Spatio-Temporal Dynamics of Environmental Resources in Taraba State, Nigeria Using Remote Sensing and GIS Techniques (2000–2022)

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ABSTRACT

The increasing exploitation of natural resources through agricultural expansion, deforestation, mining activities, settlement growth, and climate variability has accelerated environmental transformation and created challenges for sustainable resource management. This study assessed the spatio-temporal status of land, water, vegetation, soil, and atmospheric resources in Taraba State, Nigeria, using Remote Sensing and Geographic Information Systems (GIS) techniques between 2000 and 2022. A mixed-method and longitudinal research design was adopted, integrating field observations, GPS-based ground truthing, and multi-source satellite datasets. Soil characteristics, land use/land cover dynamics, surface water conditions, vegetation health, and atmospheric indicators were analyzed using ArcGIS-based spatial techniques. Results showed that surface soils were mainly sandy loam at 0 cm depth, while deeper layers (60 cm, 100 cm, and 200 cm) were dominated by sandy clay loam. Erosion susceptibility was highest in mountainous areas such as Gembu and Nguroje due to slope and soil conditions. Soil fertility assessment revealed relatively fertile alluvial soils in Karim Lamido, Lau, Gassol, and Ibi, while potassium deficiency occurred in Wukari, Donga, Ibi, Gassol, Jalingo, Ardo-Kola, and Bali LGAs. Water assessment revealed a drainage system dominated by River Benue and its tributaries, while NDWI values ranging from **0–0.6** indicated surface water availability, high moisture conditions, and seasonal flooding. Vegetation analysis showed that tree cover was the dominant land cover class, occupying approximately **16,631.84 km² (28.15%)** of the state. NDVI values reached **0.9–1.0** in Gashaka, Kurmi, and Sardauna, with the highest vegetation performance recorded in 2022 (**average NDVI = 0.89**). Atmospheric analysis revealed variations in dust, black carbon, and aerosol concentrations associated with land degradation and biomass burning. The study concludes that increasing human activities are altering environmental resources and recommends integrated land use planning, sustainable resource management, and continuous GIS-based monitoring.

Keywords: Remote sensing, Geographic Information System, NDVI, NDWI, Environmental resource assessment.

INTRODUCTION

One of the most pressing environmental challenges of the present century is the rapid depletion and transformation of natural resources due to increasing human pressures on land-based ecosystems. Globally, land, water, vegetation, and atmospheric resources are undergoing significant changes driven by agricultural expansion, mining activities, deforestation, urban growth, and infrastructure development. These changes are altering ecological balance, reducing biodiversity, and intensifying environmental risks such as soil degradation, flooding, desertification, and climate variability (Vitousek et al., 1997; Lambin et al., 2001; Foley et al., 2005). The situation is particularly critical in developing regions where land use planning and environmental monitoring systems are weak or poorly implemented.

In response to these global environmental concerns, sustainable development frameworks such as the Millennium Development Goals (MDGs) and the Sustainable Development Goals (SDGs) have emphasized the need for responsible management of natural resources. Specifically, SDGs 6, 11, 12, 13, and 15 highlight clean water management, sustainable human settlements, responsible consumption and production, climate action, and the protection of terrestrial ecosystems (United Nations, 2015). These goals underscore the interconnected nature of land, water, vegetation, and atmospheric systems, and the need for integrated spatial monitoring approaches to support evidence-based planning and environmental sustainability.

In Nigeria, rapid land use change has become a major driver of environmental degradation. Studies have shown that uncontrolled agricultural expansion, deforestation, mining activities, and unplanned urbanization have significantly altered natural landscapes across different ecological zones of the country (Mashi & Alhassan, 2004; Ifatimehin et al., 2009; Adebayo & Oruonye, 2012; Ujoh et al., 2019). These changes have led to reduced vegetation cover, declining soil quality, increased surface runoff, and deterioration in water resources. Furthermore, atmospheric conditions in many parts of Nigeria are increasingly influenced by dust emissions, biomass burning, and industrial activities, contributing to changes in air quality and local climate systems.

Taraba State, located in northeastern Nigeria within the Benue Trough region, is one of the most environmentally diverse states in the country, characterized by fertile agricultural lands, extensive forest ecosystems, savannah vegetation, river systems, and rich biodiversity. However, this ecological richness is increasingly under threat due to expanding human activities such as farming, logging, grazing, and artisanal and industrial mining. These activities have resulted in significant land cover modification, deforestation, soil exposure, and disruption of hydrological systems. Mining operations, in particular, have been associated with land degradation, vegetation removal, and localized water pollution, thereby altering both surface and subsurface environmental conditions (Ameh & Olorunfemi, 2016).

Therefore, the need for this study arises from the urgent requirement to systematically evaluate the spatio-temporal dynamics of land, water, vegetation, and atmospheric resources in Taraba State using remote sensing and GIS techniques. Such an assessment is essential for identifying patterns of environmental change, detecting areas of degradation, and generating reliable baseline data for sustainable land use planning. Without such integrated analysis, policy formulation and environmental management in the state will continue to rely on incomplete or outdated information, thereby limiting the effectiveness of sustainability interventions.

STUDY AREA

Taraba State was created from the former Gongola (Adamawa) State on 27 August 1991 by the Military Government of General Ibrahim Badamasi Babangida. It comprises 16 Local Government Areas (LGAs) and 2 Special Development Areas (SDAs), namely Ndola of Gola Area Development Association (NGADA) and Yangtu, created on 21st September 2016. The State is located in the north-east region of Nigeria with its capital at Jalingo (Figure 1). It shares boundaries with Nasarawa and Benue States in the west (109 km), Plateau State (202 km) and Bauchi State (54 km) in the northwest and north, Gombe State (58 km), Adamawa State (366 km) in the northeast, and the Republic of Cameroon (about 525 km) in the south. It lies approximately between latitude 6°30′ and 9°36′ North and longitude 9°10′ and 50° South.

The State experiences a tropical climate with an average temperature of about 33°C and distinct wet and dry seasons. The wet season lasts from May to October with an average annual rainfall of about 1,500 mm and 54.98% relative humidity, while the dry season occurs from November to April, affecting rain-fed agricultural activities (Nigeria Meteorological Agency, 2020).

Geologically, Taraba State is dominated by Precambrian basement complex rocks, with minor occurrences of Cretaceous and Holocene formations. The rocks include granite, gneiss, schist, and migmatite, which have weathered into lateritic soils in many areas such as Gembu and Nguroje. The soils include Ferric Luvisols, Lithosols, Fluvisols, Ferric Acrisols, and Humic Nitisols distributed across different parts of the State

The State is drained mainly by River Benue and its tributaries such as Taraba, Ibi, Lau, and Lamurde rivers, forming a dendritic drainage pattern. Seasonal flooding is common during the rainy season, affecting settlements and agricultural activities (NIHSA, 2021). Vegetation ranges from montane forests and grasslands in the Mambilla Plateau and southern highlands to Guinea savanna in the central and northern parts. Forest reserves such as Ngel Nyaki support rich biodiversity but are threatened by logging, agriculture, and other human activities (Sobola et al., 2021; Japhet et al., 2023; Tukura et al., 2022; Umar et al., 2025).

Economically, the State is largely agrarian, with about 75% of the population engaged in farming. Major crops include maize, rice, yam, cassava, millet, sorghum, and groundnut, while livestock rearing and fishing also support livelihoods. Artisanal mining is emerging but remains largely unregulated, contributing to land use changes such as deforestation and environmental degradation (Olagunju et al., 2019). Taraba State is culturally diverse with over eighty ethnic groups, including Mumuye, Jukun, Kuteb, Mambilla, Chamba, Tiv, and Fulani, among others. Hausa serves as a common language of communication. The population is estimated at 5,846,012 (2023), with Taraba Central being the most populated senatorial zone (Grid3 Nigeria, 2024).

