Research Journal of Pure Science and Technology E-ISSN 2579-0536 P-ISSN 2695-2696
Vol 7. No. 3 2024 www.iiardjournals.org Online version

Impact of Land Use and Land Cover Changes on Hydrological Characteristics and Drainage Density in Urban and Semi-Urban Areas of Abia State, Southeastern Nigeria

Odoh, Benard Ifeanyi[1] Nwokeabia, Charity Nkiru[*1] Odinye, Arinzechukwu Chukwuebuka[2]
[1]Department of Geophysics, Faculty of Physical Sciences, Nnamdi Azikiwe University Awka
[2]Department of Geological Sciences, Faculty of Physical Sciences, Nnamdi Azikiwe University Awka
[*]Corresponding author: cn.nwokeabia@unizik.edu.ng
DOI: 10.56201/rjpst.v7.no3.2024.pg147.163

Abstract

Understanding hydrological characteristics and drainage patterns is essential for informed watershed management and sustainable land use planning. This study investigates the impact of land use and land cover (LULC) changes between 2017 and 2023 on hydrological characteristics and drainage density in urban and semi-urban areas of Abia State, Southeastern Nigeria. The primary aim is to analyze how LULC changes affect hydrological characteristics and drainage density in selected Local Government Areas (LGAs) in Abia State. The study utilizes satellite imagery, LULC data, and Shuttle Radar Topography Mission (SRTM) elevation data obtained from the United States Geological Survey (USGS) Earth Explorer platform. The LULC classification was performed using supervised classification techniques, while the SRTM DEM data were processed to derive slope and drainage density. Change detection analysis was used to compare LULC maps from 2017 and 2023, and drainage density was calculated using the total length of streams and rivers divided by the area of the basin. The results reveal significant LULC changes over the six-year period, with a notable reduction in forested areas and an increase in built-up and agricultural land. The spatial analysis showed higher drainage densities in urban centers compared to rural areas, indicating increased surface runoff and reduced infiltration in urbanized zones. The reduction in forest cover and expansion of impervious surfaces due to urbanization have altered the hydrological characteristics of the region. High drainage densities in urban areas lead to increased runoff, posing risks of erosion and flooding. Conversely, rural areas with lower drainage densities exhibit better infiltration and groundwater recharge capabilities. These findings underscore the need for sustainable urban planning and effective watershed management practices. The study highlights the critical impact of LULC changes on hydrological characteristics and drainage density in Abia State. The findings provide valuable insights for policymakers and urban planners to implement strategies that mitigate negative environmental impacts and promote sustainable land use practices. This study is one of the first to comprehensively analyze the impact of recent LULC changes on hydrological characteristics and drainage patterns in urban and semi-urban areas of Abia State using remote sensing and GIS technologies. The integration of high-resolution satellite imagery and DEM data offers a detailed assessment, contributing to better understanding and management of the region's water resources and land use dynamics.

Keywords: *Environmental Management, Groundwater Recharge, Sedimentary Formations, Soil Erosion, Urbanization*

1. Introduction

Land use and land cover (LULC) changes significantly influence hydrological characteristics and drainage patterns, particularly in rapidly developing regions. The impact of such changes is profound in areas experiencing rapid urbanization and agricultural expansion, which often lead to alterations in natural landscapes and hydrological cycles (Nnaji et al., 2021). Land use refers to the human utilization of land, encompassing agriculture, forestry, urban development, and other activities, while land cover denotes the physical surface characteristics, including vegetation, water bodies, and artificial structures (Arowolo et al., 2018). LULC changes involve transitions from one type to another, driven by socio-economic, political, and environmental factors. In the context of Abia State, these changes are predominantly influenced by population growth, urban expansion, agricultural practices, and infrastructural development (Mashi et al., 2021).

Rapid urbanization leads to the conversion of natural landscapes, such as forests and wetlands, into built-up areas, reducing the availability of permeable surfaces. This change impacts hydrological processes by increasing surface runoff, reducing groundwater recharge, and altering the drainage density of the area. Similarly, agricultural expansion often results in deforestation and soil degradation, further influencing the region's hydrology (Ijioma, 2021).

Hydrological characteristics include various components of the water cycle, such as precipitation, infiltration, surface runoff, and evapotranspiration. These components are interconnected and influence the availability and movement of water within a watershed. Changes in LULC can significantly alter these hydrological processes (Nnaji et al., 2021). Increased impervious surfaces in urban areas lead to higher surface runoff and reduced infiltration, while deforestation can decrease evapotranspiration and increase soil erosion.

Drainage density, defined as the total length of streams and rivers per unit area, is a crucial parameter in hydrology. It reflects the efficiency of drainage networks in transporting water across a landscape. High drainage density is often associated with increased surface runoff and potential for erosion, while low drainage density indicates better infiltration and groundwater recharge (Idrees et al., 2022). LULC changes can modify drainage patterns by altering the natural flow of water, leading to changes in drainage density.

Abia State, located in southeastern Nigeria, is characterized by a diverse landscape that includes urban centers, semi-urban areas, agricultural lands, forests, and wetlands. The state experiences a tropical climate with distinct wet and dry seasons, influencing its hydrological regime. The population of Abia State has been growing rapidly, leading to increased demand for land and resources (Sampson et al., 2020). Urban centers such as Umuahia and Aba have expanded significantly, encroaching on surrounding natural landscapes and altering the region's hydrology.

The state's topography varies from low-lying coastal areas to higher elevations inland, contributing to diverse hydrological characteristics. The presence of rivers and streams, along with varying soil types and vegetation cover, adds to the complexity of the region's hydrology (Sampson et al., 2020). Understanding the impact of LULC changes on hydrological characteristics and drainage density in this diverse landscape is essential for effective water resource management and sustainable development.

Numerous studies include Aghsaei et al. (2020), Woldesenbet et al. (2017), Gashaw et al. (2018) have investigated the relationship between LULC changes and hydrological characteristics worldwide. These studies include Luo et al. (2020), Dogan and Karpuzcu (2021), have demonstrated that urbanization, deforestation, and agricultural expansion significantly impact hydrological processes and drainage patterns.

Urbanization increases impervious surfaces, leading to higher surface runoff and reduced infiltration. This change can result in increased flood risk, reduced groundwater recharge, and altered streamflow patterns. Studies have shown that urban areas exhibit higher peak discharges during storm events, leading to increased flood hazards (Pasquier et al., 2022).

Deforestation reduces vegetation cover, leading to increased soil erosion and reduced evapotranspiration. This change can increase surface runoff and sediment transport, impacting water quality and streamflow dynamics. Research has shown that deforested areas have higher runoff coefficients and greater variability in streamflow (Gelmini et al., 2022). Agricultural practices, including irrigation and land clearing, can significantly alter hydrological processes. Irrigation increases water consumption, potentially reducing streamflow and groundwater levels. Land clearing for agriculture can increase surface runoff and sediment yield, impacting water quality and aquatic ecosystems.

Remote sensing (RS) and Geographic Information Systems (GIS) are powerful tools for analyzing LULC changes and their impacts on hydrological characteristics. RS involves the acquisition of information about the Earth's surface using satellite or airborne sensors, providing data on land cover, vegetation, water bodies, and other features (Okoli et al., 2024). GIS is a spatial analysis tool that integrates and analyzes geospatial data, enabling the visualization and interpretation of spatial patterns and relationships.

