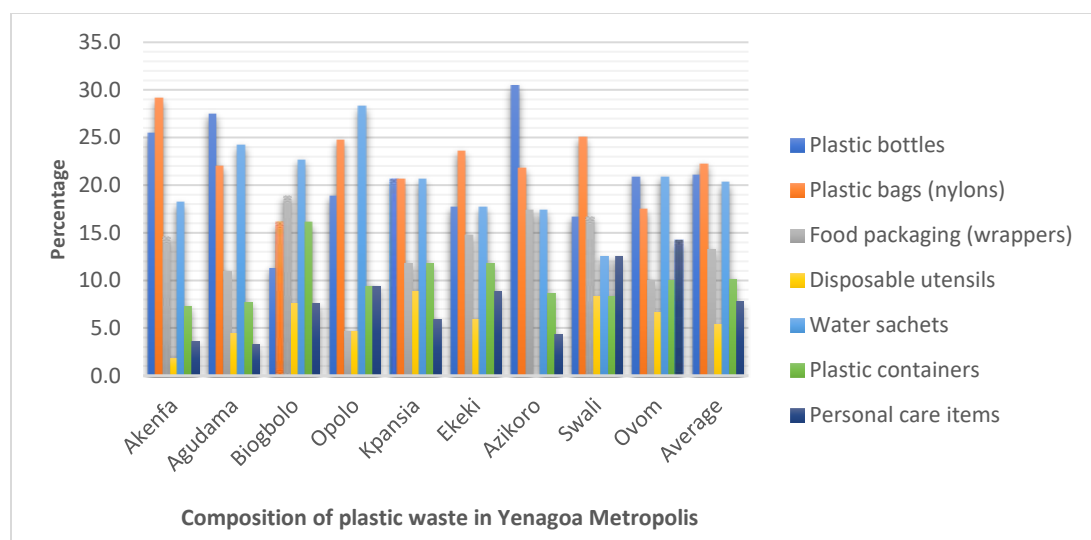


Fig. 4: Composition of plastic waste in Yenagoa Metropolis

Source: Author's fieldwork, 2024.

Moreso, food packaging waste, which includes wrappers, containers, and disposable food trays, constituted 13.3% of the total plastic waste; reflecting on the changing consumption patterns among urban dwellers (Babayemi et al., 2019). Disposable utensils and personal care plastics contribute less to the overall waste stream (5.4% and 7.7%, respectively), yet remain an environmental concern due to their persistence in the environment and limited recyclability. Similarly, Thi et.al. (2022); Fred-Ahmadu et al. (2022) have echoed on the challenges of managing such waste within a circular economic framework.

Level of awareness regarding the environmental impacts of plastic waste mismanagement

Awareness plays a significant role in plastic waste generation/management as pointed out

by Herdiansyah and Nuraeni (2024). This study shows that 49.1% respondents are aware of the importance of proper plastic waste management, with communities like Azikoro (81.3%) and Swali (62.1%), while 26.8% and 24.1% lack proper plastic waste management awareness (Chart 6). Regarding the channels/source of awareness, 40% of respondents agree that the primary source of awareness across all communities is the media (TV, radio, social media), as seen in Azikoro (64.3%) and Ekeki (61.4%) (Table 2). Awareness on the effects of improper plastic waste disposal is relatively high, with 76.1% of respondents acknowledging the consequences. Communities such as Akenfa and Swali reported 100% awareness, while areas like Kpansia (51.6%) and Ekeki (58.1%) lagged.

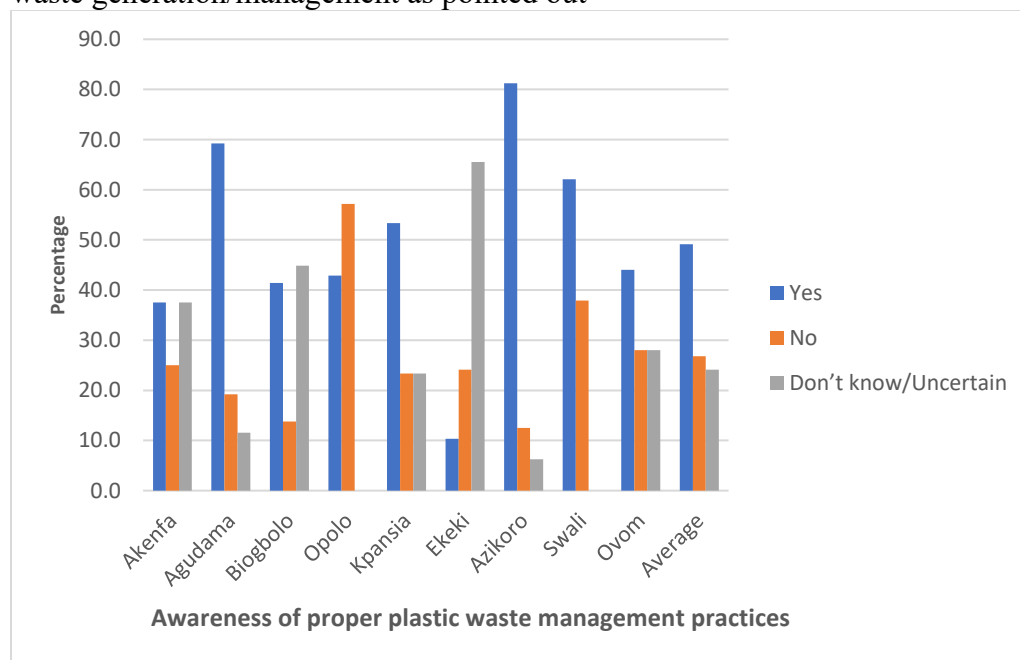


Fig. 6: Awareness of proper plastic waste management practices

Source: Author's fieldwork, 2024.

Table 1: Sources of Awareness of Proper Plastic Waste Management

S/N		Percentage									
		<i>Ak</i>	<i>Ag</i>	<i>Bio</i>	<i>Op</i>	<i>Kpa</i>	<i>Eke</i>	<i>Azi</i>	<i>Swa</i>	<i>Ov</i>	<i>Average</i>
1.	Media (TV, radio, social media)	29.4	34.6	18.3	37.7	40.0	61.4	64.3	51.9	22.8	40.0
2.	Community programs	15.3	17.9	8.5	-	-	11.4	-	7.4	22.8	9.3
3.	School or educational campaigns	25.9	14.1	28.2	27.5	20.0	27.3	21.4	29.6	31.6	25.1
4.	Personal research	18.8	21.8	18.3	17.4	40.0	0.0	14.3	11.1	22.8	18.3
5.	Friends and family	10.6	11.5	26.8	17.4	-	-	-	-	-	7.4
Total		100	100	100	100	100	100	100	100	100	100

Source: Author's fieldwork, 2024.

Note: Akenfa (*Ak*), Agudama (*Ag*), Biogbolo (*Bio*), Opolo (*Op*), Kpansia (*Kpa*), Ekeki (*Eke*), Azikoro (*Azi*), Swali (*Swa*) and Ovom (*Ov*).

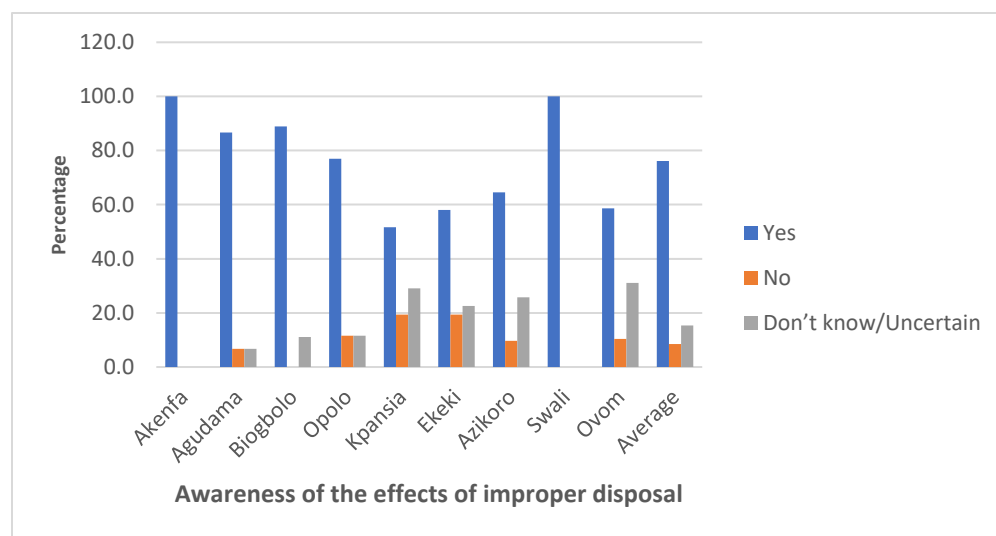


Fig. 7: Awareness of the effects of improper disposal

Source: Author's fieldwork, 2024.

Current methods of plastic waste disposal in Yenagoa Metropolis

Disposal Method

35% of respondents across all communities dispose their plastic waste through the use of public waste bins, with Akenfa (54.5%) and lowest in Kpansia (24.7%). Other commonly used methods identified include; burning

(27.9%) with Akenfa (36.4%) and Opolo (36.5%), dumping in public (20.4%) with Opolo (26.9%) and Ekeki (30.8%), while burying (6.5%) and government waste collectors (10.1%) (table 3). Studies by Nzeadibe et al. (2018) and Ikelle et al. (2023) had previously identified open burning as a major contributor to environmental pollution in urban Nigeria. All collected waste ends

up at the waste dumpsites on the outskirts of Yenagoa wetland ecosystems. These wetlands are lost while their capacity to

provide flood regulation, water filtration and other ecosystem services are weakened.



Plate 1: Piles of solid wastes at the permanent dump site at Etegwe - Tombia

Source: Author's fieldwork, 2024.

The poor disposal practices, such as open dumping and burning, exacerbate environmental risks, leading to drainage blockages (32.1%) that alter wetland hydrology, water pollution (24.8%) that

degrades aquatic ecosystems, and biodiversity loss due to habitat disruption (Harm to wildlife (10.7%) and the spread of diseases (15.9%) (Chart. 8).

Table 2: Method/Frequency of plastic waste disposal

<i>S/N</i>		<i>Percentage</i>									
		<i>Ak</i>	<i>Ag</i>	<i>Bio</i>	<i>Op</i>	<i>Kpa</i>	<i>Eke</i>	<i>Azi</i>	<i>Swa</i>	<i>Ov</i>	<i>Average</i>
<i>Method of plastic waste disposal</i>											
<i>1</i>	<i>Use of public waste bins</i>	54.5	36.6	39.2	36.5	24.7	38.5	25.0	30.0	30.4	35.0
<i>2</i>	<i>Burning</i>	36.4	34.1	29.4	36.5	31.5	30.8	16.7	30.0	5.8	27.9
<i>3</i>	<i>Burying</i>	-	7.3	-	-	11.0	-	8.3	20.0	11.6	6.5
<i>4</i>	<i>Dumping in public spaces</i>	9.1	12.2	23.5	26.9	21.9	30.8	25.0	20.0	14.5	20.4

5	Collection by waste collectors	-	9.8	7.8	-	11.0	-	25.0	-	37.7	10.1
Total			100	100	100	100	100	100	100	100	100

Source: Author's fieldwork, 2024.

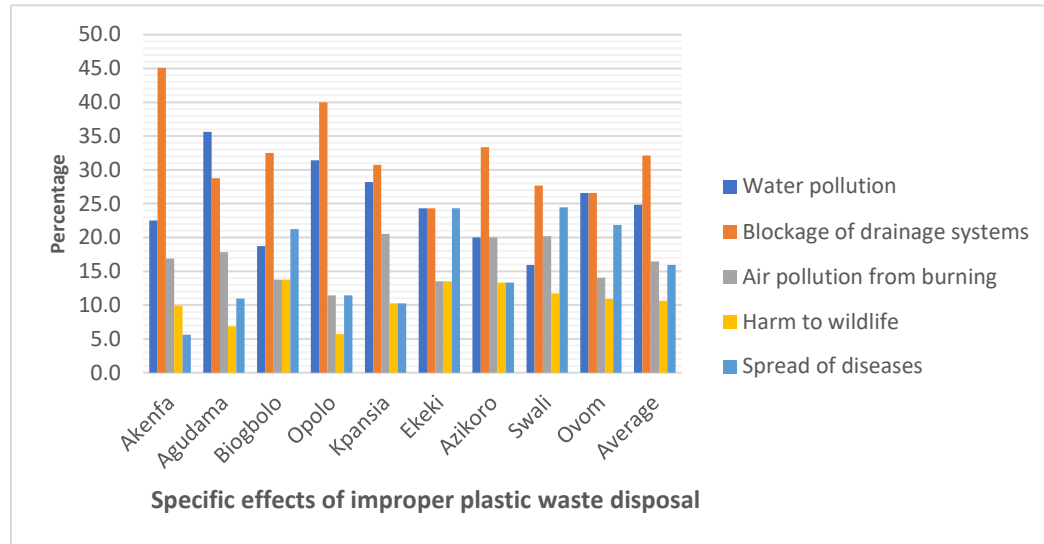


Fig. 8: Specific effects of improper plastic waste disposal

Source: Author's fieldwork, 2024.

Obstacles to plastic waste management

The most common challenge recorded is the lack of public waste bins (31.6%), particularly in Azikoro (54%) and Akenfa (34.9%) (table 4); 16.9% respondents reported the issue of irregular waste collection services, with Agudama (23.6%) and Opolo (23.6%) showing the highest proportion with regards to this (table 4). The high cost of waste collection (6.9%) and lack

of awareness about proper disposal methods (19%) are challenges that significantly affect Kpansia and Biogbolo communities. The absence of recycling facilities (25.5%) also emerged as a critical issue, with Kpansia (32.6%) and Biogbolo (31%) expressing the most concern. Similar problems were reported by Joseph et al., (2016); Van et al., (2021).

Table 3: Obstacles to plastic waste management

S/N		Percentage									
		Ak	Ag	Bio	Op	Kpa	Eke	Azi	Swa	Ov	Average
1.	Lack of public waste bins	34.9	34.7	29.8	26.4	28.3	23.6	54.0	31.7	21.0	31.6
2.	Irregular waste collection	18.6	23.6	4.8	23.6	17.4	23.6	10.0	15.8	14.8	16.9
3.	High cost of waste collection	0.0	12.5	4.8	1.8	2.2	11.2	4.0	5.0	21.0	6.9
4.	Lack of awareness of proper disposal methods	27.9	15.3	29.8	21.8	19.6	11.2	10.0	20.8	14.8	19.0

5.	Lack of plastic waste recycling facilities	18.6	13.9	31.0	26.4	32.6	30.3	22.0	26.7	28.4	25.5
Total		100	100	100	100	100	100	100	100	100	100

Source: Author's fieldwork, 2024.

Opportunities for waste reuse and recycling as a strategy for reducing impact on wetlands

There exist abundant opportunities for preventing the continued degradation of wetlands through effective plastic waste management from reuse and recycling initiatives in the study area, but both at an informal stage. 26.6% respondents manage plastic waste (plastic bottles (34.8), plastic bags (38.4) and food packaging materials (26.8) through reuse, particularly in Kpansia (29.1%) and Azikoro (28.7%). This informal reuse aligns with the findings of Alabi et al. (2019), who noted that cost-saving motives drive plastic reuse in low and middle-income regions.

The study also found that there are untapped opportunities for formalizing and promoting recycling practices; as 14% of households practice an informal recycling system through financial exchange, while 57% of respondents indicated willingness to participate in recycling activities, whereas 40.9% expressed readiness to pay for improved plastic waste management services. This presents an opportunity for policymakers and private investors to develop structured recycling programs, such as community collection points and buy-back schemes, which could incentivize household participation. Studies like Adebayo and Balogun, 2021; Kibria et al., 2023 recommended strong public support for recycling initiatives.

CONCLUSION

Understanding and preserving wetlands is crucial, given their significant role in maintaining ecological balance (water filtration, flood protection, and carbon

storage), and supporting wildlife. Unfortunately, poor plastic management among other unmanned anthropogenic activities has perverse on this natural gift as the study revealed that plastic waste accounted for 35.8% of the total waste generated in the study area; off the most common types of plastic waste in Yenagoa plastic bottles (21.0%) and plastic bags (22.2%) top among the plastic products. Regrettably, only 35% across all communities dispose of plastic waste through the use of public waste bins, while the rest sustained with other crude disposal methods, potentially to cause many harms on the wetland and its resources. It is therefore recommended that more awareness of the danger of plastic waste to the environment be carried out. Implementation of structured recycling programs, and policy interventions. More importantly, relocation of the waste dumpsites is long overdue to avoid further loss and degradation of the wetland ecosystems.

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SEASONAL ASSESSMENT OF HEAVY METALS IN WATER AND SEDIMENT FROM OSUN RIVER AND SELECTED WELLS IN OSOGBO TOWN AND THEIR IMPACTS ON AQUATIC FAUNA

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ABSTRACT

Portable sources of groundwater and surface water are constantly polluted by anthropogenic activities and have negative impacts on human and animal health. This study investigated seasonal variation in water and sediment from Osun River and selected wells in Osogbo town, Osun state, Nigeria to ascertain their impact on aquatic fauna. Water samples from ground and surface water sources were examined using standard toxicological and environmental assessment techniques. The results of the study revealed that physiochemical parameters (pH, total dissolved solids, salinity, dissolved oxygen and Biological Oxygen Demand) of surface and ground water were within the international limits except for conductivity, temperature, turbidity and Chemical Oxygen Demand). The concentration of heavy metals and anions of sediments, ground and surface water were within international limits except Cadmium and Mercury which were observed to be above the limits. However, fishes were found with high concentrations of Copper, Zinc, Iron, Magnesium, Manganese, Sodium, Potassium and Calcium higher than WHO limits. This indicates that residents need to be wary of aquatic foods due to possible bio-accumulation of the heavy metals that may impair the health of residents. Questionnaires were administered to 212 respondents to assess the levels of anthropogenic activities, sources and entry of heavy metals into Osun River and selected wells within selected communities in the study area. This study showed that there is need for appropriate treatment of water sources by government and other stakeholders. There is also need to regulate the activities of miners and residents to forestall further contamination of portable water sources in the study area.

INTRODUCTION

Groundwater recharge occurs when water from precipitation or surface water bodies infiltrate into the ground replenishing the aquifers (Harvey and Bohlke, 2003). Groundwater contributes to base flow in rivers, ensuring a sustained flow during dry periods when surface water alone may not be sufficient to maintain stream flow (Winter, 2007). The interaction of ground and surface water involves many physical, chemical and biological processes that take place in a variety of physiographic and climatic settings (Sophocleous, 2002). Surface and groundwater are important to man, animals

and environment because they serve domestic, household, industrial, transportation, fishing, tourism and cultural purposes (Oyekunle *et al.*, 2012). Heavy metals contamination of surface and groundwater, reduces the quality of drinking and irrigation water, as well as; the food web structure thereby, posing great risk to humans, animals and the environment (Adesiyun *et al.*, 2018). Heavy metals are not only regarded as natural trace components of the environment but are also commonly known as environmental pollutants particularly, when prevalent due to anthropogenic activities (Paul *et al.*, 2012). Their occurrences not only originate from natural factors such as the

weathering of rocks, but, also from anthropogenic inputs such as industrial wastes, agricultural and mining activities (Wan *et al.*, 2012). Metal concentrations in freshwater sources (rivers, lakes, etc.) can be regarded as a good indicator of the freshwater contamination (Saravanan *et al.*, 2024). This work is aimed at determining the heavy metals status in water and sediment from surface and groundwater systems and its impacts on aquatic fauna in the study area.

Materials and Methods

Study area

Osun River is located in southwestern Nigeria and is one of the key characteristics and features of Osun State (7.5629°N, 4.5200°E). It primarily flows through Osun and Oyo states. The River originates from Igede-Ekiti in Ekiti State and flows southwards into the Lagos lagoon and Gulf of Guinea. The river flows across the southern part of Osogbo city (Figure 1) and serves as habitat to various fauna.

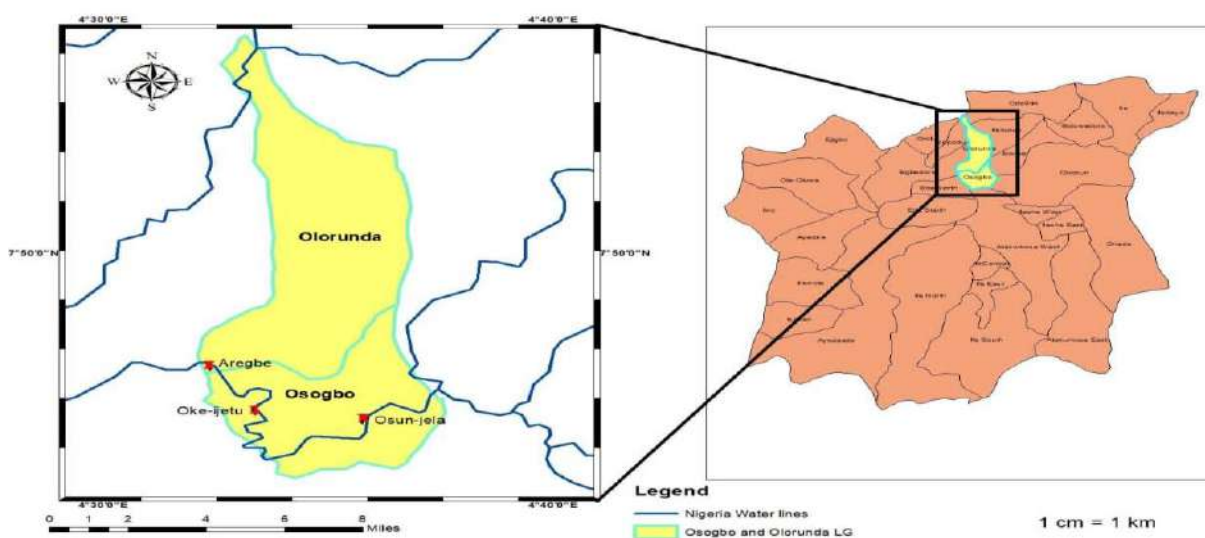


Figure 1: Map showing the study areas in Osogbo town, Osun state, Nigeria

Sample Collection

Water samples were collected from surface water (Osun River) and groundwater (well) at Osunjela (7.739645°N 4.597762°E, 7.738606°N 4.596087°E and 7.737615°N 4.595897°E), Oke-ijetu (7.742508°N 4.556423°E, 7.743365°N 4.555888°E and 7.744362°N 4.555222°E) and Aregbe (7.767707°N 4.539669°E, 7.768203°N 4.539238°E and 7.768703°N 4.539010°E). Twelve water samples were collected from surface water (Osun River) and three water from groundwater (well) at Osunjela, Oke-

ijetu and Aregbe each from upstream, midstream and downstream respectively from Osogbo town (Osogbo and Olorunda LGAs), Osun State, Nigeria in dry and wet seasons. The sampling was done for four months (March- June, 2024) because it was done at the peak of dry and wet seasons which corresponded with the peak of anthropogenic activities in the study areas. The samples were collected from upstream, midstream and downstream at a specific point respectively across the study area from the two sources [well (groundwater) and Osun River (surface water)] respectively on

monthly basis. Samples were transported to atomic absorption spectrophotometer laboratory (AAS), Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria for further analysis (Anifowose and Oyeboode, 2019; APHA, 2005; Olabanji and Oluyemi, 2011).

Digestion of water samples

25ml each of the filtered samples were measured into clean conical flasks. 15ml of freshly prepared aqua-regia was added into each flask and were each heated to near dryness. 10ml of distilled water was then added and heated again for 2-3 minutes, allowed to cool and filtered. The filtrates were each made up to mark in a 25ml flask and kept refrigerated pending metal determination by AAS (Anifowose and Oyeboode, 2019; APHA, 2005; Olabanji and Oluyemi, 2011).

CALIBRATION

Before analyzing digested water, sediment and fish samples for metal concentration, PG990 AAS was calibrated with the use of standard reference material. Each of the metals have its own different standard concentrations which were prepared from the stock solution (1000ppm) for each cation.

Determination of cations (Heavy Metals) in water

The digested water samples was analyzed with PG990 atomic absorption spectrophotometer of the Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria for the heavy metals in the samples by flame atomization, using air-acetylene flame and single element hollow cathode lamp which generated absorbance values and concentrations for each of the heavy metals were generated automatically by software called AA win. This absorption follows Beer-Lambert's law which states the absorbance to

be directly proportional to the path length in the flame and to the concentration of atomic vapor in the flame (Anifowose and Oyeboode, 2019; APHA, 2005; Olabanji and Oluyemi, 2011).

Data Analysis

Data analysis for the heavy metals involved processing and interpretation of the data generated from the Flame Atomic Absorption Spectroscopy (FAAS), using descriptive statistics.

RESULTS

Fifteen cations (Arsenic, Copper, Lead, Nickel, Iron, Zinc, Chromium, Manganese, Magnesium, Sodium, Calcium, Cadmium, Cobalt, Mercury and Potassium) were detected in the water samples from Osun River and selected wells from the study area. Thirteen cations with different concentrations were detected in both seasons {Arsenic (0.005 ± 0.003 to 0.018 ± 0.008 mg/l), Copper (0.028 ± 0.023 to 0.058 ± 0.011 mg/l), Cobalt (0.013 ± 0.001 to 0.028 ± 0.017 mg/l), Lead (0.004 ± 0.004 to 0.016 ± 0.013 mg/l), Nickel (0.014 ± 0.008 to 0.039 ± 0.008 mg/l), Iron (0.021 ± 0.013 to 0.057 ± 0.005 mg/l), Zinc (0.017 ± 0.004 to 0.047 ± 0.019 mg/l), Chromium (0.011 ± 0.001 to 0.039 ± 0.001 mg/l), Manganese (0.012 ± 0.012 to 0.025 ± 0.021 mg/l), Magnesium (0.028 ± 0.004 to 0.070 ± 0.014 mg/l), Sodium (0.018 ± 0.004 to 0.046 ± 0.006 mg/l), Calcium (0.024 ± 0.003 to 0.044 ± 0.011 mg/l) and Potassium (0.026 ± 0.014 to 0.060 ± 0.028 mg/l) (dry season)} and Arsenic (0.004 ± 0.001 to 0.105 ± 0.002 mg/l), Copper (0.036 ± 0.004 to 0.077 ± 0.011 mg/l), Cobalt (0.003 ± 0.001 to 0.020 ± 0.013 mg/l), Lead (0.004 ± 0.001 to 0.011 ± 0.003 mg/l), Nickel (0.009 ± 0.001 to 0.037 ± 0.026 mg/l), Iron (0.016 ± 0.006 to 0.067 ± 0.014 mg/l), Zinc (0.021 ± 0.006 to 0.067 ± 0.004 mg/l), Chromium (0.013 ± 0.002 to 0.043 ± 0.023 mg/l), Manganese (0.016 ± 0.014 to 0.037 ± 0.040 mg/l),

Magnesium (0.034 ± 0.005 to $0.078 \pm 0.018 \text{ mg/l}$), Sodium (0.058 ± 0.042 to $0.096 \pm 0.064 \text{ mg/l}$), Calcium (0.023 ± 0.004 to $0.096 \pm 0.064 \text{ mg/l}$) and Potassium (0.035 ± 0.024 to $0.106 \pm 0.023 \text{ mg/l}$ (wet season)) which were within WHO (2018) and EU (2020) limits. While Cadmium [$(0.014 \pm 0.008$ to $0.035 \pm 0.002 \text{ mg/l})$ (Dry

season)); (0.012 ± 0.002 to $0.026 \pm 0.003 \text{ mg/l}$) (Wet season)] and Mercury [$(0.005 \pm 0.002$ to $0.012 \pm 0.012 \text{ mg/l})$ (Dry season); (0.002 ± 0.000 to $0.080 \pm 0.003 \text{ mg/l}$) (wet season)] in Osun River and Wells exceeded 0.005 mg/l according to WHO (2018) and EU (2020) limits (Figure 2 and 3).

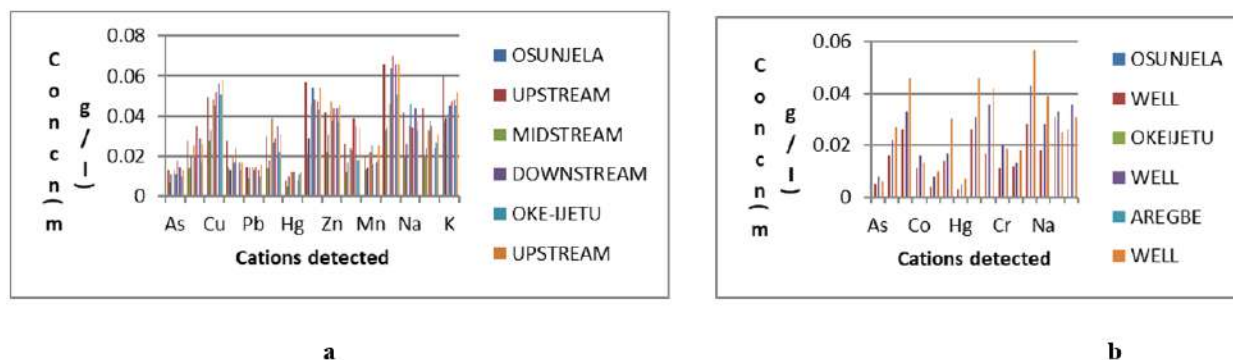


Figure 2: Concentrations of cations (heavy metals) analyzed from the surface water (Osun River) and ground water (wells) in dry season

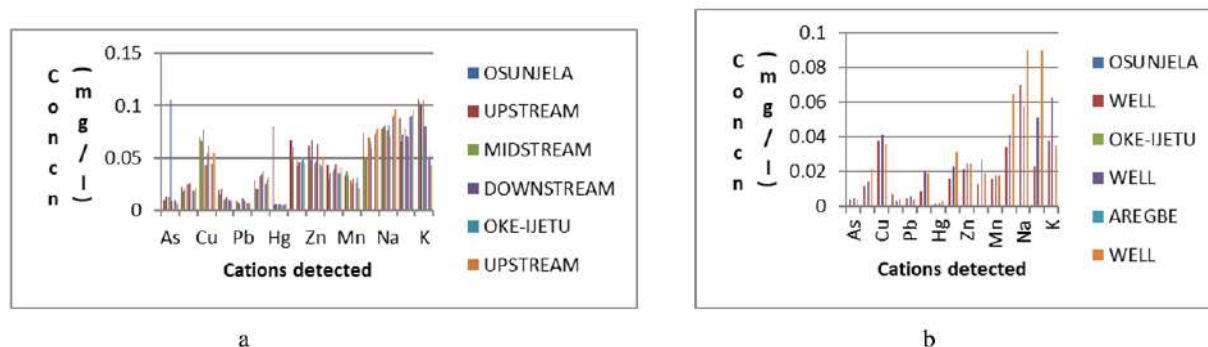


Figure 3: Concentrations of cations (heavy metals) analyzed from the surface water (Osun River) and groundwater (wells) in wet season

DISCUSSION

The study revealed that the Osun River and Groundwater systems in Osogbo Town of Osun State, Nigeria were contaminated with

fifteen cations (Arsenic, Copper, Lead, Nickel, Iron, Zinc, Chromium, Manganese, Magnesium, Sodium, Calcium, Cadmium, Cobalt, Mercury and Potassium) in Osun River and wells however, two cations

(Cadmium and Mercury) were above 0.005mg/l according to the international limits by WHO (2018) and EU (2020) in the dry and wet seasons. Adeyemi and Zacchaeus, (2021) determined the mean concentrations of eight cations (Nickel, Lead, Chromium, Manganese, Copper, Cadmium, Zinc and Iron) in groundwater (hand-dug wells and boreholes) collected from Ota and Sagamu industrial areas, Ogun State, Nigeria using Atomic Absorption Spectroscopy (AAS) where Lead and Iron exceeded the safe limits of WHO (2017) during dry and wet seasons. Mustapha *et al.* (2021) determined the mean concentrations of six cations (Zinc, Copper, Manganese, Iron, Lead and Cadmium) in Epe Lagoon, Lagos, Nigeria where Lead and Cadmium exceeded WHO (2003) safety limits.

CONCLUSION

The concentration of heavy metals in surface and ground water systems in Osogbo metropolis were within safe limits according to international standards in dry and wet seasons, although, there were slight seasonal variations across upstream, midstream and downstream. While, Mercury (Hg) and Cadmium (Cd) were observed to be high in concentrations above safety limits in both surface and groundwater systems in dry and wet seasons. This study showed that surface and groundwater systems assessed were contaminated with heavy metals in dry and wet seasons which portend health risks to consumers in the study area.

CONFLICT OF INTEREST

There is no conflict of interest amongst the authors for this paper to be published.

RECOMMENDATION

There is a need for appropriate treatment of surface and ground water systems before consumption by residents in the study area. Also, there is a need to regulate the activities of miners and residents that contribute to the

contamination and pollution of these sources of portable water to forestall public health disasters in the study area.

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IMPACT OF ANNUAL FLOODING ON AGRICULTURAL ACTIVITIES AND FOOD SECURITY IN WETLAND COMMUNITIES: A CASE STUDY OF OGBOGORO, BAYELSA STATE

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ABSTRACT

Wetland ecosystems are vital for agricultural productivity, yet recurrent flooding threatens food security and rural livelihoods. This study examines the impact of annual flooding on agricultural activities in Ogbogoro Community, Yenagoa LGA, Bayelsa State, focusing on crop losses, soil degradation, and adaptation strategies. A survey research design was employed, collecting data from 320 farmers using structured questionnaires. Descriptive statistics and Pearson correlation analysis assessed the relationship between flooding severity and agricultural losses. Findings indicate that 93.8% of respondents experience annual flooding, with 91.6% reporting severe impacts on crop yield. Cassava (14.5%), plantain (11.05%), and yam (10.3%) were most affected, while 39.7% of farmers reported total crop loss. Correlation analysis established a significant negative relationship between flooding frequency and crop productivity ($r=-0.444$, $p=0.000$). Despite adaptation strategies such as planting flood-resistant crops (30.9%) and constructing drainage systems (27.5%), 87.8% found these measures ineffective. Furthermore, 73.8% of respondents received no government support, exacerbating vulnerability. The study highlights the intersection between wetland degradation, agricultural instability, and food insecurity, underscoring the relevance of the Vulnerability Theory. Policy recommendations include strengthening early warning systems, implementing flood-resistant infrastructure, and promoting climate-smart agriculture to enhance resilience. These findings provide critical insights into sustainable wetland management and the development of adaptive strategies to mitigate the adverse effects of flooding on agricultural livelihoods. Addressing these challenges is essential for ensuring food security and economic stability in flood-prone regions of Nigeria.

Keywords: Wetland Ecosystem, Flooding and Agriculture, Food Security, Climate Change Adaptation, Sustainable Livelihoods

INTRODUCTION

Flooding has emerged as one of the most persistent environmental challenges facing wetland agricultural communities in Nigeria, particularly in the Niger Delta region. In Ogbogoro, a community in Yenagoa Local Government Area (LGA), Bayelsa State, recurrent flooding has significantly disrupted farming activities,

leading to crop destruction, soil degradation, and food insecurity. Farmers in the community report increasing flood intensity, with entire farmlands submerged annually, resulting in the Loss of staple crops such as cassava, yam, plantain, maize, rice, cocoyam, sweet potatoes, water yam, vegetables (pumpkin, okra, and spinach), and legumes (groundnuts and beans).

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Beyond direct agricultural losses, flood-induced soil erosion and waterlogging have further reduced long-term farm productivity, leaving many farmers without sustainable means of recovery. These impacts threaten the economic survival of smallholder farmers, who form the backbone of the local food production system.

Flooding in Ogbogoro is driven by both natural and anthropogenic factors. The region's low-lying topography, high rainfall intensity, and proximity to major water bodies make it highly susceptible to seasonal flooding. However, human activities such as deforestation, poor drainage systems, and unregulated land use have intensified the frequency and severity of these floods. With climate change contributing to rising sea levels and unpredictable rainfall patterns, the threat of flooding in wetland ecosystems is expected to worsen in the coming years. This presents a significant challenge to rural livelihoods, food security, and sustainable agricultural development in flood-prone regions.

There is extensive literature highlighting the socio-economic and environmental impacts of flooding on wetland agriculture, particularly in regions with limited institutional support and weak flood management infrastructure (Adekola and Mitchell, 2011; Sadiq, 2018; Eni et al., 2011). Studies have shown that flooding not only disrupts short-term agricultural production but also has long-term consequences for food security and poverty levels in affected communities (Nzeh et al., 2012; Abdullahi, 2015). While various coping strategies—such as shifting planting dates, constructing small drainage systems, and planting flood-resistant crops—have been explored, many farmers continue to struggle with severe losses due to

inadequate flood mitigation measures. In Ogbogoro, the lack of government intervention and limited access to financial and technical support have further exacerbated farmers' vulnerability to flooding disasters.

Sustainable wetland management is essential for ensuring long-term agricultural resilience and climate adaptation in flood-prone communities. Nature-based solutions, improved drainage systems, and early warning mechanisms can help mitigate the impact of annual flooding on agricultural productivity and food security. This paper investigates the impact of annual flooding on agricultural activities in Ogbogoro, Bayelsa State, with a focus on understanding the extent of crop damage, adaptation strategies employed by farmers, and the broader implications for food security in wetland communities. Addressing these challenges is critical for enhancing climate resilience and safeguarding rural livelihoods in Nigeria's flood-vulnerable regions.

Study Location, Spatial Coverage, and Approach

The geographical scope of this study is Ogbogoro Community, a rural settlement in Yenagoa Local Government Area (LGA), Bayelsa State, Nigeria. The community is geographically positioned at 4.926° N latitude and 6.324° E longitude and lies within the wetland ecosystem of the Niger Delta. Ogbogoro is bordered by the Nun River to the east, with a vast network of creeks and tributaries influencing its hydrological characteristics. The study area is highly susceptible to seasonal flooding, particularly during the rainy season, which disrupts agricultural activities and affects food security. Figures 1 and 2 illustrate the study location and its spatial coverage within Yenagoa LGA.

The research commenced with a reconnaissance survey, which allowed for a preliminary assessment of the flooding challenges and their impacts on agriculture in the community. This was followed by structured interviews and participatory rural appraisal techniques, ensuring that data collection was both scientific and inclusive. Key informant interviews (KIIs) were conducted with community leaders, local farmers, and agricultural extension officers to gain firsthand insights into the recurring flood problem and its socioeconomic consequences.

For quantitative data collection, the study employed a structured questionnaire survey, targeting farmers and residents engaged in agriculture. A total of 320 respondents were sampled across the ten compounds in

Ogbogoro, using a stratified random sampling technique. This ensured that all subgroups within the community were adequately represented. Additionally, remote sensing data and historical rainfall records were examined to provide a broader perspective on flood trends and their implications for agricultural productivity.

The study also included field observations of farmlands and flood-prone areas to document the extent of soil degradation, crop damage, and water stagnation. These observations were critical in corroborating the survey data and identifying patterns of vulnerability among farmers. Through the integration of both qualitative and quantitative approaches, this research provides a comprehensive analysis of the impact of flooding on agriculture and food security in wetland communities like Ogbogoro.