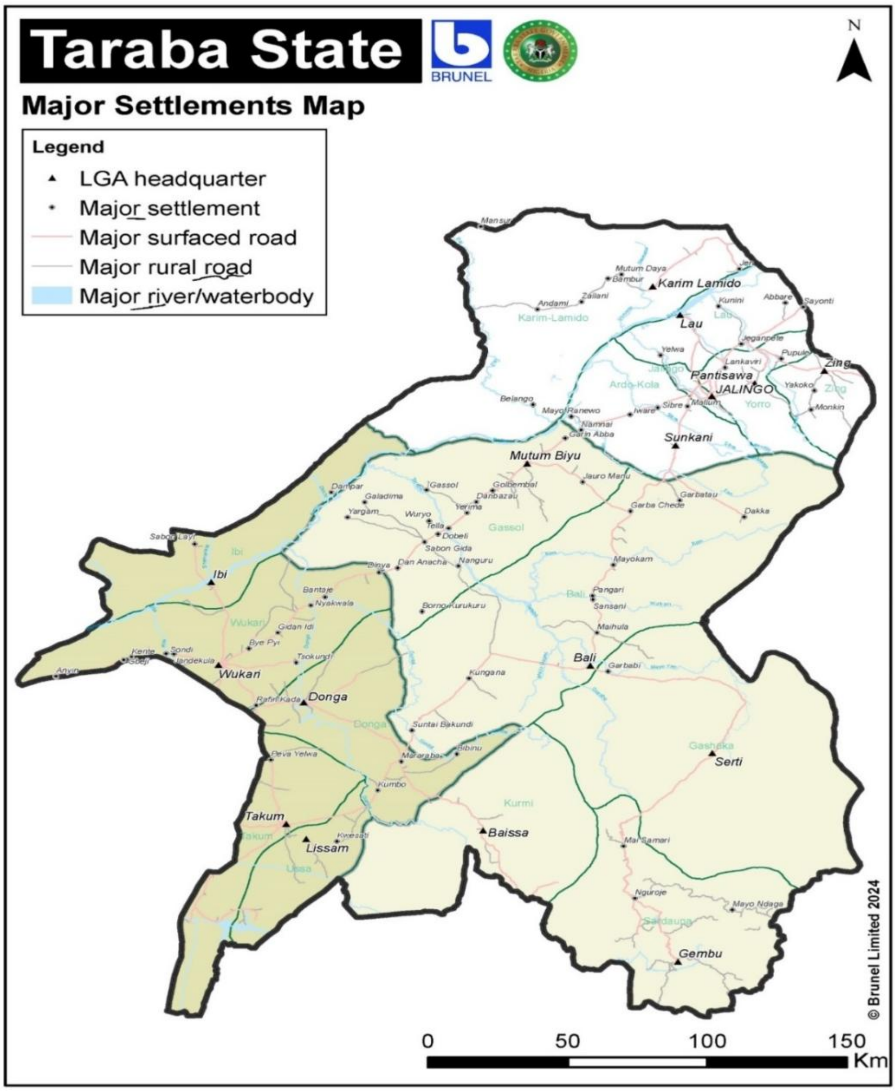

Figure 1. Map of Taraba State, the study area

(**Source:** Taraba State Government, 2024)

METHODOLOGY

This study adopts a mixed-method research design that integrates both qualitative and quantitative approaches in order to provide a comprehensive assessment of the spatio-temporal dynamics of land, water, vegetation, and atmospheric resources in Taraba State, Nigeria. The design is considered appropriate because it allows for the combination of field-based observations with satellite-derived geospatial data to better understand environmental changes over time. In addition, the study employs a longitudinal research design, which enables the evaluation of environmental change patterns between 2000 and 2022 using time-series satellite datasets. This approach is particularly suitable for examining how land use/land cover, vegetation health, surface water dynamics, and atmospheric conditions have evolved in response to both anthropogenic activities and climatic variability.

The study makes use of both primary and secondary data sources. Primary data were obtained through reconnaissance surveys, direct field observations, informal interactions with local inhabitants, and ground-truthing exercises. During these field activities, handheld Global Positioning System (GPS) devices were used to collect geographic coordinates of selected locations to support spatial validation of remotely sensed data. These field observations were essential for verifying land cover characteristics and ensuring the accuracy of satellite image classification and interpretation.

Secondary data constituted the major dataset for this study and were sourced from reputable global geospatial and environmental databases. Land use and land cover information was obtained from the European Space Agency (ESA) World Cover dataset (2020–2021), while vegetation dynamics were assessed using the Normalized Difference Vegetation Index (NDVI) derived from the AVHRR GIMMS dataset with high temporal resolution. Water resource dynamics were evaluated using the Normalized Difference Water Index (NDWI) derived from MODIS MYD09GA satellite imagery. Atmospheric conditions were assessed using NASA's MERRA-2 reanalysis datasets, which provided information on dust concentration, black carbon, and aerosol optical depth (AOD). Soil characteristics, including dominant soil types and soil organic content, were obtained from the FAO soil database and the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC). Additional supporting information was obtained from GRID3 population datasets, Nigerian Meteorological Agency (NiMET) climate records, published journal articles, government reports, and other relevant geospatial repositories.

Data collection instruments included handheld GPS devices, Google Earth Pro, reconnaissance survey tools, and direct field observation techniques. These tools were used to support spatial referencing, validation, and interpretation of satellite-derived environmental indicators. The integration of field-based data with remote sensing outputs enhanced the reliability of the study findings.

Data analysis was carried out using ArcMap 10.8.2 Geographic Information System software for spatial processing, mapping, and visualization. The satellite datasets were processed to generate spatial distributions and temporal trends of land use/land cover changes, vegetation condition (NDVI), surface water dynamics (NDWI), and atmospheric variables including dust, black carbon, and aerosol optical depth. The results were presented using maps, tables, bar charts, and pie charts to clearly illustrate spatial patterns and temporal variations across the study area.

The study was however constrained by the large spatial extent and difficult terrain of Taraba State, which limited physical accessibility to some local government areas such as Karim-Lamido, Kurmi, Sardauna, Ussa, and Ibi. Consequently, ground-truthing and field validation activities were concentrated in more accessible areas including Jalingo, Zing, Ardo-Kola, Yorro, Lau, Wukari, Gashaka, Bali, and Takum. Although this limitation slightly restricted the spatial coverage of field verification, it did not significantly affect the overall reliability and objectives of the study, as the satellite-based datasets provided comprehensive coverage of the entire state.

RESULTS AND DISCUSSIONS

Current Status of Some Soil Parameters in Taraba State

The soil content at varying depths across the State shows that the hilly regions of Gembu and Nguroje contain clay soils which are highly susceptible to erosion especially with unsustainable farming practices. At 0 cm, the predominant soil type is sandy/loam, while at depth 60 cm, 100 cm and 200 cm, the predominant soil type is sandy/clay/loam (Figure 2 a, b, c & d). Soil fertility capability is the ability of soil to provide essential nutrients to plants in adequate amounts and proportions to support plant life for optimal growth and productivity. Figure 4.4 shows the soil fertility capability distribution of Taraba State.