RS data, such as satellite imagery, can be used to classify land cover types and monitor changes over time. Techniques such as supervised classification and change detection allow for the identification and quantification of LULC transitions. High-resolution imagery provides detailed information on urban development, vegetation cover, and water bodies, facilitating accurate LULC mapping.
GIS is used to analyze spatial data and model hydrological processes. DEMs derived from RS data provide information on terrain characteristics, including slope and elevation, which are crucial for hydrological modeling (Akaolisa et al., 2023). GIS tools can delineate watersheds, analyze drainage networks, and calculate hydrological parameters such as drainage density, runoff coefficients, and streamflow. These analyses help in understanding the impact of LULC changes on hydrological characteristics.

The theoretical framework for this study is based on the hydrological cycle and the principles of watershed management. The hydrological cycle describes the continuous movement of water within the Earth's atmosphere, surface, and subsurface. Key components of the hydrological cycle include precipitation, infiltration, surface runoff, evapotranspiration, and groundwater flow. These components are influenced by land cover and land use practices.
Watershed management involves the planning and implementation of strategies to manage land and water resources within a watershed. Effective watershed management aims to balance ecological, social, and economic needs while maintaining the health of the watershed (Sadhwani et al., 2022). Understanding the impact of LULC changes on hydrological characteristics and drainage patterns is essential for informed watershed management and sustainable land use planning. The aim of this study is to analyze the impact of land use and

land cover (LULC) changes between 2017 and 2023 on the hydrological characteristics and drainage density in urban and semi-urban areas of Abia State, Southeastern Nigeria. This analysis will utilize satellite imagery, LULC data, and SRTM elevation

2. Location and Geology of the Study area

The study area encompasses several Local Government Areas (LGAs) in Abia State, southeastern Nigeria, specifically Aba North, Aba South, Oboma Ngwa, Osisioma Ngwa, Ugwunagbo, Ukwa East, and Ukwa West. These LGAs represent a mix of urban and rural landscapes, contributing to a diverse socio-economic and environmental profile. Aba North and Aba South are primarily urban, forming the metropolitan hub of Aba, a major commercial and industrial city. Oboma Ngwa, Osisioma Ngwa, and Ugwunagbo are peri-urban areas, exhibiting characteristics of both urban and rural settings. Ukwa East and Ukwa West are predominantly rural, with extensive agricultural lands and less densely populated areas.

The geographical coordinates of the study area range approximately from 5.1031°N to 5.5524°N latitude and 7.2714°E to 7.6286°E longitude as shown in Figure 1. This region is strategically located with good accessibility due to its network of major roads, including the Enugu-Port Harcourt Expressway and the Aba-Owerri Road, facilitating movement of goods and people. The presence of the railway line and proximity to the commercial seaport in Port Harcourt further enhance its connectivity.

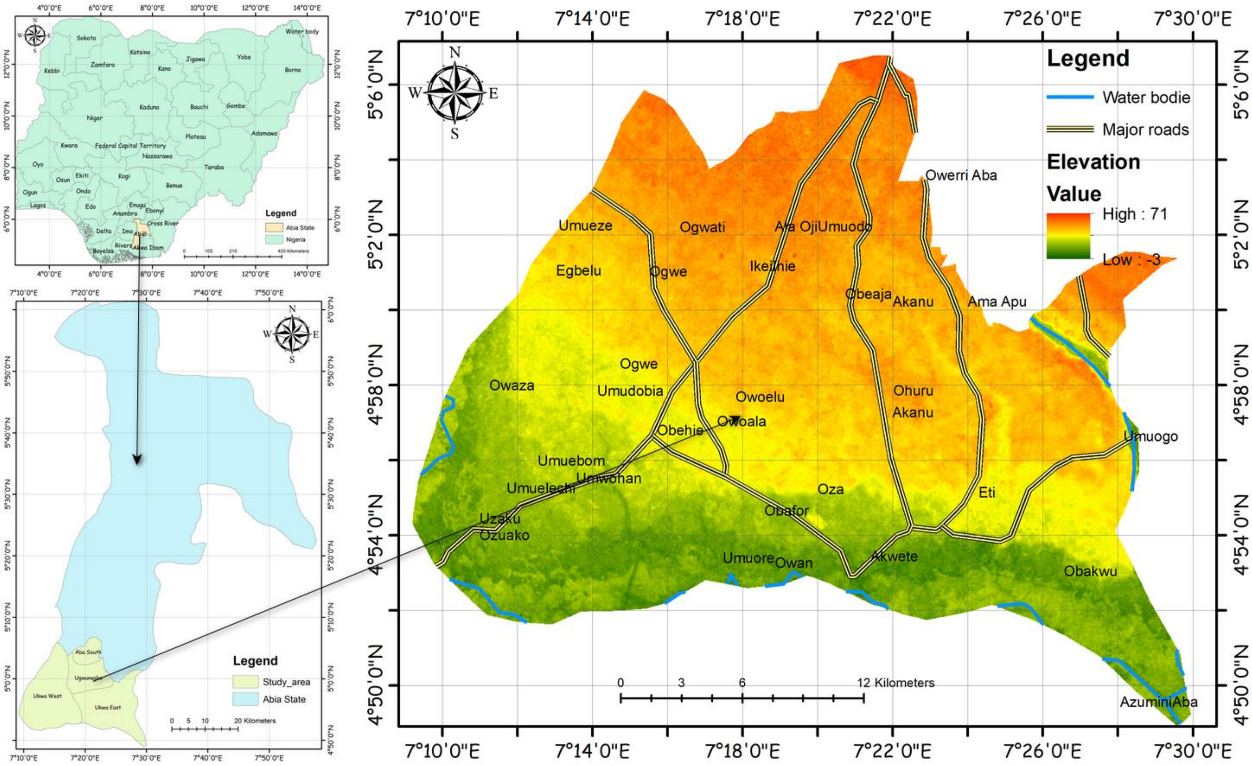

Figure 1: Map of Nigeria, Abia state and study area

The relief of the study area is characterized by gentle undulating terrain with elevations ranging from about 50 meters to 150 meters above sea level. The topography slopes generally towards the south and southwest, influencing the direction of surface runoff and drainage patterns. This relatively flat landscape facilitates agricultural activities but also poses challenges for drainage in densely populated urban areas like Aba.

The drainage system in the study area is well-defined, with several rivers and streams traversing the landscape. Major rivers include the Aba River, Imo River, and Azumini Blue

River, which play significant roles in the hydrology of the region. The Aba River, in particular, flows through the heart of the urban areas, impacting both water supply and waste management. Drainage density varies across the study area, with higher densities in the urban centers due to extensive surface runoff from impervious surfaces, and lower densities in rural areas where natural infiltration is more prevalent. The hydrology is influenced by the interplay of natural and anthropogenic factors, including urban development and agricultural practices.

The climate of the study area is classified as tropical rainforest, characterized by high temperatures, significant rainfall, and high humidity throughout the year. The region experiences two distinct seasons: the wet season (April to October) and the dry season (November to March). Annual rainfall averages between 2000 mm and 2500 mm, with the peak occurring in June and September. Temperatures range from 22°C to 32°C, with little variation throughout the year.