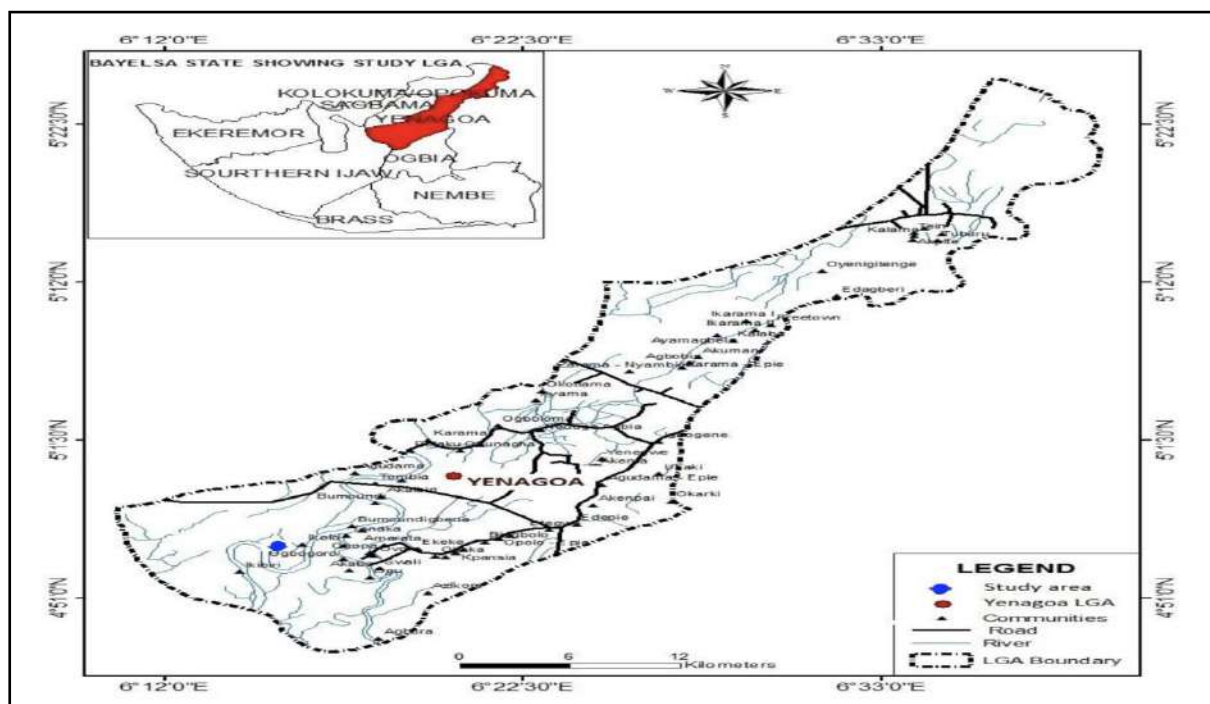


Fig 1.1: Map of Yenagoa LGA Showing the Study Area, Obogoro Community

METHODOLOGY

The study adopts a survey research design, allowing for the collection of both quantitative and qualitative data on the impact of flooding on agricultural activities in Ogbogoro Community. Primary data were gathered through structured questionnaires, direct observations, and key informant interviews with farmers, while secondary data were obtained from relevant academic journals, government reports. Using the Taro Yamane formula, a sample size of 368 respondents was selected, with a stratified random sampling technique ensuring representation across all ten compounds in the community. Data were analyzed using descriptive statistics, including percentages and frequency distributions, while correlation analysis was used to assess the statistical relationship between flooding severity and agricultural losses. Ethical considerations were upheld, with informed consent, confidentiality, and voluntary participation ensured throughout the study. Findings from this analysis provide empirical insights into the challenges faced by farmers and their coping strategies in the flood-prone wetland environment of Ogbogoro.

RESULTS AND DISCUSSIONS

Flooding Incidence, Agricultural Activities, and Farmers' Coping Mechanisms

The study finds that 93.8% of respondents experience flooding annually, while 91.6% report severe impacts on farming activities. These findings are consistent with Olanrewaju and Fadiro (2003), who noted that recurrent flooding in Nigeria has increasingly disrupted rural agricultural activities, particularly in wetland ecosystems. Furthermore, 85.6% of respondents reported that their entire farmland is affected by

flooding, reinforcing the findings of Magami et al. (2014), which identified large-scale farmland submersion as a major factor driving food insecurity in flood-prone communities.

The types of crops cultivated in Ogbogoro are disproportionately affected by flooding. Cassava (14.5%), plantain (11.05%), yam (10.3%), and vegetables (9.15%) suffer the highest levels of flood damage. These findings align with the study by Agwu and Okhimamhe (2009), who found that root crops in wetland regions are particularly vulnerable to flood-induced destruction due to prolonged waterlogging. Similarly, Bariweni et al. (2012) observed that vegetables and grains in the Niger Delta are highly susceptible to flood-related losses, further exacerbating local food insecurity.

To adapt to frequent flooding, farmers have adopted various mitigation strategies. The study finds that 30.9% of respondents plant flood-resistant crops, 27.5% construct small drainage systems, and 18.4% practice early harvesting. However, 87.8% of farmers state that these strategies are ineffective in significantly reducing flood damage, which aligns with the argument by Nwigwe and Embergo (2014) that traditional adaptation methods alone are insufficient without adequate infrastructural support. The widespread inefficacy of these coping mechanisms highlights the urgent need for improved flood control measures, such as the construction of embankments, improved drainage networks, and access to climate-resilient agricultural techniques.

Government Support and Policy Interventions

Despite the widespread impact of flooding, government intervention remains largely inadequate. The study finds that 73.8% of respondents received no financial or material assistance during flood events, while 82.2% reported that relief materials were either unavailable or rarely provided. These results corroborate Afolabi (2013), who found that government disaster response mechanisms in Nigeria often fail to meet the needs of vulnerable agricultural communities. Furthermore, only 4.1% of respondents received financial support, and 13.4% benefited from relief materials such as seeds and fertilizers. The limited nature of these interventions highlights structural weaknesses in disaster management policies, as noted by NEMA (2012).

The correlation analysis further establishes a statistically significant relationship between flooding and agricultural losses. A moderate negative correlation (-0.444 , $p=0.000$) was found between flooding frequency and crop productivity, confirming that as flooding events increase, agricultural yields decline. Similarly, farmland size correlates positively (0.304 , $p=0.000$) with crop damage, indicating that larger farms experience higher financial losses during flood events. These findings align with Etuonovbe (2011), who argued that large-scale farmlands in flood-prone areas suffer more extensive economic losses due to the higher exposure of cultivated land to floodwaters.

The study's findings support the Vulnerability Theory proposed by Blaikie et al. (1994), which posits that communities with high exposure to environmental hazards, limited adaptive capacity, and weak institutional support face greater disaster risks. The absence of robust flood mitigation infrastructure, coupled with poor government

support, increases the vulnerability of farmers in Ogbogoro. This underscores the urgent need for policy-driven interventions, including climate adaptation strategies, improved flood control infrastructure, and financial support programs for affected farmers. Strengthening institutional responses and increasing investment in flood-resilient agricultural practices will be critical in mitigating future flood-related disruptions in Ogbogoro Community.

CONCLUSION

From an agricultural and food security perspective, the study revealed that annual flooding poses a major threat to wetland farming communities like Ogbogoro. The findings confirm that recurrent floods submerge farmlands, destroy crops, and disrupt livelihoods, leaving farmers vulnerable to economic losses and food insecurity. While farmers employ various coping strategies, their effectiveness is limited due to inadequate flood control infrastructure and lack of institutional support. The literature is consistent on the increasing flood risks in wetland ecosystems due to climate change and poor land-use planning. To mitigate the impact of flooding on agricultural productivity, key interventions should include improved drainage systems, sustainable wetland management, and government-supported climate adaptation measures. Strengthening early warning systems, providing financial aid to farmers, and enforcing land-use policies will be essential in reducing flood vulnerability and ensuring long-term food security in wetland communities like Ogbogoro.

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MORPHOMETRIC AND MERISTIC CHARACTERISTICS OF *Alestes baremoze* IN RIVER KOMADUGU-YOBE, GASHUA LOCAL GOVERNMENT, YOBE STATE – NIGERIA

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ABSTRACT

Sample of 240 *Alestes baremoze* were randomly obtained from catches of fishers fishing in River Komadugu-Yobe with the aim of measuring and analysing their morphometric and meristic characteristics. The ranges and means of body weight: 1.0 – 37.0g, 17.05±10.24g; Head length: 0.40 – 6.00cm, 2.17±0.90cm; Caudal Peduncle: 0.1 – 10.5cm, 3.55cm. Range and Mean numbers of Soft Anal Fin Rays: 6 – 26, 17.29±3.77; Dorsal Fin Ray: 8 – 18, 9.27±2.47; Scale along Lateral Line: 12 – 30, 23.43±5.08; Scale above the Lateral Line: 11 – 30, 23.00±4.99; Scale below Lateral Line: 10 – 28, 19.85±5.03; Scale around Caudal Peduncle: 10 – 18, 13.85±2.06; Pectoral Fin Ray: 7 – 29, 17.64±5.60; Gill Raker on the First Arch: 0 – 14, 12.63±14.06. Generally, morphometric and meristic analyses indicated wide ranges of phenotypic plasticity. These morphological variations might be due to various factors such as age, adaptation to various ecological niches as well as indicative of ongoing evolution in nature; however, judging from the diverse population with wide ranges in morphometric and meristic characteristics of the fish species the taxonomic identification based on morphology might need to be complemented with genetic analyses for more certainty and reliability.

Keywords: River Komadugu-Yobe, Morphology, Taxonomy, *Kawara*, *Alestes baremoze*

INTRODUCTION

Silversides or pebbly fish (*Alestes baremoze*) is native to freshwater systems in Africa, flourishing well in both lentic and lotic environments. It belongs to order

Characiformes, family Alestidae. In Nigeria, specifically in Katsina State, *Alestes* is well known, it is called “*kawara*” and it is one of the most important fish species of Zobe Dam, Dutsin-Ma (Nababa et al., 2024). Knowledge

of some aspects of reproduction biology and length-weight relationship are important in studying fish biology. Length-weight relationships can be used to predict weight from length measurements (Pauly, 1993; Yusuf and Abdulkarim, 2015).

Length-weight relationship is a significant biological parameter in fishery science as it helps in easy assessment of stock variation and general well-being of fishes (Kalita et al., 2016; Yusuf and Abdulkarim, 2016). A need exists to determine the population biology of wild species for exploitation models. Progressively, studies in different parts of the world continue to investigate the length-weight relationship, fecundity, condition factor, gonadosomatic index and so forth to update the dynamics in biology of fish species. Length weight relationship and condition factor are of great importance to the fishery industry as they help to predict the best length and time suited to harvest a particular species of fish.

According to Abdulkarim et al. (2017) in their studies of the potentiality of *Brycinus nurse* for aquaculture in Nigeria, it was noted that knowledge of morphology and meristic characters of *B. nurse* will contribute to understanding aspects of its biology. Understanding the morphometric and meristic characteristic helps in comprehending the growth dynamics of *A. baremoze*, which is crucial for their management and conservation and also monitoring the condition factor gives insights into the health and overall status of the fish species within the River Komadugu-Yobe. The aim of this study was to investigate the morphometric and meristic characteristics of *A. baremoze* in River Komadugu-Yobe.

MATERIALS AND METHODS

Description of the Study Area

Gashua is a community in Yobe State in North-eastern Nigeria, the Yobe River is a few miles below the convergence of the Hadejia River and the Jama'are River. The average elevation is about 299m. The hottest months are March-May with temperature ranges of 38-40°C. In the rainy season, June-September, temperatures fall to 23-28°C with rainfall of 500 to 1000mm. River Gashua basin is the area drained in one of Lake Chad Basin sub-basins. The River Gashua average temperature and pH were 28°C and 7.5, respectively. Geographically, River Gashua basin is located approximately between latitudes 10°N to 14°20'N and Longitude 7°25'E to 13°E. The basin has a total area of 145 833Km². The hydrological boundaries of the basin transverse the States of Kano, Jigawa, Bauchi, and to a lesser extent, Plateau, Kaduna, Katsina and Borno in Nigeria and Diffa region in Niger Republic. It has a combined catchment area of 148,000 km² shared between Nigeria (north-east) and Niger (south-east).

There are two different types of soils in the study area. They are pedosols and pedalfers. The pedalfers consists of minerals and iron while the pedosols are made up of calcium. River Komadugu-Yobe basin area largely falls within Sudano Sahelian vegetation ecological zone to the northern part, the basin has tropical vegetation and is characterized by scattered shrubs, thorns such as *Acacia albida* (Gawo), *Acacia nilotica* (Gabaruwa), *Tamarindus indica* (Tsamiya), Baobab (*Kuka*) and *cummiphora* spp. Most of the trees found are xerophytic in nature while the grasses are seasonal grasses which dry up during dry season (NIPOST, 2009).

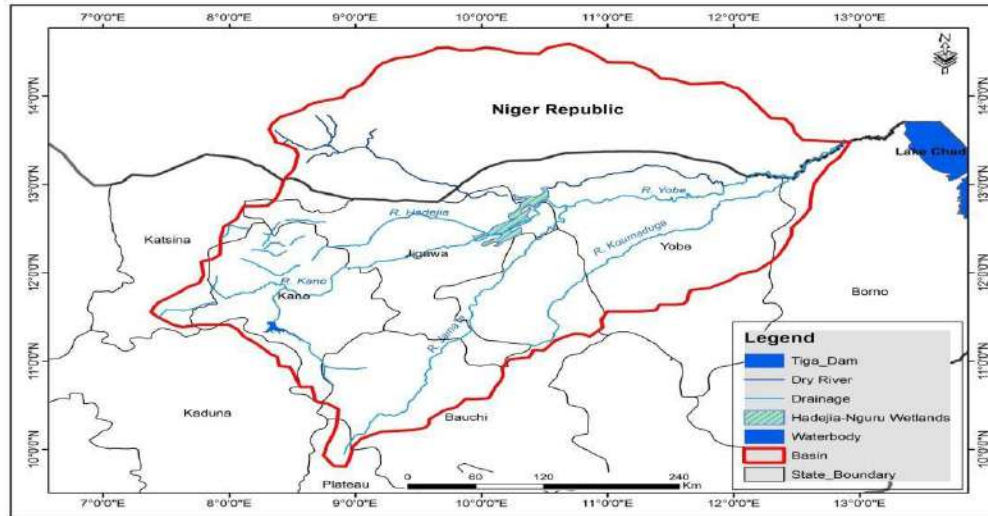


Figure 1: River Komadugu-Yobe Basin

Source: Google high resolution image (2018)

Experimental fish

Two hundred and forty (240) fish samples comprised of 240 of sexes were obtained from River Komadugu-Yobe from January to February, 2023. The number of *Alestes baremose* collected for each month was 120 samples. Fish were obtained from the fishers at the river bank of Gashua. The fish specimens were transported in ice containers to the laboratory where measurements started immediately. Each fish species was subsequently given a serial identification number after it was drained off using filter papers.

Morphometric Measurements

Morphometric parameters were measured with the help of electronic balance (digital weighing scale, model no. CS 200) and 30cm rule. All measurements of each sample were taken and recorded in the laboratory of the Department of Fisheries and Aquaculture, Federal University, Gashua.

Meristic counts

Nine (9) meristic characters were directly counted from all the samples. These included number of lateral line scales (LLS), number

of dorsal fin rays (DFR), number of dorsal fin spines (DFS), number of anal fin rays (AFR), number of anal fin spines (AFS), number of pectoral fin rays (PFR), number of pectoral fin spines (PFS), Lateral line scale (LLS), number of pelvic fin spines (PFS), number of pelvic fin rays (PFR), scales around caudal peduncle (SCP).

Statistical Analysis

The data were analysed using mean and standard deviation with MS-excel 2013 office.

RESULTS AND DISCUSSION

Morphometric Characteristics of *Alestes baremose* from River Komadugu-Yobe

The morphometric characters of samples obtained from River Komadugu-Yobe were elucidated in Table 1. In all the characters measured, mean and standard deviation number of total lengths $14.82 \pm 8.77\text{cm}$, standard length $6.87 \pm 3.28\text{cm}$, head length $2.17 \pm 0.90\text{cm}$, eye diameter $4.04 \pm 11.87\text{cm}$, caudal peduncle length $2.25 \pm 1.61\text{cm}$, height of anal fin $2.80 \pm 2.12\text{cm}$, caudal peduncle depth $3.55 \pm 2.67\text{cm}$, body depth $2.42 \pm 1.32\text{cm}$, pre dorsal length $6.05 \pm 6.07\text{cm}$, length of

dorsal height 2.45 ± 2.88 cm, length of pelvic fin 2.70 ± 3.30 cm, and body weight

17.05 ± 10.25 g. Anal fin length 1.51 ± 0.73 cm
Pectoral fin length 0.72 ± 0.99 cm

Table 1: Morphometric Characteristics (Measurement) of *Alestes baremoze* from River Komadugu-Yobe

Characters	Minimum	Maximum	Mean $\pm$ SD
Body Weight (g)	1.00	37.00	17.05 ± 10.24
Total Length (cm)	2.0	36.9	14.82 ± 8.77
Standard Length (cm)	0.6	11.0	6.87 ± 3.28
Body Depth (cm)	0.1	7.5	2.42 ± 1.32
Eye Diameter (cm)	0.1	6.0	4.04 ± 1.87
Head Length (cm)	0.4	6.0	2.17 ± 0.90
Caudal Peduncle Length (cm)	0.4	9.8	2.25 ± 1.61
Caudal Peduncle Depth (cm)	0.1	10.5	3.55 ± 2.67
Pre-Dorsal Length (cm)	0.3	43.0	6.05 ± 6.07
Dorsal Fin Length (cm)	0.3	10.2	5.50 ± 3.52
Dorsal Fin Height (cm)	0.1	13.9	2.45 ± 2.88
Anal Fin Length (cm)	0.0	2.9	1.51 ± 0.73
Pectoral Fin Length (cm)	0.0	2.9	0.72 ± 0.99

Where SD = Standard Deviation.

The body weight of fish shows a wide range, from a minimum of 1.0g to a maximum of 37.0g, with an average of 17.05g. Head length and caudal peduncle dimensions also show notable variability, with caudal peduncle depth ranging from 0.1cm to 10.5cm and an average of 3.55cm. In the present study, morphometric characteristics of fish presented in Table 1 provide valuable insight into the variability and range of body dimensions among the sampled population. The body weight of fish shows a wide range, from a minimum of 1.0g to a maximum of 37.0g, with an average of 17.05g. This substantial variation in weight may be attributed to factors such as species diversity, age, or environmental conditions affecting growth rates. The total length of fish ranges from 2.0cm to 36.9cm, with a mean of 14.82cm.

The significant standard deviation of 8.77 suggests notable size heterogeneity, which could be indicative of a population that includes individuals at different stages of development as reported by Peter (2000). Standard length, an important measure for species identification and comparison, shows a similar trend, with a minimum of 0.6 cm, a maximum of 11.0cm, and a mean of 6.87cm. Body depth, a factor influencing swimming performance and habitat preference, ranges from 0.1cm to 7.5cm, with a mean of 2.42cm. The eye diameter displays an unexpectedly large variation, ranging from 0.1cm to 6.0cm, which suggests either measurement error or an atypical individual in the sample. Further investigation into this data point might be necessary to confirm its validity.

Head length and caudal peduncle dimensions (length and depth) also show notable

variability, with caudal peduncle depth ranging from 0.1cm to 10.5cm and an average of 3.55cm, indicating structural diversity in tail morphology, which is often linked to locomotion and habitat use. The pre-dorsal length, dorsal fin dimensions (length and height), and anal fin length all contribute to the characterization of the fish's overall body shape and functional morphology. The pre-dorsal length, in particular, varies widely from 0.3 cm to 43.0 cm, with a mean of 6.05 cm, which suggests that dorsal fin positioning may differ considerably between individuals. Finally, the pectoral fin length, with a mean of 0.72 cm, appears relatively small compared to other fin dimensions, which could indicate differences in swimming behaviour or fin usage among species in the sample. Overall, the table reveals significant morphological variation within the fish population, which could reflect differences in species composition, environmental adaptation, or ontogenetic changes thereby corroborating the findings of Chindo et al. (2022) as reported in respect to *B. nurse* from Gubi dam.

Table 2 revealed the meristic characters of *A. baremoze* samples obtained from River Komadugu-Yobe. In all the characters counted, mean number of soft anal fin ray was 17.29 ± 3.77 , dorsal fin ray 9.27 ± 2.47 , Scale alone lateral line 23.43 ± 5.08 , scale above the lateral line 23.00 ± 4.99 , Scale below the lateral line 19.85 ± 5.03 , Scale around caudal peduncle 13.85 ± 2.06 , pectoral fin ray 17.64 ± 5.60 and Gill raker on the first arch 12.63 ± 14.06 . Mean number of soft anal fin ray was 17.29 ± 3.77 , dorsal fin ray 9.27 ± 2.47 , Scale alone lateral line 23.43 ± 5.08 , scale above the lateral line 23.00 ± 4.99 , Scale below the lateral line 19.85 ± 5.03 , Scale around caudal peduncle 13.85 ± 2.06 , pectoral fin ray 17.64 ± 5.60 and Gill raker on the first arch 12.63 ± 14.06 . However, unlike morphometric indices which very much age and size dependent, meristic characters are independent of fish size and do not mostly change as the fish grows (Balici et al., 2016).

Table 2: Meristic Characteristics of *Alestes baremoze* from River Komadugu-Yobe

Characters	Minimum	Maximum	Mean $\pm$ SD
Soft Anal Fin Rays	6	26	17.29 ± 3.77
Soft Dorsal Fin Ray	8	18	9.27 ± 2.47
Scale along the Lateral Line	12	30	23.43 ± 5.08
Scale above the Lateral Line	11	30	23.00 ± 4.99
Scale below the Lateral Line	10	28	19.85 ± 5.03
Scale around Caudal Peduncle	10	18	13.58 ± 2.06
Pectoral Fin Rays	7	29	17.64 ± 5.60
Gill Raker on the First Arch	0	14	12.63 ± 14.06

Where SD = Standard Deviation.

CONCLUSION

The morphometric and meristic analyses of *A. baremoze* revealed substantial diversity within the studied fish population, indicating the most likely presence of different subspecies owing to the wide range of

phenotypic plasticity. The variation in body size, fin ray counts, scales, and other features suggests that the fish are adapted to various ecological niches. While some of the data points, such as eye diameter and gill rakers, show irregularities, the overall dataset

provides valuable insights into the structural diversity and potential functional adaptations of the fish.

RECOMMENDATIONS

Further Taxonomic Identification should be carried out to ascertain the wider range in morphometric and meristic characteristics of the fish species judging from their diverse population, possibly representing multiple species, and detailed taxonomic identification, using additional morphological traits or molecular methods, is recommended to clarify species composition. Given the variability in traits like fin rays, scales, and body dimensions, an ecological study is advised to examine the environmental factors likely influencing these differences. This could involve studying the habitat preferences, feeding habits, or predator-prey interactions of the fish population.

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COMPARATIVE PHYSICOCHEMICAL PROPERTIES OF SURFACE AND GROUND WATER QUALITIES AND ITS PUBLIC HEALTH IMPLICATIONS IN OSOGBO TOWN, OSUN STATE, SOUTHWEST, NIGERIA

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ABSTRACT

Portable sources of surface and ground water are constantly polluted by anthropogenic activities and have negative impacts on human and animals' health. This study investigated the physicochemical properties of Osun River and selected wells in Osogbo town, Osun State, Nigeria, to ascertain their public health impacts. Water samples from surface and ground water systems were examined to determine their pH, total dissolved solids, conductivity, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Temperature, Turbidity, Dissolved Oxygen (DO) and Salinity values. The mean values of the pH, total dissolved solids, conductivity, BOD and COD were observed to be within international limits, while, Temperature, Turbidity and DO were above permissible limits. This study showed that surface and ground water systems assessed were contaminated with substances in dry and wet seasons occasioned by the vigorous anthropogenic activities, such as mining, agriculture, construction and waste deposits. The study recommends creation of awareness by government and other stakeholders on the extant variable cost-effective water treatment techniques to reduce the health risks of consuming polluted portable water in the study area. Also, the activities of miners and residents should be regulated to forestall the contamination and pollution of freshwater sources in the study area.

INTRODUCTION

Groundwater is regarded as one of the primary sources of drinking water in many rural and urban areas in Osun State, Nigeria (Adeyemi and Zacchaeus., 2021). Hence, a considerable population is inclined to the dangers of consuming contaminated water. Groundwater recharge occurs when water from precipitation or surface water bodies infiltrates into the ground replenishing the aquifers (Geris *et al.*, 2022) and groundwater discharge involves the release of water from aquifers to surface water bodies such as rivers, lakes and oceans (Harvey and Bohlke., 2003). Groundwater contributes to base flow in rivers; ensuring a sustained flow during dry periods when surface water alone may not be sufficient to maintain stream flow (Winter

and Schot., 2006). Groundwater transports dissolved-substances, nutrients and pollutants to rivers and streams, thereby, influencing the quality of surface water greatly (McMahon and Chapelle., 2008). The river serves as a source of water for domestic, agricultural and industrial purposes for Osun communities along its course. The river faces challenges related to pollution due to agricultural run-offs, industrial effluents and urban wastes. The major sources of portable water in major towns and cities of Osun state, Nigeria is ground water (borehole and well) and sometimes, streams and rivers especially, during the dry season in the rural semi urban settings (Odebunmi *et al.*, 2014). These water sources are the alternatives to the inconsistent flow of pipe borne water, which would have been a more reliable and safer source of

portable water in Osogbo metropolis (Oluyemi *et al.*, 2010).

Anthropological activities, such as construction, agriculture and irrigation, can alter the natural interaction between surface and groundwater (Weihua *et al.*, 2023). Geological, hydrological and other anthropogenic factors affect surface and groundwater systems that are crucial for sustainable water resource management as they release Lead, Cadmium, Mercury, Magnesium, Arsenic, Copper, Zinc, Cobalt, Manganese, Nickel, Chromium, Iron, Sodium, Potassium Sulphate, Nitrate, Chloride, Phosphate and Calcium and find their way into the food chain, and leach into the groundwater, resulting to adverse health effects in humans and animals upon consumption (Adeyemi and Zacchaeus., 2021; Nitasha and Sanjiv., 2015; Naseem *et al.*, 2021).

The establishment of various industries in Osogbo, Osun State, Nigeria has been loading the environment with increasing levels of various contaminants such as heavy metals and anions, thereby, impacting the soil and water ecosystems as well as degrading groundwater quality (Odebunmi *et al.*, 2014). The elevation in the trace metal contents of an aquatic system may arise from daily human activities, various degrees of geochemical reactions occurring in the sub-surface of the earth, runoff addition, aerial deposition and percolation-related phenomena (Ibe and Duruiké., 2005). Two of

the major problems that are contended with in Nigeria are the insufficient quantity and poor quality of surface and ground water which are major challenges affecting all its physiochemical properties and these are confronting most of the metropolitan cities in the country (Oluyemi *et al.*, 2010; Adeniyi., 2004).

MATERIALS AND METHODS

Study area

Osun River is located in southwestern Nigeria and is one of the key characteristics of the topography of the state (7.5629°N, 4.5200°E). The river primarily flows through Osun and Oyo states. Osun River originates from Igede-Ekiti (in Ekiti State) and flows southwards through into the Lagos lagoon and the Atlantic Gulf of Guinea. The study areas covered the pre-urban and urban parts of the river. The sampling locations in this study have peculiar characteristics. Osun-jela is situated beside a bridge dividing Owode town with population of 83,831 (2006 census) from Osun-jela community (a rural settlement). It is about 25m from Osogbo-Ilesa road. Oke-ijetu (urban settlement) is beside a bridge along Oke-ijetu road about 1km from Fountain University (Figure 1). Aregbe is metropolitan and is densely populated and experiences a lot of anthropogenic activities that generate both domestic and industrial wastes (Anifowose and Oyebode., 2019).

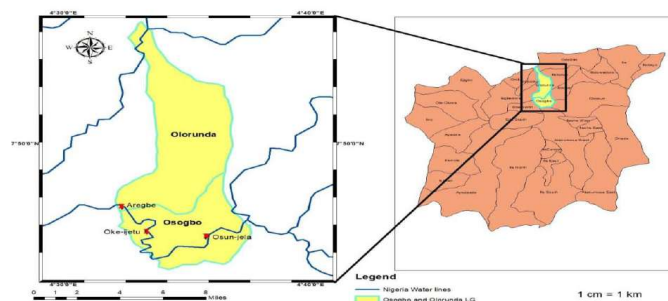


Figure 1: Map showing the study areas in Osogbo town, Osun state, Nigeria

Sample Collection

Water samples were collected from Osun River and groundwater from wells at Osunjela (7.739645°N 4.597762°E, 7.738606°N 4.596087°E and 7.737615°N 4.595897°E), Oke-ijetu (7.742508°N 4.556423°E, 7.743365°N 4.555888°E and 7.744362°N 4.555222°E) and Aregbe (7.767707°N 4.539669°E, 7.768203°N 4.539238°E and 7.768703°N 4.539010°E). The samples were separately collected four months (March- June, 2024) from upstream, midstream and downstream at specific points. Water samples were handled and transported carefully to avoid contamination or changes in metal concentrations and taken directly to laboratory prior analysis. Water samples were analyzed on site for pH, turbidity and dissolved oxygen using hand held meters respectively. Water samples were exposed to the Atomic Absorption Spectrophotometer laboratory (AAS), (APHA, 2005; Olabanji and Oluyemi, 2011; Ademoroti, 1996].

Determination of Physicochemical Parameters

The pH, temperature, turbidity, electrical conductivity, total dissolved solids, salinity and Dissolved oxygen were measured on site and recorded in the study area while Biological Oxygen Demand and Chemical Oxygen demand were measured at the ASS laboratory of the Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. Chemical Oxygen Demand was determined calorimetrically by oxidizing heptaoxochromate (VI) which produces green chromic compound (Cr^{3+}). The absorbance of the green color varied with the intensity of the color (Ademoroti, 1996).

Data Analysis

Data analysis of values obtained from heavy metal determination in water samples were

processed and interpreting using descriptive statistics.

RESULTS AND DISCUSSION

The comparative physicochemical characteristics of surface and ground water qualities in Osogbo town, Osun State, Nigeria showed the seasonal variation in cation concentrations in Osun River and well systems with the international standards. The pH of the surface water (Osun River) across Osunjela, Oke-ijetu and Aregbe at both the upstream, midstream and downstream were between 5.0 ± 0.0 and 6.0 ± 0.0 except for Aregbe downstream with $\text{mn} \pm \text{s.d}$ of 4.0 ± 1.0 in dry season while in wet season, the pH ($\text{mn} \pm \text{s.d}$) were between 4.5 ± 1.0 and 8.0 ± 0.0 respectively. The ground water pH values fluctuated between 3.50 ± 0.50 and 6.50 ± 0.50 in dry season but in wet season, the pH was between 6.0 ± 0.0 and 7.0 ± 0.0 . The pH of surface water and groundwater systems were slightly below 6.5-9.5 according to WHO (2011) and EU (2020) limits in the dry season except for the wells at Oke-ijetu. In the wet season, the wells in Oke-ijetu and Aregbe had pH values within the acceptable limits of WHO (2011) and EU (2020) (Figure 1a, 1b, 2a and 2b). Oluyemi *et al.* (2010) in his study in Ife-North Local Government of Osun, State, Nigeria, obtained pH values between 6.53-8.90; that are within the acceptable limits of WHO (2011) and EU (2020) for surface water. In another study, Adewoyin *et al.* (2013) obtained a pH range of 5.63-7.33 for groundwater systems in Ibadan, Nigeria.

The total dissolved solids (TDS) of the surface water across the upstream, midstream and downstream for dry season were 27.80 ± 21.60 - 82.65 ± 6.55 ppm and 27.85 ± 1.05 - 111.05 ± 18.65 ppm for the wet season. However, Total dissolved solids in groundwater conformed with international standards for both dry and wet seasons. Oluyemi *et al.* (2010) showed that total

dissolved solids (TDS) of surface water was between 37.80-622.50mg/l falling within the limits of WHO (2011) and EU (2020) in Ife-North Local Government of Osun, State, Nigeria. Adewoyin *et al.* (2013) showed that total dissolved solids (TDS) of groundwater obtained from Ibadan, Nigeria was between 135-248mg/l, which was within the limits of WHO (2011) and EU (2020) for groundwater.

The Salinity values varied at the downstream, midstream and upstream levels for dry and wet seasons of the surface water, ranging from 48.55 ± 32.05 - 78.65 ± 1.95 ppm and 53.6 ± 1.3 - 78.55 ± 15.95 ppm respectively. The salinity of the groundwater in dry season (18.65 ± 1.15 - 75.55 ± 23.75 ppm) was higher than that of the wet season (21.8 ± 0.5 - 45.05 ± 20.15 ppm). Oluyemi *et al.* (2010) showed that salinity of surface water was variable, ranging 300-700mg/l which were not recommended by WHO (2011) and EU (2020) limits in Ife-North Local Government of Osun, State, Nigeria. Conversely, Adewoyin *et al.* (2013) showed that salinity of groundwater system in some Ibadan town ranged between 18-133mg/l value above the recommended WHO (2011) and EU (2020) limits in Ibadan, Nigeria.

The conductivity of both the surface and ground water at the two LGAs across all conformed with the WHO (2011) and EU (2020) standards. Oluyemi *et al.* (2010) showed that conductivity was between 63-1039 μ S/cm which was within the limits of WHO (2011) and EU (2020) for surface water in Ife-North Local Government of Osun, State, Nigeria. Adewoyin *et al.* (2013) showed that conductivity was between 187-268 μ S/cm which was within the limits of WHO (2011) and EU (2020) for groundwater in Ibadan, Nigeria.

The dissolved Oxygen of surface and groundwater across the two LGAs is less than or equal to 0.72 ± 0.57 mg/l in the dry season,

and 1.10 ± 1.09 mg/l in the wet season. Oluyemi *et al.* (2010) showed that Dissolved Oxygen of surface water was between 4.48-9.48mg/l which was not recommended by WHO (2011) and EU (2020) limits, Ife-North Local Government of Osun, State, Nigeria. Adewoyin *et al.* (2013) showed that Dissolved Oxygen of groundwater was between 0.25-8.64mg/l which within WHO (2011) and EU (2020) limits, Ibadan, Nigeria.

Temperature of ground surface water varied between the seasons sampled; ranging between $30.5 \pm 0.9^{\circ}\text{C}$ and $30.7 \pm 0.9^{\circ}\text{C}$ which differs from the values obtained during the wet season ($28.4 \pm 2.1^{\circ}\text{C}$ - $30.35 \pm 0.25^{\circ}\text{C}$). The mn $\pm$ s.d of temperature of the surface water were within range of 26.85 ± 1.85 - $31.55 \pm 0.65^{\circ}\text{C}$ which were also above WHO (2011) and EU (2020) limits due to the increase in anthropogenic activities. Oluyemi *et al.* (2010) showed that temperature of surface water was between 26.5 - 33.0°C which were beyond WHO (2011) and EU (2020) limits, Ife-North Local Government of Osun, State, Nigeria. Adewoyin *et al.* (2013) showed that temperature of groundwater 23 - 29°C which were also beyond WHO (2011) and EU (2020) limit

The biological Oxygen demand (BOD) values (mn $\pm$ s.d) (mg/l) observed across the surface and ground water were below the WHO (2011) limit. However, the (BOD) values for groundwater systems were lower compared to that of surface water system in dry and wet seasons. Oluyemi *et al.* (2010) showed that (BOD) of surface water was between 0.69-6.74mg/l which was within WHO (2011) and EU (2020) limits, Ife-North Local Government of Osun, State, Nigeria. Adewoyin *et al.* (2013) showed that (BOD) of groundwater was between 0-52.19mg/l which was also within WHO (2011) and EU (2020) limits. Figure 1a, 1b, 2a and 2b

showed that turbidity (NTU) of surface water in both dry and wet seasons in Osunjela were less than in that in Oke-ijetu and Aregbe while, turbidity values of well water was extreme. Data showed that both the groundwater and surface water exhibited extreme turbidity (NTU) above the international limit (WHO, 2011). This results differ from Adewoyin *et al.* (2013) who showed that turbidity of groundwater was between 2-32.75 NTU within and beyond WHO (2011) limits.

The Chemical Oxygen demand (COD) of surface and ground water from the two LGAs were generally high at the two seasons and were above the international standards (WHO, 2011) however, at the Osunjela, Oke-

ijetu and Aregbe study sites where groundwater COD ranged between in (6.85 ± 0.62 - 8.56 ± 0.78 mg/l). It is pertinent to mention that low (COD) 8.56 ± 0.78 mg/l) was also observed in Oke-ijetu downstream. However, Adewoyin *et al.* (2013) study showed that (COD) of groundwater was between beyond WHO (2011) and EU (2020) limits, Ibadan, Nigeria.

The physicochemical parameters of the surface and ground water were found to be either beyond or within WHO (2011) and EU (2020) limits due to the increase in anthropogenic activities around the three respective study areas (Osunjela, Oke-ijetu and Aregbe) (Figure 1a, 1b, 2a and 2b).