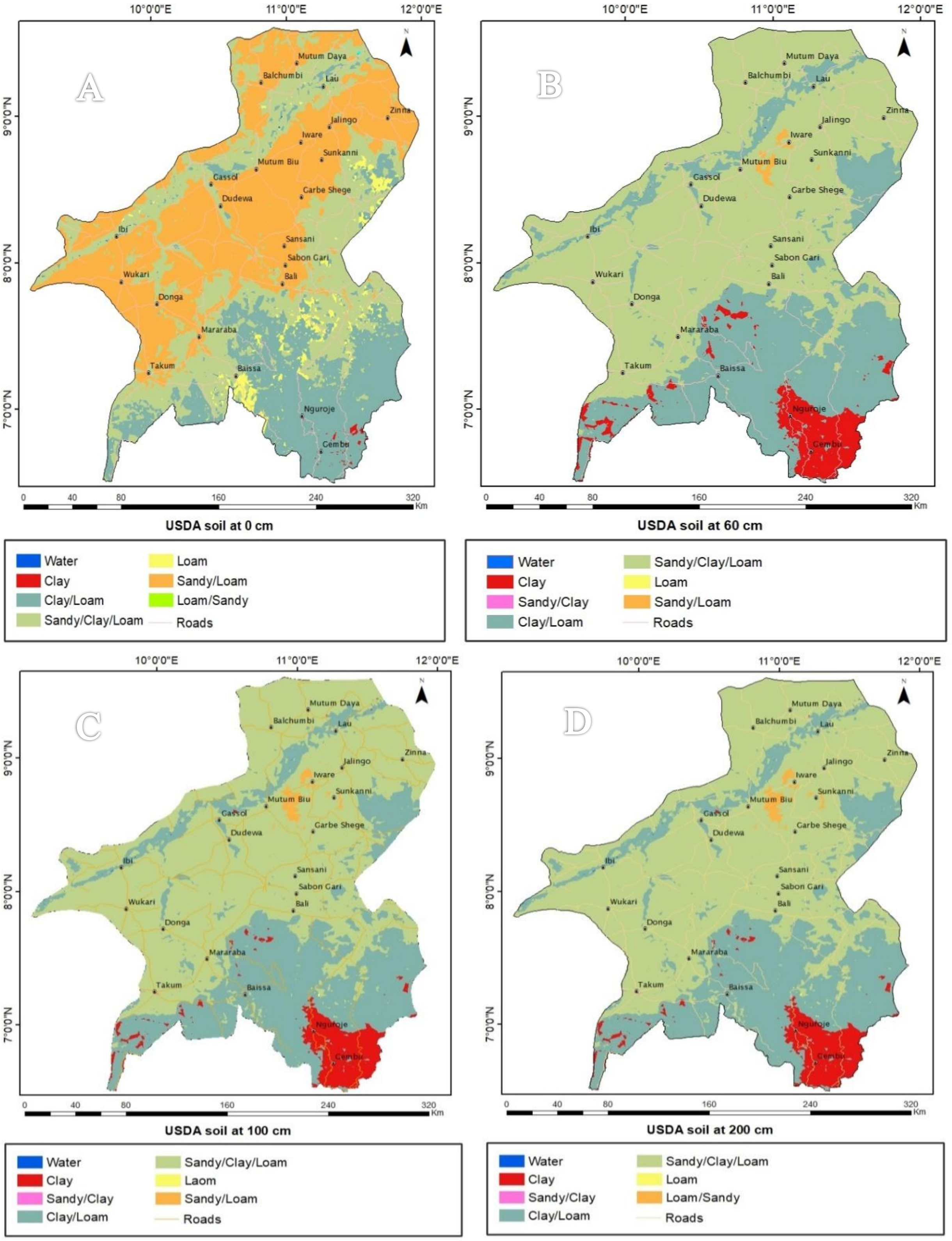

Figure 2 : Soil classification using USDA data at: (A) 0 cm; (B) 60 cm; (C) 100 cm; and, (D) 200cm (FAO, 2024)

Soil fertility is determined by several key factors including nutrient availability (such as nitrogen, phosphorus, potassium, calcium, magnesium, and trace elements), soil pH which influences nutrient solubility (with most crops performing best within pH 6–7.5), organic matter content that improves soil structure and nutrient supply, soil texture and structure which control aeration, water movement and root penetration, cation exchange capacity (CEC) which determines nutrient retention, water holding capacity influenced by soil composition, microbial activity responsible for decomposition and nutrient cycling, drainage and aeration conditions that affect root and microbial functioning, salinity and sodicity levels which can reduce plant growth, and soil depth which limits root development where shallow soils or hardpans exist. Traditionally, soil fertility is assessed through laboratory analysis of these properties, but remote sensing techniques are now increasingly used to complement field and laboratory data for spatial soil evaluation and management planning.

In Taraba State, soils are largely influenced by the Precambrian basement complex and rich alluvial deposits along the River Benue floodplains in Karim Lamido, Lau, Gassol, and Ibi LGAs, as well as along tributaries such as the Donga, Wukari, and Taraba rivers. These soils are generally fertile, with good organic matter content, loamy texture, moderate pH, and relatively good drainage, although they are highly susceptible to erosion. However, spatial variations exist, with erosion-prone areas concentrated in Sardauna, Gashaka, Kurmi, and Ussa LGAs, while potassium deficiency is more common in Wukari, Donga, Ibi, Gassol, Jalingo, Ardo-Kola, and Bali LGAs (Figure 3)

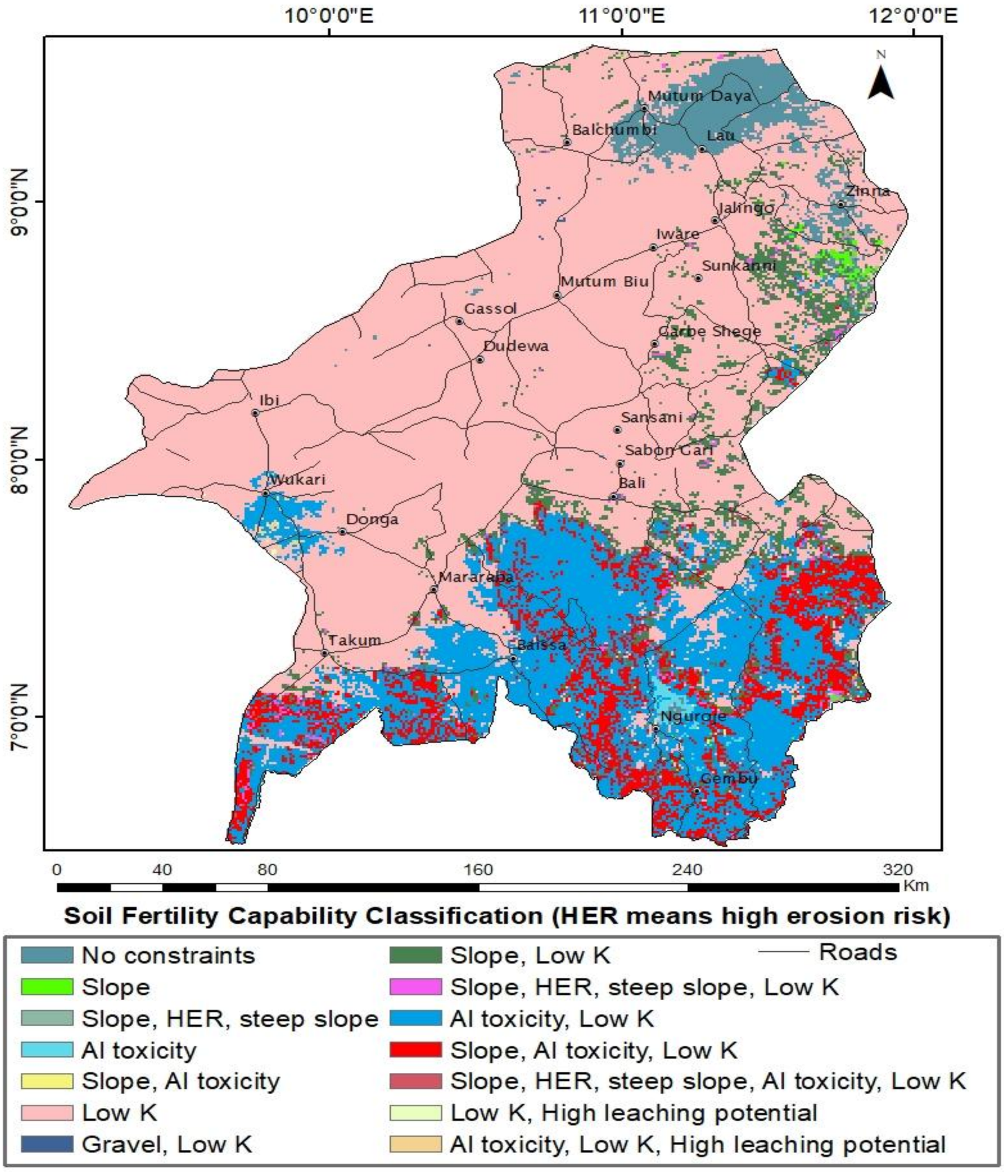

Figure 3: Soil fertility capability classification of the State (Data source: Hengl et al., 2021)

The spatial and temporal soil organic carbon (SOC) content across Taraba State (Figure 4.3) is a key indicator of soil health and ecological functioning. It enhances soil fertility and structure, improves water retention and infiltration, supports carbon sequestration for climate regulation, and provides energy for soil organisms, thereby sustaining biodiversity and ecosystem services. SOC also improves soil stability by reducing erosion risk, helps bind heavy metals to reduce pollution, and buffers soil pH variations. Overall, soil organic carbon is essential for maintaining soil quality, supporting agricultural productivity, mitigating climate change, and ensuring ecosystem sustainability.