Vegetation in the study area reflects the tropical rainforest climate, with dense, lush forests in rural areas and fragmented patches of green spaces in urban centers. The rural LGAs, particularly Ukwa East and Ukwa West, retain extensive forest cover, supporting biodiversity and traditional agricultural practices. These areas are characterized by a mix of primary and secondary forests, farmlands, and wetlands.

In contrast, urban and peri-urban LGAs like Aba North, Aba South, and Osisioma Ngwa have seen significant vegetation loss due to urbanization and infrastructural development. Green spaces are limited to parks, gardens, and roadside vegetation, highlighting the need for urban greening initiatives to mitigate environmental degradation.

The geological composition of the study area is part of the Niger Delta Basin, characterized by sedimentary rock formations. The primary geological formations include the Benin Formation, the Ogwashi-Asaba Formation, and the Ameki Formation. These formations consist mainly of sandstones, siltstones, claystones, and shales, with occasional lignite seams.

The Benin Formation, which is prevalent in the region, is composed predominantly of coarse-grained sands and gravels, providing good aquifer properties and supporting groundwater extraction for domestic and agricultural use. The Ogwashi-Asaba Formation, consisting of alternating layers of sandstones, clays, and lignite, also contributes to the area's hydrogeology. The Ameki Formation, found in some parts of the study area, is characterized by fossiliferous claystones and siltstones, indicating a marine depositional environment. This geological diversity influences soil types, groundwater availability, and natural resource distribution in the region.

In rural LGAs like Ukwa East and Ukwa West, the geological formations support fertile soils for agriculture, while in urban LGAs like Aba North and Aba South, the geological properties impact construction activities and infrastructure development. Understanding the geology of the area is crucial for sustainable land use planning, water resource management, and mitigating geological hazards such as erosion and landslides.

3. Methodology

3.1 Data Acquisition

This study aims to analyze the spatial distribution of slope and drainage density, along with the land use/land cover (LULC) changes over six years in selected Local Government Areas (LGAs) of Abia State, Nigeria, using remote sensing (RS) and GIS technologies. The goal is to assess the geological and environmental impacts of these changes to aid in effective land management and planning. Various spatial and non-spatial data were acquired for this purpose, as summarized in Table 1.

Table 1: Data table

Data Type	Source	Provider
Satellite Imagery	Earth Explorer	United States Geological Survey (USGS)
LULC Data	Earth Explorer	United States Geological Survey (USGS)
SRTM Elevation Data	Earth Explorer	United States Geological Survey (USGS)

The primary data sources include high-resolution satellite imagery obtained from the USGS Earth Explorer platform, which provides a detailed view of the LULC changes over the selected time period. Historical LULC data were also sourced from the USGS, providing classifications of land into various categories such as agricultural land, forests, urban areas, and water bodies. Shuttle Radar Topography Mission (SRTM) elevation data were obtained to provide a Digital Elevation Model (DEM) of the study area, which is critical for analyzing the terrain, including slope and drainage density. Additional data, such as administrative boundaries, hydrological features, and geological maps, were obtained from local government sources and previous studies to support the analysis.

3.2 Data Processing

The data processing phase involved several steps to prepare the acquired data for analysis. ArcGIS, a comprehensive GIS software suite, was used for spatial data manipulation and analysis.

3.2.1 LULC Classification

The preprocessed satellite images were classified into different LULC categories using supervised classification techniques. Training samples representing various land cover types (e.g., vegetation, water, urban areas) were collected, and a maximum likelihood classifier was applied to classify the images. The classification accuracy was assessed using ground truth data and accuracy metrics such as the Kappa coefficient.

3.2.2 DEM Processing

The SRTM DEM data were processed to derive slope and drainage density. The slope was calculated using the slope tool in ArcGIS, which computes the maximum rate of change in elevation for each DEM cell. Drainage density was calculated by delineating the drainage network from the DEM using the hydrology toolset in ArcGIS, which includes flow direction, flow accumulation, and stream network delineation.

3.2.3 Change Detection

To analyze the changes in LULC over the six-year period, a change detection analysis was performed. The classified LULC maps for 2017 and 2023 were compared using post-classification comparison techniques. This involved overlaying the LULC maps and identifying areas of change, quantified as the difference in the extent of each land cover type between the two years.

3.3 Data Analysis

The data analysis phase involved integrating the processed data to assess the spatial distribution of slope, drainage density, and LULC changes, and their geological and environmental impacts. Several analytical techniques and equations were employed to achieve this.

3.3.1 Drainage Density Analysis

Drainage density (D_d) was calculated using the drainage network delineated from the DEM. It was computed as:

$$D_d = \frac{L}{A} \quad (1)$$

where L is the total length of streams and rivers, and A is the area of the basin. High drainage density indicates a high potential for surface runoff and erosion, while low drainage density suggests better infiltration and groundwater recharge.

3.3.2 LULC Change Analysis

The LULC change analysis involved quantifying the extent of changes in different land cover types between 2017 and 2023. The changes were assessed using the following equation:

$$\Delta LULC = LULC_{2023} - LULC_{2017} \quad (2)$$

where $LULC_{2023}$ and $LULC_{2017}$ represent the areas of each land cover type in 2023 and 2017, respectively. The changes were visualized using maps and statistical summaries to identify trends and patterns in land use dynamics.

3.4 Geological and Environmental Impact Assessment

The impacts of slope, drainage density, and LULC changes on the geology and environment were assessed by integrating the spatial data. Areas with steep slopes and high drainage density were identified as prone to erosion and landslides. Changes in LULC were correlated with alterations in hydrological patterns, such as increased runoff in urbanized areas and reduced infiltration in deforested regions. The assessment provided insights into the environmental consequences of land use changes, such as habitat loss, soil degradation, and water quality deterioration.

The integration of remote sensing and GIS technologies enabled a comprehensive analysis of the spatial distribution of slope, drainage density, and LULC changes in the selected LGAs of Abia State. The findings from this study will inform effective land management and planning strategies to mitigate geological and environmental impacts, ensuring sustainable development in the region.

This study highlights the critical need for continuous monitoring and assessment of land use changes, especially in rapidly urbanizing regions. The methodologies and findings provide a valuable framework for similar studies in other regions, contributing to a broader understanding of the impacts of land use dynamics on geological and environmental systems.

4. Results and Discussion

4.1 Drainage Density and Area

The study area was analyzed for its drainage density distribution across different regions, with the results summarized in Table 1. Drainage density, a critical geological parameter, indicates the total length of all streams and rivers in a drainage basin divided by the total area of the basin. It reflects the interaction between precipitation and the landscape, and its values can indicate the potential for surface runoff, soil erosion, and overall watershed health.

Table 1: Drainage Density of the study area

Area (Km²)	Drainage Density (km/km²)
146.1782	0 - 66.33
305.5348	66.33 - 132.67
201.3937	132.67 - 199.01
38.6349	199.01 - 265.35
2.5222	265.35 - 331.69

The distribution of drainage density across the study area reveals significant variations, particularly between the southern and northern parts. The southern part of the study area exhibits higher drainage densities compared to the northern part, which is indicative of differing geological characteristics as shown in Figure 2.