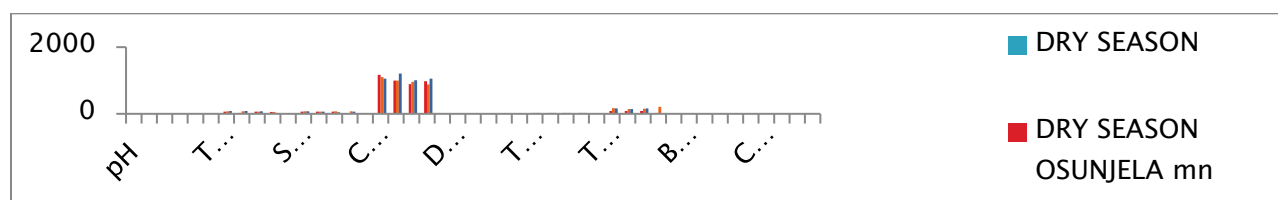


Figure 2a: Comparative seasonal physicochemical properties of cations (heavy metals) in Osun River (surface water) transversing Osogbo and Olorunda LGAs in dry season

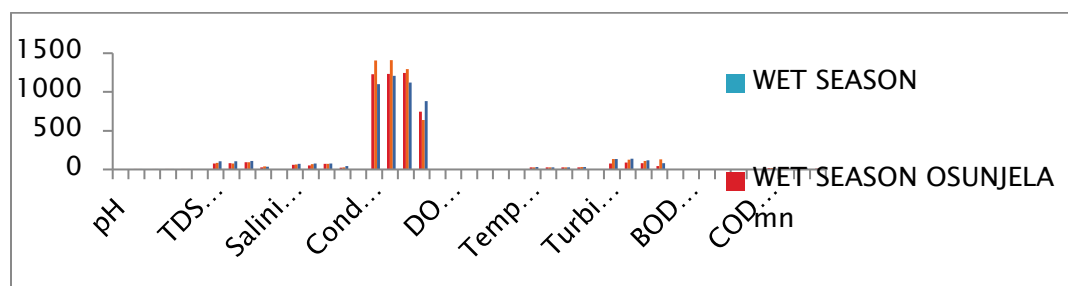
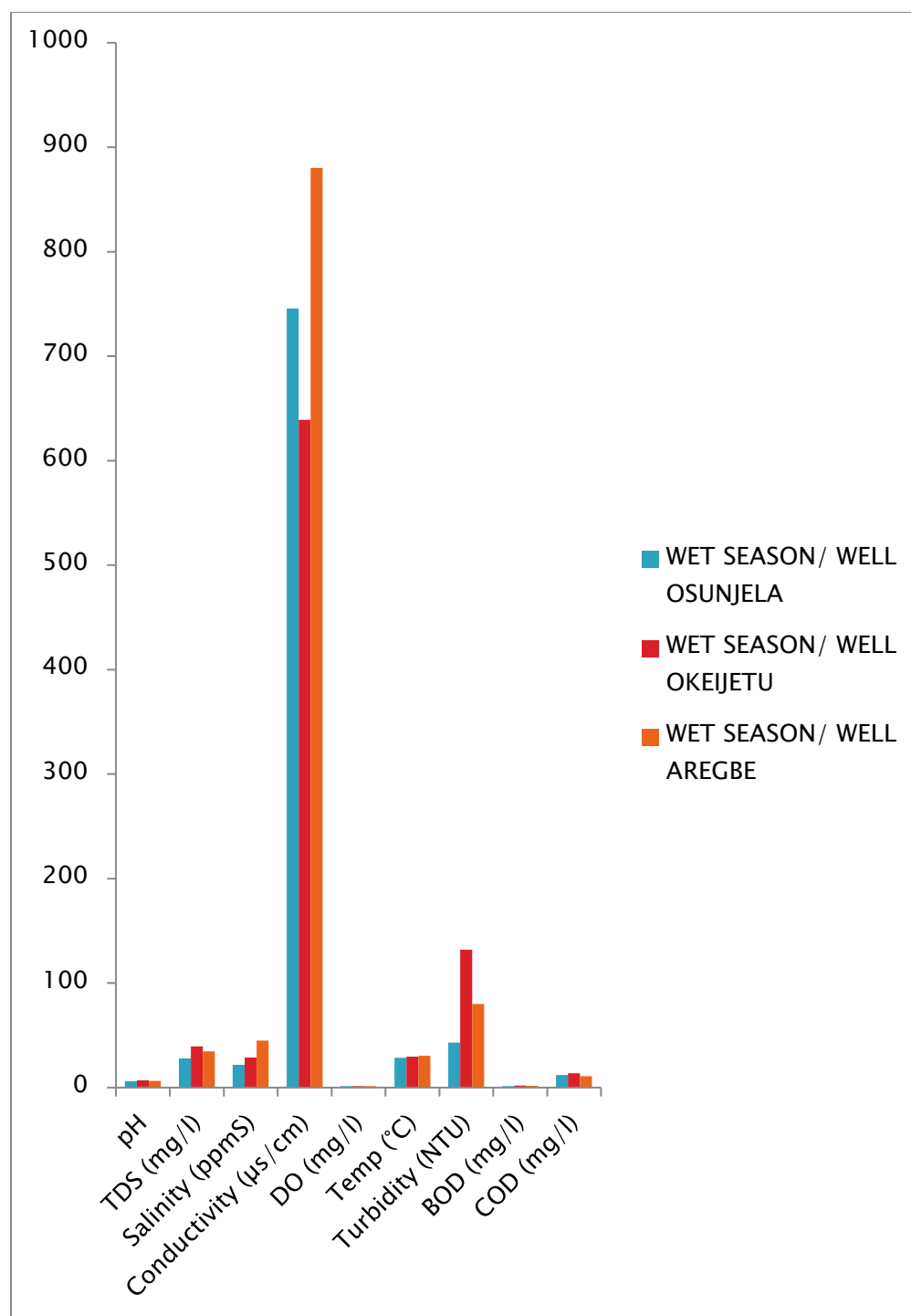


Figure 2b: Comparative seasonal physicochemical properties of cations (heavy metals) in Osun River (surface water) transversing Osogbo and Olorunda LGAs in wet season

**a**

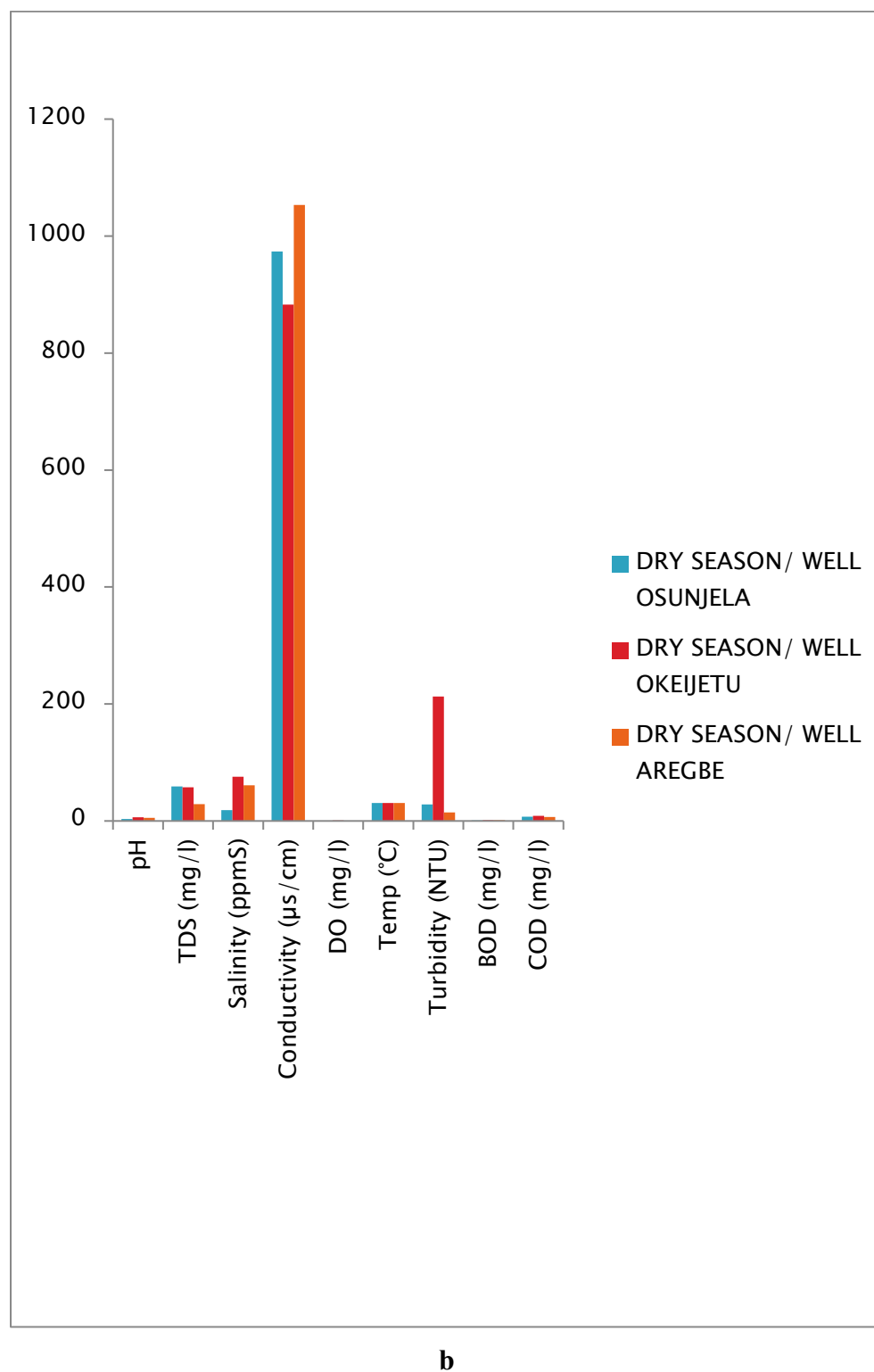


Figure 3: Comparative seasonal physicochemical properties of its Osun selected wells across Osun River transversing Osogbo and Olorunda LGAs

CONCLUSION

The quality evaluation of water sources (surface and groundwater) in Osogbo town, Osun State, Nigeria revealed that the pH, total dissolved solids, Conductivity, Biological Oxygen Demand and Chemical Oxygen Demand varied but still fell within international standards (WHO, 2011; EU, 2020) in dry and wet seasons. Few exceptions were observed in Temperature, Turbidity and Dissolved Oxygen, which were above international standards in dry and wet seasons. This study showed that surface and ground water systems assessed were contaminated with substances in dry and wet seasons which portend health risks to consumers in the study area. The study predicts the potentials for more elaborate usage of these portable water sources if they are properly treated to reduce the concentrations of substances in them in the study areas.

CONFLICT OF INTEREST

There is no conflict of interest amongst the authors for this paper to be published.

RECOMMENDATION

There is a need for appropriate treatment of surface and groundwater systems before consumption by residents in the study area. Also, there is a need to regulate the activities of miners and residents that contribute to the contamination and pollution of these sources of portable water to forestall public health disasters in the study area.

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EFFECTS OF MACA ROOT POWDER AS ADDITIVE ON THE WATER QUALITY PARAMETERS OF *Clarias gariepinus* REARED IN PLASTIC TANKS

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ABSTRACT

Effects of Maca root powder as additive on the water quality parameters of *Clarias gariepinus* reared in plastic tanks was elucidated five (5) isonitrogenous (40% crude protein) diet was formulated, where Maca root powder in form of additive was incorporated at 0.0g/100g (tm₀), 0.25g/100g (tm₁), 0.5g/100g (tm₂), 0.75g/100g (tm₃) and 1.0g/100g (tm₄) inclusion levels, diet without Maca root powder (tm₀), served as the control diet. formulated diet was fed to *C. gariepinus* fingerlings (n = 300, 10.0±0.00g) in fifteen (15) plastic tanks (n = 20) at a fixed feeding rate of 3% body weight twice daily between the hours of 8:00 - 9:00am and 4:00 - 5:00pm at regular interval and adjusted after every two (2) weeks of sampling for a period of twelve (12) weeks. water temperature, pH, dissolved oxygen, and ammonia were measured at the beginning of the experiment after which they were measured weekly throughout the period of the experiment. Data obtained were analysed using one - way analysis of variance (ANOVA) at P = 0.05. Water temperature values range from; 27.79 – 27.90°C, pH (7.72 – 7.80), dissolved oxygen (5.56 – 5.65 mg/L) and ammonia (0.03 – 0.04 mg/L) respectively. Findings from this study indicated that Maca root powder at 0.0g/100g (TM₀), 0.25g/100g (TM₁), 0.5g/100g (TM₂), 0.75g/100g (TM₃) and 1.0g/100g feed (TM₄) inclusion levels into the diet of *C. gariepinus* does not have any significant effects on the water quality parameters as elucidated in this study.

Keywords: Ammonia, Dissolved Oxygen, Feeding Trial, Temperature, Meca Root Powder.

INTRODUCTION

Feeding trial are mostly carried out in regulated environments to avoid any environmental interference which could include; natural food organisms, temperature and other water quality parameters with the variable being studied (Ali, 2022). Feeding trial is mostly conducted in tanks placed indoor or outdoor for easy and reliable data collection (Salisu *et al.*, 2024)). Considerable attention is received in recent years particularly in Nigeria on the effects of water quality on feeding fish in intensive system (Ali, 2022). Temperature, pH, dissolved oxygen and ammonia are the key water

quality parameters which affects all life the phases of fish (Babale, 2016). Temperature is a basic parameter in all aquatic environments. It is the main regulator of nearly all physio-chemical cycles and consequently of metabolism and fish pond productivity, tropical fish require water with a temperature range of 25 – 32°C to grow and reproduce (Ali, 2022). pH is a measure of acidity or alkalinity of water, water with a pH less than 7 is acidic, above 7 is alkaline while 7 is neutral, water with a pH value of about 6.5 – 9 is the best for fish culture (Elezu, 2016). The dissolved oxygen content of the pond water is one of the most critical factors in fish culture (Babale, 2016). Fish require adequate

dissolved oxygen in the water. 5 – 6ppm (mg/L) of oxygen is considered to be an absolute minimum requirement for fish (Elezu, 2016). Ammonia is a nitrogenous waste produced by either the pond organisms (including fish) or decomposition of organic matter (Babale, 2016). For catfish culture, unionized ammonia level in ponds should be maintained at less than 0.05 ppm (Elezu, 2016). Both water quality and quantity have the potential to significantly affect fish metabolism, survival and growth (Ekundayo *et al.*, 2014; Babale, 2016). It is therefore pertinent to ensure good water quality for optimum fish growth, survival and yield. It is always needful to change 40 – 50% of the water in the culture receptacle bi - weekly; this is because fresh water replenishes trace minerals that are used up in the tanks by fish, flora and fauna (Ali, 2022). This study elucidates effects of maca root powder as additive on the water quality parameters of *C. gariepinus* reared in plastic tanks was evaluated.

MATERIALS AND METHODS

Study Area

The research was conducted at the Lay – Joy Fish Farm, Gombe – Yola road, Billiri local government area (LGA), Gombe State Nigeria. Billiri LGA lies within Lat. 9°50'N; 11°09'E and Long. 9.833°N 11.150°E. It covers an area of 737km² (285 sq. m) and is 50 km away from Gombe the State capital.

Experimental Fish

Three hundred (300) *C. gariepinus* fingerlings with mean initial weight (10.0±0.00g) were stocked at twenty (20) fingerlings per tank in triplicates per treatment after one (1) week of acclimatization, the study lasted for a duration of twelve (12) weeks.

Experimental Diets

The experimental diets contained fish meal (FM), soybean meal (SBM), yellow maize meal (YMM), groundnut cake meal (GNCM) and Maca root powder. All the ingredients were grounded into a fine powder using a hammer mill and sieved by a 0.25 mm sieve. Fish meal, soybean meal, groundnut cake meal and yellow maize meal were obtained from commercial suppliers in Gombe, the vitamin/mineral premix, fish oil and chromic oxide (Cr₂O₃) were purchased from TTS Integrated Farms Nigeria Limited, Agege - Lagos, while the Maca root powder naturally derived from dry Maca (*Lepidium meyenii*) root was obtained from BonAmour Pharmacy Limited Lagos, Nigeria, imported from Piping Rock Health Products, Ronkonkoma, New - York, USA. Five (5) isonitrogenous and isocaloric diets were prepared, each diet with crude protein (CP) content at 40% CP as calculated according to Pearson's square method and gross energy content at 1,732kcal kg⁻¹ respectively for the feeding the experimental *C. gariepinus* as recommended by Ali (2022) was prepared, where the Maca root powder in form of feed additive was incorporated into the diets at 0.0g/100g (TM₀), 0.25g/100g (TM₁), 0.5g/100g (TM₂), 0.75g/100g (TM₃) and 1.0g/100g (TM₄) inclusion levels, diet without Maca root powder (TM₀), served as the control diet. (Table 1).

Experimental Design

The *C. gariepinus* fingerlings were cultured in fifteen (15) rectangular white plastic tanks (flow - through system) with a water holding capacity of one thousand litres (1,000L) each in a complete randomized design (CRD). Each tank was washed thoroughly with salt, filled to just a little over 1/3 (350 litre) capacity and stocked with twenty (20) fingerlings of *C. gariepinus* with mean initial weight (10.0±0.00g). The *C. gariepinus* fingerlings were fed the experimental diet at

3% body weight two (2) times daily between the hours of 8:00 – 9:00am and 4:00 – 5:00pm for a period of twelve (12) weeks. The quantity of feed was adjusted accordingly after every two (2) weeks of sampling for growth performance and survival rate (mean body weight and mortality). Water temperature, pH, dissolved oxygen, and ammonia were measured at the beginning of the experiment after which they were measured weekly throughout the period of the experiment. Water temperature, dissolved oxygen and pH were measured using Horiba U-22 XD multi - parameter

water quality checker while ammonia was measured using freshwater aquaculture test kit (Model AQ-2, Code 3633-03, Lamotte U. S. A.

Statistical Analysis

The data obtained were subjected to one - way analysis of variance (ANOVA) using the GraphPad instant package for windows 2010 of statistical analysis system (SAS, 2010). Mean separation was done (at $P = 0.05$) using Fisher's least significance difference (LSD) to separate the means in cases of significant difference.

Table 1: Ingredient Percentage Composition (g/100g) of Experimental Diets with Different Levels of Maca Root Powder as Additive

Ingredients (%)	TM ₀	TM ₁	TM ₂	TM ₃	TM ₄
Fish meal	20.00	20.00	20.00	20.00	20.00
Soybean meal	21.50	21.25	21.00	21.00	21.00
Groundnut cake meal	23.00	23.00	23.00	23.00	23.00
Yellow maize	30.00	30.00	30.00	29.75	29.50
Maca root powder	0.00	0.25	0.50	0.75	1.00
Fish Oil	1.00	1.00	1.00	1.00	1.00
Vegetable oil	1.00	1.00	1.00	1.00	1.00
Starch	1.00	1.00	1.00	1.00	1.00
Lysine	0.25	0.25	0.25	0.25	0.25
Methionine	0.25	0.25	0.25	0.25	0.25
*Vitamin/premix	1.00	1.00	1.00	1.00	1.00
Salt	0.50	0.50	0.50	0.50	0.50
Cr ₂ O ₃	0.50	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00

Keys: TM₀ - Maca root powder (0.0g/100g), TM₁ - Maca root powder (0.25g/100g), TM₂ - Maca root powder (0.5g/100g), TM₃ - Maca root powder (0.75g/100g), TM₄ - Maca root powder (1.0g/100g).

RESULTS

The results of the effects of maca root powder as additive on the water quality parameters of *C. gariepinus* reared in plastic tanks is presented in Table 2. Initial water

temperature value was 27.76°C. This increased in all the diets with Maca root powder and the control diet (TM₀) final values at the end of the 12 week's period of the study to a narrow range of 27.79°C – 27.90°C. There were no significant

differences ($p>0.05$) in the mean water temperature values of the experimental tanks during the feeding trial. Initial water pH value was 7.51. This increased only in the control diet (TM^0) and decreased in all the diets with Maca root powder final values to a narrow range of 7.72 – 7.80. There were no significant differences ($p>0.05$) in the mean water pH values of the experimental tanks during the feeding trial. Initial dissolved oxygen value was 5.67 mg/L. This decreased in all the diets with Maca root powder and the control diet (TM^0) final values to a narrow

range of 5.56 – 5.65 mg/L. There were no significant differences ($p>0.05$) in the mean water dissolved oxygen values of the experimental tanks during the feeding trial. Initial ammonia value was 0.02 mg/L. This increased in all the diets with Maca root powder and the control diet (TM^0) final values to a narrow range of 0.03 – 0.04 mg/L. There were no significant differences ($p>0.05$) in the mean water ammonia values of the experimental tanks during the feeding trial.

Table 2: Effects of Maca Root Powder as Additive on the Water Quality Parameters of *C. gariepinus* Reared in Plastic Tanks

Parameters	Initial	TM_0	TM_1	TM_2	TM_3	TM_4
Temperature ($^{\circ}C$)	27.76 ^a	27.79 ^a	27.83 ^a	27.86 ^a	27.89 ^a	27.90 ^a
pH	7.51 ^c	7.80 ^c	7.77 ^c	7.79 ^c	7.75 ^c	7.72 ^c
Dissolved oxygen (mg/L)	5.67 ^b	5.65 ^b	5.63 ^b	5.61 ^b	5.59 ^b	5.56 ^b
Ammonia (mg/L)	0.02 ^d	0.03 ^d	0.03 ^d	0.03 ^d	0.04 ^d	0.04 ^d

All Means values are not significantly different ($p>0.05$).

Keys: TM_0 - Maca root powder (0.0g/100g), TM_1 - Maca root powder (0.25g/100g), TM_2 - Maca root powder (0.5g/100g), TM_3 - Maca root powder (0.75g/100g), TM_4 - Maca root powder (1.0g/100g).

DISCUSSION

The water temperature values, 27.79 – 27.90 $^{\circ}C$ recorded from this study were comparable with the values, 27.78 – 27.88 $^{\circ}C$ reported by Ali (2022) for *C. gariepinus* reared in plastic tanks. All the water temperature values recorded from this study were within the acceptable recommended range. The water pH values, 7.72 – 7.80 recorded from this study were comparable with the values, 7.22 – 7.8 reported by Salisu *et al.* (2024) for *C. gariepinus* reared in rectangular plastic tanks. All the water pH values recorded from this study were within

the acceptable recommended range. The dissolved oxygen (DO) values, 5.56 – 5.65 mg/L recorded from this study were comparable with the values, 4.80 – 6.0 mg/L reported by Ogundele *et al.* (2014) for *C. gariepinus* reared in aquaria tanks. All the DO values recorded from this study were within the acceptable recommended range. The ammonia (NH_3) values, 0.03 – 0.05 mg/L recorded from this study were comparable with the values, 0.03 – 0.05 mg/L reported by Fakunle *et al.* (2014) for *C. gariepinus* fingerlings reared in plastic tanks. All the NH_3 values recorded from this study were within the acceptable recommended range.

The good water quality parameters recorded at the end of the 12 weeks' period of the study from all the diets with Maca root powder and the control diet (TM⁰) indicated that the inclusion of different levels of Maca root powder as additive used in this study does not have any negative effects on the water quality parameters.

CONCLUSION

Maca root powder at 0.0g/100g (TM₀), 0.25g/100g (TM₁), 0.5g/100g (TM₂), 0.75g/100g (TM₃) and 1.0g/100g feed (TM₄) inclusion levels into the diet of *C. gariepinus* does not have any significant effects on the water quality parameters of the culture tanks as observed in this study.

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STRATEGIES FOR ADAPTATION AND MITIGATION OF CLIMATE CHANGE EFFECTS IN NIGERIA: A REVIEW

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ABSTRACT

The world's ecosystems and societies may suffer greatly as a result of human-induced climate change. It is brought on by the release of greenhouse gases, which affect various alterations in the climate system and trap long wave radiation in the upper atmosphere, raising atmospheric temperatures. There is mounting evidence that forest ecosystems are already being impacted by climate change. Changes in growth rates, increased impacts on forest health, and death are linked to recent climate anomalies. The possibility of creating synergy between adaptation and mitigation of climate change has recently drawn attention from climate science and policy in order to reduce this threat by implementing feasible solutions.

Keyword: Climate Change, Adaptation, Mitigation, Sustainability, Synergy

INTRODUCTION

Climate change is the result of rising greenhouse gas emissions into the atmosphere due to anthropogenic activity worldwide [Elum and Momodu, 2017]. Around the planet, numerous physical and biological changes have been brought about by climate change. Human safety is at risk, the food supply is impacted, and the environment is deteriorated. Africa's developing nations are particularly susceptible to climate change and are ill-equipped to increase their resistance and adjust to it. According to empirical research, Nigeria is already dealing with environmental issues brought on by the effects of climate change [Okon *et al.*, 2021]. Nigeria is among the top ten nations most exposed to the effects of climate change, with about 6% of its land mass at risk from extreme weather events. [Okon *et al.*, 2021, World Bank Report, 2019].

Unexpected changes in temperature and precipitation, as well as extreme weather, are consequences of climate change. Perennial flooding, population and settlement

displacement, and food insecurity have all resulted from these changes [Ojo and Baiyegunhi, 2019]; increasing drought and desertification in Nigeria's various climatic zones [Shiru *et al.*, 2019]; shoreline erosion along coastal areas and changes in water temperature [Anyanwu *et al.*, 2021]; alteration of water bodies [Anyanwu and Nwajiuba 2021]; and a rise in gender inequality and intra-gender disparities, particularly among women [Jellason *et al.*, 2019]. A rise in intercommunal disputes and violence has also been linked by some to these socioeconomic effects [Ojo *et al.*, 2022]. Climate change poses a greater threat to impoverished and rural areas [Anyanwu and Nwajiuba, 2021]. This is due to the fact that subsistence farming is the main activity in rural communities. Furthermore, those places are more vulnerable to natural disasters and environmental deterioration because to the substandard living circumstances. Harvests have also been attributed to climate change, which has made rural populations more impoverished [Abraham and Fonta, and McBean, 2018]. About 30 hectares of cropland are lost to desertification per year in

Nigeria's Sahel area alone [World Bank Report, 2019]. The impoverished are particularly vulnerable to climate change, and they may oppose certain climate change mitigation measures if they jeopardize their financial security [Ajibade, 2014]. For instance, poor environmental conditions and climate fluctuation (temperature increases) are linked to an increase in the prevalence of diarrhea, measles, and malaria. [Oloukoi *et al.*, 2014]. In order to develop effective mitigation and adaptation strategies, it is necessary to understand the factors that contribute to climate change. A significant portion of research on climate change in Nigeria seems to concentrate on assessing the sensitivity of various bio-geophysical system attributes, with little attention paid to socio-economic issues. This has resulted in an isolated assessment of the impacts of climate change, presenting a lack of knowledge about the how and what of the current coping (mitigating and adaptation) strategies [World Bank Report, 2019].

SOURCES OF EMISSIONS FROM ANTROPOGENIC ACTIVITIES

According to a 2020 estimate, the total GHG emissions from Nigerian agriculture were approximately 322,000 kt CO₂-eq [World Bank Report, 2019]. Livestock accounts for 69.2% of GHG emissions in Nigeria's agricultural sector. In comparison to 2010 levels, GHG emissions are expected to rise by 94% in 2050 (67.7 Mt CO₂-eq) [Dioha and Kumar 2020]. Nigeria imports over NGN 3.35 trillion worth of food between 2016 and 2019, while exporting only NGN 803 billion during the same time period, despite having a vast quantity of arable area for crop cultivation. This demonstrates that Nigeria imports four times as much agricultural product as it exports [PwC and AfCFTA, 2020]. Even though there are a number of reasons for the drop in agricultural output,

climate change is a major one. Weather variations brought on by climate change could further reduce the nation's agricultural output, increasing imports and creating negative trade balances. In Nigeria, numerous studies on climate change adaptation and/or mitigation have been carried out.

A systematic review of the effects of climate change in Nigeria was carried out by Okon *et al.* in 2021. The agriculture sector appears to be the subject of many studies on adaptation in Nigeria. For instance, a systematic evaluation of climate change adaptation in Nigeria's agriculture sector was carried out by Onyeneke *et al.* in 2019. Similar research was done on a variety of agricultural adaptation skills by Ojo *et al.* (2022), Jellason *et al.* (2019), Ojo *et al.* (2022), Tarfa *et al.* (2019), and Ogunleye *et al.* (2021). Finding research gaps and suggesting directions for future studies are crucial. Furthermore, the ability of different industries to mitigate climate change has been the subject of numerous studies. Elum and Momodu (2017), Dioha *et al.*, (2020) Abiodun *et al.*, (2012), Adeoti *et al.*, (2014) Okoroh *et al.*, (2016) Chenge *et al.*, (2018) and Arimi *et al.*, (2014) worked on agricultural potential for Climate Change mitigation, while Ukoba *et al.*, (2020), Enongene *et al.*, [2019], Elum *et al.*, (2017) and Giwa *et al.*, (2017) investigated Nigeria's potential for mitigating climate change through renewable energy. Etermire (2021) concentrated on how important legal tools are for implementing mitigations. In order to facilitate evidence-based decision-making or policymaking, these included studies synthesized findings to present a wide range of tools for climate change mitigation in Nigeria. Furthermore, primary and/or secondary research methodologies were used in the included studies (for adaptation and/or mitigation). An increase in poverty, food insecurity, and ecological calamities is

unavoidable given the population's exponential growth and the limited resources available to support it. Therefore, in order to provide resilient and strong strategies to the impacts of climate change, it is necessary to reexamine the current mitigation, adaptation, and coping mechanisms.

Addressing Climate Change Impacts

The two main components of climate change impacts are adaptation/coping and mitigation/response. While adaptation strategies reduce exposure or susceptibility or minimize the risk of climate change impacts to a manageable level, mitigation measures try to reduce or cut GHG emissions. The UNFCCC [2008] divided the mitigation sectors into seven categories: garbage, industry, forestry, agriculture, transportation, buildings, and energy supply. Structural/physical measures (engineering and built environment, technological options, eco-system-based adaptation and service options), social measures, and institutional measures are the three categories into which the International Panel on Climate Change (IPCC) divided adaptation strategies [Noble et al., 2014]. Adaptation is sometimes associated with coping mechanisms. Climate Change Adaptation Strategy was the subject of many more studies than Climate Change Mitigation Strategy. This aligns with Nwobodo *et al.*, 2022 and Ikehi *et al.*, 2022. Only 10% of climate change initiatives are mitigation, whereas 90% are adaptation [Adeoti et al., 2014]. On the other hand, 60% of Nigeria's climate change financial allocations went toward mitigation projects over a seven-year period (2013–2020), while 40% went toward adaptation measures. This shows that mitigation initiatives are preferred over adaptation programs by the Federal Government of Nigeria (FGN). In contrast, the government is allocating a larger portion of its funding to mitigation initiatives and a

smaller portion to adaptation initiatives [Onyimadu and Uche, 2021]. Government initiatives and recognized research publications have different areas of focus. The government's commitment to the IPCC's target of keeping the rise in global temperatures below 1.5 °C by 2030 is demonstrated by its significant budgetary action or focus on climate change mitigation.

The matter of strategy is another. The increased emphasis on climate change in research papers on adaptation strategy may have to do with funding for research or determining the population's basic capacity for survival. People must pay more for mitigation measures such as energy efficiency, solar-powered street lighting, carbon taxes, and the adoption of renewable energy [Elum and Momodu 2017; Dioha and Kumar 2020]. Another element that supports the government's preference for mitigation over adaptation initiatives is political tenure. The effects of climate change frequently become apparent later on. Therefore, long-term remedial actions are necessary for adaptation programs. Programs for adaptation are long-term and might not work while a person is in office. Additionally, such initiatives might fail because of the policies' irregularities and lack of continuity. For instance, mitigation initiatives that are immediate and unmistakably significant are more prevalent among the constituency projects of federal parliamentarians. As a result, governments frequently concentrate on short-term measures, such as mitigation initiatives. Thus, a scientifically and empirically supported balance between adaptation and mitigation initiatives is required. This is because, according to Zickfeld et al. [2013], it would take thousands of years for atmospheric temperatures to return to pre-industrial levels if global emissions were to abruptly stop.

CLIMATE CHANGE MITIGATION MEASURE

Agriculture and Forestry

One strategy to lessen the effects of climate change in the agriculture industry is climate-smart agriculture (CSA). Methane (CH₄) emissions from livestock are significant [Dioha, 2020]. Higher concentrate feeding, lower manure storage temperatures (which lower methane and nitrous oxide emissions), and tree planting are other agricultural mitigation strategies. [Nwobodo *et al.*, 2022] The conversion of agricultural areas to agroforestry management will be a tactic to reduce climate change, as evidenced by the carbon sequestration capability of agro-practices like agroforestry [Adeshina *et al.*, 1999; Arimi and Omoare 2021]. In a forest in southwest Nigeria, the average tree aboveground biomass (TAGB) density is approximately 402.5 trees ha⁻¹. According to Chenge and Osho (2018), the carbon conversion fraction, also known as tree aboveground carbon (TAGC), is 52.3% of TAGB.

According to climate modeling, zonal afforestation will reduce warming in Nigeria's Savannah and Sahel regions by 0.5 °C. Warming will rise by 1 °C in Guinea, 1.5 °C in the Savannah, and 2 °C in the Sahel without afforestation [Abiodun *et al.*, 2012]. By 2030, agroforestry on 39.5 million hectares of Nigerian arable land will sequester around 1530 million tons of carbon [Adeshina *et al.*, 1999]. Howden *et al.* (2007) state that adaptation strategies in agriculture include the following:

Modifying inputs, species, and varieties to increase resistance to drought, flooding, and salinization; Modifying fertilizer rates to preserve grain or fruit quality; Modifying irrigation amounts and timing and other water management; Modifying cropping activities' timing or location.

Managing river basins to improve irrigation service delivery efficiency and avoid water logging, erosion, and nutrient leaching; expanding the use of technologies to "harvest" water and preserve soil moisture; and more efficiently using and transporting water.

Increasing revenue diversity by incorporating pursuits like fish farming in rice paddies, animal rearing, etc.

Enhancing quarantine capabilities and monitoring programs; expanding the use of integrated pest and pathogen management; and creating and utilizing pest and disease-resistant species and types.

Using climate forecasts more often to lower production risk.

Adjusting pasture rotation, changing grazing schedules, changing animal species and breeds, integrating livestock and agricultural systems, including the use of adapted fodder crops, reevaluating fertilizer inputs, and matching livestock stocking rates with pasture productivity and the use of supplementary feeds and concentrates

Changing forest management practices, such as the mix of hardwood and softwood species, timber growth and harvesting patterns, and rotation periods; switching to species or regions that are more productive in new climates; designing landscapes to minimize damage from fire and insects; modifying fire management systems; starting prescribed burning, which lowers the forest's susceptibility to more frequent insect outbreaks as a non-chemical insect control method; and modifying harvesting schedules.

Introducing agroforestry, forest conservation, and forest-based businesses to diversify rural revenue streams.

Reducing fishing to maintain fish stock yields; enhancing the environment where

breeding takes place; and modifying catch size and effort.

Waste Management

The circular economy, which includes Recovery, Reduction, Reuse, and Recycling (4Rs), is very important for mitigating emissions from the waste sector, which contributes significantly to human-made GHG emissions worldwide. The public-private partnership (PPP) is instrumental in achieving the 4Rs [Omodero and Alege, 2022], which will have a great potential to save GHG emissions, especially since burning and open-dumping are major sources of waste disposal in Nigeria. Proper waste collection offers a strong viability for energy valorization, which further mitigates emissions since bioenergy is largely carbon neutral [Elum and Momodu, 2017]. Resources can also be conserved by recovering energy and materials from waste [Okafor *et al.*, 2022]. Proper disposal to sanitary landfills may aid in energy recovery in strategies like landfill gas-to-energy (LFGTE). In the city of Ibadan in South West Nigeria alone, recycling waste is estimated to save 90 to 150 tonnes of CO₂-eq/year, while proper disposal methods will save 90 to 160 tonnes of CO₂-eq/year. However, these savings were shown to depend on proper sorting of waste at the source, and 73.3% of urban dwellers blame non-segregation of their wastes due to a lack of knowledge [Hammed *et al.*, 2018].

Fiscal Measures

Fiscal measures are essential legislative instruments in driving innovative low-carbon initiatives. The significance of climate financing (NASPA—CCN) was acknowledged in Nigeria's 2011 National Adaptation Strategy and Plan of Action on Climate Change [Onyimadu and Uche, 2021]. While there is a little correlation between CO₂ emissions and tax revenue, there is a

considerable correlation between green finance schemes and emission reduction in Nigeria [Omodero and Alege, 2022]. In order to move the economy toward low-carbon emissions, this is in favor of green bonds and a carbon tax.

According to IPCC Working Group II (WGII) Fourth Assessment Report (AR4), 2007, adaptation and mitigation under climate change will require dynamic policies to deal with the quickly changing knowledge and the high degree of uncertainty in the timing and scale of projected climate changes.

Policies to adapt to climate change will also have an impact on natural resource management and sustainable development, including those required to safeguard human and animal health, promote political rights, and encourage governance. Widespread resilience to risk requires these connections. Public and commercial actors are informed by adaptation choices about the agricultural investment and disinvestment decisions they must make in the near future. Long-term investments in plant and animal breeding programs, including those involving underutilized crops, developing quarantine systems, establishing perennial crops and forest plantations, purchasing or selling land, constructing (or decommissioning) significant infrastructure like dams and water distribution systems, flood mitigation projects, storage and transportation facilities, as well as shorter-term investments to ensure access to food and safety nets are a few example. Therefore, maximizing societal welfare under future climate risk is likely to require a combination of adaptation and mitigation, with the percentage contribution of each strategy based on monetary and non-monetary cost-benefit analyses (UNFCC, 2007).

ACTIONS NEEDED TO FACILITATE ADAPTATION RESPONSES

Climate monitoring efforts and information communication are crucial for persuading farmers that climate change projections are real and call for response actions. Information services should include surveillance of pests, diseases, and other factors of importance to production systems. Policies that support research, systems analysis, extension capacity, industry, and regional networks must be strengthened to give managers the knowledge, technical expertise, and strategic capacity to safeguard their businesses.

New technical or managerial strategies must be invested on in order to provide the options needed to address the anticipated changes in areas where the current technical options are insufficient. Improved agriculture, livestock, forest, and fisheries germplasm are among them. Where climate impacts result in significant land use changes, training for new occupations based on new land uses, industrial relocation, and people migration is required. Direct financial and material assistance, alternative livelihood options that lessen reliance on agriculture, community partnerships for food and forage banks, the creation of new social capital and information sharing, making sure that the most vulnerable have access to food aid and jobs, and the creation of backup plans are some ways to accomplish this. In order to support the new land-use and management arrangements, new institutions, policies, and infrastructure might be required, this includes updating land tenure agreements and property rights, investing in irrigation infrastructure and water-use technologies, building suitable transportation and storage facilities, and creating easily accessible and effective markets for goods, financial services like insurance, and inputs like labor, seed, and fertilizer. With focused monitoring of climate change adaptations and their costs, benefits, and consequences, policy must

continue to be able to make adjustments and improvements in adaptation through "learning by doing." Howden and associates (2007)

SYNERGIES IN ADAPTATION AND MITIGATION

In addition to improving irrigation water efficiency, reducing methane emissions through integrated rice and livestock systems—traditionally found in West Africa, India, Indonesia, and Vietnam could also improve human well-being by generating new revenue streams and enhancing the performance of cultivated agro-ecosystems.

Lowering N₂O emissions can result in less biodiversity loss and better groundwater quality. A higher demand for farmyard manure and revenue for the animal husbandry industry, which employs many impoverished people, could arise from integrating animal dung waste management technologies, including biogas capture and utilization, for reductions of CH₄ and N₂O. Restoring land through managed grazing can help sequester carbon in the soil, improve animal output, slow down desertification, and give the impoverished social stability against extreme occurrences like drought (particularly in sub-Saharan Africa). Practicing agroforestry - can improve soil carbon sequestration while also boosting agroecosystem performance and tolerance to climatic extremes by enriching soil fertility and soil water retention. (Smith *et al.*, 2007).

There are beneficial agricultural adaptation and mitigation synergies that are pertinent to food security, and these should be at the center of national and international climate policy planning and execution. These include preventing deforestation, managing and conserving forests, using agroforestry for food and energy, restoring land, recovering waste and biogas, and, generally speaking, a variety of tactics that improve the quality,

availability, and usability of soil and water resources. In addition to being the subject of research, funding, and implementation by significant international institutions and non-governmental organizations (NGOs), these tactics frequently have their roots in local cultures and expertise. They all have a tendency to significantly sequester carbon or reducing land-based greenhouse gas emissions while making production systems more resilient to growing climatic stressors. A large number of these synergies also pertain to sustainability on the social, economic, and environmental levels. Recognizing that these synergies are frequently system and location specific and must be assessed on an individual basis is crucial. Depending on the circumstances, a number of adaptation techniques may enhance the possibility for land mitigation. Increased fertilization and irrigation, for instance, may significantly improve the soils' capacity to sequester carbon in marginal semi-arid regions under the conditions of climate change. This is particularly true in sub-Saharan Africa, where carbon pools and soil quality can be restored while crop biomass production is greatly impacted by even modest increases in resource use efficiency. In situations where precipitation is higher, particularly in mid-latitudes, a transition from fallow systems to continuous agriculture, which includes cover crops as well, would enhance soil carbon sequestration capacity while optimizing production under the increased precipitation conditions. Some mitigating strategies, though, might not support adaptation. In order to improve system resilience and protect food production in the face of climate change, for example, bioenergy and certain land conservation programs may entail activities that create new competition for land and water resources (Easterling *et al.*, 2007).

CONCLUSION

There will be an inevitably experience of some degree of climate change and its associated negative effects, regardless of the mitigation approach that is selected, due to inertia with the climate and socio-economic systems that are the foundation of greenhouse gas emissions. The likely impacts, however, decrease with the timing of mitigation efforts. Nevertheless, even in the case of moderate climate change, adaptation will be required to safeguard food security and livelihoods in many developing nations that are anticipated to be the most vulnerable. This suggests that determining the best combination of adaptation and mitigation strategies to reduce the overall effects of climate change will be the main task of climate policy. This involves acknowledging that there are several mutually reinforcing synergies between particular adaptation and mitigation strategies, which may result in a more effective use of "climate response" resources. Significantly, a large number of these synergies are found in the agriculture and forestry industries and are highly relevant to rural life in poor nations.

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SPHAGNUM MOSSES (BOG/QUACK MOSSES) FOR BIOREMEDIATION: A REVIEW OF ENVIRONMENTAL POLLUTION CLEANUP STRATEGIES.

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ABSTRACT

Sphagnum mosses also known as bog / quack mosses are known for their unique traits and ecological relevance in peatlands, have emerged as viable alternatives for bioremediation of environmental contamination. This review seeks to investigate the use of sphagnum mosses in pollution clean-up efforts, with a focus on their usefulness in mitigating various forms of contamination. The review will look at the underlying mechanisms that allow sphagnum mosses to absorb and detoxify contaminants such as heavy metals, organic pollutants, and surplus nutrients in a variety of ecosystems, including wetlands, urban areas, and agricultural lands. Furthermore, practical applications of *Sphagnum* mosses in real-world bioremediation efforts been assessed, giving insight on their benefits, potential and limitations. By synthesizing available studies, this review aims to provide useful insights into the varied role of sphagnum mosses in pollution reduction. It aims to advance scientific understanding of *Sphagnum* mosses bioremediation capabilities and their incorporation into sustainable environmental management techniques. This review aims to teach researchers, policymakers, and environmental practitioners about the importance of sphagnum mosses as eco-friendly solutions to address environmental pollution, encouraging a more resilient and sustainable future.