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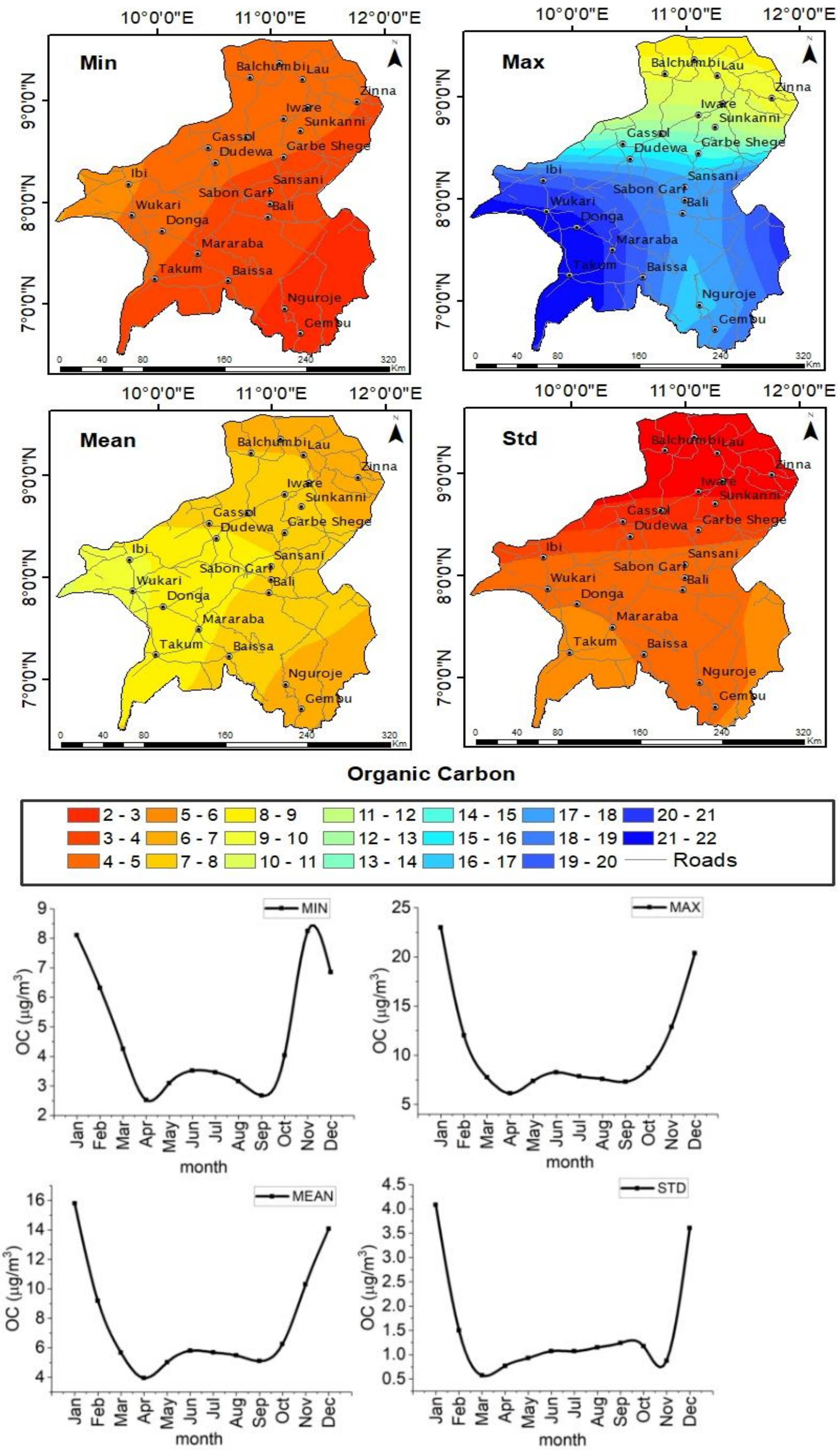

Figure 4: (A) Spatial and (B) Temporal Soil Organic Carbon Distribution across Taraba State

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Current Status of Water Resources in Taraba State

Taraba State has a diverse hydrological and drainage system (Figure 5) shaped by its relief, climate, and river networks. The major river system is dominated by the River Benue, which flows through the state and serves as the principal drainage channel receiving water from several tributaries including the Taraba, Donga, Ibi, Lau, and Lamurde rivers. The Taraba River drains central parts of the state and supports agriculture around Jalingo, while the Donga River originates from the Mambilla Plateau and supports surrounding rural communities before joining the Benue. River Ibi and River Lau also contribute significantly to drainage and agricultural activities, especially in low-lying floodplain areas. River Lamurde, which drains Jalingo, is increasingly affected by pollution, encroachment, and flooding impacts on infrastructure such as parts of the School of Nursing. The State falls within the Upper Benue Hydrological Area (Hydrological Area III) as classified by NIHSA (2021), covering about 158,900 km², with a dendritic drainage pattern typical of relatively uniform geological formations. Seasonal rainfall strongly influences river discharge, leading to high water levels during the wet season and frequent flooding in floodplain settlements, which affects agriculture, infrastructure, and land use activities across the State.

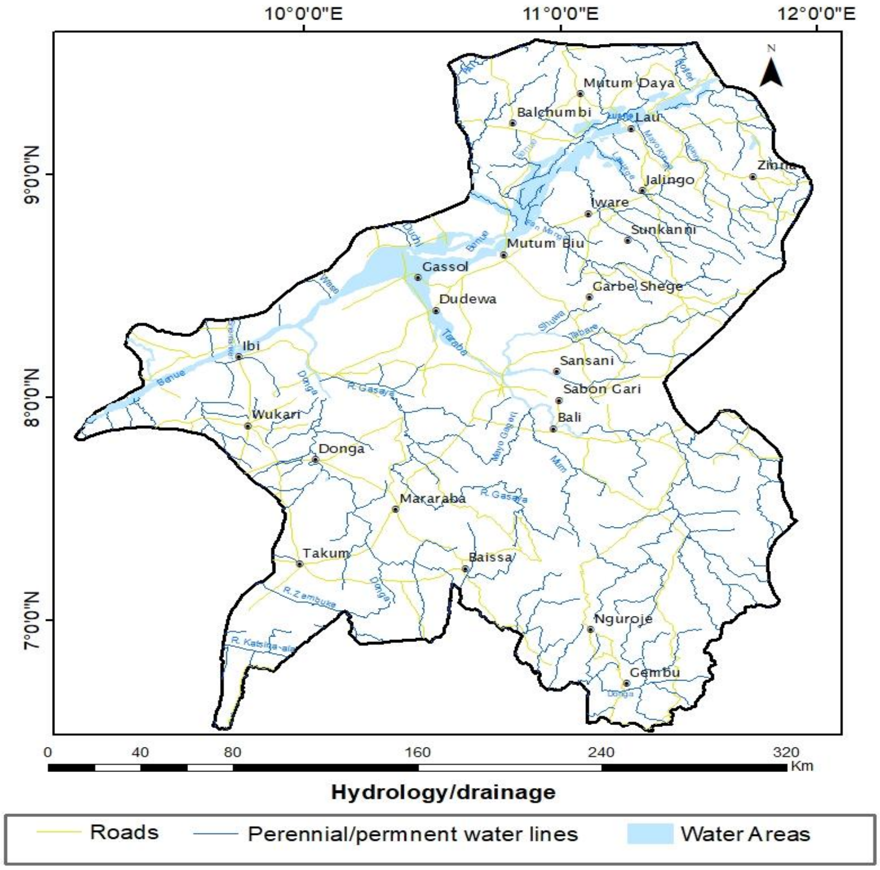

Figure 5: The drainage system of Taraba State

The Normalized Differential Water Index (NDWI) is a remote sensing tool used to assess water content and availability in vegetation and surface water bodies using reflectance values from the near-infrared (NIR) and shortwave infrared (SWIR) bands of satellite imagery such as Nigeria sat-X and Landsat. It helps distinguish open water features from soil and vegetation, with positive values (0.2–1) indicating open water, 0–0.2 suggesting high moisture or flooding conditions, -0.3–0 indicating moderate drought or non-aqueous surfaces, and -1 to -0.3 representing dry conditions.

NDWI is widely applied in agriculture and water resource management for monitoring water bodies, assessing flood risk, and guiding irrigation planning to improve crop productivity and water use efficiency. The NDWI results for Taraba State (Figure 6) show values generally ranging between 0 and 0.6, indicating persistent high humidity, seasonal flooding, and the presence of open water features. This pattern highlights flood-prone zones as well as areas with sufficient surface moisture that can support agriculture.