The northern region, characterized by lower drainage densities ranging from 0 to 66.33 km/km² and 66.33 to 132.67 km/km², covers areas of 146.1782 km² and 305.5348 km² respectively. These lower drainage densities suggest relatively flat terrain with fewer streams and rivers, indicative of more permeable soil and higher infiltration rates. This results in lower surface runoff potential and a greater capacity for groundwater recharge. The geological composition of this region likely includes porous materials that facilitate water infiltration, making it suitable for agricultural activities that depend on soil moisture.

As we move towards the southern part of the study area, the drainage densities increase significantly. The region with drainage densities between 132.67 and 199.01 km/km² spans an area of 201.3937 km². This intermediate level of drainage density suggests a more balanced interaction between surface runoff and infiltration. The geological formation here may include a mix of permeable and impermeable layers, leading to moderate runoff and erosion rates.

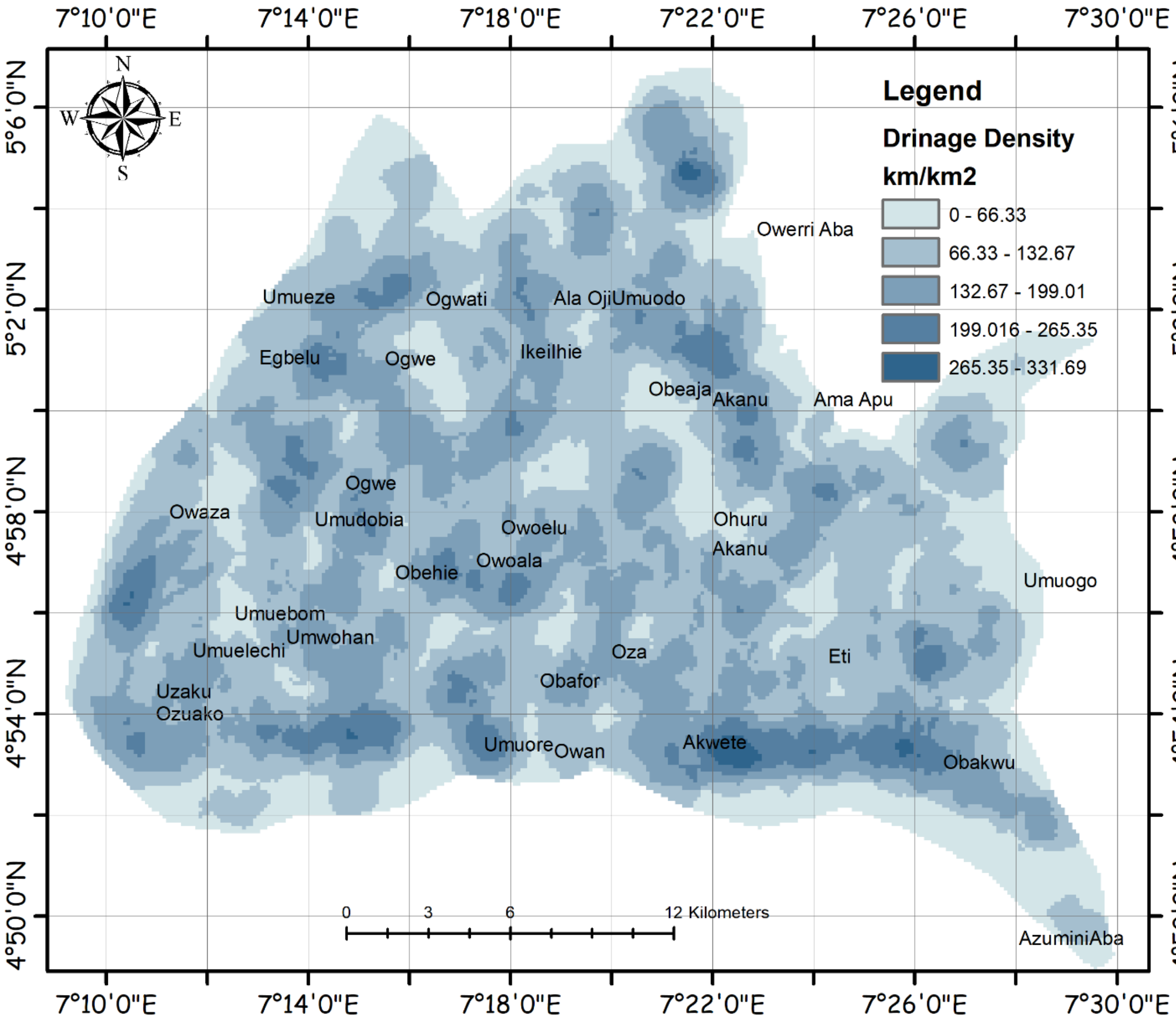

Figure 2:

Further south, the drainage density rises to 199.01 - 265.35 km/km² over an area of 38.6349 km², and reaches an extreme of 265.35 - 331.69 km/km² over the smallest area of 2.5222 km². These higher densities indicate regions with numerous streams and high runoff potential, possibly due to steeper slopes or less permeable soils. The geological features of these areas likely include more resistant rock formations or compacted soils that reduce infiltration, resulting in increased surface runoff and higher erosion rates.

The spatial variation in drainage density across the study area suggests a complex interplay between topography, soil characteristics, and underlying geology. The higher drainage densities in the southern part point towards a landscape with steeper slopes and less permeable soils, while the northern part's lower densities suggest flatter terrain and more permeable soils (Sadiq et al., 2021).

The southern regions with higher drainage density are likely influenced by tectonic activities that create steeper slopes and more resistant rock formations. These geological features contribute to higher runoff and erosion rates, necessitating effective soil conservation practices to manage erosion and maintain land stability (John et al., 2021). In contrast, the northern regions with lower drainage densities may be underlain by more stable geological formations with less tectonic influence, resulting in flatter terrain and better conditions for groundwater recharge.

The implications of these findings are significant for land use planning and water resource management. Regions with higher drainage density require focused conservation efforts to mitigate soil erosion and manage surface runoff. This can include practices such as terracing, contour plowing, and the establishment of riparian buffers. Additionally, constructing check dams, rainwater harvesting systems, and proper drainage channels can help manage runoff and reduce the risk of flooding in these areas.

4.2 Land Use and Land Cover (LULC) Analysis 2017

The study of Land Use and Land Cover (LULC) types in the study area for the year 2017 reveals diverse land use patterns, as summarized in Table 2 and illustrated in Figure 3. The analysis highlights the extent of different LULC types, which are critical for understanding the environmental and geological characteristics of the region.

Table 2: Land Use and Land Cover (LULC) Types and Corresponding Areas in 2017

LULC Type	Area (Km^2)
Water	3.76543
Trees	584.755301
Flooded vegetation	0.116536
Crops	1.750771
Built Area	95.834714
Bare ground	0.114219
Rangeland	7.906222

Trees dominate the landscape, covering an area of 584.755301 km^2. This extensive forest cover is significant from a geological perspective, as it indicates a stable ecosystem with a well-developed soil profile. Forests play a crucial role in soil conservation, water retention, and carbon sequestration. The presence of such a large forested area suggests that the region has a robust natural resource base, which can support biodiversity and contribute to ecological balance.