Keywords: Bioremediation, Environmental contamination, *Sphagnum* mosses, Sustainable management

INTRODUCTION

Sphagnum moss is a perennial plant spread in wet territories, mostly in bogs (peatlands). Sphagnum moss has empty cells helping it to retain water and different chemical compounds. . Thus, peat can be considered like a buffer for atmospheric aerosols (Mezhibor and Bonn, 2014). Mosses, though often overlooked, belong to the oldest land-plant group, the bryophytes, and have evolved unique strategies for survival. Unlike vascular plants, which have protective layers to resist desiccation and can exchange gases through stomata, mosses require wet environments for active growth. Despite their inconspicuous nature, mosses offer potential for biotechnological exploitation due to their

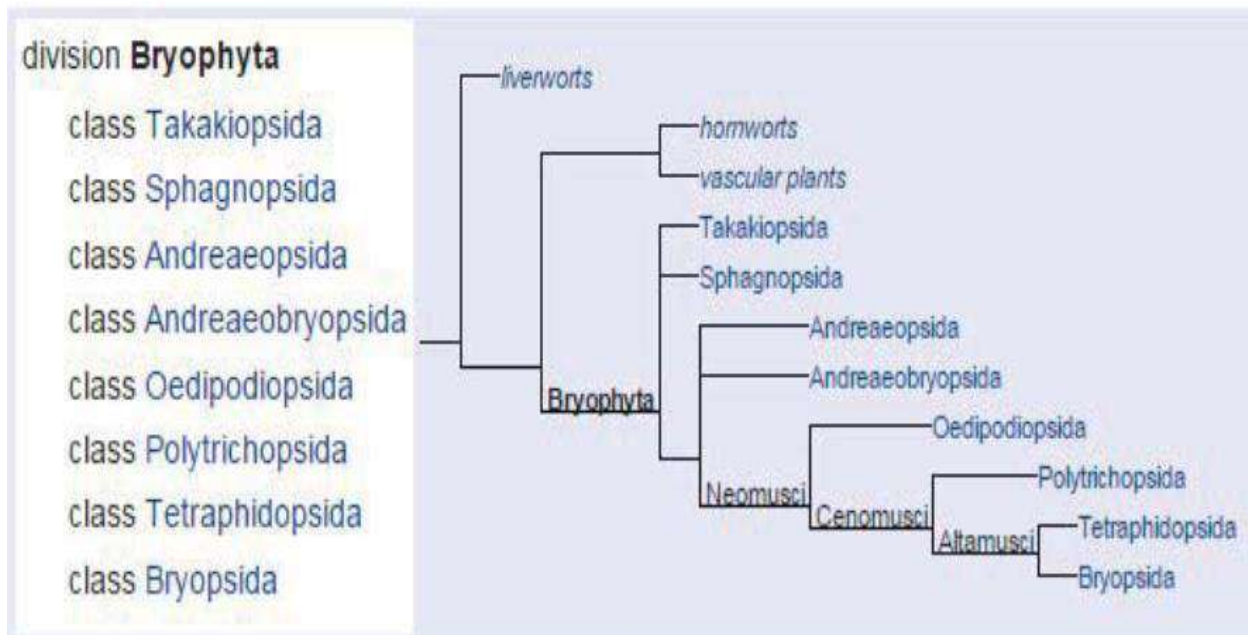
distinctive characteristics and evolutionary history (Decker and Reski, 2020). Considering that *Sphagnum* is one of the dominant vegetation constituents in peatlands, it is estimated that they can contribute to storing ca. 10% of the planet's soil organic C in the form of semi-decomposed litter, therefore, the responses of peatlands to future environmental changes and anthropogenic disturbances may be dictated by their functionalities and characteristics (Pacheco-Cancino *et al.*, 2023). Due to rapid and uncontrolled industrialization and urban-ization along with rigorous farming, the global environment has been under considerable pressure. Modern development released a

number of toxic pollutants to the atmosphere through numerous human activities (Shahid *et al.*, 2017). Anthropogenic disturbances that directly affect *Sphagnum* mosses are related to drainage, commercial extraction, or removal of the moss as donor plant material for restoration of degraded peatlands, which have the potential to affect their ecological functionality and modify C dynamics. However, land use management actions favorable for their restoration, such as assisted reintroduction, recovery of appropriate conditions for their natural recolonization, or *Sphagnum* paludiculture could counteract the negative impacts of degradation (Pacheco-Cancino *et al.*, 2023).

***Sphagnum* Mosses: Characteristics, Distribution, and Ecological Significance**

Sphagnum moss is a perennial plant spread in wet territories, mostly in bogs (peatlands).

Sphagnum moss has empty cells helping it to retain water and different chemical compounds. (Mezhibor and Bonn, 2014). The general perception of mosses as good biomonitors of air pollution may be based on two widespread, though partially erroneous assumptions, hereafter referred to as “the two myths” of the “moss biomonitoring technique”: the structural myth, and the physicochemical myth. (Varela *et al.*, 2023). *Sphagnum* mosses do not have roots and take up nutrients efficiently via their leaves and stem (Temmink *et al.*, 2017). Comparative studies of pollution sensitivity among and within different plant groups have provided many insights into mechanisms of phytotoxicity and tolerance of the major atmospheric pollutants (Bharali and Bates, 2005)



Classes of Bryophyta (Abulude *et al.*, 2021)



Capitulum of *Sphagnum* mosses

(Carbeth Plants, 2024)

A current trend in addressing air purification challenges involves the development of biotechnological filter systems that utilize specific plant crops to remove pollutants while releasing oxygen. Moss is an intriguing plant known for its capacity to achieve a high level of air purification, particularly under conditions of stable temperature and humidity (Biloshchytskyi *et al.*, 2023). Moss is a low-cost way of mapping air pollution and has the potential to revolutionize the enforcement of environmental regulations (Abulude *et al.*, 2021). Peatlands are terrestrial wetland ecosystems, where the production of natural organic matter (NOM) by plants such as *Sphagnum* moss exceeds its decomposition by microorganisms resulting in the net accumulation of peat (Bandekar *et al.*, 2022)

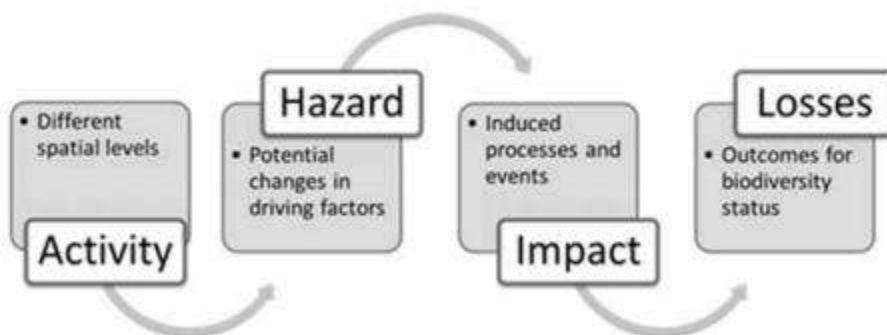
Overview of Pollution in Various Ecosystems: Types and Sources of Contaminants

Peatlands are terrestrial wetland ecosystems, where the production of natural organic matter (NOM) by plants such as *Sphagnum* moss exceeds its decomposition by microorganisms resulting

in the net accumulation of peat (Bandekar *et al.*, 2022). Moss is a low-cost way of mapping air pollution and has the potential to revolutionize the enforcement of environmental regulations (Abulude *et al.*, 2021). Comparative studies of pollution sensitivity among and within different plant groups have provided many insights into mechanisms of phytotoxicity and tolerance of the major atmospheric pollutants. As a group, bryophytes are highly sensitive to atmospheric pollution (Kalmykova *et al.*, 2008). In recent times, air quality has emerged as a single largest environmental threat, with surging cases of air pollution inflicted mortality, and major cause of public health emergency in Central and Southern Asia labeled air pollution as "one of our era's greatest scourges, on account not only of its impact on climate change but also its impact on public and individual health due to increasing morbidity and mortality." Mounting woes over public health damage due to air pollution has raised grave regulatory concerns with recent discovery of close ties COVID-19 virus spread (Chaudhuri and Roy, 2023). Moss has also been used as an ideal biological indicator

for atmospheric environmental monitoring. The use of moss bags to monitor environmental pollution originated in Europe (Hu *et al.*, 2018). Chaudhuri and Roy (2023) Studies using mosses as biomonitors of air quality contribute to the indication of trends and changes in pollution over the years and

the identification of sources of emissions of elements accumulated by mosses (Świsłowski and Rajfur, 2023). The measures required to restore peatland biodiversity can be identified adequately only on the basis of full information about the causality chain that begins with human activities.



The sequence of causality from human activity to biodiversity loss (Minayeva *et al.*, 2016b)

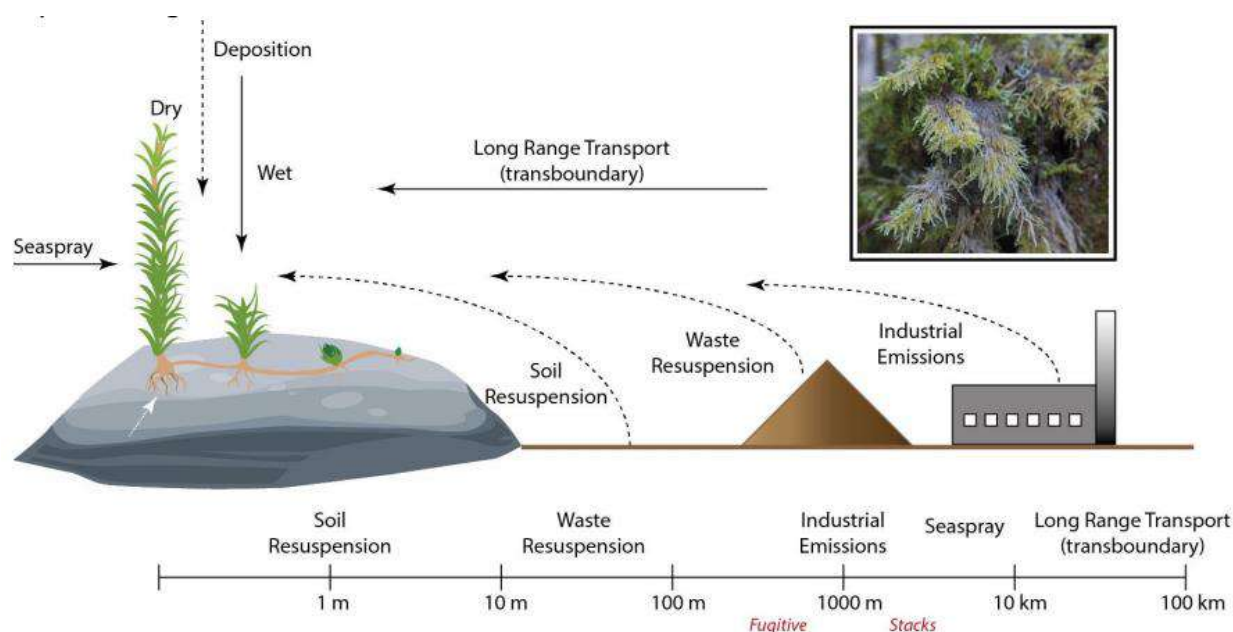


Figure 1. Conceptual model for the mechanism by which elements may be accumulated in mosses together with the range of effect. Industrial emissions may be either fugitive, low-level losses or ducted, thermally enhanced through stacks. It should be noted that there is no uptake through the

rhizoids (marked with white arrow) as these are used for anchorage only (Stephen *et al.*, 2019).

Mechanisms of Contaminant Absorption and Detoxification by *Sphagnum* Mosses

In recent years, peatlands have repeatedly been identified by the Ramsar Convention as the most important wetland type for the support of biodiversity and the regulation of natural processes. They also have been singled out for increased attention by both the Convention on Biological Diversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC) (Minayeva *et al.*, 2016). Peat moss has been studied as a material for the purification of contaminated waters for over 25 years. It has a high adsorption capacity for heavy metals compared to other natural adsorbent materials (Kalmykova *et al.*, 2008). Because they grow further above the water table than hollow mosses, hummock mosses have adaptations that allow them to tolerate (and even create) drier conditions than hollow mosses can tolerate. For instance, capitula in hummocks tend to be smaller and denser than those in hollows as more resources are put towards stem growth which in turn increases the efficacy of capillary transport and retention of water from deeper in the peat. For this reason, we hypothesized that hummocks would be more resistant to drought and lowered water tables than hollows, maintaining more stable CO₂ cycles (O'Neill *et al.*, 2022). In vascular plants, apart from the important pollutant-excluding effect of cuticle and stomata, tolerance towards SO₂ appears to be based on detoxification mechanisms. The pollutant is oxidized to the relatively harmless sulfate ion and/or reduced to sulphide (Bharali and Bates, 2005). *Sphagnum* lacks a vascular system, and relies solely on the capillary transport of water to survive, resulting in potentially high susceptibility to water stress such as more frequent or prolonged droughts that are predicted to occur with climate change (O'Neill *et al.*, 2022). The value of mosses as biomonitors of air pollution is based on the idea that wet and dry (i.e.

bulk) atmospheric deposition constitute the main sources of nutrients, and consequently pollutants, to these plants (Varela *et al.*, 2023). The presence of mosses on land is a highly relevant factor in the absorption of rainwater, reducing or eliminating the risk of water runoff and gradually allowing the water contained in them to reach the underlying soil. As mosses have neither woody conduction tissue nor lignified supporting tissue, they absorb rainwater through their entire surface. Bogs have been utilised for water remediation capacity as a tertiary wastewater treatment system since the early 1950s.

Heavy Metal Uptake and Sequestration

Despite their apparent structural simplicity, bryophytes have developed a set of different strategies to tolerate elemental stress. As a general mechanism, they can produce cell wall barriers to prevent PTEs from entering their protoplasts. For example, the moss *Scorpiurum circinatum* was shown to immobilize toxic metal ions in its cell walls; similarly, excessive Zn intake was blocked by the cell wall and plasma membrane in the moss *Pohlia drummondii* (Fasani *et al.*, 2022). Using the moss-bag method with the moss *Sphagnum junghuhnianum*, metal concentrations in mosses were correlated with traffic intensity (Świsłowski and Rajfur, 2023). Living sphagnum and subsurface horizontal flow constructed wetlands incorporating a living sphagnum layer over peat bodies have also been engineered for remediation of heavy metals through ion exchange from industry outflows such as paper production, crude oil processing, food processing including wineries and distilleries and household waste effluent in rural communities (McKeon-Bennett and Hodkinson, 2021). In Europe, use of terrestrial mosses as a bio-indicator of atmospheric metal pollution deposition from

ambient air has been reported since late sixties. Due to widespread presence, lower cost and high adsorption capacity of pollutants, terrestrial mosses are used more commonly than other sorbents. For atmospheric biomonitoring, the most commonly used method is “moss-bag technique”. Bryophytes, particularly mosses have been used since 1970s to monitor the ecosystem exposure to the several pollutants including persistent organic pollutants, trace metals and excess nitrogen. First, bryophytes lack vascular system and lack developed root system, thus mosses likely take up most of the nutrients from water that contacts their branches or leaves directly (Shahid *et al.*, 2017). *Hypnum cupressiforme* to monitor the concentration of Zn, Ni, Pb, and Cr in an industrial area in southwest Wales, whereas Cameron and Nickless used the moss bag method to monitor Zn, Pb, and Cr concentrations near a lead-zinc smelter in Britain (Hu *et al.*, 2018). Among four frequently used moss genera the genus *Sphagnum* was suggested for superior uptake of heavy metal ions. Biomonitoring is performed with the so-called moss-bag technique, the exposition of moss material in inert mesh bags at different sites of interest (Decker and Reski, 2020). Due to a lack of roots, mosses receive pollutants rather from the air than from substrates. Pollutant absorption through the leaf surface of mosses is facilitated as a waxy cuticle is missing. Their accumulation is further aided by the high surface to volume ratio of moss. Furthermore, mosses grow in various habitats around the world, even in Polar Regions. Therefore, mosses were and are applied as biomonitors, mainly for nitrogen and heavy metals, but also, although less often, for organic contaminants (Dreyer *et al.*, 2018). "Today, moss biomonitoring is a part of pollution monitoring programs in most European countries as it gives evidence of the

anthropogenic impact in urban areas due to vehicular traffic and fossil fuel combustion". Moss based biomonitoring of atmospheric pollution was pioneered by the Swedish research groups in the 1960s (Chaudhuri and Roy, 2023)

Nutrient Retention and Nutrient Cycling

Leaching of nitrogen through the moss layer plays a major role in the vegetation change by increasing the availability of N in the rhizosphere to vascular plants. As a dense cover of vascular plants has the potential to decrease moss biomass, vascular plants may also indirectly increase nitrogen leaching and availability in the root zone, as has been suggested by field studies (Fritz *et al.*, 2014). By rapidly sequestering N, *Sphagnum* acts as a nutrient filter, decreasing nutrient (pore)water concentrations in the rhizosphere of vascular plants (Temmink *et al.*, 2017). Peat moss has long been used by gardeners and horticulturalists as a substrate for growing acid loving plants and crops and for increasing the organic content of poor soils (McKeon-Bennett and Hodkinson, 2021). Despite this importance, approximately half of the peatlands in Europe and more than half in South-east Asia have been drained to be used for agricultural purposes, turning them from carbon sinks into major sources of carbon dioxide (CO₂) through accelerated peat oxidation (Käärmelahti *et al.*, 2023). Presence of moss has considerable impact on the immediate abiotic environment because mosses buffer soil moisture and temperature fluctuations. Mosses can also affect soil nutrient availability through their effects on soil temperature and their poor litter quality (Lett *et al.*, 2020). In Europe, the International Cooperation Program on the Impact of Air Pollution on Natural Ecosystems and Crops (ICP Vegetation) has been conducting moss-

based biomonitoring of various heavy and trace metals since 1995 (Chaudhuri and Roy, 2023)

CONCLUSION

Sphagnum mosses are crucial for maintaining the health and functionality of peatland ecosystems, contributing to carbon storage, water retention, and nutrient cycling. They serve as valuable indicators of environmental pollution levels and play essential roles in air purification and water remediation efforts. However, human activities such as drainage and land use changes pose significant threats to these mosses and their ecosystems. Effective restoration measures are essential for preserving their ecological functions. Moss-based biomonitoring techniques provide valuable insights into pollution levels and sources, aiding environmental management efforts. Overall, the diverse roles of *Sphagnum* mosses highlight their importance in pollution reduction, ecosystem conservation, and sustainable resource management worldwide.

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ECONOMIC BENEFITS OF SUBSTITUTING FISHMEAL WITH GRADED LEVELS OF BAMBARA GROUNDNUT (*Vigna subterranean*) MEAL IN NILE TILAPIA (*Oreochromis niloticus*) DIET

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ABSTRACT

The economic benefits of substituting fishmeal with graded levels of Bambara groundnut (*Vigna subterranea*) meal in Nile tilapia (*Oreochromis niloticus*) diet was carried out with the aim to determine the cost - benefit of feeding *O. niloticus* fingerlings using graded levels of Bambara groundnut meal as substitute for fishmeal. Five (5) isonitrogenous (35% crude protein) diets were formulate, where Bambara groundnut as substitute for fishmeal was included at; 0.0g/100g (BM₀), 5.00g/100g (BM₁), 10.00g/100g (BM₂), 15.00g/100g (BM₃) and 20.00g/100g (BM₄) graded levels, diet without Bambara groundnut (BM₀) served as the control diet. Diets were fed to *O. niloticus* fingerlings (n = 150, 6.0±0.00g) in fifteen (15) plastic tanks (n = 10) at a fixed feeding rate of 3% body weight twice daily for a period of twelve (12) weeks and cost - benefit analysis was calculated for each diet. Mean net profit value (₦569.00) along with the benefit cost ratio value (2.27) were highest in control diet (BM₀), while profit index value (2.94) was highest along with the least (best) incidence of cost value (₦0.81) in diet BM₃. This indicated that Bambara groundnut meal can be used in graded levels or as total replacement for fish meal in *O. niloticus* feed.

Keywords: Cost – Benefit, Incidence of Cost, Mean Yield Cost and Mean Net Profit.

INTRODUCTION

The advancement in intensive aquaculture is always encountered with the high cost of feed, which accounts for approximately 70 to 80% of the total costs of production thereby causing declined in profits (Ishaku *et al.*, 2023). An attempt to increase the economic benefits is to reduce the feed cost as minimal as possible; one way to do this is to explore cost - benefit analysis of the different feeds and the protein sources such as Bambara

groundnut (*Vigna subterranea* L.) that can be used as an alternative to fish meal for lowering the cost of production. The cost - benefit analysis of Nile tilapia (*Oreochromis niloticus*) farming is a topic that has garnered significant attention in recent years (Sogbesan and Bashir, 2018). Cost - benefit analysis (CBA), also called benefit costs analysis (BCA) is a practical approach to estimate the strengths and weaknesses of the ways used to make a decision about the freedom of choice which give the ideal focus

to successfully bringing an advantage or profit at the same time preserving savings-for instance, in transaction, activities, and functional business necessity (Ali *et al.*, 2024). A CBA can be used to evaluate the complete or likely causes of actions, or to approximate (or assess) the value against the cost of a resolution, program, or strategy (Mohammed *et al.*, 2020). It is often utilized in commercial transactions, business or in the course of decision making (especially public policy), and project investment. CBA is associated and regulated for the time value of money; all flows of benefits and cost over time are demonstrated on a common basis in terms of their net present value, regardless of whether they are incurred at different times (Ali *et al.*, 2024). Other related techniques include cost-utility analysis, risk-benefit analysis, economic impact analysis, fiscal impact analysis, and social return on investment (SROI) analysis (Umar *et al.*, 2019). Therefore, this study is focused on the economic benefits of substituting fishmeal with graded levels of Bambara groundnut (*Vigna subterranea*) meal in Nile tilapia (*Oreochromis niloticus*) diet.

MATERIALS AND METHODS

Study area

The study was conducted at the Lay – Joy fish farm, Gombe – Yola Road, Billiri local government area (LGA), Gombe State Nigeria. Billiri LGA lies within latitude 9°50' and 11°09'N and longitude 9.833° and 11.150°E. It covers an area of 737km² and is 50 km away from Gombe the state capital.

Experimental fish

One hundred and fifty (150) *O. niloticus* fingerlings with mean initial weight (6.0±0.00g) were stocked at ten (10) fingerlings per tank in triplicates per treatment after one (1) week of

acclimatization, the study lasted for a duration of twelve (12) weeks.

Experimental diets

The experimental diets contained fish meal (FM), Bambara groundnut meal (BGNM), soybean meal (SBM), yellow maize meal (YMM), groundnut cake meal (GNCM). All the ingredients were grounded into a fine powder using a hammer mill and sieved by a 0.25 mm sieve. Fish meal, soybean meal, groundnut cake meal and yellow maize meal were obtained from commercial suppliers in Gombe, the vitamin/mineral premix, fish oil and chromic oxide (Cr₂O₃) were purchased from TTS Integrated Farms Nigeria Limited, Lagos. Five (5) isonitrogenous and isocaloric diets were prepared, each diet with crude protein (CP) content of 35% CP as calculated according to Pearson's square method and gross energy content at 1,732kcal kg⁻¹ respectively for the feeding the experimental fish as recommended by Mohammed *et al.* (2024) was prepared, where Bambara groundnut as a substitute for fishmeal was included at; 0.0g/100g (BM₀), 5.00g/100g (BM₁), 10.00g/100g (BM₂), 15.00g/100g (BM₃) and 20.00g/100g (BM₄) feed graded levels, diet without Bambara groundnut (BM₀) served as the control diet (Table 1).

Experimental design

The *O. niloticus* fingerlings were cultured in fifteen (15) rectangular plastic tanks (flow - through system) with a water holding capacity of one thousand litres (1,000L) each in a complete randomized design (CRD). Each tank was washed thoroughly with salt, filled to 1/5 (200L) capacity and stocked with ten (10) fingerlings of *O. niloticus* with mean initial weight of 6.0±0.00g. The *O. niloticus* fingerlings were fed experimental diet at 3% body weight two (2) times daily between the hours of 8:00 – 9:00am and 4:00 – 5:00pm for a period of twelve (12) weeks. The quantity of feed was adjusted accordingly

after every two (2) weeks of sampling for growth performance and survival rate (mean body weight and mortality). Water temperature, pH, dissolved oxygen, and ammonia were measured at the beginning of the experiment after which they were measured weekly throughout the period of the experiment. Water temperature, dissolved oxygen and pH were measured using Horiba U – 22 XD multi – parameter water quality checker while ammonia was measured using freshwater aquaculture test kit (Model AQ – 2, Code 3633 – 03, Lamotte, USA). Data on cost - benefit analysis was collected.

Cost - Benefit Analysis of *O. niloticus* Fingerlings Fed Graded Levels of Bambara Groundnut as Substitution for Fishmeal

The cost - benefit analysis of the *O. niloticus* fingerlings fed graded levels of Bambara groundnut as substitution for fishmeal was calculated using the method of Sogbesan and Ekundayo (2014) as follows:

Investment cost analysis (ICA)
 = cost of feed (₦)
 + cost of fish stocked (₦)

Profit index (PI)
 = net profit (₦)/cost of feed (₦)

Incidence of cost (IC)
 = cost of feed (₦)
 /weight of fish produce (g)

Benefit cost ratio (BCR)
 = net profit (₦)
 /investment cost analysis

Cost benefit analysis was based on the following:

- i. A major assumption was that all other operating costs for the *O. niloticus* production remained the same for all the dietary treatments. Thus, cost of feed was the only economic criterion (expenditure) considered in this study.
- ii. Cost of feed was based on the prevailing market prices of the *O. niloticus* fingerlings feed as at the time of purchase (that is time of commencement of the experiment).
- iii. Value of *O. niloticus* produced (cost of fish cropped) depends on the selling price of *O. niloticus* per kg (3,500/kg) in the markets around Gombe as at the end of the experiment.
- iv. Cost of producing graded levels of Bambara groundnut diet depended on the cost of obtaining the Bambara groundnut.
- v. Total weights of *O. niloticus* fingerlings produced were obtained from the total weight of fish recovered at the end of the feeding trial.

Data analysis

The data collected were analyzed using the cost - benefit analysis models as described by Ali (2022).

Table 1: Ingredient Percentage Composition (g/100g) of Experimental Diets with Graded Levels of Bambara Groundnut

Ingredients (%)	BM ₀	BM ₁	BM ₂	BM ₃	BM ₄
Fish meal	20.00	15.00	10.00	5.00	00.00
BGN meal	0.00	5.00	10.00	15.00	20.00
Soybean meal	20.00	20.00	20.00	20.00	20.00
GNC meal	24.00	24.00	24.00	24.00	24.00
Yellow maize	30.00	30.00	30.00	30.00	30.00

Fish oil	1.00	1.00	1.00	1.00	1.00
Vegetable oil	1.00	1.00	1.00	1.00	1.00
Starch	1.00	1.00	1.00	1.00	1.00
Lysine	0.50	0.50	0.50	0.50	0.50
Methionine	0.50	0.50	0.50	0.50	0.50
*Vitamin/premix	1.00	1.00	1.00	1.00	1.00
Salt	0.50	0.50	0.50	0.50	0.50
Cr ₂ O ₃	0.50	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00

Keys: BM₀ - Bambara groundnut (0.0g/100g), BM₁ - Bambara groundnut (5.00g/100g), BM₂ - Bambara groundnut (10.00g/100g), BM₃ - Bambara groundnut (15.00g/100g), BM₄ - Bambara groundnut (20.00g/100g), BGN - Bambara groundnut and GNC - Groundnut cake.

RESULTS

Results of the cost - benefit analysis of the *O. niloticus* fingerlings fed graded levels of Bambara groundnut as substitution for fishmeal is shown in Table 2. *O. niloticus* fingerlings fed the control diet (BM₀) which was Bambara groundnut at 0.0g/100g feed had the highest mean final body weight value (234.00g), while the fish fed diet BM₄ (Bambara groundnut at 20.00g/100g) feed had the least mean final body weight value (155.00g). There was an increased in the mean cost of feed from the value of ₦120.00 in fish fed diet BM₄ to the value of ₦200.00 from fish fed the control diet (BM₀) respectively. The least mean cost of feed value ₦120.00 was recorded from fish fed diet BM₄. The investment cost analysis value (₦250.00) was highest in fish fed the control

diet (BM₀), followed by those from fry fed diet BM₁ (₦230.00), BM₂ (₦210.00) and BM₃ (₦190.00) respectively, while the least value (₦170.00) was recorded from fish fed diet BM₄. The highest mean net profit value (₦569.00) was recorded from the fish fed the control diet (BM₀), while the least value (₦372.50.00) was recorded from the fish fed diet BM₄. The highest profit index value (3.10) was recorded from the fish fed diet BM₄, while the least value (2.48) was recorded from the fish fed diet BM₁. The least (better) incidence of cost value (₦0.77) was recorded from the fish fed diet BM₄, while the highest (poor) value (₦0.93) was recorded from the fish fed diet BM₁. Also, the results indicated that fish fed the control diet (BM₀) had the highest benefit cost ratio value (2.27), while the fish fed diet BM₁ had the least value (1.99).

Table 2: The Cost - Benefit Analysis of *O. niloticus* Fingerlings Fed Graded Level of Bambara Groundnut as Substitution for Fishmeal

Parameters	BM ₀	BM ₁	BM ₂	BM ₃	BM ₄
Mean final weight (g/fish)	234.00	193.00	181.00	172.00	155.00
Mean cost of feed/g (₦)	200.00	180.00	160.00	140.00	120.00
Cost of fingerlings (₦/fish)	50.00	50.00	50.00	50.00	50.00
Investment cost analysis (₦)	250.00	230.00	210.00	190.00	170.00

Cost of fish/kg (₦)	3500	3500	3500	3500	3500
Mean yield cost/fish (₦)	819.00	675.50	633.50	602.00	542.50
Mean net profit (₦)	569.00	445.50	423.50	412.00	372.50
Profit index	2.85	2.48	2.64	2.94	3.10
Incidence of cost (₦)	0.85	0.93	0.88	0.81	0.77
Benefit cost ratio (BCR)	2.27	1.93	2.01	2.16	2.19

Keys: MB₀ - Bambara groundnut (0.0g/100g), MB₁ - Bambara groundnut (5.00g/100g), MB₂ - Bambara groundnut (10.00g/100g), MB₃ - Bambara groundnut (15.00g/100g), MB₄ - Bambara groundnut (20.00g/100g).

DISCUSSION

The mean final body weight values, 155.00 – 234.00g recorded from this study were comparable with the values 147.69g – 243.50g reported by Mohammed *et al.* (2024) for *O. niloticus* fed Bambara nut. Findings from this study indicated that the experimental diets were well utilized by the *O. niloticus* fingerlings. Sogbesan and Bashir (2018) reported that the dietary treatment with the highest weight gain also produced fish with the highest value for *O. niloticus* fed fermented cassava (*Manihot esculentus*) leaf meal supplemented diets. The mean net profit values, ₦372.50 – ₦569.00 recorded from this study were comparable with the values, ₦286.00 – ₦512.80 reported by Ali (2022) for *C. gariepinus* fed betaine additive diet. This indicated that the control diet and the used of graded level of Bambara groundnut as replacement for fish meal resulted to higher mean net profits in this study. The profit index values, 2.48 – 3.10 recorded from this study were higher than the values, 1.58 – 1.95 reported by Alatisie *et al.* (2019) for *C. gariepinus* fingerlings fed boiled baobab (*Adansonia digitata*) seed meal – based diets. The profit index values recorded from this study revealed that more profit was generated, this finding further buttresses the fact that the diets were better utilized. The incidence of cost values, ₦0.77 – ₦0.93 recorded from this study were comparable

with the values, ₦0.33 – ₦0.41 reported Alatisie *et al.* (2019). The least (best) incidence of cost value recorded from the fish fed diet TB₄ indicated that the used of Bambara groundnut as substitute for fish meal at 20.00g/100g produced the most cost - effective diet. The benefit cost ratio values, 1.93 – 2.27 recorded from this study were lower than the values, 1.41 – 1.55 reported by Umar *et al.* (2019) for *O. niloticus* fed camel testicles - based diet. Wambua (2018) stated that when the benefit cost ratio value is greater than one or equal to one it indicated profitability, but less than one indicated lack of viability or unprofitability of the venture. Therefore, since the benefit cost ratio values in all the diets were greater than one, it indicated that feeding *O. niloticus* fingerlings with graded levels of Bambara groundnut meal as substitute for fish meal is economically efficient and beneficial; over the study duration, the stream of benefits exceeds the costs incurred.

CONCLUSION

Findings from this study revealed that Bambara groundnut meal can be used in graded levels as partial or total substitute for fish meal in formulating *O. niloticus* feed as a result of the highest profit index, least (better) incidence of cost and the highest benefit cost ratio values recorded from this study in which Bambara groundnut was used

as both partial and complete substitute for fish meal.

RECOMMENDATIONS

Bambara groundnut meal has the potential to substitute fish meal by up to 100% inclusion level, subsequently reducing expenditure on feed meal without compromising the cost - benefit.

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WATER PURIFICATION AND ANTIMICROBIAL EFFICACY OF *MORINGA OLEIFERA* DRIED AND MACERATED SEED

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ABSTRACT

Moringa oleifera is an economically important plant with multipurpose benefits. The seed of this plant has been known as a coagulant as well as an antimicrobial agent in water treatment. Availability of clean drinking water is still a major concern in most developing countries especially in rural areas. A simple and cost-effective method for water purification is required for rural communities. The method involves the use of moringa seed both dried and macerated in purifying borehole and well water in the community. Experiments in this study are conducted using jar test set up at varying times and concentrations. The water samples were subjected to purification studies and treated with dried and macerated moringa seed. Treated water samples were subjected to bacteriological analysis using most probable number technique. The total mesophilic bacteria, total mesophilic fungi, and total coliforms of borehole water after treatment with moringa seed are 190×10^1 cfu/ml, 6×10^1 cfu/ml, and 2 MPN/ml respectively, while the total mesophilic bacteria, total mesophilic fungi, and total coliforms of well water after treatment is 210×10^1 cfu/ml, 10×10^1 cfu/ml and 425 MPN/ml respectively. The pH and the temperature of the treated water fall between WHO standards. Thus, this study evaluates the efficacy of *Moringa oleifera* dried and macerated seed as an antimicrobial agent in water treatment and purification.

Keywords: *Moringa*, antimicrobial properties, water, microorganisms

INTRODUCTION

Water is one of the most essential necessities of human life. Unavailability of clean water contributes to several human diseases and morbidity (Rashid *et al.*, 2018). Most rural communities especially in developing countries such as Nigeria lack access to safe drinking water, and globally, at least 2 billion people use contaminated drinking water sources (WHO, 2019). This situation has resulted in health hazards, especially the transmission of diseases such as diarrhea, cholera, dysentery, typhoid, and polio which cause considerable mortality (WHO, 2019). The United Nations (UN, 2018), reported that 2.1 billion people live today without access to safe drinking water at home. World Health Organization (WHO, 2017) reported that almost 159 million people depend on surface

water, and universally, at least 2 billion people use drinking water contaminated with faeces. Researchers show that progress in the population's way of life in terms of production and consumption has resulted in an exponential increase in household waste (Chaouki *et al.*, 2021).

Conventional drinking water treatment comprises coagulation, flocculation, sedimentation, filtration, and disinfection processes (Abiyu *et al.*, 2018). Researchers have discovered that physicochemical processes such as coagulation and flocculation can minimize pollution and provide clean water (Manhokwe and Zvidzai, 2019). Coagulation-flocculation is commonly included either as a pre-treatment phase or as a post-treatment step depending on the types of water and the overall

treatment plan used. Coagulation is the mechanism by which a given colloidal suspension or solution is destabilized while flocculation refers to the incorporation of destabilizing particles to come together and thus form large agglomerates, which can normally separate by settling gravity. Coagulation frequently takes 10 seconds but flocculation takes 20 – 45 min. The resulting destabilized particles are sufficiently stuck and settle in the following treatment unit (Narmatha *et al.*, 2017).

Moringa oleifera seed, a natural coagulant is one of the most important ingredients in water purification. *Moringa oleifera* belongs to the Moringaceae family and is widely spread throughout tropical countries. It is a non-toxic and drought-tolerant tree that possesses medicinal and nutritional properties, including water-purification properties (Hellsing *et al.* 2014). From existing reports, there were allegations that the powder of *Moringa oleifera* seeds has antimicrobial properties and acts as an agent against microorganisms that are present in drinking water and decrease the number of bacteria (Mangale *et al.*, 2012). The advantages of natural coagulants include being environmentally sustainable, environmentally friendly, inexpensive, and a simple process for developing countries. The performance is independent of raw water pH safe for human health, and antibiotic impact on various bacteria and fungi. The alkalinity of the water can be significantly reduced, compared to chemical coagulants. Natural coagulants are cost-effective. According to Vigneshwaran *et al.*, (2020), the widespread use of aluminum-based chemical coagulants causes a variety of neurological problems, whereas bio-coagulants have natural properties that make them toxic to aquatic life. Different researchers have studied natural coagulants such as biowastes (Atchudan *et al.*, 2020), *Moringa oleifera* (Rocha *et al.*, 2020), *Moringa* oil (Chitra and

Muruganandam, 2019), Microbial polysaccharides (Saleem and Bachmann, 2019). In less developed populations, natural coagulants are commonly used as a point-of-use product, as they are fairly cost-effective compared to chemical coagulants. It is not difficult to use the seeds as a natural coagulant because the use of natural coagulants in the water treatment process is expected to provide more advantages than the use of synthetic materials as they are natural and reported safe to be consumed (Hendrawati *et al.*, 2016). Therefore, the aim of this study is to determine the efficacy of Indigenous *Moringa* seed as an antimicrobial agent against some potable water around the Oke-Baale axis of Osogbo, Osun State, Nigeria.

MATERIALS AND METHODS

Study area

The study area used in the course of this research was Osun State University, Osogbo, Osun State, Nigeria which is located in the Southwestern part of Nigeria with latitude 7.5876°N and longitude 4.5624°E.

Sample collection

Water samples were collected from three different areas within the university which include groundwater, borehole water, and bottled water respectively. All samples were obtained aseptically and transported to the Microbiology laboratory, Osun State University, Nigeria.

Collection and identification of *Moringa* seeds

Seeds of *Moringa oleifera* were collected from the *Moringa* tree at Modakeke in Osun State, Nigeria which was identified and authenticated by the Department of Plant Biology, Osun State University, Osogbo, Nigeria.

Preparation of *M. oleifera* seeds for extraction

The seeds were air-dried and ground to powdered form using a sterile laboratory mortar and pestle. The powder was then macerated and stored in an air-tight container for further analysis and extraction.

Extraction of active compounds from *M. oleifera* seeds

Aqueous extraction

With slight modification to the method of Lar *et al.*, (2011), forty grams (40g) of the powdered seed was weighed and dissolved in 320 mL of distilled water. The mixture was heated at 60°C in a water bath and filtered while hot. Hot water was continuously added to the residue and subsequently filtered. The procedure was repeated three times and the filtrate was evaporated to dryness at 60 °C.

Ethanol extraction

According to the method of Lar *et al.*, (2011), forty grams (40g) of the seed powder was dissolved in 320 mL of ethanol and allowed to stand for 48 hrs. The residue was then transferred into a soxhlet apparatus with ethanol for 48hrs and then evaporated to dryness at 60 °C.

Water treatment with dried and macerated *Moringa* seed

Dried and macerated *Moringa* seed in concentration of 0.001, 0.002, 0.004, and 0.008 g/mL were transferred into the well water, borehole, and bottled water samples respectively. The mixture was allowed to stay at room temperature for 72 hours and the experiment was carried out in duplicate. Chlorine (5 mg/mL) was used as a positive control for the experiment and the raw water samples with no addition dried and macerated *Moringa* seed were used as a negative control (Amadi and Ayogu, 2005).

Water treatment with *Moringa* seed extracts:

Different concentrations of aqueous *Moringa* extracts and ethanol extract with the range

0.04 g/mL, 0.02 g/mL, 0.01 g/mL, and 0.005 g/mL were transferred into the well water, borehole, and bottled water samples respectively. The mixture was allowed to stay at room temperature for 72 hours and the experiment was carried out in duplicate. Chlorine (5 mg/mL) was used as a positive control for the experiment and the raw water samples with no addition of extract were used as a negative control. The treated water was filtered into a sterile flask with sterile Whatman filter No. 4.

Determination of microbiological quality of the water

The microbial analysis was performed to determine the total mesophilic bacteria count, total mesophilic fungal count, and estimation of the most probable number (MPN) of faecal coliform bacteria in before and after treatment. With modification to the method of Amadi and Ayogu, (2005), for the total mesophilic bacterial counts, 100 µL of the treated and untreated water sample was spread on nutrient agar plates and incubated at 37°C for 24 hours. For total mesophilic fungal counts, 100 µL of the treated and untreated water sample was spread on potato dextrose agar plates and incubated at 25°C for 72 hours. Colonies observed on each plates were counted and recorded.

Determination of most probable number (MPN)

The water sample was thoroughly mixed. Using a 10 ml sterile syringe, 10 ml of water was added to each of the five bottles containing 10 ml of lactose broth (double strength), 1 ml of the water sample was then added into each of the 5 bottles containing 10 ml of lactose broth (single strength) and 0.1ml of water sample then was added into each of the five bottles containing 10ml of lactose broth (single strength). Durham tube was added to each bottle. The inoculated broths were incubated at 37°C for 24 hours with the bottles loosely capped. Following

incubation, the positive tubes were streaked on already prepared Eosin methylene blue agar for a confirmatory test. The plates were checked for greenish metallic sheen; the results were observed and recorded using Cheesbrough (2000) standards.

Physicochemical analysis of the water sample

The physicochemical parameters of the water samples were determined before and after treatment with *M. oleifera*. The pH, temperature, total dissolved solids (TDS), and conductivity of the water were determined using a multimeter analyzer (HACH, Cloverland), and the values for each of the parameters were recorded (Alo *et al.*, 2012).