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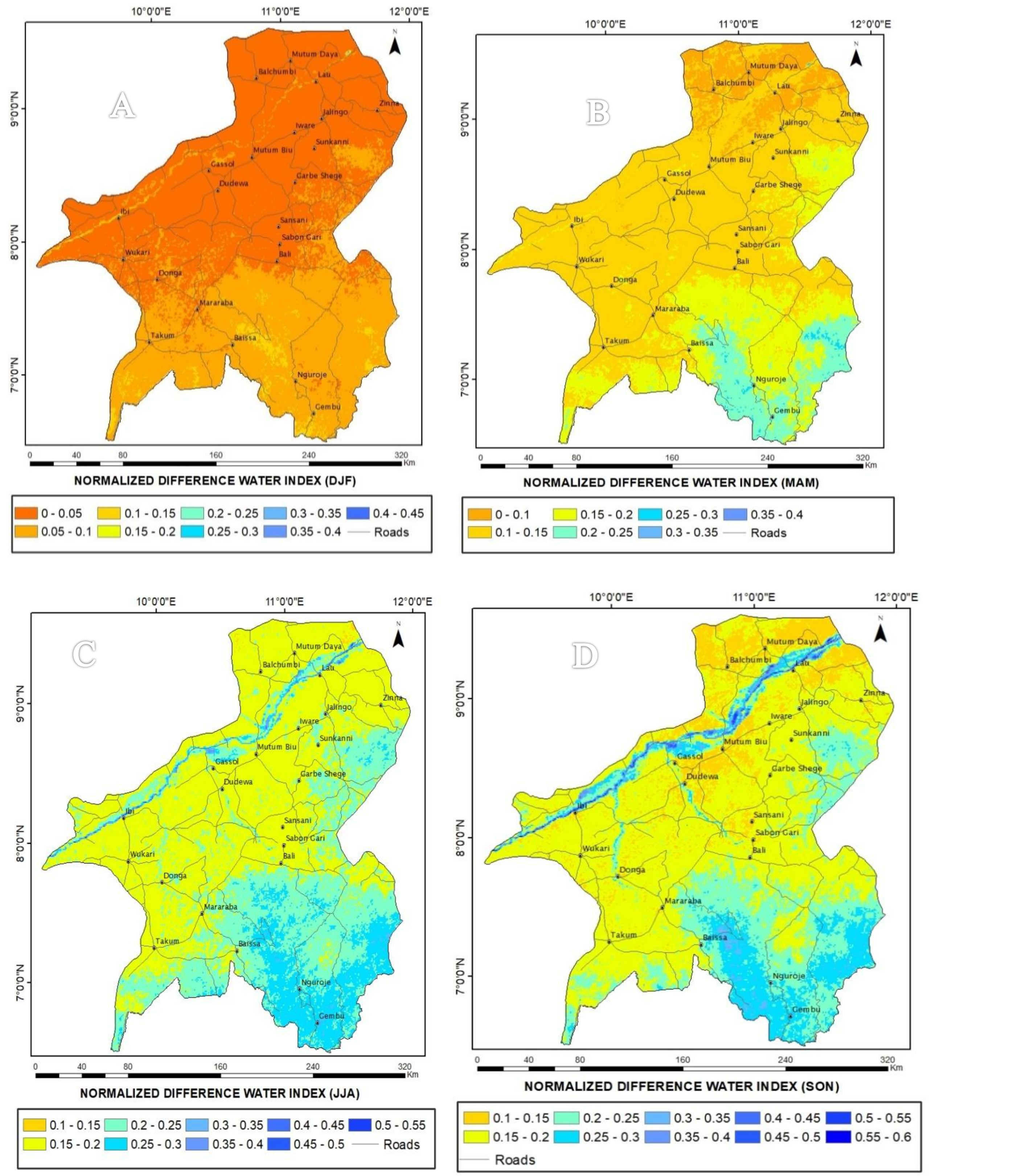

Figure 6: The NDWI distribution across Taraba State by season (a) December January February; (b) March, April & May; (c) June, July August; and, (d) September, October & November

Water resources in Taraba State are mainly used for irrigation and fishing. The river systems, especially the River Benue and its tributaries, provide essential water for dry-season farming, supporting the cultivation of crops such as maize, rice, and vegetables, particularly in floodplain areas. They also serve as important sources of fish and livelihood for local communities, with fishing activities widely practiced across the state. A notable example is the annual Nwonyo Fishing Festival held at River Ibi, which highlights the cultural and economic importance of fisheries in the area.

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Plate 1: Sights at the Nwonyo Fishing Festival held 19th & 20th April, 2024. The Governor of Taraba State, HE Dr. Agbu Kefas attended the closing ceremony along with all top TRSG Government Officials.


Plate 2: Rivers are a main transportation mode for rural folks in Taraba State

Hydroelectric Power Generation: The Kashimbila HEP project is a good example of one of the keys uses to which the river systems in Taraba State can be put. The facility is a multipurpose dam built to generate 40 MW of electricity, for irrigation, flood control, fisheries and water supply for domestic and industrial purposes. The proposed Mambila dam is expected to be the largest HEP project in Nigeria with 3050 MW.

Domestic and Industrial Use: Rivers are crucial for supplying water for domestic use and small-scale industries, particularly in rural areas where alternative water sources may be limited, but also in urban centres where there is huge demand for water for domestic, commercial, recreational and other uses.


Plate 3: Potable water supply is a major problem in most parts of rural Taraba State

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The major environmental concerns relating to water in Taraba State include flooding, erosion, and declining water quality. Flooding is a natural phenomenon but is worsened by unplanned land use, with factors such as rainfall intensity, soil conditions, basin size, and drainage patterns influencing flood vulnerability (Adelalu and Bwadi, 2023). In Taraba State, seasonal floods during the rainy season frequently affect both rural and urban areas, disrupting livelihoods and damaging infrastructure, with high-risk LGAs including Yorro, Ardo-Kola, Jalingo, Ibi, Wukari, Karim Lamido, Lau, Kurmi, Gassol, and Gashaka (NIHSA, 2021). Riverbank erosion is also significant, particularly in high rainfall and disturbed landscapes such as around the Mambilla Plateau, Jalingo, Gassol, Karim Lamido, and Lau. Water quality is further threatened by agricultural runoff and improper disposal of domestic, abattoir, and healthcare wastes, worsened by the absence of sanitary landfill facilities, leading to likely discharge of wastes into river systems. Overall, these challenges highlight the need for improved water resource management and environmental planning in the State.

Current Status of Vegetation and Biodiversity of Taraba State

Land use and land cover classification involves identifying and grouping land based on its use (such as agriculture and settlements) and its physical cover (such as forests and water bodies), and it is essential for environmental monitoring, planning, resource management, and policy development. The land use and cover map of Taraba State (Figure 7) shows that tree cover dominates with 16,631.84 km² (28.15%), while bare land is the least extensive category, indicating strong potential for biodiversity conservation and eco-tourism. However, this is increasingly threatened by unplanned human activities such as illegal mining, logging, charcoal production, fuelwood collection, unsustainable farming, and poor waste disposal. At a broader scale, Nigeria has experienced significant forest loss, with about 178 kha of humid primary forest lost between 2002 and 2023, representing 14% of total tree cover loss, alongside a 9.4% decline in primary forest area. Overall, the country lost about 1.33 Mha of tree cover between 2001 and 2023, resulting in substantial CO_2 emissions and reduced carbon sequestration capacity, highlighting serious environmental sustainability concerns.