Built areas account for 95.834714 km^2, reflecting the extent of urbanization within the study area. The geological implications of extensive built-up areas include changes in natural drainage patterns, increased surface runoff, and potential risks of soil erosion and flooding. Urban areas tend to replace natural vegetation with impervious surfaces such as roads and buildings, which can significantly alter the hydrological cycle. Effective urban planning and the implementation of green infrastructure are essential to mitigate these impacts.

Water bodies cover 3.76543 km^2, which is relatively small but vital for the region's hydrology. Water bodies, including rivers, lakes, and reservoirs, play a crucial role in groundwater recharge, flood control, and providing habitats for aquatic life. The geological setting around these water bodies needs careful management to prevent pollution and maintain water quality.

Flooded vegetation, covering an area of 0.116536 km², indicates regions that are seasonally or permanently inundated. These areas are critical for maintaining hydrological balance and supporting unique ecosystems. Geologically, flooded areas can influence sediment deposition and soil fertility, which are important for agricultural productivity.

Crops occupy 1.750771 km², reflecting the agricultural activities in the region. Agriculture has a direct impact on soil health and requires careful management to prevent degradation. The small area under cultivation suggests limited agricultural expansion, which could be due to soil constraints or land use policies aimed at preserving natural landscapes.

Bare ground, accounting for 0.114219 km², represents areas with little to no vegetation cover. These areas are particularly susceptible to erosion, especially during heavy rainfall events. The geological stability of these regions needs to be assessed to implement appropriate soil conservation measures.

Rangelands cover 7.906222 km², supporting grazing and livestock activities. Rangelands play a significant role in maintaining soil structure and fertility. However, overgrazing can lead to soil compaction and erosion, which necessitates sustainable grazing practices to preserve soil health and productivity.

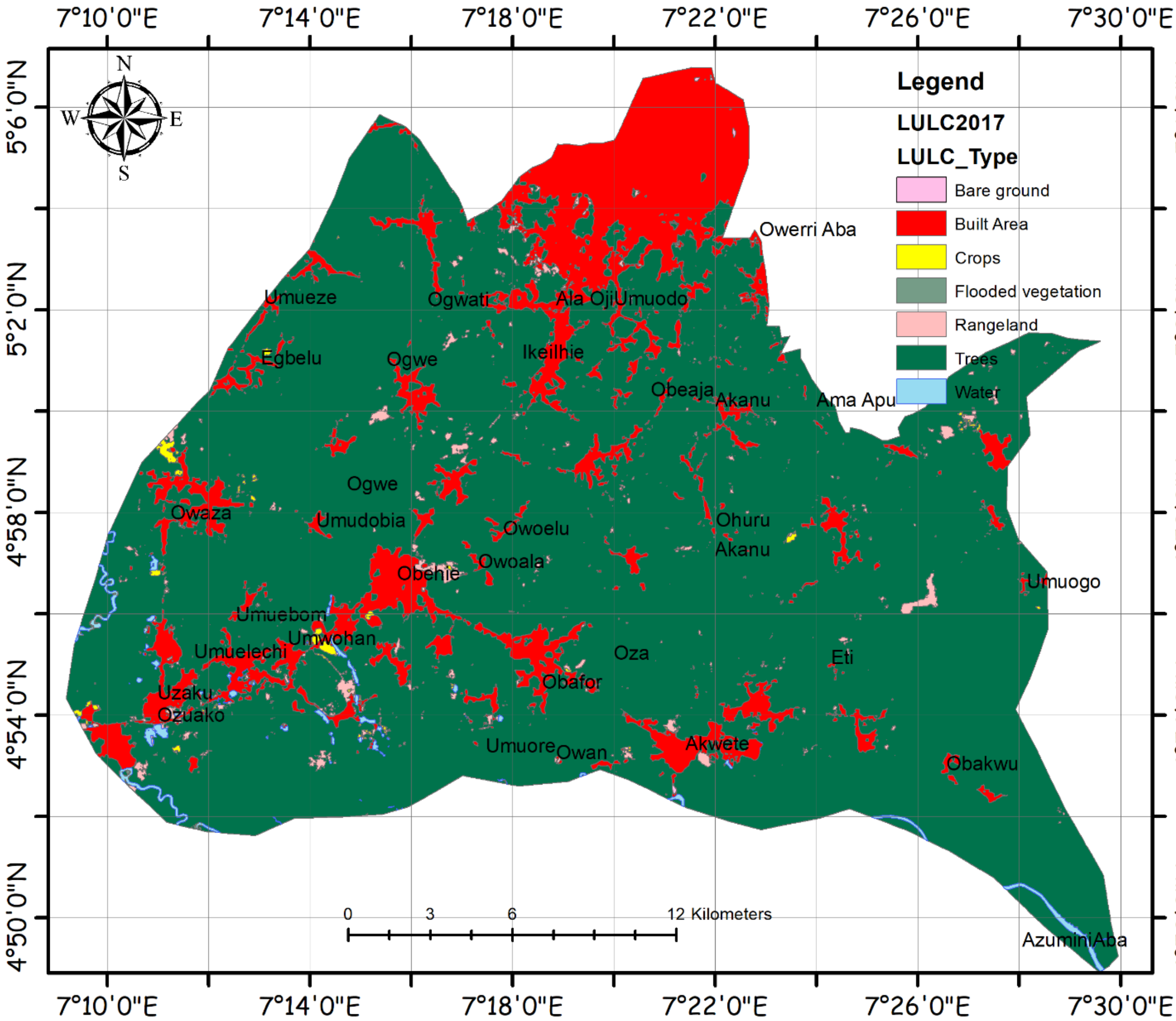

Figure 3: Spatial Distribution of Land Use and Land Cover (LULC) Types in the Study Area for 2017

The analysis of LULC types also reveals that Aba South, as a rural area, is more populated within the study area. This population density in rural regions like Aba South has significant implications for land use and resource management. Higher population density can lead to increased demand for land, water, and other natural resources, which may exert pressure on the local environment.

The diverse land cover types reflect the varying geological and ecological conditions across the study area. The extensive forest cover suggests regions with favorable soil and climatic conditions for tree growth, whereas the presence of built-up areas indicates zones of urban expansion and development. Water bodies and flooded vegetation highlight the importance of managing hydrological systems to prevent issues such as waterlogging and pollution (Akinola et al., 2021). Cropland and rangeland areas underscore the need for sustainable agricultural and grazing practices to maintain soil health and productivity.

The dominance of trees (584.755301 km²) and built-up areas (95.834714 km²) highlights the dual focus of the region on conservation and development. The relatively small areas of water bodies, flooded vegetation, and bare ground emphasize the need for targeted geological and environmental management strategies. Sustainable management practices are crucial for maintaining the ecological balance and ensuring the long-term viability of natural resources.

4.3 Land Use and Land Cover (LULC) Analysis for 2023

The Land Use and Land Cover (LULC) analysis for the year 2023 provides a comprehensive overview of the spatial distribution and extent of different land cover types in the study area, as summarized in Table 3 and illustrated in Figure 4. This analysis is critical for understanding the geological characteristics, environmental dynamics, and anthropogenic impacts in the region.