Phytochemical analysis of *Moringa* seed extracts

With slight modification to the method of Odeja *et al.*, (2015), the phytochemical

contents of the extract were analyzed for the presence of alkaloids, saponins, tannins, steroids, flavonoids, anthraquinones, and phenol.

RESULTS

Water treatment with dried and macerated seed

The result of the total mesophilic bacteria, total mesophilic fungi, and total coliforms present in untreated borehole and well water is shown in **Figure 1 and 2**. It was observed that total mesophilic bacteria 190×10^1 cfu/mL, total mesophilic fungi 6×10^1 cfu/mL, and total coliforms 2 MPN/mL were recorded in the borehole water while the total mesophilic bacteria 210×10^1 cfu/mL, total mesophilic fungi 10×10^1 cfu/mL, and total coliforms 425 MPN/mL were present in the well water. However, no colony was seen in the untreated bottled water.

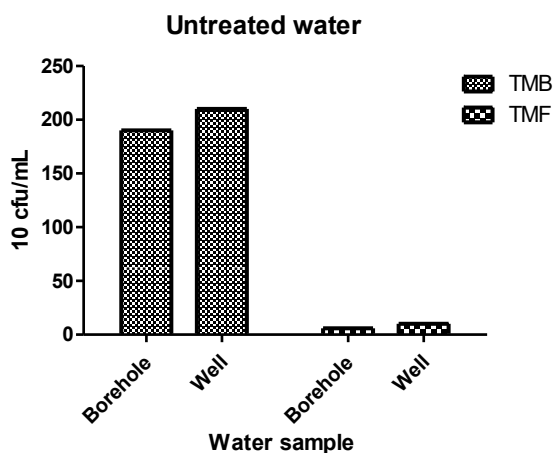


Figure 1: Total mesophilic bacteria and total mesophilic fungi present in untreated water sample

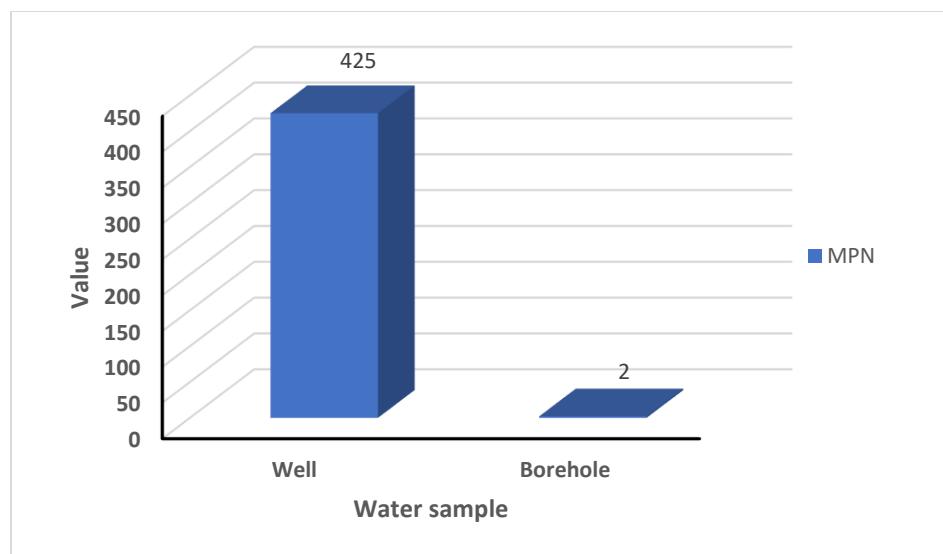


Figure 2: Total coliforms present in untreated water samples

The treatment with different concentrations of dried and macerated *Moringa* seed is shown in Table 1. It was observed that as the concentration of the seed increased in borehole water, there was an increase in the

microbial load of the treated water with time. However, as the concentration of the seed increased in well water, there was variation in the microbial load of the treated well water with time Figure 3.

Table 1: Total mesophilic bacteria (TMB) for borehole water after treatment with *Moringa* dried and macerated seed

Concentration (g/ml)	Treatment					
	Dried seed (10cfu/mL)			Macerated seed (10cfu/mL)		
	Time					
	24hrs	48hrs	72hrs	24hrs	48hrs	72hrs
0.001	200	NTC	NTC	120	NTC	NTC
0.002	240	NTC	NTC	200	NTC	NTC
0.004	NTC	NTC	NTC	NTC	NTC	NTC
0.008	NTC	NTC	NTC	NTC	NTC	NTC

Key: Numerous to count (NTC), colony forming unit (cfu)

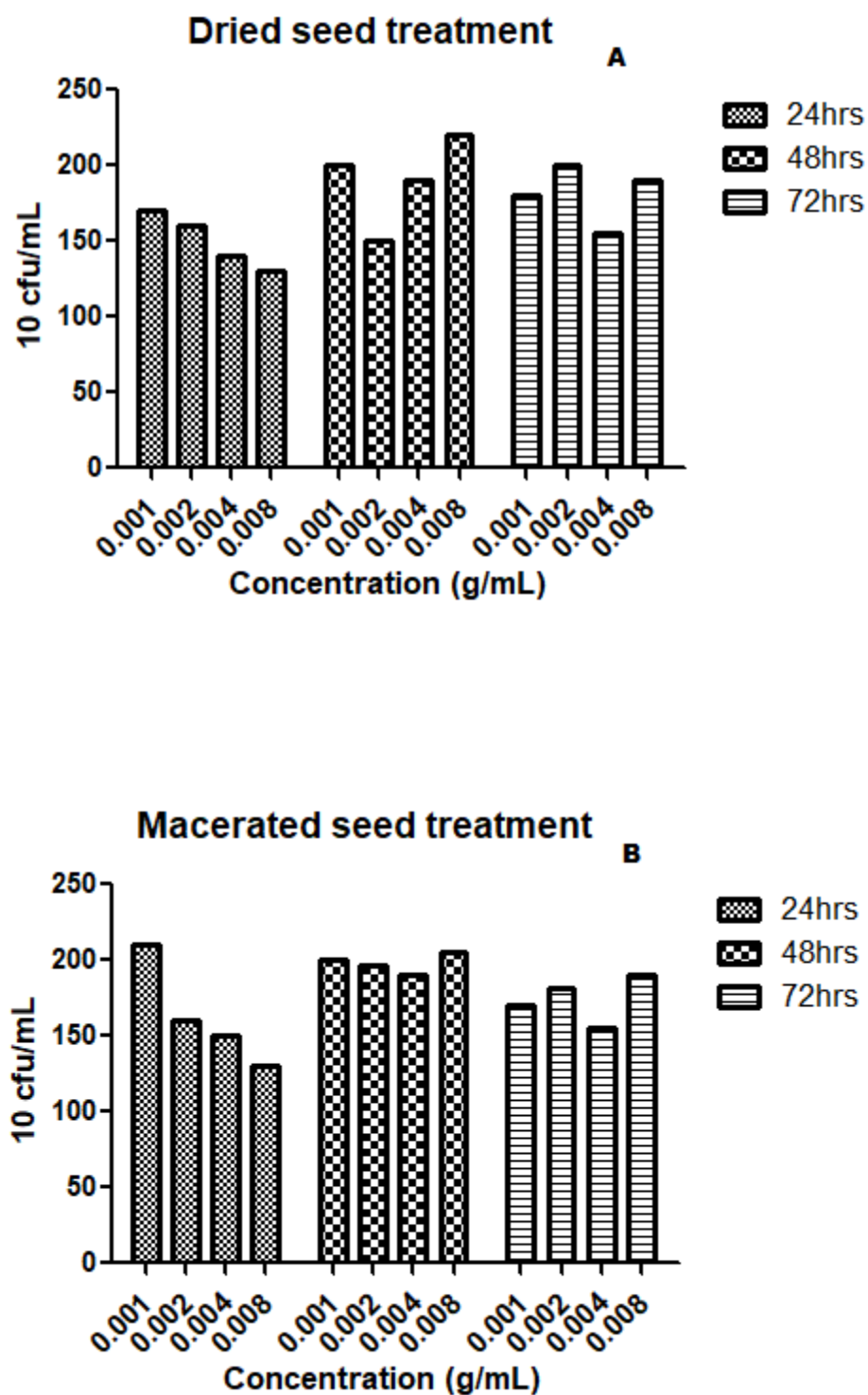


Figure 3: Total mesophilic bacteria (TMB) for well water after treatment with *Moringa* (A) dried seed (B) macerated seed.

The total mesophilic fungi present in the treated borehole water is shown in Table 2. It was observed that as the concentration of the *Moringa* dried and macerated seed increased there was an increase in the fungi load while an increase in the treatment time led to a

decrease in the fungi load. In addition, for well water treatment, as the concentration of *Moringa* dried and macerated seed and treatment time increased, there was an increase in the fungi load Table 3.

Table 2: Total mesophilic fungi (TMF) for borehole water after treatment with *Moringa* dried and macerated seed

Concentration (g/mL)	Treatment					
	Dried seed (10cfu/mL)			Macerated seed (10cfu/mL)		
	TIME					
	24hrs	48hrs	72hrs	24hrs	48hrs	72hrs
0.001	8	0	0	46	0	0
0.002	1	1	0	77	0	1
0.004	0	1	0	27	0	0
0.008	42	1	2	38	0	0

Key: Colony forming unit (cfu)

Table 3: Total mesophilic fungi (TMF) for well water after treatment with *Moringa* dried and macerated seed

Concentration (g/mL)	Treatment					
	Dried seed (10cfu/mL)			Macerated seed (10cfu/mL)		
	TIME					
	24hrs	48hrs	72hrs	24hrs	48hrs	72hrs
0.001	0	0	1	1	17	1
0.002	1	0	1	1	2	1
0.004	1	1	3	1	2	1
0.008	1	5	1	1	5	19

Key: Colony forming unit (cfu)

The total mesophilic bacteria for borehole and well water treated with aqueous and ethanol seed extracts is presented in Table 4 and 5. The table shows that as treatment

concentration and time increase; there is an increase in the microbial load. Chlorine was used as a control and it reduced the microbial load to zero.

Table 4: Total mesophilic bacteria (TMB) after treatments of borehole water with aqueous and ethanol seed extracts.

Concentration (g/ml)	Treatment						Control (10cfu/mL)
	Aqueous Extract (10cfu/mL)			Ethanol Extract (10cfu/mL)			
	TIME						
	24hrs	48hrs	72hrs	24hrs	48hrs	72hrs	No growth
0.05	NTC	NTC	NTC	NTC	NTC	NTC	
0.1	NTC	NTC	NTC	NTC	NTC	NTC	
0.2	NTC	NTC	NTC	NTC	NTC	NTC	
0.4	NTC	NTC	NTC	NTC	NTC	NTC	

Key: Numerous to count (NTC), colony forming unit (cfu)

Table 5: Total mesophilic bacteria (TMB) after treatments of well water with aqueous and ethanol seed extracts.

Concentration (g/ml)	Treatment						Control (10cfu/mL)
	Aqueous Extract (10cfu/mL)			Ethanol Extract (10cfu/mL)			
	TIME						
	24hrs	48hrs	72hrs	24hrs	48hrs	72hrs	No growth
0.05	NTC	NTC	NTC	NTC	NTC	NTC	
0.1	NTC	NTC	NTC	NTC	NTC	NTC	
0.2	NTC	NTC	NTC	NTC	NTC	NTC	
0.4	NTC	NTC	NTC	NTC	NTC	NTC	

Key: Numerous to count (NTC), colony forming unit (cfu)

The result of the total mesophilic fungi for water treated with aqueous and ethanol extract is shown in Table 6 and 7. It was observed that as the concentration and time

of treatment increased, there was an increase in the microbial load in the treated borehole and well water.

Table 6: Total mesophilic fungi (TMF) for borehole water after treatment with aqueous and ethanol seed extracts

Concentration (g/ml)	Aqueous (10cfu/ml)		Treatment		Extract	Control
			Extract	Ethanol (10cfu/ml)		
	TIME					
	24hrs	48hrs	72hrs	24hrs	48hrs	72hrs
0.05	2	0	0	0	3	0
0.1	2	1	0	1	2	3
0.2	11	3	0	1	11	1
0.4	30	60	10	14	NTC	0
No growth						

Table 7: Total mesophilic fungi (TMF) for well water after treatment with aqueous and ethanol seed extracts

Concentration (g/ml)	Treatment						Control	
	Aqueous (10cfu/ml)	Extract			Ethanol Extract (10cfu/ml)			
		TIME						
	24hrs	48hrs	72hrs	24hrs	48hrs	72hrs		
0.05	0	4	10	1	3	1	No growth	
0.1	7	5	11	1	16	6		
0.2	34	47	70	0	18	25		
0.4	52	61	61	36	100	51		

The result of the most probable number (MPN) of the treated water is shown in Table 8. No MPN value was recorded in borehole water with all the treatments and in well water with aqueous and ethanol extract of

Moringa seed. A reduction in the MPN of dried seed treatment 4 MPN/mL and macerated seed treatment 2 MPN/mL was recorded in the well water.

Table 8: Most probable number for borehole and well water after treatment with *Moringa* seed.

	Borehole		Well water	
	Treated	Control	Treated	Control
<i>Moringa oleifera</i>	MPN	MPN	MPN	MPN
Dried seed	0	0	4	0
Macerated seed	0	0	2	0
Aqueous extract	0	0	0	0
Ethanol extract	0	0	0	0

Key: Most probable number (MPN)

The physicochemical analysis of the untreated and treated water samples is presented in Table 9. The pH and temperature reduced after treatment while the

conductivity and total dissolved solids (TDS) increased with dried and macerated treatment but reduced in the seed extracts treatment.

Table 9: Physicochemical analysis of water samples before and after treatment with *Moringa* seed and extracts.

Parameters	Untreated			Treated									
				Dried seed		Macerated Seed	Aqueous Extract		Ethanol extract		Chlorine (control)		
	Bottled water	Borehole	Well water	Borehole	Well water	Borehole	Well water	Borehole	Well water	Borehole	Well water	Borehole	Well water
pH	6.67	7.25	6.91	6.55	5.46	6.42	4.64	7.25	6.6	6.91	6.62	7.44	6.87
Temperature (°C)	26.7	26.9	25.9	25.9	25.2	25.7	25.4	25.1	25.6	25.4	25.7	25.4	25.3
Conductivity (µS)	0.08	0.3	0.11	0.33	0.12	0.38	0.47	0.26	0.08	0.26	0.08	0.33	0.1
Total dissolved solid (ppm)	0.04	0.15	0.05	0.17	0.06	0.19	0.24	0.13	0.04	0.13	0.04	0.17	0.05

The qualitative phytochemical assay of ethanol and aqueous seed extracts is shown in Table 10. The table shows that ethanol seed

extract contains saponins and steroids while the aqueous seed extract contains steroids, flavonoids, alkaloids, and anthraquinones.

Table 10: Qualitative phytochemical assay of ethanol and aqueous seed extracts of *Moringa oleifera*

S/N	Phytochemicals	Ethanol extract	Aqueous extract
1	Alkaloids	—	+
2	Steroid	+	+
3	Flavonoids	—	+
4	Saponins	+	—
5	Tannins	—	—
6	Anthraquinones	—	+
7	Phenols	—	—

DISCUSSION

The result of this study indicated that bottled water is free from microorganisms. Therefore, there is no need for further treatment. The borehole and well (groundwater) water contain microorganisms especially coliforms which makes it unsafe for human consumption and other domestic uses as it could cause gastrointestinal infections and diseases. This result is in agreement with the report of Lar *et al.*, 2011 who reported the presence of some gram-negative bacteria causing gastrointestinal infections.

However, treatment of water with *Moringa* dried, macerated, aqueous, and ethanol extracts (Tables 1, 2, 4, and 5) shows that the total mesophilic bacteria (Tables 1 and 4) of borehole water increased with an increase in the concentration of seed and treatment time while the total mesophilic bacteria for well water after treatment with *Moringa* dried and macerated seed varies with an increase in concentration and treatment time but without any significant changes. The total mesophilic

fungi (Tables 2 and 5) of the borehole and well water were reduced but varied with increasing concentration and treatment time. This result is consistent with the report by Delelegn *et al.*, 2018 who reported that increase in the concentration of the seed leads to an increase in the turbidity of the water. The total fecal coliform (Table 3) after treatment was reduced with borehole water being reduced to zero while well water treated with dried and macerated seed was reduced to 4 MPN/ml and 2 MPN/ml respectively. Seed extracts reduced the total fecal coliform to zero. This result is in agreement with the study by Delelegn *et al.*, 2018 who reported the reduction in the total faecal coliforms using *Moringa* seed. The results presented in this study suggested that *Moringa* seed serves as nutrients for the growth of some bacteria species which increases the microbial load but inhibit the growth of fecal coliforms and fungi. A recent report by Chandrashekar *et al.* (2020) indicated that crude extract and coagulant protein from *Moringa* seeds exhibited cell

aggregation and growth inhibition of six different pathogenic microorganisms including *E. coli* and *Salmonella Paratyphi B* and they attributed this to the presence of peptides with antibacterial property in the *Moringa* seeds. The antibacterial effects of the *Moringa* seed extract observed in the present study could be attributed to its possession of antibacterial proteins or the presence of various phytochemicals with antimicrobial properties in the seeds as reported by Begum et al. (2021). The results from this work indicated that *Moringa* seed solution showed antimicrobial efficacy against coliform bacteria, and fungi count but not for mesophilic bacteria which is in contrast with Alo *et al.*, 2012 which reported that *Moringa* seed extracts reduced the total mesophilic bacteria present in the water sample. Also, the results for total coliforms were in agreement with the report of Babu and Chaudhuri (2015) and fall into the range given by Cheesbrough, 2000 for WHO standards for drinking water. Chlorine used as a control reduces the total mesophilic bacteria, total mesophilic fungi, and total fecal coliforms to zero.

The physicochemical analysis of the treated water (Table 6) shows that there is a reduction in the pH and temperature. Although there is an increase in the conductivity and total dissolved solids but on treatment with seed extracts, there was a reduction in the values. This observation is in agreement with the findings of Shan et al. (2017) who reported an increase in TDS content of water with increasing concentration of *Moringa* seed. Kithaka et al. (2022) reported a significant increase in TDS of water with increased concentration of *Moringa* seed powder and showed the existence of a strong positive relationship between *Moringa* seed coagulant concentration and TDS. The slight decrease in the pH following treatment with *Moringa* seed solution may be due to hydrogen ions of

the weak acidity of the *M. oleifera* solution. These results are in agreement with the report of Alo *et al.*, 2012 that the pH is in line with the standard pH for portable water (6- 8.5).

The phytochemical analysis (Table 7) of the extracts shows that ethanol extracts contain saponin and steroids while aqueous extract contains steroids, flavonoids, alkaloids, and anthraquinones which is in agreement with Fahey, 2005, which reported that alkaloids, flavonoids, saponins were present in the extracts of *M. oleifera* seed. The phytochemicals in the extracts are known to have some antimicrobial properties (Fahey, 2005).

CONCLUSION

This study has successfully revealed that dried, macerated and seed extracts of *M. oleifera* seed possess antimicrobial properties against fecal coliforms and mesophilic fungi though may serve as nutrients for mesophilic bacteria. These extracts could serve as promising natural antimicrobial agents with potential applications in controlling coliform bacteria which are indicators of pathogenic organisms in water samples. The technique is simple and can be used anywhere without high technical assistance. While water purification using chlorine can be very dangerous for human consumption because of its corrosiveness, *M. oleifera* can be cultivated very cheaply at the household level or in small communal nurseries which is to be encouraged in the rural population.

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PHYSICOCHEMICAL PARAMETERS OF HADEJIA-NGURU WETLANDS IN NORTHERN NIGERIA

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ABSTRACT

The study was conducted on some physicochemical parameters of Hadejia-Nguru wetlands in northern Nigeria. The wetlands water samples were collected from four stations: Katuzu (A) and Gada (B) in Gashua; Daban Yan Kifi (C) and Solon (D) in Nguru. Some parameters were measured in situ while others ex situ whereby collected water samples were taken to Chemistry Laboratory in Federal University Gashua, Yobe State for analyses. The data generated were statistically analysed descriptively with mean and standard deviation. Mean water temperature was highest in A ($23.06 \pm 1.87^\circ\text{C}$) and lowest in C ($21.32 \pm 1.03^\circ\text{C}$). Total Dissolved Solids mean values were highest in B with $188.6 \pm 0.51\text{ppm}$ and lowest in A with $88.6 \pm 0.51\text{ppm}$; Dissolved oxygen mean values were maximum in D ($17.0 \pm 0.21\text{mg/l}$) and minimum in A ($8.35 \pm 0.16\text{mg/l}$). Electrical conductivity mean values ranged from 10.0 ± 0.06 to $9.73 \pm 0.36\mu\text{S/cm}$ in C and B respectively. pH values ranged from 7.23 ± 0.35 to 9.85 ± 0.51 in D and A respectively. Chloride and phosphate had highest mean values with $18.7 \pm 0.02\text{mg/l}$ and $1.46 \pm 0.01\text{mg/l}$ in B and A respectively while had lowest mean values with $9.03 \pm 0.01\text{mg/l}$ and $0.27 \pm 0.02\text{mg/l}$ in C and D respectively. Total Hardness had mean values ranging from 8.83 ± 0.05 to $12.5 \pm 0.17\text{ppm}$ in A and B respectively while turbidity mean values ranged from 0.01 ± 0.00 to 2.27 ± 3.29 in D and A respectively. The physicochemical parameters of Hadejia-Nguru wetlands were within tolerable limits to fish and other aquatic organisms. Therefore, it is recommended that earthen ponds should be constructed close to the wetlands in order to boost aquaculture production of the area.

Keywords: Gashua, Total Hardness, Electrical Conductivity, Hadejia-Nguru Wetlands, Turbidity, pH, TDS, DO

INTRODUCTION

Water is very important to the aquatic organism including fish for survival, growth,

excretion, nutrition and reproduction. Water is one of the most important and abundant compounds of the ecosystem. All living

organisms on earth need water for their survival and growth (Bronmark and Hasson, 2005). Fisheries support significantly the provisions of Food with relatively cheap animal protein, job opportunities and other socioeconomic benefits for individuals and society at large, thereby making them inevitable resources to humanity. Aquaculture production is rising in comparison to artisanal sources, and between 2007 and 2017, it accounted for 22% of all domestic fish production (FAO, 2018). Demand for fish in Nigeria exceeds its supply with domestic production being very low compared to the rate of human population growth (Dadi-Mahmud et al., 2014).

Aquatic productivity might seemingly unlimited, however, it was realized with the increasing knowledge of the dynamics of fisheries and development of aquaculture that living aquatic resources are not infinite rather are renewable within certain rate thereby requiring proper management for sustainability (Yusuf and Abdulkatim, 2015; Ekpo et al., 2016; Yusuf, 2017; Nababa et al., 2024). Water quality affects the general condition of culture organisms as it determines the health and growth condition of culture organisms; quality of water is therefore an essential factor to be considered when planning for aquaculture production. Although the environment of culture fish is a complex system, consisting of several water quality variables, however, dissolved oxygen is more important and critical parameter requiring continuous monitoring in aquaculture production system (Timmons et al., 2004; Abdulkarim and Yusuf, 2015).

According to Omitoyin (2007) fish respond to varying degrees of water quality; for instance, *Clarias spp.* can survive in poor quality of water while sensitive species like tilapia and carp cannot; hence, regular monitoring of water quality parameters is very important in any fish farm or aquatic ecosystem. Water quality can be assessed by

various physiochemical and biological factors, as they may directly or indirectly affect its quality and consequently its suitability for the distribution and production of fish and other aquatic fauna (Abdulkarim and Lamai, 2012) these in turn do affect the aquatic biodiversity (Abdulkarim et al., 2019).

Many workers have reported the status of water bodies (lentic and lotic) after studying various kinds of pollutants altering water quality characteristic (physical, chemical and biological) (Abubakar et al., 2024). All living organisms have varying tolerable limits specific parameter of water quality and they have range within which they perform optimally. A sharp drop or an increase of the limit has adverse effect on their body function (Davenport, 1993).

Hadejia-Nguru wetlands cover much area and the hydrological system passes through many prominent cities in northern Nigeria serving many purposes such as fishing and drinking for many people. Preliminary survey before the commencement of this research revealed that some commercially important fish species in the wetlands include *Oreochromis niloticus*, *Clarias gariepinus*, *Labeo cubae labeo*, *senegalensis* and *Heterotis niloticus*. Therefore, this makes the water body important to investigate its water quality parameters such as temperature, turbidity, total dissolved solid, pH, hardness and dissolved oxygen (D.O). Hence, this study is aimed at determining some aspects of the physicochemical parameters of Hadejia-Nguru wetlands in northern Nigeria for the purpose of exploring the aquaculture potentials of the wetlands.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in Hadeja, Gashua and Nguru wetlands of northern Nigeria. It is commonly called Hadejia-Nguru

Wetlands. Nguru is a community in Yobe State in north-eastern Nigeria while Gashua wetland is few miles below the convergence of the Hadejia River and the Jama'are River in Bauchi State. Average elevation of the two Local Government Areas (LGA) were approximately 450 meters (1,480 feet) above sea level. The population of Nguru is 150,632. The two hottest months with average highs of 38 – 40°C are March and April. Temperatures drop to 23 – 28°C

during the rainy season which is from June to September, and there is 500 – 1000mm of rainfall. The area is located approximately between latitudes 12°52'-13°45'N and longitudes 10°27'-12°09'E of the equator, it with land area of 916km². It is bounded to the north by Karasuwa LGA, to the south by Machina LGA and to the west by Bade LGA. Nguru is located along Gashua-Kano Road (NIPOST, 2009). Figure 1 elucidates further.



Figure 1: Map of Yobe State showing Hadejia, Nguru and Gashua (Hadejia-Nguru) Wetlands in Northern Nigeria

Source; Goggle Map

Sampling Techniques

Water Sample

Water samples were collected weekly from January to March, 2024 in the morning (8:00am – 11:00am). Four stations were sampled: Katuzu (A) and Gada (B) in Gashua; Daban Yan Kifi (C) and Solon (D) in Nguru. The Sampling materials were labelled according to the name of sampling point and 3 replications for each sample of water collected.

Analysis of Water Sample

The equipment's and instruments used in this study were all calibrated. The glasses were rinsed with nitric acid and distilled water (deionized water). Physicochemical parameters such as temperature, turbidity, pH were analysed on the field while Dissolve Oxygen, Total Hardness, Chloride, Phosphate of the water were analysed in the Chemistry Laboratory, Federal University Gashua using LaMotte aquaculture kit and Spectrometer while Total Dissolve Solids and Electric Conductivity were done using digital

meter. The analyses were done based on the works of Itah (1994).

Temperature

The temperatures of the samples were taken, using a thermometer. The bulb of the thermometer was dipped into the water sample in a beaker and allowed to stand for some minute before the reading was taken.

Electric Conductivity (EC) and Total Dissolved solids (TDS)

Electrical Conductivity Meter (Model: Hanna Instrument H18733) was used. The EC meter probe was rinsed with distilled water and inserted into the sample in a beaker, conductivity reading was displayed. Same meter was used to determine Total Dissolved Solids.

pH

The pH was determined with a pH meter (Model: Mettler Toledo Mp 220). The pH meter probe was inserted into the water sample in a beaker, the READ key was pressed and the pH reading was taken (Itah,1994).

Turbidity

The sample was placed in the turbidimeter bottle and the bottle wiped clean with a cloth to erase any finger print that may affect the reading. The bottle was then placed on the turbidimeter and the READ key pressed, the turbidity reading was displayed.

Dissolved Oxygen

The dissolved oxygen was determined using ALPHA (2010) method. A reaction cell was filled to overflow and 1 glass bead was added into it. Oxygen reagent O₂-1k was added (5 drops). Another 5 drops of oxygen reagent O₂-2k were added and mixed for 10 seconds. Lastly 10 drops of oxygen reagent O₂-3k was added mixed and dissolved oxygen value read out in the spectrophotometer at a wavelength of 498 nm.

Total Hardness

One mL of the sample was placed in a reaction cell and 1mL of total hardness reagent H-1k added with a pipette. Three minutes' reaction time was allowed before total hardness was determined in spectrophotometer at a wavelength of 450 nm.

Chloride

5mL of the water sample was placed in a test tube and 2.5mL of chloride reagent Cl-1 was added and mixed. Chloride reagent Cl-2 was also added, shaken and allowed to stand for 1 minute before reading out the chloride concentration from the spectrophotometer at a wavelength of 460 nm.

Phosphate

5mL of the water sample was placed in a test tube and 0.5mL of the phosphate reagent PO₄-1A added to it and mixed. This was followed by the addition of 1 level spoonful of phosphate reagent PO₄-2A. 5minutes reaction time was allowed before reading out the phosphate concentration at a wavelength of 420 nm.

Statistical Analysis

Data were analysed using descriptive statistics to obtain mean and standard deviation.

RESULTS AND DISCUSSION

This study, was carried out on the Hedajia-Nguru wetlands' water that pass through Gashua with two stations: Katuzu and Gada and Hadejia-Nguru passing through Nguru with two stations too – Daban Yan Kifi and Solon. Table 1 revealed the physicochemical parameters of the water of wetlands of Hadejia-Nguru having range of mean temperature from 21.32±1.03 to 23.06±1.87°C. The water temperature recorded in Hadejia-Nguru wetlands falls within the permissible limit for freshwater fish farming in tropical regions as recommended by the Ornamental

Aquaculture Trade Association [OATA] (2008). Also, Boyd (1990) and Apollos et al. (2016) reported that the ideal temperature range for warm-water fish growth is 25 to 32°C. Although the temperature in this

study is slightly below 25°C but the upper limit of the standard deviation is approximately 25°C ($23.06 + 1.87^\circ\text{C} = 24.93^\circ\text{C}$).

Table1: Physicochemical Parameter (Mean $\pm$ Standard Deviation) of Water of Hadejia-Nguru Wetlands

Samp ling Locat ion	Temper ature [°C]	pH	Turbi dity	Electric al Conduct ivity ($\mu\text{S}/\text{cm}$)	Total Dissol ved Solid (ppm)	Dissol ved Oxyg en (mg/l)	Total Hard ness (ppm)	Chlor ide (mg/l)	Phosp hate [PO ₄] (mg/l)
Gash ua									
Katuz u	23.06 $\pm$ 1. 87	9.85 $\pm$ 0.51	2.27 $\pm$ 3.29	10.0 $\pm$ 0.0 04	88.6 $\pm$ 0. 51	8.35 $\pm$ 0.16	8.83 $\pm$ 0.05	16.1 $\pm$ 0.1	1.46 $\pm$ 0. 01
Gada	22.93 $\pm$ 1. 62	7.57 $\pm$ 0.29	0.16 $\pm$ 0.10	9.73 $\pm$ 0.3 6	124.8 $\pm$ 1.73	9.25 $\pm$ 0.37	12.5 $\pm$ 0.17	18.7 $\pm$ 0.02	1.311 $\pm$ 0.01
Ngur u									
Dabar Yan Kifi	21.32 $\pm$ 1. 03	8.23 $\pm$ 0.07	0.87 $\pm$ 0.64	10.0 $\pm$ 0.0 6	106.1 $\pm$ 1.03	8.46 $\pm$ 0.09	10.6 $\pm$ 0.09	9.03 $\pm$ 0.01	0.64 $\pm$ 0. 04
Salon	22.62 $\pm$ 3. 38	7.23 $\pm$ 0.35	0.01 $\pm$ 0.00	10.0 $\pm$ 0.0 0	118.2 $\pm$ 0.46	17.0 $\pm$ 0.21	11.8 $\pm$ 0.05	9.87 $\pm$ 0.01	0.27 $\pm$ 0. 02

The turbidity of water of Hadejia-Nguru wetlands ranged from 0.01 $\pm$ 0.00 to 2.27 $\pm$ 3.29 in Solon and Katuzu respectively which is relatively low and is an indication of high penetration of light that promotes primary productivity of the ecosystem through photosynthesis. Hence the wetlands Total dissolved solids (TDS) correlates with electrical conductivity; electrical conductivity means of Hedajia-Nguru ranged from 10.0 $\pm$ 0.06 to 9.73 $\pm$ 0.36 $\mu\text{S}/\text{cm}$ while Total Dissolved Solids mean values were from 188.6 $\pm$ 0.51 to 88.6 $\pm$ 0.51ppm. However, according to Anago et al. (2013) and Abdullahi and Abolude (2006) electrical conductivity values below 50 $\mu\text{S}/\text{cm}$ are considered low; from 50 to 600 $\mu\text{S}/\text{cm}$ are considered medium and above 600 $\mu\text{S}/\text{cm}$ are

are reach in primary producers that are fundamentals to food chain and webs. However, the relatively low turbidity might be due to the fact that the study was conducted during dry season as turbidity is usually relatively higher in rainy season.

considered high, subsequently, the values in this study could be considered low.

pH values ranged from 7.23 $\pm$ 0.35 to 9.85 $\pm$ 0.51 in Solon and Katuzu respectively. The mean pH values from Zobe reservoir were within the range of 5.90 ± 0.497 to 9.00 ± 0.497 as reported by Nababa et al. (2024). Scheffer (2006) recommended pH range of 6.0 – 9.0 for aquatic life. The results of this study also corroborate with that of Apollos et al. (2016) who also reported similar results from Zobe reservoir and as well were in

conformity with the findings of Abdulkarim and Lamai (2012) who reported pH ranging from 5.8 to 9.0 in Gubi Dam, Bauchi State. In same trend, Ibrahim et al. (2009) reported pH range from 6.5 to 8.5 in Kontagora reservoir, Niger state, Nigeria.

Dissolved Oxygen (DO) mean values were maximum in Solon ($17.0 \pm 0.21 \text{ mg/l}$) and minimum in Katuzu ($8.35 \pm 0.16 \text{ mg/l}$). DO is the most important parameter of water quality for living organisms due to essentiality of oxygen in respiration. Utang and Akpan (2012) recommended a concentration level of DO of at least 5 mg/l as being desirable, lower values can cause stress to the fish while less than 2mg/l is lethal capable of causing death. The annual DO values from 6.00mg/L to 8mg/L were reported by Nababa et al. (2024) for Zobe reservoir. The DO in this study are relatively high which is a good index of favourable condition for aquatic living organisms in Hadejia-Nguru wetlands. DO could determine the spatiotemporal distribution of aquatic fauna amongst other factors (Abdulkarim et al., 2020).

Other parameters include Chloride and phosphate which had highest mean values of $18.7 \pm 0.02 \text{ mg/l}$ and $1.46 \pm 0.01 \text{ mg/l}$ in Gada and Katuzu respectively and had lowest mean values of $9.03 \pm 0.01 \text{ mg/l}$ and $0.27 \pm 0.02 \text{ mg/l}$ in Daban Yan Kifi and Solon respectively. Total Hardness had mean values ranging from 8.83 ± 0.05 to $12.5 \pm 0.17 \text{ ppm}$ which fall within acceptable ranges based on recommendations of OATA, (2008).

CONCLUSION

Most of the physicochemical parameters: temperature, turbidity, total dissolve solid, pH, hardness, dissolved oxygen, electric conductivity, Chloride and Phosphate analysed were within tolerable ranges for aquatic organisms across Hadejia-Nguru wetlands within the period of study.

RECOMMENDATION

Earthen ponds may be constructed around these wetlands in order to boost fish production potential of the area as aquaculture will complement the capture fisheries for greater yields and enhanced sustainability.

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IN VITRO STUDIES ON NITROGEN FIXATION AND CARBON SEQUESTRATION TRENDS OF *Bradyrhizobium japonicum*

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ABSTRACT

The urgent need to address climate change, fueled by greenhouse gas (GHG) emissions, underscores the importance of mitigation strategies. *Bradyrhizobium* species contribute significantly to ecosystem health through their dual role in carbon sequestration and biological nitrogen fixation, leveraging nitrogenase to convert atmospheric nitrogen into ammonia. This study investigated the nitrogen fixation and carbon sequestration potential of *Bradyrhizobium japonicum*, a nitrogen-fixing bacterium that forms symbiotic relationships with soybean plants. The results showed significant increases in ammonium nitrogen and total organic carbon (TOC) contents in inoculated soil samples compared to controls at (24, 48, 72, 96, 120 and 144) hours respectively. Notably, the highest ammonium nitrogen production was recorded at 120 hours, with inoculated samples (7.41 ± 0.03) outperforming controls (4.64 ± 0.01) at ($p \leq 0.05$). TOC contents peaked at 96 hours in controls (2.12 ± 0.02) and continued to increase at inoculated samples reaching a maximum at 144 hours (3.99 ± 0.02). These findings suggest that *B. japonicum* enhances soil nutrient availability and carbon sequestration, making it a promising candidate for soil rehabilitation programs, particularly in nitrogen-deficient and degraded soils.

Keywords: Biofertilizer, Climate change, Ecosystem restoration, Nutrient cycling, Symbiosis.

INTRODUCTION

Nitrogen fixation, facilitated by the symbiotic relationship between plants and *Bradyrhizobium*, is a crucial process for plant growth and development, ranking in importance just after photosynthesis. This process involves the formation of nodules on plant roots, particularly in leguminous plants such as soybeans, Bambara groundnuts amongst others thereby, enhancing nitrogen availability and contributing to agricultural productivity (Kamiya and Weber, 2024). These bacteria can transform atmospheric nitrogen (N_2) into plant-usable forms, including ammonia (NH_3) and nitrate (NO_3^-), making this essential nutrient available to plants (Chaudhary et al., 2022; Kimball, 2022; Dolla et al., 2023). The nitrogen-fixing capability of *Bradyrhizobium* species is mediated by the enzyme nitrogenase, which

catalyzes the ATP-dependent reduction of atmospheric nitrogen (N_2) to ammonia (NH_3), a critical step in biological nitrogen fixation (Britto and Kronzucker, 2002). A plethora of literature through genomotaxonomic view of *Bradyrhizobium* species further established the fact that mutualistic interactions exist between *Bradyrhizobium* species and leguminous plant roots, enabling the fixation of atmospheric nitrogen and enhancing soil fertility (Chhetri et al., 2019; Ormeño-Orrillo and Martínez-Romero, 2019). The capacity of these bacteria to fix nitrogen yields multifaceted benefits for plants, ranging from enhanced growth and productivity to stress tolerance (Zahran, 1999; Graham and Vance, 2003; Fahde et al., 2023). Inoculation of degraded soil with *Bradyrhizobium japonicum* can stimulate autonomous nitrogen fixation, leveraging

the bacterium's inherent capacity to convert atmospheric nitrogen into bioavailable forms (Zveushe et al., 2023). This process, although less efficient than symbiotic nitrogen fixation, can augment soil nitrogen pools, enhancing fertility and potentially supporting subsequent plant growth. The effectiveness of this approach is contingent upon various factors, including soil properties and the specific *B. japonicum* strain employed.

The rapid increase in greenhouse gas (GHG) emissions is precipitating climate change, highlighting the urgent need for effective mitigation measures to stabilize the climate system (Hannam, 2024). Carbon sequestration plays a critical role in climate change mitigation by capturing and storing atmospheric carbon dioxide (CO₂), thereby attenuating its accumulation and associated climate impacts (Benson and Surles, 2006; Nazir et al., 2024). Soil carbon sequestration has emerged as a key strategy in sustainable agriculture, offering a range of benefits including climate regulation through carbon storage, soil fertility enhancement, as well as, improved agricultural productivity and resilience (Metz et al., 2005; Nazir et al., 2024). Growing awareness of agriculture's environmental footprint has sparked interest in soil carbon management, with soil organic carbon being a key determinant of soil health, structure, fertility, water retention and overall ecosystem function (Lal, 2015; Madubuike et al., 2023; Hannam, 2024). The sequestration of carbon in forests and other ecosystems contributes to the preservation of biodiversity, as these ecosystems sustain a wide range of flora and fauna, enhancing ecosystem complexity and function (Lal, 2018; Yin et al., 2023; Weiskopf et al., 2024). Our study examined the nitrogen-fixing and carbon-sequestering abilities of *Bradyrhizobium japonicum* in inoculated soil samples over 140 hours, providing insights into its potential applications in sustainable agriculture and ecosystem restoration.

MATERIALS AND METHODS

Study Area

This study was conducted at the Federal University of Technology, Owerri, Imo State, Nigeria, situated at 73 meters above sea level (latitude 5°39' N, longitude 7°00' E). The region's climate is tropical humid, with a bimodal rainfall pattern and distinct wet (April to October/November) and dry (December to March) seasons. The area receives significant rainfall, averaging 2500 mm annually, with varying humidity levels and a mean temperature of around 29°C, supporting a lush, rainforest-like ecosystem.