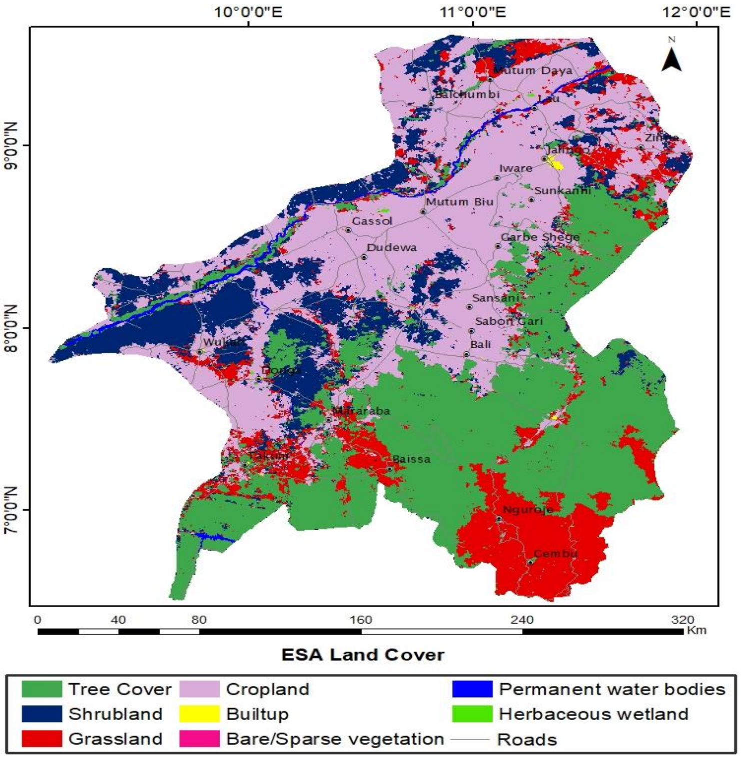

Figure 7: Land use/cover for Taraba State (Data Source: Zanaga et al., 2021)

The Normalised Difference Vegetation Index (NDVI) is a remote sensing indicator used to assess vegetation health, density, and coverage using satellite imagery, with values ranging from -1 to 1, where higher positive values (0.6–1) indicate healthy and dense vegetation. NDVI analysis for Taraba State (Figures 8-12) shows that vegetation condition is highest in Gashaka, Kurmi, and Sardauna LGAs during the dry season (DJF), improves with the onset of rainfall (MAM), and becomes almost uniform across the State during JJA and SON, with most areas recording high values between 0.9 and 1. The analysis further reveals that areas such as Zing, parts of Lau, Karim Lamido, Yorro, and Ardo-Kola require irrigation support due to lower vegetation performance, making them more vulnerable to drought and land degradation. In contrast, central and southern parts of the State show strong vegetation recovery and are more suitable for conservation efforts amid increasing human activities such as farming, logging, and urban expansion. Annual NDVI trends (2000–2025) indicate peak vegetation conditions in 2022 with an average value of 0.89, while overall NDVI dynamics are influenced by both human activities and climate variability, including droughts, floods, agriculture, mining, and deforestation.