Table 3: Land Use and Land Cover (LULC) Types and Corresponding Areas in 2023

LULC Type	Area (Km²)
Water	4.50008
Trees	487.749451
Flooded vegetation	0.316989
Crops	6.904555
Built Area	154.081325
Bare ground	0.006505
Rangeland	40.676751

The analysis reveals significant changes in land use patterns compared to previous years, reflecting dynamic environmental processes and human activities. Trees remain a dominant land cover type, occupying 487.749451 km². However, there is a noticeable reduction in forested areas, which may be attributed to deforestation and land conversion for other uses. The loss of forest cover has profound geological implications, including increased soil erosion, reduced carbon sequestration, and altered microclimates. Forests play a crucial role in maintaining soil stability and hydrological cycles; thus, their reduction can lead to adverse environmental effects.

Built areas have expanded significantly to cover 154.081325 km². This expansion indicates urban growth and development, which often result in increased impervious surfaces, altered natural drainage patterns, and potential risks of flooding and soil erosion. The geological impact of urbanization includes changes in groundwater recharge rates, increased surface runoff, and the potential for land subsidence. Effective urban planning and the incorporation of green infrastructure are essential to mitigate these impacts and promote sustainable urban growth.

Water bodies now cover 4.50008 km², an increase from previous assessments. This expansion may result from natural changes in the hydrological cycle, such as increased rainfall or human activities like the creation of artificial lakes and reservoirs. Water bodies are critical for maintaining regional hydrology, supporting biodiversity, and providing resources for human use. Geologically, the presence of water bodies influences sediment deposition, soil moisture levels, and groundwater recharge. Protecting these water resources from pollution and over-extraction is vital for sustaining their ecological and geological functions.

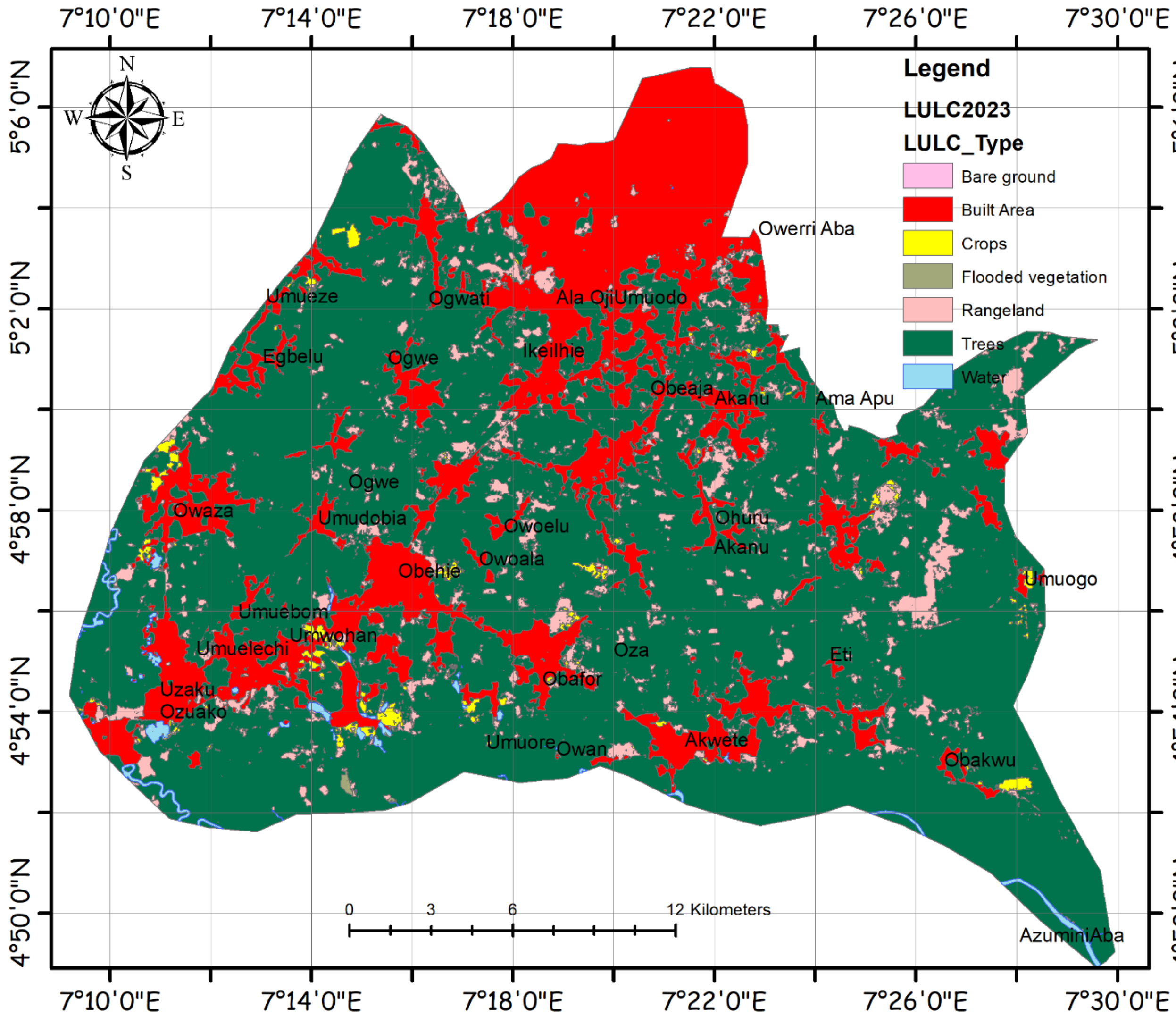

Figure 4: Spatial Distribution of Land Use and Land Cover (LULC) Types in the Study Area for 2023

Flooded vegetation, covering 0.316989 km², highlights areas that are seasonally or permanently inundated. These areas are essential for maintaining hydrological balance, supporting unique ecosystems, and influencing sediment and nutrient dynamics. The presence of flooded vegetation indicates areas with high water tables or poor drainage, which can impact soil development and stability. Managing these regions involves ensuring that water flow and quality are maintained to support both ecological and geological health.

Crops have expanded to cover 6.904555 km², indicating an increase in agricultural activities. Agriculture directly impacts soil health through practices such as tilling, irrigation, and the use of agrochemicals. Sustainable agricultural practices are necessary to prevent soil degradation, enhance fertility, and maintain productivity. The increase in cropland suggests a greater demand for food production, which must be balanced with soil conservation strategies to ensure long-term agricultural viability.

Bare ground has decreased to 0.006505 km², indicating a reduction in areas with little to no vegetation cover. Bare ground is highly susceptible to erosion, especially during heavy rainfall events. The reduction in bare ground suggests that either vegetation has naturally regenerated, or land use practices have been altered to reduce erosion risks. From a geological perspective, maintaining vegetative cover is crucial for soil conservation and preventing land degradation.

Rangeland, now covering 40.676751 km², supports grazing and livestock activities. Rangelands play a significant role in maintaining soil structure and fertility through the natural processes of grazing and nutrient cycling. However, overgrazing can lead to soil compaction, reduced vegetation cover, and increased erosion. Sustainable grazing practices are essential to maintain the health and productivity of rangelands.

The analysis also reveals that Aba South, as a rural area, remains more populated within the study area. This higher population density in rural regions like Aba South has significant implications for land use and resource management. Increased population density can lead to greater demand for land, water, and other natural resources, exerting pressure on the local environment and necessitating effective management strategies.