Sample Collection and Sample Processing

Between October and November 2024, soil samples were collected from twenty-five different points at a depth of 4 inches in FUTO farms using a sterilized soil auger. The samples were aseptically transferred to sterile plastic containers and transported to the laboratory within one hour for analysis. To prepare the samples, they were air-dried to reduce moisture content and filtered to remove large particles and debris, ensuring a uniform sample for further analysis.

Isolation Procedure:

Bradyrhizobium japonicum was isolated from soil samples following Gault and Schwinghamer's (1993) protocol. Soil suspensions were serially diluted, inoculated into Jensen's medium and incubated. Turbid cultures were plated on Jensen's agar, and pure isolates were obtained for further analysis.

Characterization of Bacterial Isolates

Bacterial isolates were characterized using various morphological and biochemical tests, including gram staining, catalase, oxidase, phosphate solubilization and carbohydrate fermentation tests. The isolates were then identified according to Bergey's Manual of Determinative Bacteriology, 9th edition (Holt et al., 1994).

Determination of Colony Forming Units (CFU)

Bradyrhizobium japonicum was isolated on Jensen agar medium and the number of colonies formed was enumerated. The average number of colony-forming units (CFU) per millilitre was calculated using the formula outlined by APHA (2017):

CFU/ml = (Number of colonies x Dilution factor) / Volume of inoculum

Preparation of 0.5 McFarland Turbidity Standard

A 0.5 McFarland turbidity standard was prepared by mixing approximately 0.5 g of commercial McFarland standard powder with 99.5 mL of distilled water. The mixture was homogenized using a vortex mixer and its turbidity verified by measuring absorbance at 625 nm using a spectrophotometer, as described by CLSI (2020).

Establishment of Soil Microcosms

Following the protocol of Bashan et al. (2014), 500 g of degraded soil was sterilized, adjusted to optimal moisture and inoculated with 10 mL of 0.5 McFarland standard inoculum. The samples were then incubated at 28°C and 60% humidity for 7 days and analyzed in triplicates at 24-hour intervals over 6 days to assess microbial activity.

Determination of Ammonium Nitrogen

Soil samples were extracted with 2 M potassium chloride (KCl) solution, followed by centrifugation at 10,000 rpm for 10 minutes. The resulting supernatant was analyzed for ammonium nitrogen using spectrophotometry at 630 nm, with results expressed in mg/kg, based on the method by Carter and Gregorich (2007).

Determination of Total Organic Carbon (TOC)

According to the method adapted from Nelson and Sommers (1996), soil samples were treated with potassium dichromate (K₂Cr₂O₇) and sulphuric acid (H₂SO₄) to

oxidize organic carbon. After heating and cooling, ferrous sulphate (FeSO₄) was added. The resulting solution was then analyzed using spectrophotometry at 590 nm to determine total organic carbon (TOC) content, which was expressed as a percentage using a standard calculation formula:

TOC (%) = Absorbance of sample / Absorbance of standard x Concentration of standard / Sample weight x 100

Statistical Analysis

All data samples from each experimental group, in triplicate, were analyzed statistically using one-way analysis of variance (ANOVA) with Minitab 2017. The means were separated using Dunnett's multiple comparison test at a significance level of $p \leq 0.05$. Results were presented as mean $\pm$ standard deviation (SD).

RESULTS AND DISCUSSION

The bacterial growth enumeration results (Table 1) yielded an average count of 6.4×10^5 CFU/mL, based on triplicate colony counts from the second dilution factor, which had the highest number of countable colonies. The colonies, measuring 1-3 mm in diameter, reached maximum size within 6-8 days and were characterized by their cream-colored, mucoid, circular, convex, and smooth appearance. Biochemical tests (Table 2) confirmed the isolate as *Bradyrhizobium japonicum*, exhibiting the following characteristics: gram-negative, rod-shaped, microaerophilic, and fermentative. The strain tested positive for catalase, oxidase, motility, ornithine decarboxylase, and glucose utilization, but negative for phosphate solubilization and urease activity. Results from this study showed smooth, round and mucoid colonies, which is indicative of the production of extracellular polysaccharides. This mucoid characteristic is essential for the bacterium's ability to form biofilms and establish effective nodules on plant roots. The presence of a single polar flagellum or multiple lateral flagella indicated that

Bradyrhizobium japonicum is motile, which is important for its ability to colonize plant roots and establish symbiotic relationships. The growth characteristics of *Bradyrhizobium japonicum* indicated that it has a relatively slow growth rate, with a generation time of around 2-4 hours. This growth rate is consistent with other *Bradyrhizobium* species. The optimal growth conditions for *Bradyrhizobium japonicum* are consistent with the physiological characteristics, with optimal growth occurring at temperatures between 28-30°C and pH values between 6.5-7.5.

The catalase production test of *Bradyrhizobium japonicum* showed positive result which is adjacent to the Rhizobial isolates of alfalfa as in the biochemical characterization performed by Shahzed et al. (2012). It means that the

Rhizobial isolates of the present study contain the catalase enzyme which decomposes the hydrogen peroxide to release oxygen. This conformed that the *Bradyrhizobium japonicum* is the cytochrome containing aerobic bacteria as described by Chhetri, Subedee and Pant (2019), that *Rhizobia* are aerobic bacteria utilizing oxygen as the terminal electron acceptor. This bacterium's ability to fix nitrogen through its symbiotic relationship with legumes contributes significantly to soil nitrogen levels, especially in degraded soils, where nitrogen is often a limiting factor for plant growth. The morphological and biochemical results confirmed that the isolated strain possessed the necessary traits to enhance soil fertility and promote plant growth in nitrogen-depleted environments.

Table 1: Growth Enumeration Chart of *Bradyrhizobium japonicum*.

Sample dilution used	Volume of inoculum (ml)	Colony counts				Colony forming unit (CFU)/ml	Colony morphology			
		1	2	3	Mean		Size mm	Shape and Surface	colour	Others
10 ⁻²	0.01	54	66	72	64	6.4 x 10 ⁵ CFU/ml	1-3	circular, convex and smooth	cream	mucoid

Table 2: Microbial Characterization Chart of *Bradyrhizobium japonicum*.

Test	Result
Pigmentation	Cr
Gram/Shape	-/R
Spores	-
Motility	+
Oxygen utilization	µA
Catalase	+
Oxidase	+
Acid from glucose	+
CHOs attack [F/O/-]	F

Indole	-
Phosphate solubilization	-
Ornithine decarboxylase	+
Urease	-
Gas from Glucose	+

Cr = cream, R = rod, μ A = microaerophilic, F = fermentative, O = oxidative, (+) = positive, (-) = negative

Table 3 shows a moderate but significant increase in ammonium nitrogen levels in soil samples inoculated with *B. japonicum* (2.80 ± 0.02) compared to control samples (2.16 ± 0.02) within 24 hours ($p \leq 0.05$). This trend continued, with significant increases observed at 48, 72, 96, 120, and 144 hours. The highest ammonium nitrogen levels were recorded at 120 hours in both control (4.64 ± 0.01) and inoculated samples (7.41 ± 0.03). However, a moderate decrease was observed in both groups at 144 hours. Notably, the ammonium nitrogen content in inoculated samples consistently exceeded that of their control counterparts. The experiment began with degraded soil samples exhibiting low levels of ammonium nitrogen, characteristic of nutrient-poor soils. This was likely due to limited organic matter and insufficient nitrogen-fixing organisms. However, soils treated with *Bradyrhizobium japonicum* showed a significant increase in ammonium nitrogen content over time. This increase can be attributed to *B. japonicum*'s nitrogen-fixing ability, which converts atmospheric nitrogen into a plant-available form.

Our findings align with previous research, such as Gitonga et al. (2021), which demonstrated the benefits of *Bradyrhizobia* inoculation in promoting soybean growth. Similarly, Bitire (2022) found that *B. japonicum* inoculation outperformed

nitrogen fertilizer application in enhancing plant growth and yield. These results validate *B. japonicum*'s potential for sustainable agriculture.

The experiment's different phases revealed distinct patterns in nitrogen fixation. During the initial phase (24-48 hours), control soil samples showed minimal nitrogen fixation, whereas *B. japonicum*-inoculated soils exhibited a moderate increase. As the experiment progressed, particularly at the exponential phase (48-96 hours), the inoculated soils continued to show higher levels of ammonium nitrogen, indicating increased nitrogen fixation.

Our results are consistent with Saranraj et al. (2021), who reported significant nitrogen fixation by *B. japonicum*. Additionally, Zveushe et al. (2023) demonstrated the benefits of co-inoculation with *B. japonicum* and *Saccharomyces spp.* in enhancing nitrogen fixation and soil health.

The stationary phase (120-144 hours) saw a slight decrease in ammonium nitrogen content, potentially due to nutrient depletion and waste accumulation. Nevertheless, *B. japonicum*-treated soils maintained higher levels of ammonium nitrogen compared to control soils. These findings highlight *B. japonicum*'s potential to enhance soil fertility and promote plant growth in degraded environments.

Table 3: Ammonium Nitrogen contents of degraded soil samples

AMMONIUM NITROGEN (mg/kg)						
SAMPLE	HOURS					
	24	48	72	96	120	144
C	2.16±0.02 ^a	2.53±0.15 ^a	3.54±0.02 ^a	4.47±0.07 ^a	4.64±0.01 ^a	3.76±0.02 ^a
I	2.80±0.02	3.46±0.02	5.47±0.02	6.98±0.04	7.41±0.03	7.19±0.06

C = Control soil, I = Inoculated soil. Values are mean ± standard deviation from triplicates. Means not labelled with the letter “a” are significantly different from the control level means across the columns of each time interval at ($p \leq 0.05$).

Table 4 exhibited a minimal but significant increase in total organic carbon (TOC) content in soil samples inoculated with *B. japonicum* (1.48 ± 0.01) compared to control samples (1.29 ± 0.02) within 24 hours ($p \leq 0.05$). Significant increases in TOC were observed in inoculated samples at 48, 72, 96, 120, and 144 hours compared to controls. The control samples peaked at 96 hours (2.12 ± 0.02), then declined slightly at 120 hours (1.85 ± 0.02) and 144 hours (1.64 ± 0.04), whereas inoculated samples reached their highest TOC content at 144 hours (3.99 ± 0.02), with the lowest content at 24 hours (1.48 ± 0.01). The inoculation of soil samples with *Bradyrhizobium japonicum* significantly enhanced total organic carbon (TOC) levels compared to control samples across various time intervals (24-144 hours). During the initial lag phase (24-48 hours), the inoculated cells adapted to the environment, and metabolic activities gradually increased, resulting in lower TOC levels. As the cells entered the exponential phase (48-96 hours), their metabolic activities, including carbon sequestration, accelerated, leading to a

notable increase in TOC levels in inoculated samples.

Notably, during the stationary phase (120-144 hours), control samples exhibited a slight decline in TOC levels, whereas inoculated samples displayed a significant rise in TOC, peaking at 144 hours. This increase can be attributed to the production of extracellular polymeric substances (EPS) and exopolysaccharides by *B. japonicum*, which improves soil structure, aeration, and water-holding capacity, creating a favorable environment for carbon sequestration (Costa et al., 2018; Bhattacharyya et al., 2022).

The symbiotic relationship between *B. japonicum* and plant roots also enhances organic carbon production through root exudates and decaying plant matter (Zahran, 1999; Franche et al., 2009). Our findings underscore the potential of *B. japonicum* to enhance soil fertility and promote sustainable agriculture practices, consistent with research on elevation's indirect effects on carbon sequestration in a forest ecosystem (Ali et al., 2023).

Table 2: Total Organic Carbon (TOC) contents of degraded soil samples

TOTAL ORGANIC CARBON (%)						
SAMPLE	HOURS					
	24	48	72	96	120	144
C	1.29±0.02 ^a	1.37±0.04 ^a	1.48±0.02 ^a	2.12±0.02 ^a	1.85±0.02 ^a	1.64±0.04 ^a
I	1.48±0.01	2.12±0.03	2.60±0.01	3.23±0.03	3.64±0.03	3.99±0.02

C = Control soil, I = Inoculated soil. Values are mean ±standard deviation from triplicates. Means not labelled with the letter “a” are significantly different from the control level means across the columns of each time interval at ($p \leq 0.05$).

CONCLUSION

Our investigation into *Bradyrhizobium japonicum*'s capabilities revealed its substantial potential for nitrogen fixation and carbon sequestration, providing valuable insights into its role in restoring soil health, particularly in degraded ecosystems. Characterization of *B. japonicum* confirmed its identity as a nitrogen-fixing bacterium that forms symbiotic relationships with leguminous plants, thereby enhancing soil nitrogen levels. Our study demonstrated that *B. japonicum*'s inoculation significantly increased ammonium nitrogen and total organic carbon in degraded soils, indicating its contribution to nutrient accumulation and carbon storage. These findings further suggested that *B. japonicum* can improve soil fertility, promote long-term sustainability, and reduce reliance on synthetic fertilizers. Therefore, our results position *B. japonicum* as a promising tool for soil rehabilitation, especially in nitrogen-deficient areas. By harnessing its natural ability to enhance soil fertility, we can promote sustainable agricultural practices and environmental conservation. This study provides a foundation for further research on optimizing *B. japonicum*'s use

and exploring its broader applications in soil health management and crop production.

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ECO/PH25/EAC15**IMPACT OF CLIMATE CHANGE ON WETLAND FOREST PATHOGENS AND BIOGEOCHEMICAL CYCLES: IMPLICATIONS FOR PLANT HEALTH, ECOSYSTEM RESILIENCE, AND SOCIOECONOMIC SUSTAINABILITY.**

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ABSTRACT

Wetland ecosystems provide vital services, including carbon sequestration, water filtration, and biodiversity support. However, they are increasingly threatened by climate change, which alters both pathogen dynamics and biogeochemical processes within these ecosystems. This review explores the dual impacts of climate change on wetland forest pathogens and methane emissions from wetland trees. We examine the genetic responses of wetland plants to disease stress, the role of volatile organic compounds (VOCs) and methane (CH₄) emissions in these ecosystems, and the implications for plant health and ecosystem resilience. Additionally, the socioeconomic consequences of disease outbreaks and methane flux in wetland systems are discussed, with a focus on strategies for enhancing sustainability through integrated management and restoration approaches. Understanding these complex interactions is crucial for developing effective conservation policies and mitigating climate-driven risks to wetland forests.

Keywords: Ecosystem, Wetland conservation, Methane, Volatile organic compounds (VOCs), Global warming.

ECO/PH25/WBC04**EVALUATION OF MANGROVE SPECIES - *Nypa fruticans* WURMB FRUIT AS BIO-FERTILIZER****Ejims, Cynthia Ifeoma and Okonwu, Kalu****Department of Plant Science and Biotechnology, University of Port Harcourt, Port Harcourt, Nigeria.***Email: kalu.okonwu@uniport.edu.ng***ABSTRACT**

The study evaluated the nutrient and anti-nutrient composition of mangrove species - *Nypa fruticans* Wurmb. fruit ash with a view of using it as bio-fertilizer. The fresh and mature fruits of *N. fruticans* were collected, cut into halves and sun-dried for over a month. The dried sample was burnt in a stainless bowl, sieved after it was reduced to ash. Standard procedures were followed in the determination of the phytochemical, proximate and mineral composition of *N. fruticans* fruit ash. Results from phytochemical composition revealed the following: phenol (0 mg/g), flavonoid (25.40%), alkaloid (10.28%), saponin (27.70%), oxalate (0.006%), tannin (0mg/kg), phytate (0%), and cyanogenic glycoside (0.20 mg/kg). Proximate composition showed that the fruit contained 4.38% protein, 4.37% carbohydrates, 1.20% lipids, 0.85% moisture, 58.81% ash, and 30.39% crude fiber. The mineral content of the fruit ash were as follows: magnesium (2,851.34 mg/kg), calcium (3,391.09 mg/kg), potassium (59,294.14 mg/kg), iron (3,454.52 mg/kg), sodium (11,860.58 mg/kg), and zinc (247.26 mg/kg). The percentage concentration of the ash content resulted in the higher concentration of mineral contents. This observation suggests that the fruit ash of this mangrove species - *N. fruticans* can possibly be used as bio-fertilizer.

Keywords: Anti-nutrient, minerals, nutrient, *Nypa fruticans*, phytochemicals

ECO/PH25/WVSE11**EFFECTS OF SOIL PHYSICO-CHEMICAL PROPERTIES ON SURVIVAL AND EARLY SEEDLING GROWTH OF A MANGROVE SPECIES (*Syzygium guineense* var. *littoral* Keay) IN THE NURSERY****Omokhua, G. E., Fredrick, C. and Monday, A. W.***Department of Environmental Forestry and Wildlife management**Faculty of Agriculture, University of Port Harcourt**Corresponding author: charity.fredrick@uniport.edu.ng***ABSTRACT**

This study on the effect of soil physicochemical properties on seedling survival and growth of *Syzygium guineense* var. *litorale* was conducted in the nursery in the Department of Environmental Forestry and Wildlife Management, University of Port Harcourt. A completely randomized design with three replicates was adopted in this investigation. Soil samples from three different zones of the mangrove were collected as treatments (land ward, middle and water front) while topsoil outside the mangrove was collected as the control treatment. Each treatment had 30 plastic bucket filled with soil from the three zones and the control, totalling 120 plastic buckets. One wildling of the species was transplanted into each plastic bucket filled with their respective soil medium from each zone. Data were collected for 6 months on survival percentage and increase in growth indices of the species. All data collected were analysed using descriptive statistics and analysis of variance. The results on survival percentage of *S. guineense* var. *litorale* had $98.67 \pm 0.33\%$ for the landward zone of the mangrove, followed by the forest top soil as control had a mean of $83.33 \pm 1.67\%$. while the middle and water front of the mangrove had 0% survival respectively. The mean monthly height increment for the landward and forest topsoil were $6.03 \pm 0.58\text{cm}$ and $5.61 \pm 0.58\text{cm}$ respectively. The study revealed that *S. guineense* does not tolerate high acidity, salinity and clay conditions in the mangrove. Therefore, it is recommended that any reforestation programmes of the species should be confined to the landward zone of the mangrove ecosystem.

ECO/PH25/WBC05

COMMUNITY BASED WETLAND CONSERVATION: A CASE STUDY OF JOINKRAMA COMMUNITY OF AHOADA WEST LOCAL GOVERNMENT AREA OF RIVERS STATE, NIGERIA.

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ABSTRACT

Wetland degradation in Nigeria is a significant issue, primarily driven by human activities like oil exploration, urbanization, agriculture, and pollution. This study explored community-based wetland conservation in Joinkrama Community of Ahoada West Local Government Area of Rivers State, Nigeria. The research aimed to promote community-led conservation initiatives, enhance livelihoods, and protect biodiversity in the region. Data was collected using a well-structured questionnaire, administering surveys to key stakeholders and community leaders to gather information on their perceptions, attitudes, and practices related to wetland conservation. Data analysis was carried out using thematic analysis to identify themes and patterns, while quantitative analysis was done using statistical methods to identify trends and correlations. Findings showed that local communities demonstrated varying awareness and knowledge about wetland conservation. Key threats to wetlands included pollution, deforestation, and overfishing. The study also identified challenges and opportunities for sustainable wetland management. This study recommends empowering local communities to take ownership of wetland conservation efforts through education and training. It emphasizes the need for developing and implementing community-based management plans that balance conservation goals with community needs.

Keywords: Wetland degradation, Community-based conservation, biodiversity, sustainable management, pollution

ECO/PH25/WBC03**EVALUATING SEED BANK COMPOSITION AND DIVERSITY IN SELECTED SPENT OIL WASTE DUMPSITE IN OBIO/AKPOR LOCAL GOVERNMENT AREA PORT HARCOURT.****Amadi, N¹., Konyeme, T.E. , Okubor, P.C³., and Gbosidom, V.L⁴**¹*Department of Plant Science and Biotechnology, Faculty of Science, Rivers State University Nigeria.*^{2and3}*Department of Biological Sciences, University of Delta, Agbor- Delta State.*⁴*Department of Science and Laboratory Technology, Kenule Beson Saro-Wiwa Polytechnic, Bori Rivers State**Corresponding Author Email: noble.amadi1@ust.edu.ng***ABSTRACT**

The soil seed bank comprises seeds present in the soil that have not yet germinated but remain dormant with the potential to grow under favourable environmental conditions. This study aims to assess the composition and diversity of soil seed banks in selected oil waste-contaminated sites in Port Harcourt. Soil samples were collected from three locations in Obio/Akpor Local Government Area Ozuoba, Choba, and Alakahia alongside their respective control sites. Samples were obtained at 0-5 cm, 5-10 cm, and 10-15 cm using a soil auger. The collected samples were air-dried, sieved, and subjected to laboratory analysis to determine their physicochemical properties. A seedling emergence test was conducted using a standard method to evaluate seed viability, density, and species composition. The emergence of seedlings was monitored over 12 weeks. The results indicated that the highest number of individual seedlings (19) was recorded at the Choba control site, while the Choba waste dumpsite had the lowest species count. Among the waste dumpsites, the Ozuoba spent oil waste dumpsite recorded the highest number of individuals. At a depth of 0-5 cm, the highest seedling count was observed at the Alakahia dumpsite (21), while the control site recorded 324 seedlings at the same depth. For the 5-10 cm depth, Ozuoba had the highest seedling count (17), whereas at 10-15 cm, the highest count was recorded at Choba. Species diversity analysis revealed that waste dumpsites exhibited more uniform dominance, abundance, and species distribution compared to the control sites. A significant variation in seedling emergence was observed between contaminated sites and their respective controls. The Alakahia commercial dumpsite had the highest total number of individual species, suggesting that the waste composition in this area created favorable conditions for the growth of certain plant species. These findings indicate that indiscriminate oil waste disposal and pollution have altered soil conditions, impacting plant biodiversity. This study highlights the need for improved waste management strategies to minimize soil contamination and its effects on plant biodiversity.

ECO/PH25/WRS06**COMPARATIVE PHYSICOCHEMICAL PROPERTIES OF SURFACE AND GROUND WATER QUALITY AND ITS PUBLIC HEALTH IMPLICATION IN OSOGBO TOWN, OSUN STATE, SOUTHWEST, NIGERIA*****Adeyemo, S. O.¹, Fasasi, K. A.¹ and Surakat, O. A.¹**¹*Department of Animal and Environmental Biology, Faculty of Basic and Applied Sciences, Osun State University, Osogbo, Nigeria**Corresponding author's e-mail: sefiyaholuwakemi@gmail.com***ABSTRACT**

Portable sources of surface and ground water are constantly polluted by anthropogenic activities and have negative impacts on human and animals' health. This study investigated the physicochemical properties of Osun River and selected wells in Osogbo town, Osun State, Nigeria, to ascertain their public health impacts. Water samples from surface and ground water systems were examined to determine their pH, total dissolved solids, conductivity, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Temperature, Turbidity, Dissolved Oxygen (DO) and Salinity values. The mean values of the pH, total dissolved solids, conductivity, BOD and COD were observed to be within international limits, while Temperature, Turbidity and DO were above permissible limits. This study showed that the surface and ground water systems assessed were contaminated with substances in dry and wet seasons occasioned by the vigorous anthropogenic activities, such as mining, agriculture, construction and waste deposits. The study recommends creation of awareness by government and other stakeholders on the extant variable cost effective water treatment techniques to reduce the health risks of consuming populated portable water in the study area. Also, the activities of miners and residents should be regulated in the contamination and pollution of freshwater sources in the study area.

Keywords: Anthropogenic activities, surface water, groundwater, Osun River, fresh water

ECO/PH25/WAF06**EFFECT OF ARTIFICIAL CHEMICAL INDUCED-RIPENING OF FRUITS IN BAYELSA STATE, NIGERIA****Lilian Andrew¹, Commander N. Thomas¹ and Ayodele A. Oyedeji^{1,2}**¹*Department of Biological Sciences, Niger Delta University, Wilberforce Island, Nigeria*²*Department of Biological Sciences, University of Africa, Toru-Orua, Nigeria**E-mail for correspondence: andrewlilian@yahoo.com; +2348039590690***ABSTRACT**

The nutritional demand in society today requires facilitation fruit ripening to meeting human consumption needs. This study seeks to test the effects of artificial ripening on orange fruit using calcium carbonate (CaCO₂), its influence on the proximal composition, anti-nutrient, mineral composition and vitamins. The orange fruits were carefully washed with distilled water drained and selectively picked into ten liters bucket with air tight cover, and kept in a dark cupboard with the inscription of numbers of day. Perforated plastic sieve was already placed at the bottom of the bucket with five (5g) grams of Calcium carbide (CaC₂). Proximate analysis and test for anti-nutrient was done using the procedures of Association of Analytical Chemists (AAC). The mineral content was calculated by using the following equation: Mineral content (mg/100g) = (a – b) x V/ 10W. Foods Titrimetric Method was carried out to determine the vitamin of the orange fruit. The result revealed that the water content was higher in fresh rip orange compare to the calcium carbide, suggesting the ability of the chemical to absorbed water. Other nutrient like crude ash, proteins, fibre, lipid and energy was higher at day than any other test day including the fresh orange fruit. The presence of anti-nutrient compound like Tannins, phytate and oxalate were reported. This result implies that calcium carbide induce fruit ripening has no alteration of its chemical composition. The analysis of orange for vitamin shows that the vitamin content was higher in the fresh orange compared to calcium carbonate-induced ripening. This observation implies that the naturally ripped orange is more nutritious than the chemically induced orange. Calcium carbonate is viable chemical in inducing orange ripening and do not alter the chemical composition of the fruit in cause of initiating ripening. Fruits whose ripening was chemically induce by the use of calcium carbide is eatable as its chemical composition is intact and could confer the required nutritional energy to consumers.

Keywords: Edible plants, fruits, ripening effect, proximate analysis, vegetation

SUSTAINING LIVELIHOODS AMID WETLAND DECLINE: EVIDENCE FROM THE UPPER BENUE RIVER BASIN, ADAMAWA STATE.

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ABSTRACT

Wetlands are critical to rural livelihoods in Adamawa State, providing food, water, medicinal plants, and seasonal farming opportunities. However, climate change and unsustainable land use are increasingly degrading these ecosystems. This study assesses the contribution of wetland resources to sustainable livelihoods in selected communities along the Upper Benue River Basin. Using a mixed-method approach remote sensing, household surveys, and focus group discussions data were collected from 150 respondents across three wetland-dependent settlements. Findings reveal a 25% decline in wetland cover over two decades, linked to prolonged dry spells and human encroachment. Key livelihood activities such as fishing, vegetable farming, and plant harvesting have been severely impacted, resulting in reduced income and food security. Despite these challenges, communities practicing integrated farming and resource diversification showed better resilience. The study recommends climate-smart practices, community-led restoration, and policy enforcement to sustain wetland ecosystems and the livelihoods they support. Strengthening local adaptation strategies is essential for ecological and socioeconomic resilience in the face of climate change.

EFFECTS OF MICROPLASTICS ON THE HISTOSTRUCTURE OF *Clarias gariepinus* (AFRICAN CATFISH) GUT AND GILLS

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ABSTRACT

Microplastics are tiny plastic particles (<5mm), which cause great threat to aquatic life. The aim of this study was to determine the effects of microplastic waste on the histostructure of the gills and gut of *Clarias gariepinus*. African catfish, *Clarias gariepinus* (120 individuals) were exposed to microplastics through their feed for four weeks. The fish were also feed for another 4 weeks without the microplastic to assess recovery. The microplastics sizes used were 0.05mm (T1) and 0.1mm (T2) and a control group containing no microplastics. The fish were separated based on the microplastics been feed to them with two tanks for each group. Fishes were sacrificed weekly and the gills and gut were removed and preserved for further analysis. The histostructure of the gills and gut were analysed using standard histological techniques. The results indicated fusion of the secondary lamellae, disruption of the secondary lamellae as well as oedema of the primary lamellae in gill histostructure of the T1 and T2 samples. There was loss of the mucosal glands and thinning and disintegration of epithelial lining in the histostructure of the guts of the T1 and T2 while the control samples showed normal cell structure. The gills showed a more lingering effect in the recovery weeks than the guts. This study showed that the damages caused by microplastic contamination on the gut and gills of *Clarias gariepinus* are reversible if the source of contamination is removed.

Keywords: Microplastics, Histostructure, *Clarias gariepinus*, Guts, Gills

EC0/PH25/WRS05**ECOLOGICAL ASSESSMENT OF SUSTAINABLE LIVELIHOOD IN PARTS OF ILAJE LITTORAL COMMUNITIES, ONDO STATE USING SOCIO-ECONOMIC AND HUMAN RESOURCE CAPITAL INDICES****Gbayisemore O. O¹., Edwin-Wosu, N. L^{2*} .and L.C. Osuji³**¹*Niger Delta Development Commission (NDDC) Headquarters, Eastern Bypass, Marine Base, Port Harcourt, Rivers State*²**Department of Plant Science and Biotechnology, Faculty of Science, University of Port Harcourt, Choba, PMB 5323, Rivers State, Nigeria.*³*Institute of Natural Resources, Environment and Sustainable Development (INRES) University of Port Harcourt***Corresponding Author's Email: nsirim.edwin-wosu@uniport.edu.ng***ABSTRACT**

The scenarios of livelihood for several decades in the coastal ecosystem of Ilaje in which fishing and aquaculture are the two main livelihoods have not been a sustainable way of life following environmental shocks, trends, and seasonality resulting to a chaotic economic situation. This study was aimed at evaluating the socio-economic and human resource indices in ecological alternatives of livelihood opportunities in Ilaje Coastal ecosystem. Results revealed across studied communities male > female gender though in variation and vice versa among communities, the highest percentage (32%) age bracket (36 to 46>) with more male than female across the community. The marital status revealed variation across the communities with the highest percentage (88%) of marriage in Molutehin, highest percentage (28%) of single hood in Ikorigho besides the pocket cases of divorce, widow and widows in study area. Educational level revealed a greater percentage (60%) of inhabitants finishing secondary school at Ikorigho and Molutehin, 64% for tertiary education in Odonla, 8% non-formal education in Ikorigho and Awoye, and 40% illiteracy in Odun-Igo. Socio-economic revealed fishing (56%) in Awoye and trading (44%) in Molutehin and Awoye. The weekly income among household revealed communities still struggling to have a basic necessity of life. Different levels of cost of living among inhabitants ranged from being expensive (Odonla), very expensive (Ikorigho, Molutehin and Odun-Igo) to being affordable (Awoye). In conclusion it becomes significant that alternative livelihoods than fishing and aquaculture can sustainably raise the socio-economic status of the rural dwellers among coastal communities of Ilaje.

Keywords: Livelihood, Human index, education, marriage, socioeconomic index.

ECO/PH25/WAF12**GROWTH AND YIELD PERFORMANCES OF SIXTEEN OKRA (*ABELMOSCHUS ESCULENTUS* (L.) MOENCH) VARIETIES IN A HIGH RAINFALL REGION****Precious Allen Nwine, V. Wilson, M.T.V Adeleke***Department of Plant Science and Biotechnology, Rivers State University, Port Harcourt
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This study investigated the growth and yield components of sixteen okra varieties in the high rainfall and humid conditions of Port Harcourt, Rivers State, Nigeria. The research was carried out at the Botanical Garden of the Department of Plant Science and Biotechnology, River State University, Port Harcourt. Seeds of sixteen okra varieties (NHOKO595, NHOKO188, NHOKO195, NHOKO158, NHOKO637, NHOKO614, NHOKO617, NHKO595, NHOKO618, NHOKO177, F1 Kirikou, NHOKO157, NHOKO631, NHOKO155, NHOKO150 and Local variety) were sown into polythene bags (55x45x45cm) containing sandy-loam soil at the rate of three seeds per bag and later thinned at two weeks after planting to one plant per bag, with six replications arranged in a Completely Randomized Design in an open field. Data collected included, fruit shape index, number of fruits, fruit yield, number of aborted fruits, fruit width, fruit weight, number of flowers, number of fruits, leaf area, fruit length, number of locules, number of seeds, and yield. The results showed significant differences ($P \geq 0.05$) in fruit shape, number of aborted flowers, fruit weight, fruit width, fruit length, number of locules, and number of seeds. However, there were no significant differences in fruit length, yield/tons, number of flowers, and number of fruits. NHOKO597 had a greater number of flowers, and largest fruit width. Also, NHOKO177 produced more seeds and locules per fruit. The variability in some attributes of okra genotypes could be attributed to differences in genetic constitution. The NHOKO597 variety produced the highest number of fruits, number of flowers, and fruit width, and may be attractive to farmers and also possess a better market value/appeal and it is thus recommended for okra production in Port Harcourt, Rivers State.

ECO/PH25/WAF05**IMPACTS OF SALT STRESS ON THE GROWTH AND YIELD PARAMETERS OF MAIZE (*ZEA MAYS* L.)****E. T. Jaja, Nkaire, I. C., K. A. Kpekot,***Department of Plant Science and Biotechnology, Rivers State University**Corresponding Author: Nkaire, I. C.**Ikenna.nkaire@ust.edu.ng***ABSTRACT**

Maize (*Zea mays* L.) is an annual plant of the family *Poaceae*. Maize is a staple food and can be prepared into various food dishes and also serves as raw material for biofuel production. Numerous studies on some plants have shown that plant growth, development and yields are affected by salt stress. This study was carried out at the Botanical Garden of the Department of Plant Science and Biotechnology (PSB) in Rivers State University (RSU), Port Harcourt having latitude and longitude of (4.804°N and 6.980°E), annual rainfall of (200.45mm) and annual temperature range of (25°C - 27°C), to investigate the impact of salt stress on the growth and yield parameters of maize which. Sandy-loamy soil used for this study was collected from the above study area. Maize grains (SAMMAZ-51) were subjected to viability test and germination percentage was determined. Viable seeds were sown into polybags filled with 15kg of soil at the rate of 2-seeds per bag having 4 treatments (10mM-T1, 30mM-T2, 50mM-T3, Control-T4) replicated 8-times and arranged in a Completely Randomized Design (CRD). Data collected were plant height, number of leaves, days to tasseling, days to cobbing, number of cobs, weight of cob with and without husk. There were no significant differences ($P \leq 0.05$) in the data collected. Although, Control had higher values in plant height, number of leaves, number of cobs, and weight of cob with and without husk compared to other treatments.

Keywords: T1 – 10mM NaCl, T2 - 30mM NaCl, T3 - 50mM NaCl, T4 – Control

ECO/PH25/EAC10**PLANT-POLLINATOR INTERACTIONS IN THE FACE OF CLIMATE CHANGE: UNDERSTANDING ECOLOGICAL SHIFTS AND CONSERVATION PRACTICES IN OPANDA-NIMBO ECOLOGICAL ZONE.**

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ABSTRACT

Plant-pollinator interactions are crucial for maintaining ecosystem health, biodiversity, and food security. However, these interactions are facing unprecedented challenges due to climate change. Rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events are disrupting the delicate balance between plants and their pollinators. This study investigated the impact of climate change on plant-pollinator interactions, with a focus on understanding ecological shifts and informing conservation practices in Opanda-Nimbo Agricultural Zone. Combination of field observations, experiments, and statistical modeling were used to examine the responses of plant-pollinator communities to climate change in different ecosystems of Opanda-Nimbo Agricultural Zone. The results showed that climate change is altering the phenology, distribution, and abundance of both plants and pollinators, leading to mismatches and disruptions in their interactions. It was also found that these disruptions can have cascading effects on ecosystem function and biodiversity. The study also highlighted the importance of understanding the ecological adaptations and resilience of plant-pollinator communities in the face of climate change. The key traits and characteristics that enable plants and pollinators to cope with changing environmental conditions, such as flexibility in pollination systems and ability to adapt to new habitats were identified. Conservation practices and efforts focus on maintaining and restoring habitat diversity, promoting ecological connectivity, and supporting the resilience of plant-pollinator communities were recommended. Additionally, the need for further research on the complex interactions between climate change, plant-pollinator interactions, and ecosystem function were also recommended.

Keywords: Climate change, plant-pollinator interactions, ecological shifts, conservation practices, ecosystem resilience.

ECO/PH25/WBC07**ASSESSMENT OF WATER HYACINTH (*EICHHORNIA CRASSIPES* [MART.] SOLMS) AND MALEFERN (*DRYOPTERIS FILIX-MAS* [L.] SCHOTTAS HYPERACCUMULATORS OF ZINC AND COPPER IN WATER ENVIRONMENT****Albert, E., Tanee, F. B. G. and *Obiri, E.***Department of Plant Science and Biotechnology**Faculty of Science, University of Port-Harcourt, Port-Harcourt, Nigeria**ejikeme.albert@uniport.edu.ng**Corresponding author e-mail: elizeobiri@gmail.com***ABSTRACT**

The potential of *Eichhornia crassipes* and *Dryopteris filix-mas* to accumulate zinc (Zn) and copper (Cu) in the aquatic system was evaluated on samples of the two plants collected from the shoreline of the Sombreiro River at Ahoada, Rivers State, to provide knowledge on the interaction of the plants with the two heavy metals. The shoot parts as samples of the two plant species were collected from the shoreline along the river course at three sample stations, 1 km apart from each other, and were analysed for their metal concentrations. Result indicated that *E. Crassipes* accumulated 40.6 mg/kg, 32.2 mg/kg, and 35.3 mg/kg, while *D. filix-mas* had 29.8mg/kg, 18.0mg/kg, and 3.7mg/kg concentrations of zinc from sample stations 1, 2, and 3, respectively. *E. crassipes* from sample stations 1, 2, and 3 accumulated 14.2 mg/kg, 16.1 mg/kg, and 12.3 mg/kg, and *D. filix-mas* recorded 9.8mg/kg, 14.2mg/kg, and 7.0 mg/kg of Z non-sample stations 1, 2, and 3 respectively. From the result obtained, *E. crassipes* accumulated higher concentrations of the two metals assessed than *D. filix-mas*. It can be concluded that *E. crassipes* can be used for phytoextraction of metal-polluted environments.

ECO/PH25/WRS08**ENVIRONMENTAL SUSTAINABILITY: ECOLOGICAL FOOTPRINT ANALYSIS OF IBADAN NORTH, NIGERIA****Henry Sawyerr¹, Edet Otto^{2*}, and Micheal Akinyemi³**^{1, 2, and 3}*Department of Environmental Health, Kwara State University, Malete, Nigeria*²*Department of Environmental Health, Ajayi Crowther University, Oyo, Nigeria***Corresponding Author: klinzmannia@gmail.com**Phone: +2348067381083***ABSTRACT**

The ecological implications of global development have been a primary focus in discussions surrounding sustainability. As urban development expands globally, addressing its many ecological concerns becomes imperative. However, the ecological footprint (EF) analysis of urban sustainability within the sub-Saharan region, particularly Nigeria, remains largely unexplored. Here, we used the EF indices to explore the environmental sustainability of Ibadan City, one of Nigeria's fastest-growing urban centres. We implemented a bottom-up EF approach in the study, employing a cross-sectional design. We used an EF questionnaire to gather monthly household consumption data on food, energy, and water. We analysed these data descriptively and methodologically using EF formulae. Findings indicate environmental sustainability, as reflected in the low EF of 0.43gha/capita, with the energy footprint accounting for the majority (93%) at 0.4gha/capita. In comparison, the food footprint had the lowest share (below 3%) at 0.01gha/capita. Our findings demonstrate the significant impact of energy consumption on the overall EF, reinforcing the need for more sustainable energy solutions in urban planning, thus contributing to urban sustainability by informing urban planning and energy policy in alignment with the global sustainability drive.

Keywords: Ecological footprint, Environmental sustainability, Urban Sustainability, Sustainability, Nigeria

ECO/PH25/WAF20

CRITICAL PERIOD OF INTERFERENCE OF *Sesbania pachycarpa* DC. WITH OKRA (*Abelmoschus esculentus* (L.) Moench.) IN IBADAN, NIGERIA**¹Oyelade, E.A. and ¹Olubode, O.S.**¹Department of Crop Protection and Environmental Biology, University of Ibadan, Nigeria

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ABSTRACT

Weed control is a main agronomic practice for profitable crop production. Okra (*Abelmoschus esculentus* (L.) Moench.) is cultivated in all agro-eco zones in Nigeria for its immature fruits and leaves. Weeds reduce accounts for up to 50% yield loss in okra production. Few studies have evaluated interference *S. pachycarpa* with other crops, there is documented data its critical period of interference (CPWI) with okra in Ibadan where it has become invasive.