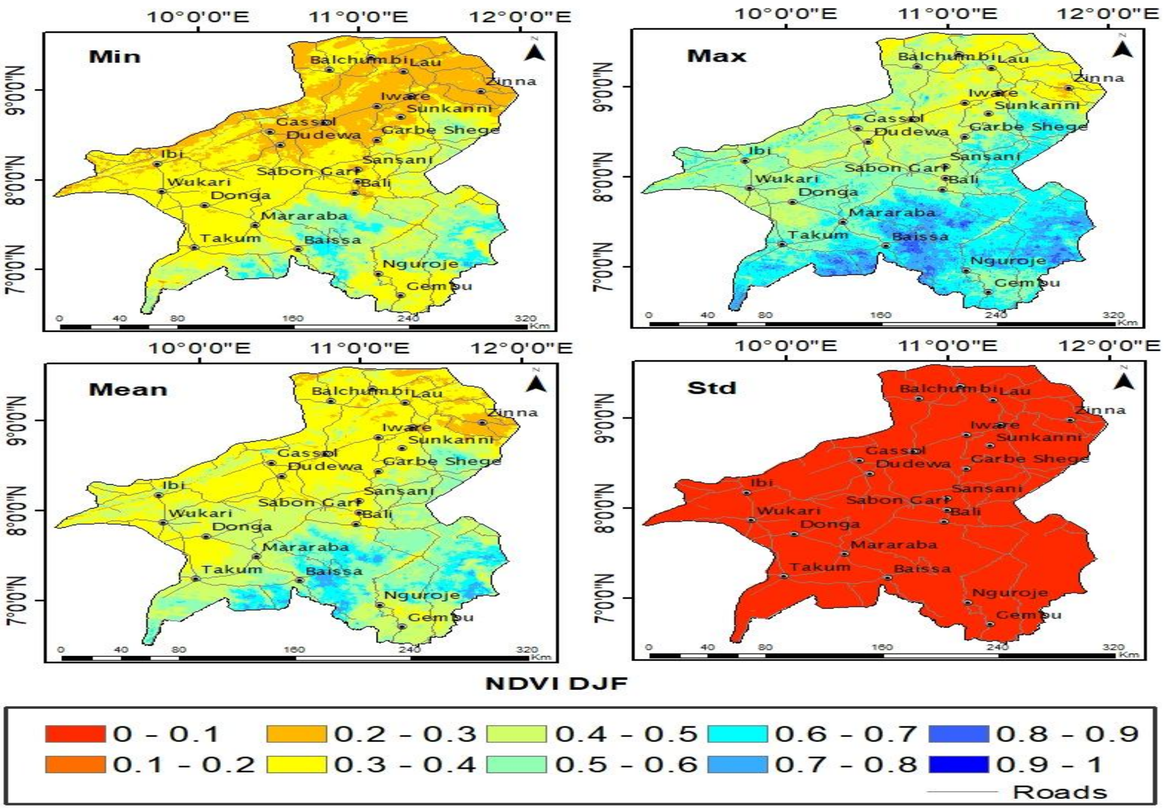

Figure 8: The Seasonal (December, January & February) NDVI map of Taraba State

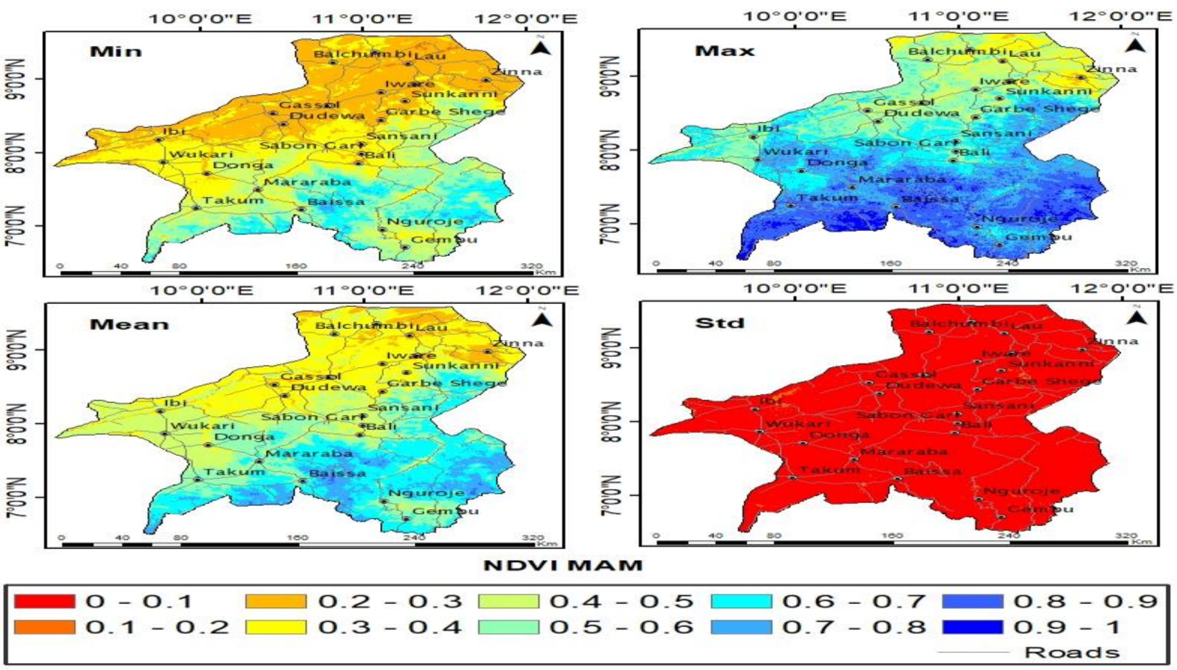

Figure 9: The Seasonal (March, April & May) NDVI map of Taraba State

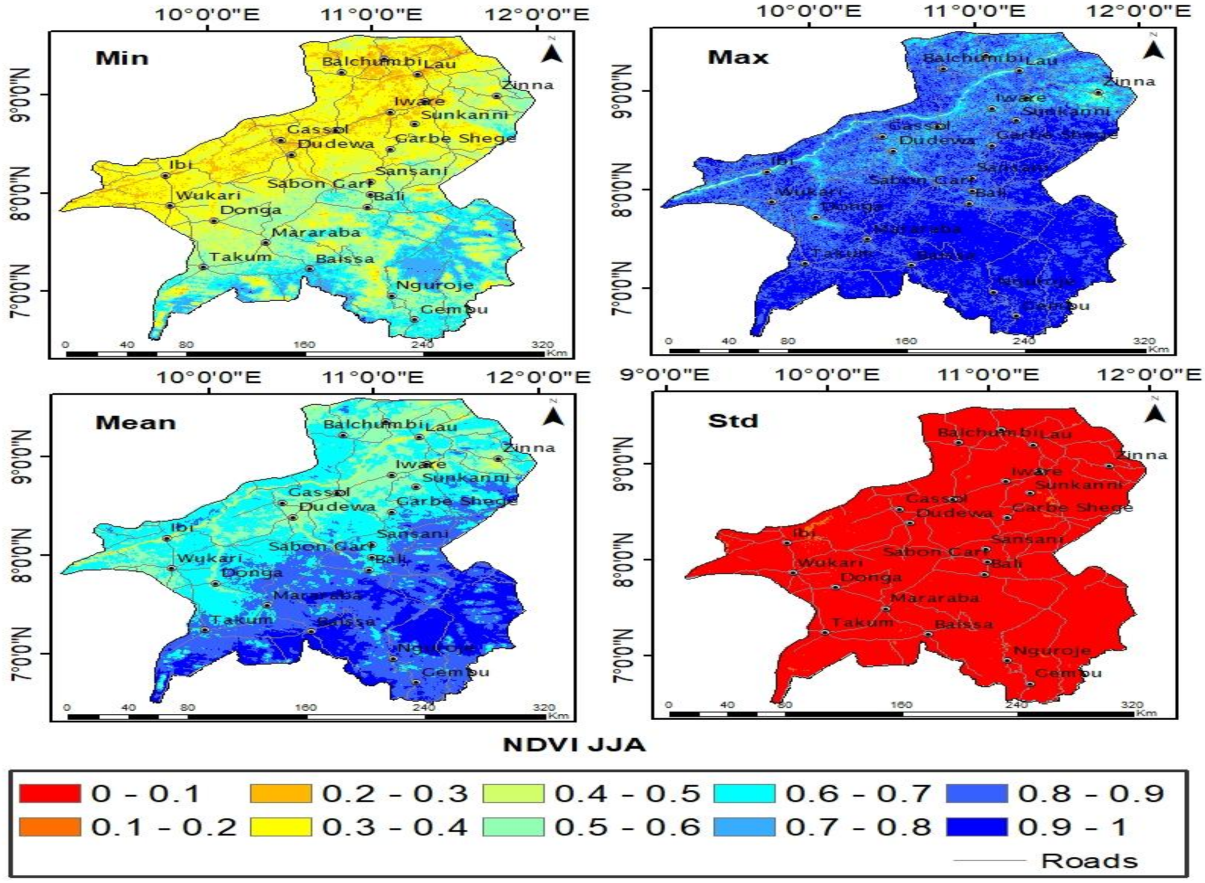

Figure 10: The Seasonal (June, July & August) NDVI map of Taraba State

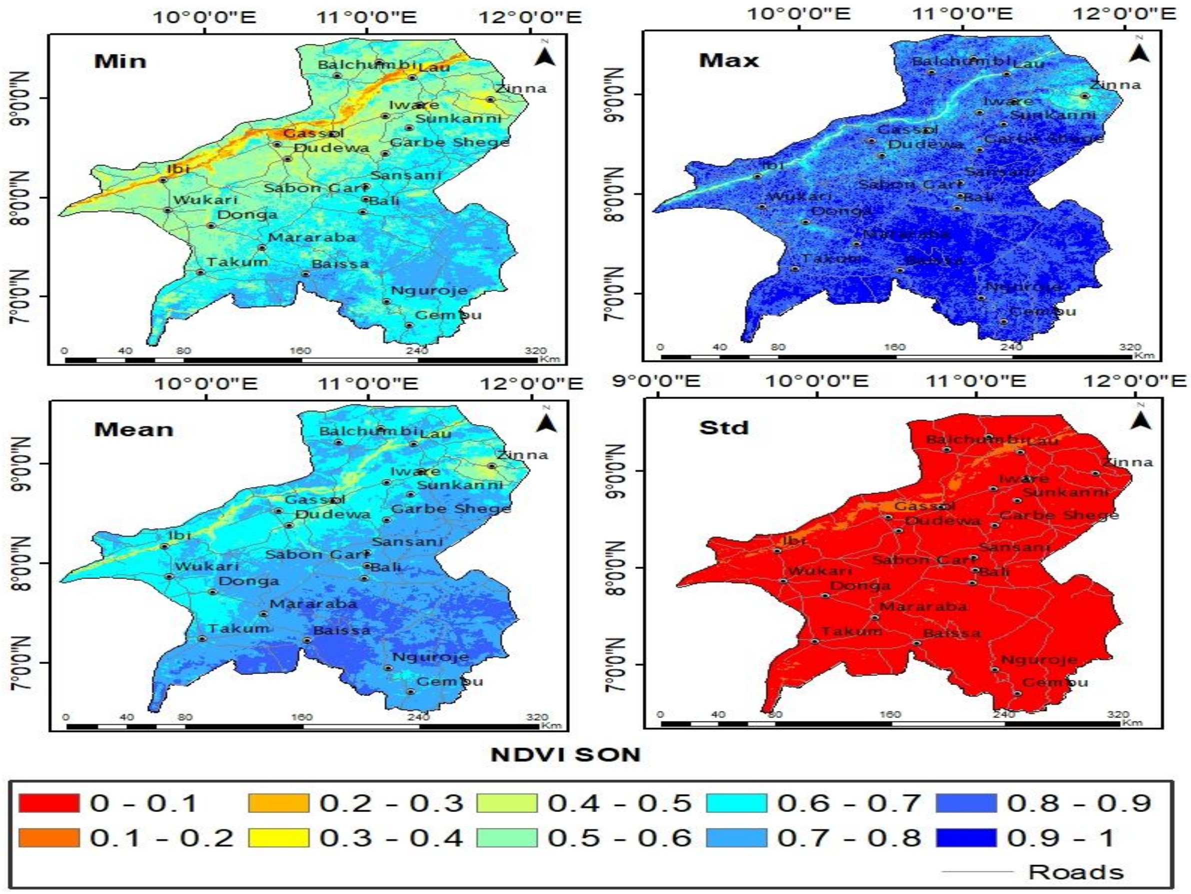

Figure 11: The Seasonal (September, October & November) NDVI map of Taraba State

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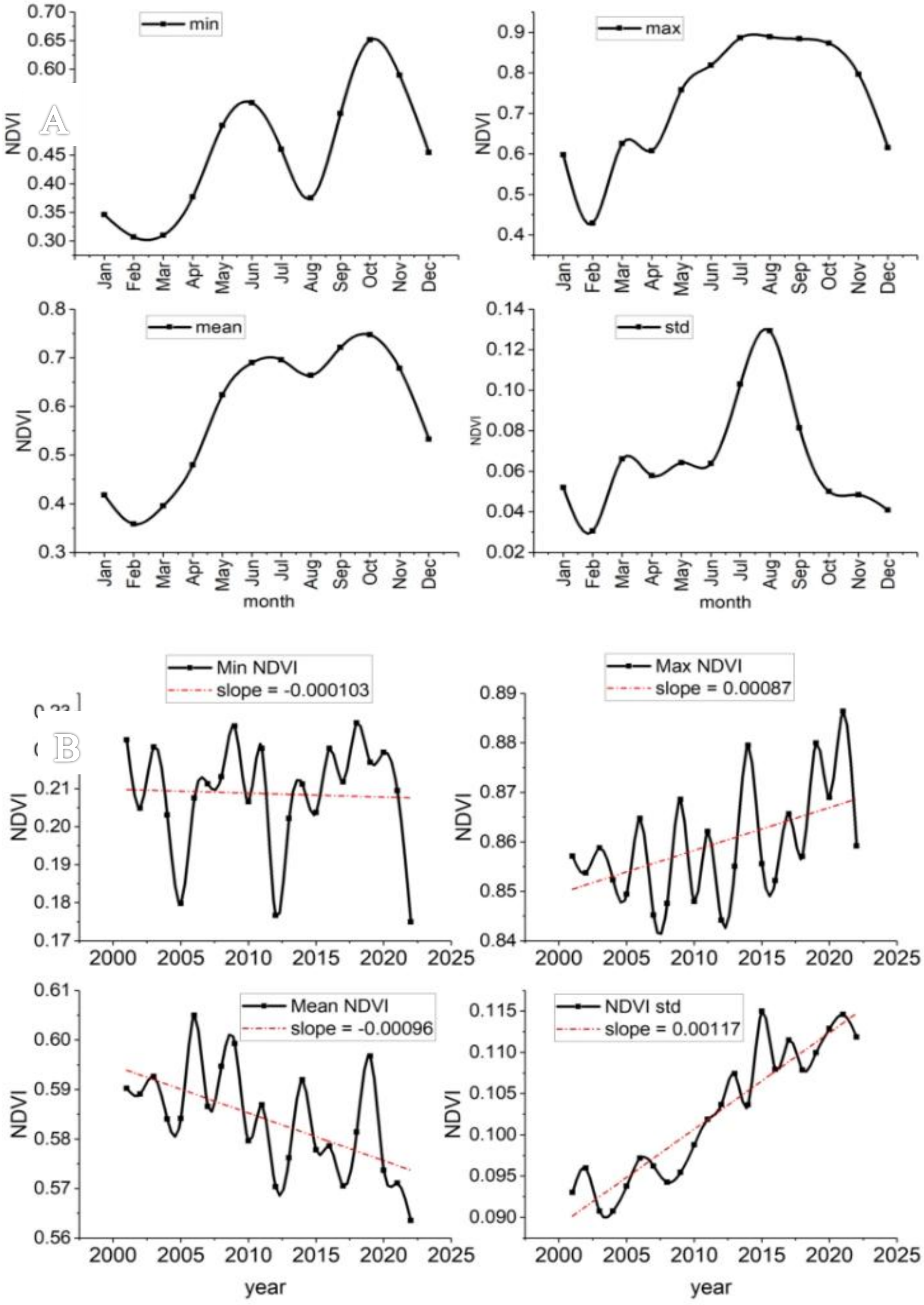