The diverse land cover types reflect the varying geological and ecological conditions across the study area. The reduction in forest cover and the expansion of built areas and cropland indicate significant changes in land use practices and human activities. Water bodies and flooded vegetation emphasize the importance of managing hydrological systems, while the presence of rangeland underscores the need for sustainable grazing practices. The dominance of trees and the significant expansion of built-up areas highlight the dual focus of the region on conservation and development (Hasselerharm et al., 2021). The increase in water bodies, cropland, and rangeland areas emphasizes the need for targeted geological and environmental management strategies to balance ecological health and human needs.

4.4. Implications of LULC Changes on Hydrological Characteristics and Drainage Density in Abia State (2017-2023)

The study aims to analyze the impact of land use and land cover (LULC) changes between 2017 and 2023 on the hydrological characteristics and drainage density in urban and semi-urban areas of Abia State, Southeastern Nigeria. This analysis utilizes satellite imagery, LULC data, and SRTM elevation to draw insights into these changes.

The LULC data for 2017 and 2023 reveals significant shifts in land use patterns, which have profound implications on the region's hydrology and drainage density.

In 2017, the study area was predominantly covered by trees (584.755301 km²), with significant areas of built-up land (95.834714 km²), water bodies (3.76543 km²), crops (1.750771 km²), and rangeland (7.906222 km²). By 2023, there was a marked decrease in tree cover to 487.749451 km² and a notable increase in built-up areas to 154.081325 km². Additionally, water bodies expanded to 4.50008 km², cropland increased to 6.904555 km², and rangeland grew substantially to 40.676751 km². Flooded vegetation also saw an increase from 0.116536 km² to 0.316989 km², while bare ground decreased significantly from 0.114219 km² to 0.006505 km².

These changes in LULC types can be correlated with alterations in drainage density across the study area. In regions where drainage density is low (0 - 66.33 km/km²), such as the 146.1782 km² area, the increase in built-up areas and reduction in tree cover likely contribute to increased surface runoff and decreased infiltration. Urbanization, characterized by impervious surfaces, reduces the natural absorption of rainwater, leading to higher runoff volumes and potential flooding. The expansion of built-up areas from 95.834714 km² to 154.081325 km² exacerbates these effects, particularly in semi-urban regions where drainage systems may not be adequately developed to handle increased runoff.

In areas with moderate drainage density (66.33 - 132.67 km/km² and 132.67 - 199.01 km/km²), encompassing 305.5348 km² and 201.3937 km² respectively, the increase in cropland from 1.750771 km² to 6.904555 km² and the expansion of rangeland from 7.906222 km² to 40.676751 km² indicate significant land use changes. Agricultural activities and grazing can lead to soil compaction, reduced infiltration, and increased erosion. These activities, combined with the reduction in tree cover, likely impact the hydrological balance by increasing surface runoff and altering the natural drainage patterns.

High drainage density areas (199.01 - 265.35 km/km² and 265.35 - 331.69 km/km²) covering 38.6349 km² and 2.5222 km² respectively, are more sensitive to changes in land cover due to their inherent geomorphological characteristics. The expansion of water bodies from 3.76543 km² to 4.50008 km² and the increase in flooded vegetation suggest changes in local hydrology, possibly due to altered precipitation patterns or human interventions such as the construction of reservoirs. These changes can influence sediment deposition, water quality, and the overall hydrological dynamics of the region.

The reduction in forest cover and the expansion of built-up areas, cropland, and rangeland have significant implications for the hydrological characteristics and drainage density of the study area. Increased urbanization and agricultural activities lead to higher surface runoff, reduced groundwater recharge, and potential for increased flooding and soil erosion (Ewane & Lee, 2020). Effective land use planning and sustainable management practices are essential to mitigate these impacts and maintain the ecological and hydrological balance of the region

5 Conclusion

The comprehensive analysis of the study area, focusing on drainage density and land use and land cover (LULC) changes between 2017 and 2023, reveals critical insights into the region's hydrological characteristics and geological dynamics. The findings underscore the complex interplay between natural processes and human activities, highlighting the need for sustainable management practices to maintain ecological balance and support the region's development.

The study area's drainage density varies significantly, with higher densities in the southern regions and lower densities in the northern regions. This variation indicates differing geological characteristics, with flatter terrain and more permeable soils in the north and steeper slopes with less permeable soils in the south. Northern regions with low drainage densities (0 - 66.33 km/km²) cover 146.1782 km² and 305.5348 km², suggesting high infiltration rates and lower surface runoff potential. These areas are likely suitable for agriculture due to their stable geological formations and better groundwater recharge conditions. Southern regions exhibit higher drainage densities (132.67 - 199.01 km/km² and above), covering smaller areas of 38.6349 km² and 2.5222 km². These areas are characterized by numerous streams, high runoff potential, and increased erosion risks due to steeper slopes and more resistant geological formations.

There was a significant reduction in tree cover from 584.755301 km² in 2017 to 487.749451 km² in 2023. This decrease is likely due to deforestation and land conversion for urban and agricultural purposes. The loss of forest cover has implications for soil stability, carbon sequestration, and local climate regulation. Urban expansion is evident with built-up areas increasing from 95.834714 km² in 2017 to 154.081325 km² in 2023. This growth contributes to increased impervious surfaces, altered drainage patterns, and higher surface runoff, leading to potential flooding and soil erosion. The area under crops expanded from 1.750771 km² in 2017 to 6.904555 km² in 2023. While this supports food production, it also impacts soil health and requires sustainable agricultural practices to prevent degradation. There was a substantial increase in rangeland from 7.906222 km² in 2017 to 40.676751 km² in 2023. Overgrazing in these areas can lead to soil compaction and erosion, necessitating effective grazing management. The increase in water bodies from 3.76543 km² to 4.50008 km² and flooded vegetation from 0.116536 km² to 0.316989 km² reflects changes in hydrological conditions, possibly influenced by both natural factors and human interventions such as reservoir construction.

The changes in LULC types have profound implications for the region's hydrology and drainage density. The reduction in forest cover and expansion of urban areas contribute to increased surface runoff, reduced groundwater recharge, and heightened flood risks. Agricultural expansion and rangeland growth also impact soil structure, infiltration rates, and erosion dynamics.

In regions with low drainage density, the increase in built-up areas and reduction in tree cover exacerbate surface runoff and decrease infiltration, highlighting the need for improved urban planning and green infrastructure. In areas with moderate drainage density, the expansion of cropland and rangeland necessitates sustainable agricultural and grazing practices to balance runoff and infiltration rates.

High drainage density areas, sensitive to changes in land cover, require careful management to maintain hydrological balance and water quality. The increase in water bodies and flooded vegetation suggests a need for targeted interventions to manage sediment deposition and support aquatic ecosystems.

The study highlights the significant impact of LULC changes on hydrological characteristics and drainage density in Abia State. The reduction in forest cover, expansion of urban and agricultural areas, and changes in water bodies underscore the need for integrated land and water management strategies. Sustainable practices are essential to mitigate the adverse effects of urbanization, agricultural activities, and environmental changes, ensuring the long-term viability of the region's natural resources and ecological health. Effective land use planning, conservation efforts, and the implementation of green infrastructure are critical to maintaining the ecological and hydrological balance in Abia State.