The experiment was carried out in the Crop Garden of the department of Crop Protection and Environmental Biology (CPEB) in the University of Ibadan, Ibadan (7°27'047N, 3°53' 832 E). The study consisted of two sets of treatments, with one set kept weed-free for 2, 4, 6, 8 and 10 weeks after sowing okra and subsequently left weedy (wf-wd); while the other set of treatments were weedy for 2, 4, 6, 8 and 10 weeks and subsequently weed-free (wd-wf). A Completely Randomized Design was used for the experiment with 12 treatments replicated three times. Experimental units were planted 36 experimental pots, each filled with 4kg soil. Data were collected on number of leaves/plants, Plant height and fruit weight. All data collected were analyzed using analysis of variance at 5% probability.

The number of leaves of okra plant showed no significant difference across all treatment, except at wd-4-wf, wd-6-wf, wd-8-wf and wf-8-wd when number of leaves were significant. The number of leaves at wd-8-wf was highest (8.33±0.323). Plant height of treatment wf-6-wd was the highest (55.67cm), closely followed by wf-10-wd (54.97cm). The wd-12-wd and wf-4-wd respectively had the lowest plant heights. The wf-8-wd and wf-2-wd treatments produced the highest fresh fruits weight (53.967g and 44.633g respectively); while treatment wd-12-wf (all time weedy) had the lowest yield mean value. Continuous weed interference up to 8 weeks resulted in low yield when compared to the yield of okra plant left weed-free and CPWI was calculated to be 4-8 weeks.

Sesbania pachycarpa is capable of reducing okra yield by 4.6 – 47.32% depending on duration of interference. Application of the critical period of interference (CPWI) will reduce indiscriminate application of herbicide to control *S. Paracycarpa* infestation in okra.

Keywords: *Sesbania pachycarpa*, CPWI, weed management, Okra, Weed competition, *Abelmoschus esculentus*

ECO/PH25/WDR05**ANTHROPOGENIC FACTORS INFLUENCING WETLAND DEGRADATION IN SATURU FOREST RESEARVE, SOKOTO STATE NIGERIA.****¹KASIMU A.S, and ¹NAZIRU H.***¹Department of Biology, Faculty of Science and Science Education, Shehu Shagari University of Education Sokoto, Sokoto State Nigeria. PMB 2297 Nigeria.**Corresponding author's e-mail: kasimu.abubakar@ssues.edu.ng; GSM: 07033056987***ABSTRACT**

This study examined the anthropogenic factors contributing to wetland degradation in Saturu Forest Reserve, Sokoto State, Nigeria. Data were collected from 100 key respondents across five forest communities, with 20 participants selected from each. Semi-structured questionnaires were administered through interview schedules to gather information from local communities. The data were analyzed using frequency distribution and multiple regression. Findings revealed that 82% of respondents were economically active, 37.7% had formal education, 83% owned farms, and 86.3% were married. Regression analysis identified non-formal education, land clearing for agriculture, and extensive animal grazing as significant drivers of anthropogenic activities affecting wetlands. Additionally, temperature and precipitation fluctuations were found to contribute substantially to wetland degradation. The study recommends targeted interventions to restore and sustainably manage wetland ecosystems while providing alternative livelihood options for local communities. This approach aims to reduce dependence on harmful anthropogenic practices and mitigate further degradation.

Keywords: Anthropogenic factors, wetland degradation, Saturu forest reserve. Sokoto, Nigeria.

ECO/PH25/WAF01**ACCUMULATION OF HEAVY METALS IN SURFACE WATER AND FISH TISSUES (*Clarias gariepinus*) OF NAFADA CORRIDOR, RIVER GONGOLA COMPLEX, GOMBE STATE, NIGERIA****¹ABUBAKAR B., ²ABUBAKAR K.A¹, ¹YARIMA R., ¹NURA A. G.,**¹*Department of Biological Science Gombe State University, Gombe, Nigeria*²*Department of Zoology Modibbo Adama University of Technology Yola, Nigeria**Corresponding Author's E-mail baraatuabubakar2014@gmail.com***ABSTRACT**

This study Bioaccumulation of heavy metals in in surface water and fish tissues (*Clarias gariepinus*) was carried out in Nafada corridor of River Gongola for period of eighteen months (18). Fish and water samples were brought to the laboratory, Fish tissues (Gills, Liver and Muscle) were carefully removed the samples were digested to detect the concentration of heavy metals using AAS machine. The result revealed that accumulation of heavy metals in surface water were found to be higher in Zinc 0.63 ± 0.02 in the month of May and lower in Lead which is not detected in the month of July. In fish tissues, liver recorded the high concentration followed by gills and muscles, the concentration of heavy metals follows the order $Zn > Cd > Cu > Mn > Pb$. The analysis shows that there is significant difference ($p \leq 0.05$) between the months throughout all the organs observed. Zinc concentration ranges, in gills (0.33 ± 0.01 ab and 0.14 ± 0.01 h), liver (0.64 ± 0.03 b and 0.15 ± 0.01 i) muscles 0.33 ± 0.01 a and 0.16 ± 0.17 . >Cadmium ranges in gills (0.16 ± 0.17 and 0.13 ± 0.01) liver (0.42 ± 0.01 and 20 ± 0.00) muscles (0.38 ± 0.01 and 0.21 ± 0.01) copper in gills (0.72 ± 0.01 and 0.72 ± 0.01) liver (0.57 ± 0.01 and 0.16 ± 0.17) muscles (0.37 ± 0.00 and 0.37 ± 0.00). manganese in gills 0.62 ± 0.01 and 0.32 ± 0.00) liver (0.48 ± 0.01 and 0.30 ± 0.01) muscles (0.14 ± 0.01 and 0.33 ± 0.02). Lead in gills (0.34 ± 0.2 and 0.00 ± 0.00) liver (0.14 ± 0.02 and 0.33 ± 0.00 and) muscles (0.36 ± 0.01 and 0.21 ± 0.02). Benthic fish *Clarias gariepinus* tend to have high accumulation of heavy due to their uptake on sediment, the need for continuous monitoring to prevent accumulation of heavy is recommended.

Keywords: Nafada corridor, *Clarias gariepinus*, Fish tissues, Gills, Liver and Muscle.

ECO/PH25/EAC06**CHARACTERIZATION AND PHYSICOCHEMICAL PROPERTIES OF SOIL UNDER DIFFERENT DEPTH IN IJEGBA FOREST, ABEOKUTA, OGUN STATE, NIGERIA.**

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ABSTRACT

Soil characterization and classification is vital to know the potential and limitations of the soil resources for agricultural production, and for devising relevant soil management strategies. The study characterized and evaluates the physicochemical properties of the soils in Ijegba forest for sustainable agricultural practices. Three representative soil profiles were opened randomly within the study area and samples were collected at depths 0-30cm, 30-60cm and 60-90cm with a total of 15 replicates at varying altitude and slopes, representing different physiographic positions: upper slope, middle slope and lower slope. The profiles were subjected to detailed morphological, physical and chemical analyses. The collected soil samples were analyzed for soil texture (sand, silt and clay), bulk density, pH, organic matter, total nitrogen, available phosphorus, exchangeable bases (Na, K, Ca and Mg) and available micronutrients (Zn, Cu, Fe and Mn). The data obtained from the laboratory analysis were subjected to one way ANOVA using SPSS version 26. Means were separated using DMRT at ($P < 0.05$). The result revealed significant variability in soil properties across the depth and profiles where the structure across the different depths varied from moderately medium subangular blocky to weak coarse granular structures. The soils colour also varied from very dark brown (10YR2/2) to reddish yellow in profile 1, while in profile 2, the colour varied from very dark brown (10YR2/2) to strong brown (7.5YR4/6) and then to yellow (10YR7/8) but red colour (2.5YR4/6) was observed at the deepest depth in profile 3. Bioactivities were common in all the profiles. Consistency varied from friable at the surface for all the profiles to loose at the subsurface and became firm at the deepest layer for profile 1. The soils exhibited a sandy loam to sandy clay loam texture with high sand content in the surface layer and decreasing with depth as clay content increased at the deeper layer of the profile. Bulk density values ranged from 0.96 at the 0-30cm depth in profile 1 and had the highest recorded values at 60-90cm depth 1.82g/cm³ with corresponding porosity values indicating the surface area were less compacted and more conducive for plant growth. Soil pH remained slightly acidic to neutral (5.94, 6.60 and 6.08) at depth 0-30cm, 30-60cm and 60-90cm. The highest concentration of total nitrogen (0.19%) and organic carbon (2.13%) were observed in the surface layer (0-30cm) corresponding with high organic matter from the input of litter. Available phosphorus was low at depth 60-90cm (1.22mg/kg) and was higher at depth 30-60 cm (8.60mg/kg). Micronutrients analysis indicated that Manganese (Mn) and Iron (Fe) were most concentrated at the upper horizon but decline sharply with depth. Correlation analysis indicated strong relationship between organic matter content, total nitrogen and organic carbon content ($r > 0.98$), emphasizing the role of organic input in maintaining soil fertility. A strong negative correlation was found between sand and clay content ($r = -0.85$) indicating water retention and nutrient dynamics. Based on the analysis of the soil properties, The soil were classified as Alfisols, characterized by high base saturations, distinct horizons, favorable physical structures making them suitable for agricultural and forestry uses. The study concludes that Ijegba forest soils are highly suitable fertile. However, the observed decline in nutrient concentration with depth emphasizes the need for depth-specific soil management practices.

ECO/PH25/WRS01

COMPARATIVE STUDY OF PARAMETERS OF STAGNANT AND RUNNING WATER OBTAINED FROM KAURA NAMODA, ZAMFARA STATE

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ABSTRACT

Water is essential in all human activities and its quality is crucial for public health. This study investigates physicochemical parameters of stagnant and running water sources in Kaura Namoda, Zamfara state, Nigeria. The aim was to compare the water quality parameter of stagnant and running water sources including their suitability for domestic use. Total of 10 stagnant and 10 running water were collected from different location in Kaura Namoda. The samples were analyzed for physicochemical parameter such as pH, Temperature, Turbidity, Total Dissolved Solid, Electrical Conductivity, Alkalinity, and Total Hardness. The results showed significant differences ($p < 0.05$) between the physicochemical of stagnant and running water sources. Stagnant water had higher values of pH, turbidity, TDS and EC while the running water has the lower value of these parameters. The study concluded that running water sources has better quality than stagnant water; however, both water sources require treatment before use for domestic purposes in order to ensure the health safety of the consumers.

Keywords: Stagnant Water, Running Water, Physicochemical, Kaura-Namoda

ECO/PH25/EAC02

ASSESSMENT OF PHYSICOCHEMICAL AND BACTERIOLOGICAL WATER QUALITY OF HADEJIA-NGURU WETLANDS.**Lydia Oluwatosin Odewade^{1*}, Sharifa Ibrahim Suleiman¹ and Joseph Oluwaseun Odewade²**¹*Department of Environmental Management, Faculty of Earth and Environmental Sciences, Bayero University, Kano, Kano State, Nigeria*²*Department of Microbiology, Faculty of Life Sciences, Federal University Dutsin-Ma, Katsina State, Nigeria***Corresponding author's email: loluwatosin.em@buk.edu.ng***ABSTRACT**

This study assessed water quality of riparian portions of Hadejia-Nguru wetland through bacteriological and Physico-chemical analyses. Field studies were conducted in three communities during early and late dry seasons. Spatial concentrations of Physico-chemical parameters (Temperature, Turbidity, EC, pH, TDS, BOD, DO, Na⁺, Ca²⁺, K⁺, NO₃⁻, PO₄³⁻) were determined using standard analytical methods, while bacteriological analyses were performed using standard microbiological techniques. The results revealed that there were no significant ($p > 0.05$) variations in the concentrations of the physicochemical parameters (temperature, EC, TDS, BOD, Na⁺, Ca²⁺, K⁺, NO₃⁻, and PO₄²⁻) and were within the WHO and NSDWQ recommended standards across the study sites - Adiyani, Ngurodi, Ngarbi and groundwater. Also, turbidity and DO mean concentrations were beyond the recommended standards by WHO and NSDWQ in all the sampling sites. Moreover, water samples collected during the late dry season exhibited significant variation ($p < 0.05$) between the physicochemical parameters mean concentrations and the bacteriological mean counts compared to those collected during the early dry season. The mean bacteriological counts across all sites varied significantly ($p < 0.05$). Ngurodi exhibited the highest counts of Aerobic Mesophilic Bacterial (AMBC) at 4.41×10^9 cfu/ml, Total Coliform count exceeding 1100 cfu/ml, and Fecal Coliform count of 5 cfu/ml, while the groundwater sites had the lowest counts of 3 cfu/ml). Pathogenic bacteria such as *Salmonella spp.*, *Shigella spp.*, *Staphylococcus aureus*, and *Escherichia coli* were detected across all sites, indicating potential health risks associated with waterborne diseases. The study concludes that due to the presence of pathogenic bacteria in the wetland studies, prior treatment of the water must be done before consumption.

Keywords: Wetland, water quality, physicochemical and bacteriological parameters

ECO/PH25/EAC03**BLACK SOLDIER FLY LARVAE TECHNOLOGY: TRANSFORMING WASTE INTO OPPORTUNITY IN NIGERIA**

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ABSTRACT

Issues of growing waste generation, stagnating productivity of agriculture, and environmental degradation interweave challenges to the developmental trajectory of Nigeria with significant development impacts. Urbanisation has occurred at a staggering rate in conjunction with growing population which places enormous strain on already overburdened waste management infrastructure, resulting in overflowing landfills and polluting masses that cause public health worries. At the same time, the agricultural sector upon which the Nigerian economy relies heavily, is faced with declining soil fertility, dependence on environmentally damaging synthetic fertilizers and significant post harvest losses significantly impeding its ability to deliver on food security and economic growth. These are interconnected challenges and so require innovative and sustainable solutions. The Black Soldier Fly Larvae (BSFL) technology is a compelling answer to organic waste management with the potential to transform organic waste management and its residues into valuable resources for agriculture and other sectors. BSFL are voracious feeders of an almost unlimited range of organic waste, including food scraps, agricultural byproducts like cassava peels and maize stover and even animal manure. It reduces the volume of waste destined for landfills drastically, thereby minimizing other associated environmental impacts of landfill disposal of such waste, including leachate contamination of groundwater and the release of greenhouse gases, like methane. However, BSFL technology provides a means to increase agricultural productivity in areas beyond waste reduction. The excrement, or frass, produced by the larvae of black soldier flies is an organic nutrient rich fertilizer that can be used to revitalize depleted soils, such as structure, water retention and microbes. As a natural fertilizer, this alternative to synthetic fertilizers is a sustainable solution and reduces the potentially harmful impacts of synthetic fertilizers on the environment and ecosystems. In addition, the BSFL themselves are a protein and fat resource, which are a sustainable and locally produced alternative to regular animal feed sources like fishmeal and soybean meal. It relieves pressure on wild fish stocks and creates less environmental cost of industrial livestock feed production. In this paper, the multifaceted applications of BSFL technology are examined with respect to the Nigerian context. The paper explores its ability to reduce waste, allow for composting, and dispose of animal feeds, and its uses in water purification systems in constructed wetlands and bioremediation of contaminated soils. We also stress the potentials of BSFL farming to create new forms of economic opportunities with rural communities especially, for poverty alleviation and sustainable livelihood development. To this end, if BSFL technology is widely adopted and responsibly employed, Nigeria has a great chance of achieving its sustainable development goals while simultaneously creating economic growth while improving the well being of its citizens.

Kywords: Black soldier fly, Waste-to-wealth, Insect larvae, Organic fertilizer, Organic waaste

ECO/PH25/WVSE04**FLORISTIC IMPORTANCE AND FARMER'S PERCEPTION OF *ALTERNANTHERA BRASILIANA* (L.) O. KUNTZE IN IBADAN, NIGERIA****Olubunmi E. POPOOLA, *Rasheed O. AWODOYIN, Kehinde R. EGBERONGBE and Oluseun S. OLUBODE***Department of Crop Protection and Environmental Biology, Faculty of Agriculture, University of Ibadan, Nigeria.***Corresponding author: frawodoyin@gmail.com; 08061347554***ABSTRACT**

Alternanthera brasiliana (AB) is recently observed, among the few shrubs that are interacting with other flora in Ibadan and environs, assuming an invasive status and is seen as a threat to native plant ecosystems, agriculture and biodiversity of herbaceous flora. This study was conducted to determine its floristic importance relative to other weed species in selected locations in Ibadan, and the farmer's perception of its infestation in the ecosystem. Floristic survey of populations of *Alternanthera brasiliana* relative to populations of other weed species was conducted along The Polytechnic, Ibadan (Poly) and University of Ibadan (UI) routes using purposive sampling technique, with species composition data obtained from 1m x 1m quadrat laid at eight and nine sampling points at the Poly and UI, respectively. Also, structured questionnaire (250) were administered in the four Agricultural Development Programme (ADP) Zones in Oyo State to determine the extent of distribution of *A. brasiliana*, its perception by the farmers and the rate of succession of weed species on farmlands in the zones. The Relative importance values of AB was highest at the sites enumerated (29.10 - Poly and 24.80 – UI) and the Shannon-Wiener index were 2.42 and 2.57 at the Poly and UI, respectively. Ninety-four percent of the farmers in the surveyed area acknowledged that *A. brasiliana* is difficult to control once it infested the farm and 57.6% alluded to its reduction of crop yield. Generally, the farmers are aware of its invasiveness, rapid growth rate, flowering and seeding at very early age, and identified its ethnobotanical value in the treatment of children during teething.

Keywords: *Alternanthera brasiliana*, Invasive Plant Species, Floristic Distribution, Weed Infestation, Weed Management.

Acknowledgements

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ECO/PH25/EAC08

THE EFFECT OF AMENDMENTS ON SOIL CHEMICAL CHARACTERISTICS

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Sub-theme: Wetland Resources and Sustainable Livelihood

ABSTRACT

Crude oil contamination negatively impacts soil chemical properties leading to decreased soil fertility, poor plant growth, and disrupts microbial ecosystems. This experiment aimed to assess the effects of different levels of organic and synthetic amendments on the chemical properties of contaminated soil. *Telfairia occidentalis* waste (TOW) and Petroleum Remediation Product (PRP) were applied as organic (200g, 400g, and 600g) and synthetic (200ml, 400ml, and 600ml) amendments, respectively, and they were incorporated into 2kg of soil across six replications, with a control soil without amendments. Soil samples were collected at 2 and 4 months to evaluate the impact of the amendments on soil chemical properties, including EC, CEC, pH, P, K, TOC, Moisture content, N and TPH. The results revealed that the amendments significantly influenced EC, pH, P, K and TPH at $p=0.05$. Data generated showed that PRP showed significant increase in EC at 2 months in 600ml and 400ml while at 4 months, increase was observed at 400ml and 200ml. At 2 months TOW enhanced pH in 400g whereas at 4 months increment was observed in 200g. The highest increases in P and K were observed in the 600g TOW at 2 and 4 months. TPH was highest in the 400ml PRP treatment at 2 months and in the unamended polluted control soil at 4 months. Overall, the study demonstrated that applying organic and synthetic amendments enhances depleted soil nutrients, though their effectiveness varies among specific nutrients. Among the treatments, organic amendment (TOW) proved the most effective in nutrient optimization, cost efficiency, and environmental sustainability.

Keywords: Petroleum Remediation Product (PRP), *Telfairia occidentalis* Waste (TOW).

ASSESSMENT OF THE DRIVERS AND IMPACTS OF ELEPHANT CROP RAIDING IN THE COASTAL VILLAGES OF EPE, LAGOS-STATE

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ABSTRACT

Elephant crop raiding is a pressing issue that affects both farmers and elephants in various regions around the world, including Nigeria. This study employed both qualitative and quantitative methods in assessing the drivers (causes) and impacts of Elephant crop raiding in the coastal villages of Epe. Purposive sampling technique was used to select respondents from a total of five (5) villages in the study area. The criteria for the selection were based on proximity of these villages to the forest edge, conflict prevalence and intensity of farming activities in the study area. The affected farmers in the selected villages were identified through snow balling where 50 copies of a semi-structured questionnaire were administered in each of the five (5) villages of the study area. Statistical package for social sciences (SPSS) was used to analyze the data. Results show that the mean age of the respondents was 44 years and mostly married (76.0%). Majority (70.0%) has primary education and majorly practicing farming as major occupation (68%). Results further shows that land use activities have greatly increased in the past 10 years (mean = 1.40) and rise in water levels (mean = 1.32) is the major driver (causes) of elephant crop raiding in the community. It was also revealed that planting of pepper or other non-attractive crops/plants (mean = 1.92) as fencing is the most effective mitigation methods in reducing elephant crop raiding within the community while crop damage (mean = 3.56) and income reduction (mean = 1) has been the major concern of the respondents in the study area. The study revealed that the problem of elephant crop raiding in the coastal communities of Epe, Lagos, is a multifaceted one with significant implications for local populations. The study recommends that government or NGO's should develop and support alternative livelihoods to promote diversified income sources of the respondents in the community.

Keywords: Crop-raiding, Drivers, Coastal, Impact, Conflict

ECO/PH25/WDR02**EMULSIFICATION POTENTIAL FILAMENTOUS FUNGI ISOLATED FROM *CYPERUS POLYSTACHYOS* (MANY-SPIKED FLAT SEDGE) RHIZOSPHERE SOIL*****Akomah-Abadaike, O.N¹ and Adeyemi S. O¹**

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ABSTRACT

This study investigated the emulsification potential of filamentous fungi isolated from the rhizosphere soil of *Cyperus polystachyos* (many spiked flatsedge), focusing on their suitability for biosurfactant production. Soil samples were collected from the rhizosphere zone, and physicochemical properties were analyzed, including pH, electrical conductivity, nitrate, phosphate, and trace metal concentrations, using standard soil analysis methods. The soil was found to be acidic (pH 5.76) with moderate electrical conductivity (318 $\mu\text{S}/\text{cm}$) and nutrient-rich conditions, containing nitrate (7.129 mg/kg), phosphate (1.312 mg/kg), iron (115.162 mg/kg), and zinc (12.513 mg/kg). Fungal strains were isolated from the rhizosphere soil using serial dilution and plating techniques on Potato Dextrose Agar. The isolates were identified based on morphological characteristics and included *Aspergillus sp.*, *Cladosporium sp.*, *Penicillium sp.*, and *Fusarium sp.* Each fungal strain was then cultured in a liquid medium, and its emulsification potential was assessed over a 28-day period using the emulsification index (E24). To perform the E24 assay, 2 mL of the fungal culture supernatant was mixed with 2 mL of a hydrocarbon substrate, vigorously shaken, and allowed to stand for 24 hours. The height of the stable emulsion layer was measured, and the E24 index was calculated as the ratio of the emulsion height to the total mixture height, expressed as a percentage. Among the tested isolates, *Penicillium sp.* Demonstrated the highest emulsification activity, achieving an E24 index of 50%, with an emulsion height of 1.5 mm out of a total of 3.0 mm. *Aspergillus sp.* and *Fusarium sp.* Displayed limited activity, with E24 indices ranging from 0% to 10%, while *Cladosporium sp.* Showed no emulsification activity. These results highlight *Penicillium sp.* As a promising candidate for biosurfactant production, potentially influenced by the unique chemical properties of the rhizosphere soil. This study emphasizes the potential of rhizosphere fungi in sustainable biosurfactant applications for industrial and environmental purposes. Future research should explore optimizing culture conditions, molecular characterization of biosurfactants, and scaling up production to enhance their commercial viability

Keywords: Emulsification, Filamentous fungi, Rhizosphere, Biosurfactant, *Cyperus polystachyos*

ECO/PH25/WDR03**LATEST PERCEPTIONS OF NiCl_2 IN SOILS ON THE GROWTH OF *CAPSICUM FRUTESCENS* L. AND *CAPSICUM ANNUUM* L. PLANTS****U. A. Akporobaro^{1*}, J. A. Obiaigwe², S. N. Iweriolor³**^{1,2}*Department of Plant Science and Biotechnology, Faculty of Science, University of Delta, Agbor, Delta State, Nigeria*³*Department of Microbiology, Faculty of Science, University of Delta, Agbor, Delta State, Nigeria**Corresponding author's Email: agnesuyoyou@gmail.com, mobile: 09043635144***ABSTRACT**

The attributes and clear performance of crops transplanted in soils contaminated by NiCl_2 treatments was confirmed by using chloride as a nickel compound. The study was conducted as a field experiment in pots. This study aims to apply NiCl_2 to loamy and sandy soil to assess the effects on *Capsicum frutescens* and *Capsicum annuum* growth. The soil treatments were 0, 100 and 250 ppm. Thirty-six experimental buckets were prepared for the study. Each bucket contains 4.50 Kg of soil and was treated with 25 mL (total of 125 mL) of NiCl_2 solution every 5 days for 25 days. Seedlings of the pepper after 35 days of germination were transplanted into their various pots. Plant height, number of leaves and branches, fresh weight of shoots and roots, and the morphology of the plants were the parameters collected. Two plants were measured in each pot and their average was recorded. Results from the study revealed that the toxicity effect of Ni^{2+} in a growing plant is dependent on the species of plant grown in certain types of soil. *Capsicum annuum* plants in loamy soil (0, 100, and 250 ppm) showed no significant difference in the morphological parameters.

Keywords: *Capsicum annuum*, *Capsicum annuum*, Pepper, Loam, Soil nutrients.

ECO/PH01/WRS03

DISTRIBUTION OF *Bambusa vulgaris* Schrad. ex J.C. Wendl IN NIGERIA AND THE DETERMINATION OF ITS POTENTIAL AS A BIOENERGY CROP**¹Olaitan Patricia Olaleye, ¹Oluseun Sunday Olubode and ²Maxwell Chibiko Obiakara**¹*Department of Crop Protection and Environmental Biology, Faculty of Agriculture, University of Ibadan, Ibadan, Nigeria*²*Agramondis Limited, Ikeja, Lagos Nigeria**Corresponding Author's Email: patriciaolaitan@gmail.com***ABSTRACT**

Bamboo (*Bambusa vulgaris*), a renewable lignocellulosic material and non-food biomass, has great potential alternative energy production. Exploring the distribution of bamboo presents a unique opportunity to align bioenergy development with environmental conservation. The study determined the distribution pattern of bamboo in two ecological zones in Nigeria and to determine its a bioenergy crop. Three locations each in the lowland rainforest (Ondo State) and derived savanna (Oyo State) were purposefully sampled with three bamboo clumps randomly selected in each location. Top, middle and base of three matured *B. Vulgaris* trees (≥ 5 m long) were sampled per location. The samples were analysed for proximate, calorific content. Bioclimatic variables from AFRICLIM v3.0 and data from Global Biodiversity Information facility (GBIF) were used to model climatic niche of bamboo. Spatial MaxEnt v3.4.0 was used to create distribution and habitat suitability maps. Questionnaires (180) were purposively administered to respondents in three local government areas in bamboo localities in the two states. All data were analysed for statistical differences using descriptive and inferential statistics at $p=0.05$. In Nigeria, very high stable (0.75-1.00) bamboo populations were found in Ekiti, Ondo, Enugu, Cross River, Benue and Taraba States. There were no significant differences in all fuel properties evaluated. Volatile matter (81%, 80%) and ash content (2%,1%) of the samples from Ondo state were lower values compared to Oyo. Samples from Ondo States (48%,45%) had higher carbon and oxygen (43%,42% respectively) content than the samples from Oyo state. The calorific content of the bamboo biomass samples collected from the lowland rain forest was not significantly different from than that of the derived savanna. Many respondents (93.1%) observed changes in the distribution of bamboo over the past few years due to exploitation. Potential of bamboo as a viable energy plant indicate needs for its conservation and regeneration. Proactive measures should be made to protect and restore bamboo habitats through intentional cultivation and plantation establishment, which is currently almost non-existent in Nigeria.

Keywords: *Bambusa vulgaris*, Bamboo conservation, Lowland rainforest, Derived savannah, Bioenergy crops, Renewable energy.

Acknowledgement

The authors acknowledge the support of the Tertiary Education Trust Fund (TETFund), Nigeria for funding attendance at this conference. The support provided opportunity to present our research findings and also to professionally engage with other scholars and researchers.

ECO/PH25/WDR15**HEAVY METAL DETERMINATION OF FOUR ACCESSIONS OF BAMBARA NUT (*VIGNA SUBTERRANEA*) IN CRUDE OIL POLLUTED SOIL****Bulo Precious Tombari and Ochekwu, Edache Bernard***Department of Plant Science and Biotechnology, University of Port Harcourt**Email: edacheb@gmail.com***ABSTRACT**

A study on heavy metal analysis of four accessions of Bambara nuts (*Vigna subterranea*) TVSU-1526, TVSU-1532, TVSU-1548 and TVSU-2067 in crude oil polluted soil was conducted in the centre of Ecological Studies, University of Port Harcourt. The control soil were obtained from the University of Port Harcourt Agriculture Farm and Research Institute while the polluted soil was obtained from Ogale, Eleme in Rivers State. The experiment had 5 treatments (The four accessions of bambara nut and one control). The treatments were replicated four times. Viable seeds of the different accessions of Bambara nut were planted and morphological and physicochemical parameters were taken. The results shows that plants in the unpolluted soil grew well compared to plants in polluted soil which did not do so well. The morphological parameters conducted were plant height, number of leaves and leaf area. The heavy metal from the four accessions were analyzed for its content in the plant and soil using the atomic absorption spectrophotometer (AAS). The results obtained indicates no concentration of cadmium, lead and nickel in both control and polluted soil, In accessions TVSU-1526, TVSU-1532, TVSU-1548 and TVSU-2067 Zinc had concentrations 5mg/kg, 4mg/kg, 6mg/kg and 5mg/kg for soil respectively and 1mg/kg for control. Copper was negligible in polluted and unpolluted soils. There was no content of cadmium, lead and nickel in plants. In accessions TVSU-1526, TVSU-1532, TVSU-1548 and TVSU-2067 Copper had concentrations of 12mg/kg, 12mg/kg, 11mg/kg and 8mg/kg respectively for plants grown in the crude oil polluted soil and 9mg/kg, 8mg/kg, 7mg/kg and 4mg/kg respectively for plants in unpolluted soil. In accessions TVSU-1526, TVSU-1532, TVSU-1548 and TVSU-2067, Zinc presented 28mg/kg, 35mg/kg, 22mg/kg and 23mg/kg respectively for plants in polluted soil and 5mg/kg, 4mg/kg, 3mg/kg and 5mg/kg for control. Hence, Bambara nuts should not be grown in crude oil polluted soil as there is very high uptake of zinc which is harmful to crop growth and in general crop production and the human health.

Keywords: Heavy metals. Bambara nuts, crude oil, polluted soil

ECO/PH25/EAC01

PREVALENCE OF GASTROINTESTINAL PARASITES AND MANIFESTATION OF DISEASE CONDITION IN AFRICAN GIANT RATS (*CRICETOMYS GAMBIANUS* W.) IN CAPTIVITY**Badmus, Hafiz Ayinde¹, Olaogun, Sunday Charles², and Adedokun, Rahamon A. Moshood²**¹*Department of Crop Protection and Environmental Biology, University of Ibadan, Nigeria*²*Department of Veterinary Medicine, Faculty of Veterinary Medicine, University of Ibadan, Nigeria***Corresponding author: badmus.hafiz@gmail.com +2348038267691***ABSTRACT**

African giant rat (AGR) (*Cricetomys gambianus*) is a small mammal species belonging to the order Rodentia of the family Nesomyidae. Its domestication could serve as an alternative source of animal protein to fight malnutrition among the people. However, it has been reported to be a vector of zoonotic diseases as it harbours parasites of public health importance. This study was therefore aimed to investigate the prevalence of gastrointestinal parasites and manifestation of disease conditions in AGR in captivity. Forty (40) sexually mature AGRs (20 females and 20 males) caught from the wild in Ibadan were housed in a fabricated metal cage (one per housing unit) for 4 weeks. A total of 40 faecal pellet samples were collected for parasitological analysis to ascertain their state of health. Postmortem examination were carried out and tissue samples from lungs, liver, testis/epididymis were collected for microbiological analysis of the defective tissues. Results showed that some of the wild-caught AGRs harboured parasitic nematodes - *Heterakis spumosa*, *Trichuris* sp., and *Strongyloides ratti*, and cestode - *Hymenolepis* sp. Female AGRs had all the three parasitic nematodes - *Heterakis spumosa* (62.5%), *Trichuris* sp (25.0%), and *Strongyloides ratti* (12.5%). Male AGRs had *Heterakis spumosa* (81.8%) and *Strongyloides ratti* (9.1%). Manifestations of the disease condition include inflammation of manus and pes, pus coming out from anus, lesion at the extreme of the pinna, different appearance of lesions around the face. Post-mortem examination indicated hemorrhages on both lungs and inflamed epididymis.

Conclusively, African giant rats harbor some gastrointestinal parasites which could adversely affect their domestication. It is therefore advised that the likelihood of the parasites in this rodent species should be considered in any plan for their domestication.

Keywords: Gastrintestinal parasites, African giant rats, Captivity, Domestication

ECO/PH25/WRS10**ECOSYSTEM SERVICES IN THE WETLANDS OF NIGER DELTA REGION****Otukam, Nwabuife Trinity., Ochekwu, E.B. and Ugiomoh, I.G***Department of Plant Science and Biotechnology, University of Port Harcourt***ABSTRACT**

The wetlands of the Niger Delta, the largest in Africa and among the most biodiverse globally, provides critical ecosystem services that sustain livelihoods, support biodiversity and stabilize the environment. These services include provisioning services such as food, freshwater, and timber; regulating services like water purification, flood control and climate regulation; cultural services encompassing recreation, tourism, and spiritual significance and supporting services such as soil formation, nutrient cycling, and habitat provision. Despite their immense value, these wetlands face threats from oil and gas exploration, deforestation, pollution, climate change, invasive species, and urbanization. These activities have led to habitat degradation, biodiversity loss, and declining ecosystem functionality. Sustainable management through community-based conservation, and strengthened policy frameworks are essential for preserving these ecosystems. Initiatives such as fostering community participation, enforcing conservation policies, supporting alternative livelihoods and promoting research and monitoring to guide adaptive management is helping in the sustainable management of these wetlands. The Niger Delta wetlands' preservation is vital for ecological balance, human welfare, and global environmental health.

Keywords: Ecosystem services, wetlands, Niger Delta, Pollution, Conservation policies

ECO/PH25/WDR17**COMPARATIVE STUDIES OF HEAVY METAL UPTAKE ABILITIES OF SOME PLANT SPECIES IN THE FAMILIES OF AMARANTHACEAE, EUPHORBIACEAE, AND POECEAE.****¹AMADI, N and ²GBOSIDOM, VL**

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ABSTRACT

Heavy metal contamination significantly threatens soil health, ecosystems, and human populations, primarily driven by industrial, agricultural, and other human activities. This study investigates the heavy metal uptake potential of selected plant species from the families Amaranthaceae, Euphorbiaceae, and Poaceae to assess their suitability for phytoremediation. Systematic sampling was conducted between coordinates Lat: 4.9046N, Long: 6.9630E, and Lat: 4.9044N, Long: 6.9628E. The results revealed that among the sampled species, *Cyperus esculenta* exhibited the highest cadmium (Cd) accumulation at 6.1 mg/kg, while *Amaranthus sp.* also demonstrated substantial absorption at 8.5 mg/kg. Other noteworthy species included *Utricularia sp.* (3.31 mg/kg), *Echinochloa colon* (2.68 mg/kg), *Ageratum conyzoides* (2.18 mg/kg), *Ludwigia sp.* (2.22 mg/kg), and *Eleusine indica* (2.13 mg/kg). The findings suggest that *Amaranthus spp* was particularly effective for Cd removal from contaminated soils. Therefore, it is recommended to prioritize this species family in phytoremediation projects to enhance soil health and mitigate contamination.

ECO/PH25/WAF16**FERTILITY ASSESSMENT AND MANAGEMENT OF SOME WETLAND SOILS OF AKWA IBOM STATE, NIGERIA FOR SUSTAINABLE CROP PRODUCTION.****OBONG, OBONGINYANG EDEM***Department of Crop and Soil Science, Ignatius Ajuru University of Education**Rumuohumeni, Port Harcourt, Rivers State, Nigeria.**Email: princeobonginyangedem@gmail.com***ABSTRACT**

Fertility Assessment of some wetlands soils in Akwa Ibom States was studied for their potentials and constraints to crop production. The aim was to identify soil parameters that limit crop productions in these soils. A total of ninety-six surface (0-15cm) and sub-surface (15-30cm depth) soil samples obtained from ten locations of wetlands were subjected to routine laboratory and statistical analysis using standard methods. Random sampling technique were employed in the collections of soil samples. Results revealed that the sand component of the soil which ranged from 11.0g/kg to 92.2g/kg decreased with increased soil depth. The clay and silt fractions ranged from 20g/kg to 530g/kg and 40g/kg to 560g/kg respectively. The highest sand content was obtained at 0-15cm top soil. The result showed that nutrient status of some of the soils were moderate as revealed by their estimated levels of availability. The soil were acidic in reaction. Mean P^H value were 4.8 in the surface soils and 4.6 in the subsurface soils. Total Nitrogen, calcium, sodium and electrical conductivity were all less than the critical levels in the soils but moderate to high in organic matters, available phosphorus, exchangeable potassium, base saturation and micro nutrient (Fe and Mn). The main constraints of these soils to sustainable crop production were therefore, the low chemical fertility (high acidity condition, low exchangeable calcium and nitrogen concentrations). However, short and long season crops can be grown at either subsistence or commercial level. Ordinarily, fertilizer and lime could be recommended as measures to increase yield of crops, but these inputs are both unaffordable and unavailable at critical periods, alternatively, also for effective management of these soils, application of organic manure (including cattle manure) would supply the basic cations including K, as well as reduce soil acidity. Therefore, the farmers are encouraged to harness cheap resources available on the farms such as mulch and bio-fertilizer to improve and maintain soil nutrient (potentials) rather than rely on inputs that are normally not accessible for their utilization.

Keywords: Fertility Assessment, Wetland soils, Sustainable crop production.

ECO/PH25/WVSE08

HARNESSING THE ECOLOGICAL AND SOCIO-ECONOMIC BENEFITS OF AQUA-SILVICULTURE IN WETLAND AGROFORESTRY SYSTEM: ISSUES, CHALLENGES AND WAY FORWARD

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ABSTRACT

Aqua-silviculture, also referred to as aqua-forestry, may be defined as a land use system whereby cultivation of aquatic trees is intentionally integrated with rearing of aquatic animals on the same land unit, having a symbiotic relationship ecologically and economically. It is a new name coined from a set of old agroforestry practices that has the potential for increased productivity, sustainable resource utilization and encouragement of adoptability in agroforestry practices in wetlands across Nigeria. It is an innovative and environmentally friendly approach in agroforestry practices that can increase fish yields, diversify farmers' income, improve water quality, contribute to climate change resilience and mitigation, enhance aquatic biodiversity conservation and provide nutrient elements for accelerated tree growth and development in a complex chain of bio-geochemical cycles within the ecosystem. However, issues and challenges such as the absence of a regulatory policy framework, adoptability, capacity building, development land and water, pest and disease management strategies need to be addressed and overcome in order to reap the potential benefits of aqua-silviculture in the largely agrarian communities of wetlands, especially in the Niger Delta Region of Nigeria. This paper aims to provide some insight into the ecological and socio-economic potentials of aqua-silviculture, while highlighting its challenges and issues that need to be surmounted, in order to harness the full benefits of the innovative approach in agroforestry.

ECO/PH25/WDR07**NATURE-BASED SOLUTIONS FOR WETLAND RESTORATION: A STRATEGIC APPROACH TO FLOOD MITIGATION AND BIODIVERSITY CONSERVATION IN KARIM LAMIDO, TARABA STATE****¹AKPAMI, Robo Samaila, ²GIDADO, Usman Muhammad and ³ISAH, Idris Iliyasu***^{1and2} Department of Architecture, Ahmadu Bello University, Zaria**³ Department of Urban and Regional Planning, Ahmadu Bello University, Zaria**Corresponding author: Akpamirobo@gmail.com***ABSTRACT**

Wetlands are vital ecosystems that support biodiversity, regulate floods, and improve water quality, yet they are increasingly degraded due to climate change, invasive species, unsustainable agriculture, and urbanization. This study explores the effectiveness of Nature-Based Solutions (NBS) in restoring degraded wetlands as a dual strategy for flood mitigation and biodiversity conservation, focusing on Karim Lamido in Taraba State, Nigeria. Key NBS strategies examined include hydrological restoration, replanting native vegetation, and establishing buffer zones. Using a descriptive approach, the research integrates literature review, field surveys, photographic documentation, and Geographic Information System (GIS) analysis to assess flood risks and restoration impacts. Findings indicate that NBS significantly enhance habitat quality, species diversity, and flood resilience by improving water retention and reducing flood peak levels. Additionally, NBS prove to be cost-effective compared to traditional flood control infrastructure, offering co-benefits for ecological health and community resilience. The study underscores the scalability of NBS for wetland restoration and calls for policy interventions to mainstream NBS in flood management and biodiversity conservation efforts.