Figure 12: Temporal NDVI Occurrence across Taraba State (A) Annually; and, (B) 2000 – 2025

The NDVI prediction for different land cover types (Figure 13) was done using the Auto-Regressive Integrated Moving Average (ARIMA), a versatile model used for forecasting weather and geographical data. The purpose of this prediction is to provide valuable information for informed decision making by relevant Taraba State Government MDAs towards agricultural management and crop monitoring, environmental monitoring and management, disaster management and preparedness, forestry and land use planning, vegetation-climate interactions, carbon sequestration estimation, biodiversity and conservation planning, and public health applications.

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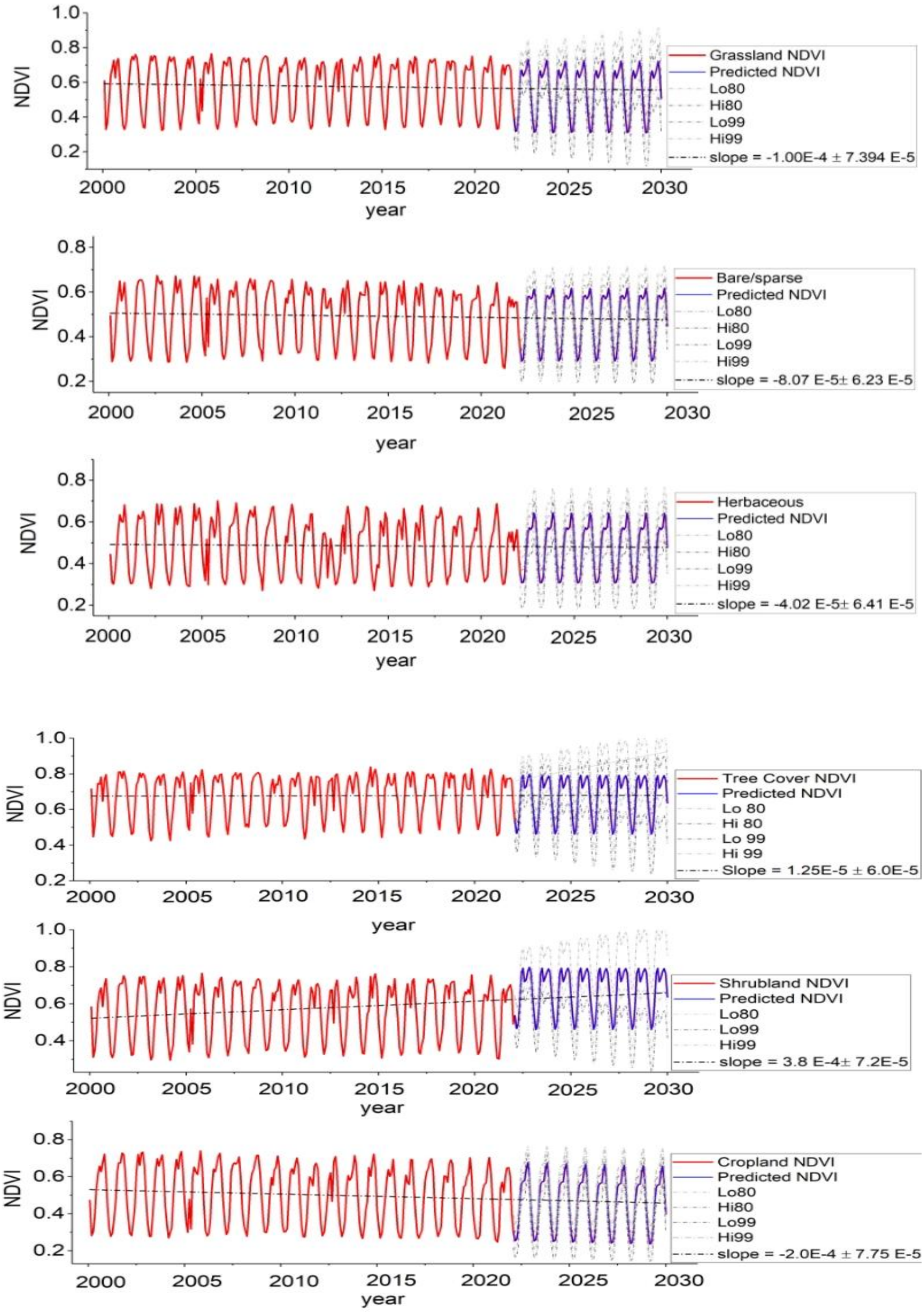

Figure 13: Predicted NDVI in different land cover classes for Taraba State 2000 - 2030

Discussion of Findings

The study reveals substantial spatial and temporal changes in Taraba State's soil, vegetation, water, land, and atmospheric resources between 2000 and 2022. Sandy-loam surface soils, particularly in the hilly areas of Gembu and Nguroje, are highly vulnerable to erosion, while nutrient availability and soil organic carbon vary according to vegetation cover, land use, and management practices. Forested and floodplain areas retain higher soil carbon than degraded landscapes.

The River Benue and its tributaries dominate the state's dendritic drainage system. NDWI results indicate abundant seasonal surface water but also frequent flooding in low-lying LGAs such as Jalingo, Ibi, Wukari, and Karim Lamido. Vegetation is healthiest in Gashaka, Kurmi, and Sardauna, while lower NDVI values in Zing, Lau, Ardo-Kola, and Jalingo reflect agricultural expansion, deforestation, and urban pressure. Although vegetation conditions peaked in 2022, ARIMA projections suggest possible future decline if current land-use pressures continue.

Surface water remains essential for irrigation, fishing, transportation, domestic use, and hydropower, but its quality is increasingly threatened by agricultural runoff, waste disposal, and urban encroachment. Rising dust, black carbon, and aerosol levels also indicate environmental stress associated with biomass burning, fuelwood use, agricultural activities, and land degradation. Overall, environmental change across Taraba State is driven by the interaction of natural processes, ecological sensitivity, population pressure, and unsustainable land-management practices

CONCLUSION AND RECOMMENDATIONS

This study assessed the spatio-temporal dynamics of land, water, vegetation, soil, and atmospheric resources in Taraba State between 2000 and 2022 using remote sensing and GIS techniques. The findings reveal that the state is experiencing significant environmental changes driven by both natural processes and human activities. Soil analysis showed variation in texture from sandy loam at the surface to sandy clay loam at deeper layers, with some areas being highly susceptible to erosion and nutrient imbalance, particularly potassium deficiency in several LGAs. Soil organic carbon was higher in forested and floodplain zones but declined in disturbed and intensively used areas, indicating progressive soil degradation in some parts of the state. The hydrological analysis revealed a well-developed drainage system dominated by the River Benue and its tributaries, with NDWI results indicating persistent seasonal moisture and flooding conditions in many low-lying areas, particularly during the rainy season.

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