References

Aghsaei, H., Dinan, N. M., Moridi, A., Asadolahi, Z., Delavar, M., Fohrer, N., & Wagner, P. D. (2020). Effects of dynamic land use/land cover change on water resources and sediment yield in the Anzali wetland catchment, Gilan, Iran. *Science of the Total Environment*, *712*, 136449. https://doi.org/10.1016/j.scitotenv.2019.136449

Akaolisa, C. C., Agbasi, O. E., Etuk, S. E., Adewumi, R., & Okoli, E. A. (2023). Evaluating the Effects of Real Estate Development in Owerri, Imo State, Nigeria: Emphasizing Changes in Land Use/Land Cover (LULC). *Journal of Landscape Ecology*, *16*(2), 98–113. https://doi.org/10.2478/jlecol-2023-0012

Akinola, F. F., Osadare, T., & Adebayo, S. A. (2021). INFLUENCE OF DIFFERENT LAND USE TYPES ON PHYSICAL CHARACTERISTICS OF SOIL IN EKITI- STATE, NIGERIA. *Journal CleanWAS*, *5*(2), 47–53. https://doi.org/10.26480/jcleanwas.02.2021.47.53

Arowolo, A. O., Deng, X., Olatunji, O. A., & Obayelu, A. E. (2018). Assessing changes in the value of ecosystem services in response to land-use/land-cover dynamics in Nigeria.

Science of the Total Environment, *636*, 597–609. https://doi.org/10.1016/j.scitotenv.2018.04.277

Dogan, F. N., & Karpuzcu, M. E. (2021). Effect of land use change on hydrology of forested watersheds. *Ecohydrology*, *15*(1). https://doi.org/10.1002/eco.2367

Ewane, B. E., & Lee, H. H. (2020). Assessing land use/land cover change impacts on the hydrology of Nyong River Basin, Cameroon. *Journal of Mountain Science/Journal of Mountain Science*, *17*(1), 50–67. https://doi.org/10.1007/s11629-019-5611-8

Gashaw, T., Tulu, T., Argaw, M., & Worqlul, A. W. (2018a). Modeling the hydrological impacts of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia. *Science of the Total Environment*, *619–620*, 1394–1408. https://doi.org/10.1016/j.scitotenv.2017.11.191

Gashaw, T., Tulu, T., Argaw, M., & Worqlul, A. W. (2018b). Modeling the hydrological impacts of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia. *Science of the Total Environment*, *619–620*, 1394–1408. https://doi.org/10.1016/j.scitotenv.2017.11.191

Gelmini, Y., Zuecco, G., Zaramella, M., Penna, D., & Borga, M. (2022). Hysteresis in streamflow-water table relation provides a new classification system of rainfall-runoff events. *Hydrological Processes*, *36*(9). https://doi.org/10.1002/hyp.14685

Hasselerharm, C. D., Yanco, E., McManus, J. S., Smuts, B. H., & Ramp, D. (2021). Wildlife-friendly farming recouples grazing regimes to stimulate recovery in semi-arid rangelands. *Science of the Total Environment*, *788*, 147602. https://doi.org/10.1016/j.scitotenv.2021.147602

Idrees, M. O., Olateju, S. A., Omar, D. M., Babalola, A., Ahmadu, H. A., & Kalantar, B. (2022). Spatial assessment of accelerated surface runoff and water accumulation potential areas using AHP and data-driven GIS-based approach: the case of Ilorin metropolis, Nigeria. *Geocarto International*, *37*(27), 15877–15895. https://doi.org/10.1080/10106049.2022.2102236

Ijioma, U. D. (2021). Delineating the impact of urbanization on the hydrochemistry and quality of groundwater wells in Aba, Nigeria. *Journal of Contaminant Hydrology*, *240*, 103792. https://doi.org/10.1016/j.jconhyd.2021.103792

John, K., Afu, S. M., Isong, I. A., Aki, E. E., Kebonye, N. M., Ayito, E. O., Chapman, P. A., Eyong, M. O., & Penížek, V. (2021). Mapping soil properties with soil-environmental covariates using geostatistics and multivariate statistics. *International Journal of Environmental Science and Technology*, *18*(11), 3327–3342. https://doi.org/10.1007/s13762-020-03089-x

Luo, X., Li, J., Zhu, S., Xu, Z., & Huo, Z. (2020). Estimating the Impacts of Urbanization in the Next 100 years on Spatial Hydrological Response. *Water Resources Management*, *34*(5), 1673–1692. https://doi.org/10.1007/s11269-020-02519-2

Mashi, S. A., Chup, C. D., & Agoha, S. C. (2021). Influence of Urban Growth on Landuse/Cover in Umuahia, Abia State Nigeria. *Journal of Geography, Environment and Earth Science International*, 147–157. https://doi.org/10.9734/jgeesi/2021/v25i1030321

Nnaji, C. C., Ogarekpe, N. M., & Nwankwo, E. J. (2021a). Temporal and spatial dynamics of land use and land cover changes in derived savannah hydrological basin of Enugu State, Nigeria. *Environment, Development and Sustainability*, *24*(7), 9598–9622. https://doi.org/10.1007/s10668-021-01840-z

Nnaji, C. C., Ogarekpe, N. M., & Nwankwo, E. J. (2021b). Temporal and spatial dynamics of land use and land cover changes in derived savannah hydrological basin of Enugu State, Nigeria. *Environment, Development and Sustainability*, *24*(7), 9598–9622. https://doi.org/10.1007/s10668-021-01840-z

Okoli, E., Akaolisa, C. C. Z., Ubechu, B. O., Agbasi, O. E., & Szafarczyk, A. (2024). Using VES and GIS-Based DRASTIC Analysis to Evaluate Groundwater Aquifer Contamination Vulnerability in Owerri, Southeastern Nigeria. *Ecological Questions*, *35*(3), 1–27. https://doi.org/10.12775/eq.2024.031

Pasquier, U., Vahmani, P., & Jones, A. D. (2022). Quantifying the City-Scale Impacts of Impervious Surfaces on Groundwater Recharge Potential: An Urban Application of WRF–Hydro. *Water*, *14*(19), 3143. https://doi.org/10.3390/w14193143

Sadhwani, K., Eldho, T. I., Jha, M. K., & Karmakar, S. (2022). Effects of Dynamic Land Use/Land Cover Change on Flow and Sediment Yield in a Monsoon-Dominated Tropical Watershed. *Water*, *14*(22), 3666. https://doi.org/10.3390/w14223666

Sadiq, F. K., Maniyunda, L. M., Anumah, A. O., & Adegoke, K. A. (2021). Variation of soil properties under different landscape positions and land use in Hunkuyi, Northern Guinea savanna of Nigeria. *Environmental Monitoring and Assessment*, *193*(4). https://doi.org/10.1007/s10661-021-08974-7

Sampson, I., Bankole, A. S., & Innocent, W. I. (2020). Spatio-Temporal Analysis of Land Use Changes in South-Eastern States, Nigeria. *International Journal of Scientific and Research Publications*, *10*(4), p10060. https://doi.org/10.29322/ijsrp.10.04.2020.p10060

Woldesenbet, T. A., Elagib, N. A., Ribbe, L., & Heinrich, J. (2017). Hydrological responses to land use/cover changes in the source region of the Upper Blue Nile Basin, Ethiopia. *Science of the Total Environment*, *575*, 724–741. https://doi.org/10.1016/j.scitotenv.2016.09.124