Keywords: Biodiversity Conservation, Ecological Restoration, Flood Mitigation, Nature-Based Solutions, Wetland Degradation

ECO/PH25/WDR08**HEAVY METAL DETERMINATION IN SOIL CONTAMINATED WITH CRUDE OIL IN BODO COMMUNITY, GOKHANA LGA, RIVERS STATE****ONYEDEKE, PEACE CHIZOBA¹ and OCHEKWU, EDACHE BERNARD²***Institute of Natural Resources, Environment and Sustainable Development (INRES), Faculty of Science, University of Port Harcourt**Department of Plant Science and Biotechnology, University of Port Harcourt***ABSTRACT**

Soil contamination by heavy metals and hydrocarbons is a critical environmental challenge, particularly in regions affected by crude oil spills. This study investigates heavy metal and hydrocarbon contamination in soils from Bodo, Gokana Local Government Area, Rivers State, focusing on parameters such as pH, nutrients, heavy metals, hydrocarbons, and microbial populations. Soil samples were collected from five designated locations, including surface soil (0–15 cm) and sub surface soil (15–30 cm), as well as three control stations. Analytical procedures followed EPA Method 3050B for digestion, with concentrations quantified using Atomic Absorption Spectroscopy (AAS). Sulphate, phosphate, and nitrate levels showed no significant differences ($p > 0.05$) between contaminated and non-contaminated soils. Heavy metal analysis revealed statistically significant differences in zinc ($p = 0.04$), iron ($p = 0.05$), and chromium ($p = 0.04$) levels, whereas lead, manganese, arsenic, and copper levels were not significantly different. Cadmium was undetected in all samples. Total Petroleum Hydrocarbon (TPH) concentrations were significantly higher in contaminated soils ($p = 0.002$). Microbial analysis indicated elevated Hydrocarbon Utilizing Bacteria (HUB) and Fungi (HUF) counts in contaminated samples, confirming enhanced microbial activity in hydrocarbon-affected soils ($p < 0.05$). Overall, the values reported for most parameters were within their respective regulatory limits.

Keywords: Heavy metals, contaminated soil, crude oil, hydrocarbon, microbial population

ECO/PH25/WVSE14**ETHNOBOTANICAL SURVEY OF MALARIA-TREATING PLANT SPECIES IN IJESA REGION, OSUN STATE, NIGERIA****Cole Alice Temitope¹, Abodunrin Toyin Aanuoluwa² and Akande Funke Karimont²**

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ABSTRACT

The research work shows information on traditional use of plant species for the treatment of malaria and the data included were gathered based on custodians of knowledge on ethno-medicine on their knowledge of the use of plant species for malaria treatment to make a compendium of malaria-treating plant species in the study area. This project examined the traditional use of plant species for the treatment of malaria in Ijesa region of Osun State, Nigeria. The data gathered was based on 100 respondents using Stratified random sampling to select custodians of knowledge on ethno-medicine for interview on their knowledge of the use of plant species for malaria treatment using semi structured questionnaire to make a compendium of malaria-treating plant species in the study area. Methods of preparation and dosage of administration were noted and documented, all mentioned plants were collected and identified at the herbarium of the Environmental Biology department, Osun State College of Technology, Esa Oke and Fidelity ratio was determined to establish the popularity of the prominent identified plant species. The result revealed that plant species identified for treating malaria in the study area were thirty-eight (38) species belonging to 27 families and the species that were reported to be used mostly were *Azadirachta indica*, *Mangifera indica*, *Cymbopogon giganteus* and *Tithonia diversifolia*. And all these species had an average rating of 4 out of 5 in terms of efficacy at treating malaria symptoms. Other species used with lower frequencies were *Citrus aurantifolia*, *Chromolaena odorata*, *Lawsonia inermis* and *Bambusa vulgaris*. Also, the study discovered that majority of the participants used traditional remedies as their primary treatment for malaria rather than pharmaceutical drugs and varieties of medicinal plant species were used by the Ijesa people for treatment of malaria. Further research is recommended to assess the efficiency of these and other plant species for treating malaria symptoms as well as the potential in the development of medicinal products.

Key words: Ethnobotanical, compendium, pharmaceutical, antioxidant, annihilative

ECO/PH25/WBC11**METABOLIC ENGINEERING FOR BIOFUEL PRODUCTION**

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ABSTRACT

Metabolic engineering is a multidisciplinary field that combines principles of chemistry, biology, genetic and engineering to manipulate and optimize cellular metabolic pathway for production of valuable compounds such as biofuels, pharmaceuticals and industrial chemicals. It offers an alternative approach in which synthetic pathways are engineered into user friendly hosts for the production of these fuel molecules. This field has gain significant attention and importance in recent years due to its potential to address global challenges related to energy. The goal of metabolic engineering is to design and modify microbial to enhance the ability to produce desired products in a more efficient and cost-effective manner. It plays a crucial role in the production of biofuels which are inflammable fuels made from biomass like starch and agricultural waste. It is classified based on their production like bioethanol, biodiesel and biogas. Biofuel is of great importance because it can reduce greenhouse gas emissions and also create new opportunities for the economic development. The challenges for scaling up biofuel production are infrastructure requirement, technology limitations etc. This paper concludes that by re-designing and fine-tuning metabolic pathways in microorganisms, building infrastructure and improving technology, researchers can enhance their ability to produce biofuel in a cost –effective and sustainable manner.

Keywords: Metabolic Engineering, Biofuel, Sustainable fuel production, Micro-organism, Renewable resources.

ECO/PH25/WVSE17

PUBLIC AWARENESS AND COMMUNITY PARTICIPATION IN ARGUNGU FISHING FESTIVAL, KEBBI STATE, NIGERIA.

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ABSTRACT

This study examined the public awareness and community participation in the Argungu Fishing Festival, Kebbi state, Nigeria. Data used for the study was obtained from both primary and secondary sources. Primary sourced data were obtained with the use of a structured questionnaire and interview while the secondary sourced data was obtained from government publications on Argungu community. A total of 40 tourists and 400 community participants were randomly selected as sample for the study. The study's data were analyzed using descriptive and inferential statistical methods. Results obtained in the study showed that 70% of the tourists were not aware of the fishing festival, and only 30% of the tourists were aware of the fishing festival, while 100% of the participants from the communities were aware of the activities of Argungu fishing festival. The community participants were more informed on the Argungu fishing festival activities compared to the tourists; this was an indication of lack of publicity of the Argungu fishing festival. Findings obtained in the study on stakeholders' participation in the festival revealed that they have an acceptable level of participation in some of the major events due to no special criteria or taboos associated with participating in the festival events.

ECO/PH25/WBC10**COMPARATIVE ASSESSMENT OF THE PHYTODIVERSITY AND ECOSYSTEM DYNAMICS OF WETLANDS WITHIN AND AROUND THE UNIVERSITY OF PORT HARCOURT****Asaye, D.C., Agbagwa I.O. and Ochekwu, E.B.***Department of Plant Science and Biotechnology, Faculty of Science, University of Port Harcourt, Choba, PMB 5323, Rivers State, Nigeria.**Email: asayebelema@yahoo.com and edacheb@gmail.com***ABSTRACT**

This study was conducted to investigate the comparative assessment of phytodiversity and ecosystem dynamics of wetland within and around university of Port Harcourt. Phytosociological attribute of the plant were studied using 250x40m vegetative plots of 4 randomly laid subsets of 10x10m quadrats. Soil and water samples were collected using soil auger and 25cl containers respectively. The samples were analysed for physiochemical parameters. A total of 113 plant species belonging to 52 families was enumerated during the floristic survey. The taxonomic structure and species composition varies among the wetlands with Aminigbo Choba (76 plant species, 37 families) and Nmpiripa Alia (81 plant species, 41 families) that were dominated by Asteraceae and Poaceae families. The structure of wetland is modification by the low percentage of tree and shrub layers having reduced forest cover with increased herb layer. The maximum importance index value (IVI) for tree, shrub and herb layer was found to *Elaeis guineensis*, *Salacca zalacca*, and *Culcasia scandens* respectively. The phytodiversity measure revealed that Nmpiripa Alia had higher Shannon, Simpson's and Magalef's indices for shrub and herb layer. The wetland soil were acidic, with bioavailability of heavy metals following this sequence of concentration Fe>Mn>Zn>Cu for both wetlands. The pH value for water were within acceptable limit of 6.5-8.5, alkalinity and total hardness were above permissible limit of 200mg/L while TDS was below the limit of 500mg/L. This shows that wetlands are modified by disturbance from anthropogenic activities, urban growth and population increase across the university has negatively impacted on the biodiversity of the wetlands which tends to transform the wetland into a xeric habitat. Therefore, it is recommended to develop more sustainable rural livelihood, apply conservation techniques to stimulate tree regeneration and limit dependency on the wetland to reduce anthropogenic incursion.

Keyword: Phyto-diversity, ecosystem dynamics, wetland, anthropogenic, conversation, Physio-chemical parameters.

ECO/PH25/WDR14**COMPARATIVE ANALYSES OF HEAVY METALS IN TWO DIFFERENT SOIL TYPES IN THE FEDERAL CAPITAL TERRITORY, NIGERIA****BRAIDE, ONENGIYE OLAKUNLE¹ AND OCHEKWU, EDACHE BERNARD²**¹: *Federal ministry of Environment, Abuja*²: *Department of Plant Science and Biotechnology, University of Port Harcourt**Email: braideolakunle@gmail.com, edacheb@gmail.com***ABSTRACT**

This study presents a comparative analysis of heavy metal concentrations obtained in soils from dumpsites and quarry sites within the Federal Capital Territory (FCT) of Nigeria. The research aims to assess the extent of soil contamination, identify primary contamination sources, and evaluate potential health and environmental risks associated with heavy metal exposure. The heavy metals analysed include arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), copper (Cu), zinc (Zn), and nickel (Ni). Soil samples were collected from Mpape and Gosa dumpsites as well as from quarries located in Kuje and Bwari while a control sample was collected from a fallow land. The study used pollution indices, geo-accumulation indices, enrichment factors, and ecological risk assessments to evaluate the levels of contamination. Results indicate significant contamination levels for Cd, Pb, and Ni, particularly in soils from the dumpsite, with Gosa exhibiting the highest levels of pollution. Manganese (Mn), Cu, and Zn levels are more moderate but still pose contamination concerns. The quarry sites, while also contaminated, show lower pollution levels compared to the dumpsites while the control site exhibited minimal contamination. The ecological risk analysis reveals that dumpsites pose severe risks to public health and the environment, mainly due to high levels of Cd and Pb. The findings suggest that immediate action is needed to mitigate heavy metal pollution dumpsites and quarry sites. The results will be disseminated to raise awareness and support informed decision-making for improved environmental management in the FCT

Keywords: Heavy metals, dumpsites, Soil types, Pollution indices, FCT

ECO/PH25/WDR19**GEOGENIC ASSESSMENT OF HEAVY METALS IN DISTURBED WETLANDS WITHIN UYO METROPOLIS****Ogbemudia, F. O¹, Anwana, E. D², Ukafia, P. O³, Okon, Ememobong⁴***Department of Botany and Ecological Studies, Faculty of Biological Sciences, University of Uyo.**Corresponding Author: ukapentecost13@gmail.com***ABSTRACT**

In Akwa Ibom State, wetlands have been threatened by anthropogenic activities like waste discharge, industrialization and infrastructural developments. These activities for years have led to the contamination of these ecosystems by varying proportions of heavy metals. This calls for concern because above their permissible limits, they become toxic to macrophytes and also affect their growth and distribution. To this end, it was pertinent to geochemically assess heavy metal contamination in rural and urban wetlands in Akwa Ibom State, Nigeria. At different rooting depths (0 – 15 cm and 15 – 30 cm), soil samples were collected and analyzed for Lead (Pb), Zinc (Zn), Iron (Fe), Nickel (Ni) and Cadmium (Cd) using standardized methods. From the results, variations occurred in heavy metal contents in the wetland soils. It revealed that the mean values of Fe (713.22 ± 59.39), Pb (5.95 ± 0.42), Zn (88.54 ± 8.03) and Cadmium (1.53 ± 0.65) were higher in the urban pond while Ni (9.45 ± 1.56) was higher in the rural pond. Heavy metal contamination status was assessed using indices such as enrichment factor, geo-accumulation index, contamination factor and degree of contamination. The calculated enrichment factor values for the studied metals in both ponds revealed that Cd and Ni showed deficiency to minimal enrichment while Zn and Pb showed moderate and significant enrichment status. Geo-accumulation index values in the two ponds revealed that Cd had an unpolluted status, Fe and Ni showed an unpolluted to moderately polluted status while Zn and Pb contents showed amoderately polluted to highly polluted status. The values obtained for contamination factor showed a moderate contamination status for Cd, considerable contamination for Fe and Ni and a very high contamination status for Zn and Pb. Also, a very high contamination degree was recorded in both ponds with a higher value obtained in the urban pond (39.08) than in the rural pond (33.71). Cluster analysis was employed to show the heavy metals source apportionment in the wetlands. The result from this study clearly shows that presently, these wetlands are contaminated due to increased anthropogenic activities like waste discharge. To this end adequate measures should be put in place by relevant authorities to checkmate and regulate human activities around wetlands in order to protect them from further deterioration and contamination.

ECO/PH25/WDR01**NATURE-BASED SOLUTIONS FOR RESTORING DEGRADED WETLAND ECOSYSTEMS: A STRATEGY FOR FLOOD CONTROL AND BIODIVERSITY CONSERVATION****¹AKPAMI, Robo Samaila. Majiyebo, ²GIDADO, Usman Mohammed. And ³Isah ILYASU Idris***^{1and2} Department of Architecture, Ahmadu Bello University, Zaria**³ Department of Urban and Regional Planning, Ahmadu Bello University, Zaria**Corresponding author: Akpamirobo@gmail.com***ABSTRACT**

Wetlands play a crucial role in supporting biodiversity, regulating floods, and purifying water, yet these ecosystems face significant degradation due to climate change, invasive species, unsustainable agricultural practices, and urbanization. This degradation has heightened flood risks and led to biodiversity loss. This research investigates the potential of Nature-Based Solutions (NBS) to restore degraded wetlands as a dual strategy for flood mitigation and biodiversity conservation, with a focus on the Nigerian context. The study examines the floodplains of Karim Lamido in Taraba State and the Hadejia-Nguru Wetlands in Jigawa State as case studies. Key NBS strategies explored include hydrological restoration, replanting native wetland vegetation, and establishing buffer zones. A mixed-methods approach is utilized, encompassing a review of existing literature, field surveys, photographic documentation, and environmental assessments using Geographic Information System (GIS) tools to monitor flood risks and evaluate restoration outcomes. The findings demonstrate significant improvements in species diversity and habitat quality, alongside measurable reductions in flood risks. Enhanced water retention capacity and decreased flood peak levels underscore the effectiveness of NBS in achieving ecological and hydrological balance. Moreover, the study highlights the cost-effectiveness of NBS compared to conventional grey infrastructure for flood control, while emphasizing its co-benefits for community resilience and ecological health. The research underscores the scalability and sustainability of NBS for wetland restoration. It calls for coordinated policy interventions prioritizing ecological restoration and advocating for broader adoption of NBS as a transformative approach to addressing the intertwined challenges of flooding and biodiversity loss.

Keywords: Biodiversity Conservation, Ecological Restoration, Flood Mitigation, Nature-Based Solutions, Wetland Degradation

ECO/PH25/WVSE13**PHYTOCHEMICAL COMPOSITIONS OF *Piper guineensis* (SCHUMACH AND THONN), *Gongronema latiafolium* (BENTH) AND *Lasienthera africanum* (P. BEAUV)****Sub theme; Wetlands, agroecology, aquaculture and food security.****Nnadi, P.C, Tamunopekerebia, G.N, Saragoro –David, N.***Forestry and Environment Department, Rivers State University, Port Harcourt, Nigeria.**Email address: picaso1ng@yahoo.com*

ABSTRACT

This research was carried out in Food Science and Technology laboratory, Faculty of Agriculture, Rivers State University, Port Harcourt. The leaves of *Piper guineensis*, *Gongronema latiafolium*, *Lasienthera africanum* were used in the phytochemical analysis in the laboratory. It was analysed for Alkaloids, Flavonoid, Total Phenol, Terpenoid. Mean separation was done using analysis of variance. The results on Phytochemicals shows that *Lasienthera africanum* had the highest mean value for Total phenol (9.56 ± 0.11), Flavonoids (13.99 ± 0.00) and Alkaloids (35.90 ± 0.05), followed by *Piper guineensis* which had for Total phenol (5.22 ± 0.00), Flavonoid (8.57 ± 0.02) and Terpenoid (8.53 ± 0.37) while *Gongronema latiafolium* had the least in Phenol (4.63 ± 0.01) and Flavonoid (6.17 ± 0.01). The research shows that the leaves of *Piper guineensis*, *Gongronema latiafolium* and *Lasienthera africanum* contains phytochemicals such as phenol, Terpenoid, Flavonoid and Alkaloids which have medicinal and nutritional values and can be consumed and also used by pharmaceutical industries.

ECO/PH25/EAC17**THE IMPACTS OF ANTHROPOGENIC ACTIVITIES IN THE NIGER DELTA ON CLIMATE CHANGE: CHALLENGES AND PROSPECTS FOR SUSTAINABLE DEVELOPMENT****Tariwari C. N. Angaye¹, and Augustus N. Ebelegi²***¹Toxicology Research Unit, Department of Biological Sciences, Niger Delta University, Bayelsa State, Nigeria**² Institute for Climate Change, Niger Delta University, Bayelsa State, Nigeria**Corresponding Author Email: ebelegiaugustus@ndu.edu.ng***ABSTRACT**

This review examines the influence of anthropogenic activities on climate change in the Niger Delta region of Nigeria, highlighting anthropogenic actions as drivers for impact of climate change within the region. The region, rich in oil and gas resources, faces severe environmental degradation due to activities sustained oil exploration, gas flaring, deforestation, and industrial pollution. These activities exacerbate the impacts of climate change due to increased greenhouse gas emissions, destruction of carbon sinks, and alteration of weather patterns. Rising sea levels, coastal erosion, biodiversity loss, and declining agricultural productivity further threaten the region's ecological and socio-economic stability. This review identifies some major institutional challenges such as weak governance, over-reliance on oil, and environmental injustice that infringe on the livelihoods of inhabitants of both urban and rural dwellers. It also explores prospects for sustainable development through renewable energy, environmental restoration, economic diversification, and improved policy frameworks. Additionally, this review synthesizes recent literature, offering policy recommendations and calling for further research into community-based climate adaptation and environmental governance. Finally, It concludes that addressing these issues through integrated and inclusive strategies is vital for the sustainable future of the Niger Delta.

Keywords: Climate Change, Anthropogenic Activities, Niger Delta, Environmental Degradation, Sustainable Development

ECO/PH25/WRS11

WETLANDS OF SOUTHWEST NIGERIA: IMPORTANCE, EMERGING CHALLENGES, TRENDS, AND STRATEGIC PATHWAYS FOR SUSTAINABLE MANAGEMENT

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ABSTRACT

Wetlands are vital ecological zones that offer numerous supports that sustain the environment and local livelihoods. Wetlands in Southwestern Nigeria provide essential habitats for diverse plant and animal species, contribute notably to agriculture through initiatives such as the FADAMA projects, and support both fishing and ecotourism activities. Despite this importance, the ecosystem continues to face threats from urban expansion, unsustainable farming practices, pollution, and climate change. This paper synthesizes the ecological and socioeconomic significance of wetlands in Southwest Nigeria, reviews current trends in wetland degradation that are peculiar to Wetland in Southwestern Nigeria and identifies key challenges undermining their sustainability. It further emphasizes policy, and management gaps and discusses pathways to nature-based solutions, community-led conservation efforts, and the integration of wetland management into regional planning frameworks. The study highlights the need for preemptive strategies and collaborative governance to preserve the ecological integrity of wetlands and enhance their resilience in the face of increasing anthropogenic pressures.

ECO/PH25/WBC17**FISH SPECIES COMPOSITION IN RIVER YADZARAM, MUBI-NORTH ADAMAWA STATE, NIGERIA****Buba, Z.M., Isa, D.T.***Department of Zoology, Adamawa State University, Mubi, Adamawa State, Nigeria.**Corresponding Author: Zainab B. Mshelia, Department of Zoology, Adamawa State University, P. M. B. 25, Mubi, Adamawa State, Nigeria.**Email: zainabbubamshelia@gmail.com**GSM: 08051008223, 07063218395***ABSTRACT**

Fish are important because they contribute as much as 17% of the global animal protein. Fish and fisheries have been increasingly threatened or even disrupted by man-made induced environmental changes, such as pollution, clearance for farmlands and cutting of trees for firewood (deforestation), habitat alteration like river impoundment, poor management and over exploitation. This decrease in resources availability does not only result in poor income but also in well-being of fishing households and community. To address these knowledge gaps, it is important to conduct a comprehensive investigation on the fish species composition in River Yadzaram, Mubi-North, Adamawa State, Nigeria, from May to July 2024. The research aims to assess the variety of fish species and their spatial distribution along the river. A total of 11 species from 11 families were identified, with *Oreochromis niloticus* being the most abundant with seventy (70), followed by *Citharinus citharus* fifty-four (54), while *Clarias gariepinus* and *Schilbe uranoscopus* were the least represented with three (3) in number. The highest species distribution was recorded in July, attributed to favourable environmental factors such as increased water volume and temperature, food availability, and breeding season. The findings suggest that *Oreochromis niloticus* plays a dominant ecological role in the river, reflecting similar trends observed in other Nigerian freshwater bodies. Seasonal variations significantly affected fish species abundance and distribution. The researcher highlights the need for further investigation into the factors influencing low species richness and also recommends habitat restoration, sustainable fishing practices, and a long-term monitoring program to preserve the river's biodiversity.

Keywords: Composition, Fish, Species, River, Yadzaram, Mubi

ECO/PH25/WAF14

GROWTH PERFORMANCE AND NUTRIENT UTILIZATION OF *Clarias gariepinus* (BURCHELL, 1822) FINGERLINGS FED VARYING LEVELS OF CO-MIXED OF BETAINES/ β -GLUCAN AS FEED ADDITIVE

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ABSTRACT

This study evaluates the growth performance and nutrient utilization of *C. gariepinus* fingerlings fed varying levels of co-mixed of betaine/ β -glucan as feed additive. Co-mixed of betaine/ β -glucan was included into formulated feed with 40% crude protein at; 0.0g/100g (BBG0 i.e. control), 0.325g/100g (BBG1), 0.75g/100g (BBG2), 1.125g/100g (BBG3) and 1.50g/100g (BBG4) in triplicates. Feed was fed to *C. gariepinus* fingerlings (n = 300, 10.0 $\pm$ 0.00g) in fifteen (15) plastic tanks (n = 20) at fixed feeding rate of 3% body weight twice daily between 8:00 – 9:00am and 4:00 – 5:00pm at regular interval and adjusted after every two (2) weeks of sampling for a period of twelve (12) weeks. Data was collected and analysed using one-way analysis of variance (ANOVA) at P = 0.05. Mean weight gain (MWG) 190.0 $\pm$ 2.0 g/fish, daily weight gains (DWG) 2.26 $\pm$ 0.02 g/day, specific growth rate (SGR) 1.53 $\pm$ 0.10 %/day, feed conversion ratio (FCR) 1.40 $\pm$ 0.15, protein efficiency ratio (PER) 1.77 $\pm$ 0.20 and survival rate 90.0 $\pm$ 1.5 % were all better in diet BBG2. Inclusion of varying levels of co-mixed of betaine/ β -glucan did not result in statistically significant changes (p>0.05) in MWG, DWG, SGR, FCR and PER, however, there was a significant (p<0.05) changes in survival rates of the *C. gariepinus* fingerlings. Therefore, co-mixed of betaine/ β -glucan at level of inclusion of 0.75g/100g (BBG2) is recommended.

Keywords: Adjusted, Daily, Evaluate, Formulated Feed, Sampling.

ECO/PH25/WDR19**MICROPLASTIC REMOVAL FROM WATER USING AGRICULTURAL WASTE-DERIVED ACTIVATED CARBON****Chukwudi^a, Peter, Nduka-Chukwudi^b, Chidimma Adamma and Mbong^a, Emem Okon.**^a*Admiralty University of Nigeria (ADUN), Ibusa Delta State, Nigeria*^b*National Inland Waterways Authority, Onitsha, Nigeria.**Corresponding author: chukwudi.peter@adun.edu.ng***ABSTRACT**

This study used activated carbon produced from rice husks and coconut husks to remove microplastics from water. Microplastics (500 microns) were prepared by simulated abrasion. Agricultural wastes, rice husks (RH) and coconut husks (CH) (1.18mm mesh size), were carbonized at 500⁰C and 400⁰C respectively in electric muffle furnace for 45mins. Activation of the carbonized wastes was done using 20% H₃PO₄ solution at a ratio of 4:1 (RH) and 3:1(CH) (Acid: Char). The adsorption studies were carried out by pouring 250 ml of deionized water intentionally polluted with 0.4g of the prepared microplastics samples into the columns and allowed to run until the filtrates were collected in weighed beakers (for about 10 minutes). The columns contained doses of the activate carbons as follows: column I: 7 g of activated carbon produced from rice husks; column II: 15 g of activated carbon produced from rice husk; column III: 7 g of activated carbon produced from coconut husk; column IV: 15 g of activated carbon produced from coconut husk; column V: 3.5 g activated carbon produced from rice husk + 3.5 g activated carbon produced from coconut husk; column VI: 7.5 g activated carbon produced from rice husk + 7.5 g activated carbon produced from coconut husk; column VII: 7 g of commercial activated carbon; column VIII: 15 g of commercial activated carbon. The adsorbents used before and after the adsorption studies were characterized using Scanning Electron Microscopy (SEM) examination. The data obtained were analysed with one-way analysis of variance (ANOVA). After activation of the adsorbents, rice husk had a higher yield (28.93%) than coconut husk (7.87%). Microplastics were 100% removed by the activated carbons. Adsorbent efficiency ranged from 0.01 to 0.054; adsorption capacity, 2.44 to 22.61 and adsorption efficiency, 18.28% to 93.75% for overall treatment of the water. Generally, 7 g of the adsorbents had higher adsorbent efficiency, adsorption capacity and adsorbent efficiency than 15 g of the activated carbon. Image of the SEM showed the activated carbons having well-developed pores before the adsorption studies and diminishing porosity with entrapped contaminants after the adsorption studies. The 15 g of commercial carbon had higher adsorption efficiency (91.48%) than the rest doses of the adsorbents. The performance of the activated carbon can be summarized as: 7 g dose: column 5>column 3>column 7>column 1; 15g dose: column 8>column 2>column 4>column 6.

Keywords: Activated carbon, Coconut husks, Microplastics, Rice husks

ECO/PH25/WAF13**INDUCING TUBER FORMATION IN *DIOSCOREA BULBIFERA* ACCESSIONS THROUGH THE USE OF MINISSETTS.****DENGIMO, KEME¹., LOVE AJAKA AKONYE²., KALU OKONWU³.***Department of Biological Sciences, University of Africa, Toru-orua, Bayelsa State.**Department of Plant Science and Biotechnology, University of Port Harcourt, Choba Rivers State.**Department of Plant Science and Biotechnology, University of Port Harcourt, Choba Rivers State.**Kdengimo4real2020@gmail.com.**08065562569**Love.Akonye@uniport.edu.ng**Kalu.Okonwu@uniport.edu.ng***ABSTRACT**

Dioscorea bulbifera a species of yam in the family *Dioscoreaceae* produces aerial bulbils in addition to underground tuber. The process of partitioning in this plant is poorly coordinated, as result tuber formation do not occur in most cases. Therefore, mini-setting was used as a signal induction mechanism to enable meristematic cells proliferate into tuber formation. Result revealed 25% of plant grown by whole bulbils produced tubers, while 80% of plants grown by minisett produced bulbils. Accession TDb3086 grown with whole bulbil had the highest average bulbil weight (218.71g), while its mini-set had and average bulbil weight of 53.24g. Accession TDb 3692 grown with mini-sett had the highest bulbil weight 119.83g, while its mini-set had and average bulbil weight of 171.73g. Average Bulbil weight was higher than average tuber weight in both whole bulbils grown plants (control) and mini-sett plants.

ECO/PH25/WAF15**COMPARATIVE STUDY ON THE EFFECTS OF SOIL TYPES ON LEAF AREA DEVELOPMENT IN *Ocimum Sanctum* SEEDLINGS****¹FRIDAY ODEYOMA EGBERI and ²GODSPOWER OYUB***Department of Biology Education, School of Sciences, Delta State College of Education, Mosogar, Nigeria.**Department of Integrated Science Education, School of Sciences, Delta State College of Education, Mosogar, Nigeria.**Corresponding Author's Email: egberiodes@gmail.com**Corresponding Author's Phone Number: +2347035922677***ABSTRACT**

Ocimum sanctum L. (holy basil) is a medicinal plant of significant therapeutic and commercial value across the herbal, cosmetic, and pharmaceutical sectors. Optimizing soil conditions is essential to maximize its agronomic performance and the yield of economically important secondary metabolites. This study investigates the effects of three soil types—sandy, loamy (humus-rich), and clay—on the vegetative growth of *O. sanctum* under controlled greenhouse conditions, with a focus on leaf area as a key morphological indicator. Quantitative analysis revealed that plants grown in loamy soil developed significantly larger leaf areas (2167.80 ± 60.77 cm²) compared to those in sandy soil (682.00 ± 18.94 cm²) and clay soil (498.60 ± 15.32 cm²), with all differences statistically significant at $p < 0.05$. Loamy soil also supported greater stem height and more extensive root systems, attributed to its balanced texture and superior water and nutrient retention. In contrast, sandy soil exhibited moderate growth performance due to limited moisture and nutrient retention, while clay soil, despite its high nutrient content, restricted root expansion through compaction and poor aeration, resulting in the smallest leaf area and stunted above-ground growth. The observed morphological differences had a direct impact on total biomass and are correlated with potential increases in essential oil and eugenol yield. These findings underscore the critical role of soil type in influencing both the vegetative traits and the economic output of *O. sanctum*, offering valuable recommendations for optimized cultivation practices.

Keywords: *Ocimum sanctum*, soil type, leaf area, biomass yield, secondary metabolites, medicinal plant cultivation

ECO/PH25/EAC14

THE ROLE OF *Hevea brasiliensis* (RUBBER-TREE) PLANTATIONS IN ECOLOGICAL ADAPTATIONS AND CLIMATE CHANGE MITIGATION

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ABSTRACT

The global warming and climate change problem is attributed mainly to high concentration of Carbon-dioxide (CO₂) in the atmosphere. Capturing CO₂ from the atmosphere and storing it in forests and agro-ecosystems through phototropic Carbon sequestration is a strategy that has been prioritized for reducing atmospheric CO₂ concentration to mitigate the climate change effects. The objectives of this study were to examine biomass productivity and Carbon sequestration capability of *Hevea brasiliensis* (rubber-trees), and the role of the species in climate change mitigation. Five plantations of different age levels (4, 6, 14, 18 and 25 years) were selected for sampling. From each plantation, one-hectare area was sub-divided into 25 quadrants (20 x 20 m²) as temporary sampling plots; four (4) quadrants were randomly selected as permanent sample plots per hectare, resulting to a total of 20 sample plots. Diameters at breast height (DBH) of all individual trees within each plot were measured. Total heights as well as diameters at base, middle and top of two mean trees were measured within each plot. Data were analysed using Microsoft Excel. Higher biomass productivity and Carbon sequestration capacity were proven eco-physiological characteristics of *Hevea brasiliensis* that makes the species recommendable for application in climate change mitigation/adaptation. For instance, results of the study showed that above-ground Carbon sequestration of 25-year-old rubber plantation was 175.7 Mg C/ha which was slightly higher than 171.5 Mg C/ha for the reference natural forest in the study area. The study also showed the successful application of rubber trees in ecological adaptations e.g. reclamation of degraded landscapes/watersheds as well as adapting marginal lands for productive climate-smart agriculture to better the socioeconomic status of people highly vulnerable to climate change. As at the time of this study, the 70-hectare rubber-tree plantations that were examined had removed a total of 3.15 Giga grams CO₂ from the atmosphere (1 Giga grams = 10³ Mega grams = 10³ tons). This was considered very significant in view of the fact that it is an on-going ecosystem service of the plantations in helping to mitigate global warming induced by atmospheric CO₂ pollution.

Keywords: Rubber-tree Biomass, Carbon Sequestration, Climate Change Mitigation

ECO/PH25/WVSE06**EFFECT OF AQUEOUS EXTRACTS OF MORINGA, NEEM, PAPAYA AND BITTER LEAVES ON THE NUTRITIONAL AND ANTI-NUTRITIONAL COMPOSITION OF *Dioscorea bulbifera* (AERIAL YAM) MINI-SETT****TEKE, E. C¹; AKONYE, L. A²; EREMRENA, P. O²**¹*Department of Biological Science, University of Africa Toru Orua, Sagbama LGA, Bayelsa State, Nigeria*²*Department of Plant Science and Biotechnology, University of Port Harcourt, Choba, Rivers State, Nigeria.**Corresponding Author Email: teke.calmday@uat.edu.ng**Tel: 234 (0)8064844050***ABSTRACT**

The use of plant extracts on the exposed surfaces of the mini-sett to mitigate pest attack and infection is a common practice amongst farmers. As a result, it is important to investigate the effects of these extracts on the biochemical composition of crop, as they can positively impact it. This study was aimed at evaluating the effect of aqueous extracts on nutritional and anti-nutritional composition of *Dioscorea bulbifera*. The research was conducted on the research farm at University of Port Harcourt, Choba, Rivers State, between November 2022 and September 2023 cropping seasons. Five accessions of *D. bulbifera* were cut into mini-sett and soaked in aqueous plant extract treatments. The five different treatments were; *Azadirachta indica* NT (neem treatment), *Carica papaya* PT (papaya treatment), *Vernonia amygdalina* BT (bitter leaf treatment), *Moringa oleifera* MT (moringa treatment) and no extract CT (control treatment). Planting was done in polyethylene bags filled with sandy soil and arranged randomized complete block design (RCBD). Leaves were collected at eight (8) weeks after planting (WAP), for biochemical analysis. All analysis were carried out based on standard methods. One-way analysis of variance (ANOVA) was used to analyse the results. Least Significant Difference (LSD) was used for mean separation where significant different ($P \leq 0.05$) existed. The results obtained for nutritional composition; carbohydrate 56.67-98.08%, protein 1.79 -21.7%, ash 0.29-7.30%, fibre 0.57-4.60%, fats 0.11-2.49% respectively and for anti-nutrients; phytates 0.50-13.60mg/100g, tannins 0.39-4.73mg/100g, oxalates 0.79-9.59mg/100g, saponins 0.61-7.41mg/100g and trypsin inhibitor 0.22-2.71mg/100g. Results reveal that papaya treatment was observed to selectively increase carbohydrate content of treated plants but did not increase other nutritional constituents and inhibited the production of all antinutrients. The findings support the use of eco-friendly, plant extracts, with potential implications for enhanced crop value, health benefits, and reduced dependency on synthetic agrochemicals.

Keywords: plants extract, biochemicals, nutritional constituents, anti-nutrients

A SURVEY OF VEGETABLES SOLD IN ABRACA MARKETS, ABRACA, DELTA STATE, NIGERIA

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ABSTRACT

This study investigated the vegetables sold in Abraka Markets (main and small), Delta State, Nigeria. The researcher interviewed vegetable sellers in both main and small markets in Abraka, Delta State, Nigeria. Data collection involved structured interviews focusing on the types of vegetables sold, duration of storage and preferences for certain vegetables. Plant identification was conducted using the database of the Royal Botanical Garden. Ethical considerations were strictly adhered to, ensuring voluntary participation and confidentiality of respondents. The survey showed that all respondents were female between 31-40 years. The study identified 13 vegetables belonging to 12 families in both markets. In Abraka Main Market, the most frequently sold vegetable was *Telfairia occidentalis* (Ugu leaf) at 86.67%, followed by *Talinum fruticosum* (Waterleaf) at 66.67%. In Abraka Small Market, *Telfairia occidentalis* also dominated at 87.5%, with *Allium cepa* (Onion) at 75%. The study highlights the critical role of middle-aged women in the vegetable trade in Abraka markets and underscores the importance of understanding vegetable diversity, availability and quality to enhance food security and nutritional well-being in the region. The findings provide valuable insights for policymakers and stakeholders aiming to improve vegetable supply chains and support local agricultural practices in Delta State, Nigeria.

Keywords: Vegetables, Markets, Survey, Delta State

ECO/PH25/WVSE19**THE ROLE OF MICROBIOME IN THE SUSTENANCE OF MANGROVE ECOSYSTEM SERVICES AND THE DANGERS OF THEIR DISTURBANCE VIA COASTAL DEVELOPMENT****Elijah I. Ohimain***Department of Microbiology, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria.
eohimain@gmail.com***ABSTRACT**

This review presents the importance of mangrove ecosystems, their exploitation for economic development and the consequent environmental impact with emphasis on Nigerian mangroves. Mangroves are unique wetlands that occur in the intertidal zone of tropical coastlines. Mangrove ecosystems are hotspots for biodiversity and carry out ecosystem services, which can be categorized into regulatory, supporting, provisioning and cultural services. Mangrove protect the coastline from sea surges and coastal erosion and contain abundant natural resources, which coastal communities rely upon for their survival. It has been observed that mangrove contain unique microbial signature that reflects its health, and enables it to carry out the ecosystem services. Economic development in the Niger Delta mangrove area including oil and gas exploration, crop and fish farming, infrastructure especially roads and canals, reclamation and urban encroachment, effluent and solid waste disposal, has impacted the ecosystem, reducing its ecosystem services especially the capacity to mitigate flooding and erosion. The situation could be compounded by the construction of the 700km coastal road from Calabar to Lagos, which passes through the mangrove ecosystem and the exotic nipa palm that is fast displacing native mangrove species along the entire Nigerian coastline and beyond. Disturbance of mangrove during construction activities, often result in the exposure of pyrites and their microbiological and physicochemical oxidation causing acidification, that destroys the ecosystem even further. Mangrove microbiome also key roles in the sustenance of mangrove ecosystem and their function and restoration and rehabilitation of degraded mangroves.

Keywords: Acidification, anthropogenic activities, climate change, oil and gas exploration, mangrove disturbance, mangrove microbiome, wetlands

ECO/PH25/WVSE09**IMPACT OF LAND USE AND LAND COVER CHANGES ON LAND SURFACE TEMPERATURE IN FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI, NIGERIA**

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ABSTRACT

Land use and land cover change is one of the key drivers of environmental degradation due to its broad implications for ecological, social, economic and climate systems. This study assessed the trends of land use and land cover changes (LULCC) and its impacts on Land Surface Temperature (LST) within the Federal University of Technology, Owerri (FUTO), for the time series of 1984, 2004 and 2024. Multi-temporal satellite imageries of the study periods were obtained from the United State Geological Survey. The data were pre-processed and classified into different LULC types using supervised classification techniques base on Maximum Likelihood Algorithm. Kappa coefficient and Mono-window algorithm were used to determine the accuracy of the classification and the LST respectively. Five LU/LC classes - dense vegetation, farm/grass land, built up, bare land and water body were identified, and each had experienced changes at varying rates within the study periods. Dense vegetation lost 1514.6ha, while farm/grass land, built up, bare land and water body gained 1065.15ha, 271.98ha, 106.83ha and 70.64ha respectively between 1984 and 2024. The accuracy of the classifications using Kappa coefficient was 86%, 90% and 95% for 1984, 2004 and 2024 respectively. The mean LST increased progressively from 20.38°C, to 25.54°C and 28.96°C in 1984, 2004 and 2024 respectively. Dense vegetation and water bodies showed a strong inverse relationship with LST, while built-up areas and bare land exhibited a strong direct relationship with LST. LULCC affected the LST within the study periods. Infrastructure development, soil mining, and agricultural expansion were the key drivers of LULCC in FUTO. Therefore, appropriate land use planning and effective management are highlighted to ensure sustainable land use and holistic development within the university.

Keywords: Land use and land cover, Land surface Temperature, Remote sensing, Environmental degradation

Subtheme: Remote sensing, geospatial technologies and mathematical modelling in wetland studies.