International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(RESEARCH ARTICLE)

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Hydrological changes and water resource management: Insights from LULC Analysis in Southeastern Nigeria

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International Journal of Science and Research Archive, 2024, 12(02), 1430–1444

Publication history: Received on 12 June 2024; revised on 28 July 2024; accepted on 30 July 2024

Article DOI: https://doi.org/10.30574/ijsra.2024.12.2.1349

Abstract

Land use and land cover (LULC) changes are critical indicators of environmental dynamics and human activities. In southeastern Nigeria, the Ezza North, Ezza South, Abakalik, and Ikwo LGAs have experienced substantial LULC changes from 2017 to 2023. Understanding these changes is vital for sustainable environmental management and development planning. The study aims to analyze the LULC changes between 2017 and 2023 in the specified LGAs and assess their environmental, economic, and social implications. This analysis will inform policy recommendations for sustainable land management. The study utilized satellite imagery and Geographic Information System (GIS) techniques to compare LULC data from 2017 and 2023. The data were classified into categories such as built-up areas, tree cover, croplands, rangelands, flooded vegetation, bare ground, and water bodies. A Digital Elevation Model (DEM) was also used to analyze the slope and its impact on land use and hydrological processes. The analysis revealed significant changes in LULC. Built-up areas expanded from 16.84 km^2 in 2017 to 66.54 km^2 in 2023, indicating rapid urbanization. Tree cover decreased from 156.40 km^2 to 101.76 km^2, reflecting considerable deforestation. Croplands increased from 90.80 km^2 to 124.65 km^2, showing a rise in agricultural activities. Rangelands, although still the dominant land cover, slightly decreased from 1353.11 km^2 to 1329.08 km^2. Flooded vegetation and bare ground areas also saw reductions, while water bodies experienced a slight increase. The expansion of built-up areas highlights the ongoing urbanization driven by population growth and economic development. This urban sprawl often results in habitat loss, fragmentation, and increased pollution. The reduction in tree cover points to significant deforestation, likely due to agricultural expansion and urban development, leading to adverse effects like reduced carbon sequestration and increased soil erosion. The increase in croplands is essential for food security but necessitates sustainable practices to prevent environmental degradation. The slight decrease in rangelands underscores the need for sustainable grazing practices to maintain ecosystem health. The reductions in flooded vegetation and bare ground indicate changes in hydrological regimes and successful land reclamation efforts, respectively. The increase in water bodies, although minimal, underscores the importance of water resource management in the region. The LULC changes in the Ezza North, Ezza South, Abakalik, and Ikwo LGAs from 2017 to 2023 reflect significant environmental transformations with profound implications. The findings highlight the need for integrated land management strategies to balance urbanization, agricultural expansion, and environmental conservation. Effective policies must address the challenges of deforestation, soil erosion, and sustainable water resource management to ensure long-term ecological and economic stability. This study provides a comprehensive analysis of LULC changes in a rapidly developing region of southeastern Nigeria, combining satellite imagery with GIS techniques and slope analysis. The insights gained are critical for informing sustainable land use policies and mitigating the adverse impacts of rapid urbanization and agricultural expansion.

Keywords: Urbanization; Deforestation; GIS Analysis; Hydrological Processes; Environmental Management

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1. Introduction

The intricate relationship between hydrological changes and water resource management has garnered significant attention over recent decades, especially in the context of rapid urbanization, deforestation, and climate change (Arnone et al., 2018). As human activities increasingly alter natural landscapes, understanding these changes becomes critical for sustainable water resource management (Arowolo et al., 2018). Land Use and Land Cover (LULC) analysis has emerged as a pivotal tool in this domain, offering invaluable insights into how alterations in land cover and land use patterns influence hydrological processes and water availability (Olorunfemi et al., 2018; Leta et al., 2021).

Water is a fundamental resource essential for life, economic development, and ecosystem health. Effective water resource management ensures the availability of adequate and safe water for drinking, agriculture, industry, and environmental sustainability (Ngene et al., 2021). However, managing water resources is fraught with challenges, especially in regions experiencing significant land use changes and climatic variations. The balance between water supply and demand is delicate, and any disruption can lead to severe consequences, including water scarcity, pollution, and habitat degradation (Abdulmalik et al., 2019).

Hydrological changes refer to variations in the water cycle, encompassing alterations in precipitation patterns, evapotranspiration rates, surface runoff, groundwater recharge, and river flows (Fasipe & Izinyon, 2021). These changes can result from natural phenomena such as climate variability or anthropogenic activities like urbanization, deforestation, and agricultural expansion (Akinwumi et al., 2020). Urbanization typically leads to increased impervious surfaces, reducing infiltration and increasing surface runoff, which can exacerbate flood risks and reduce groundwater recharge (Anker et al., 2019). Conversely, deforestation can alter evapotranspiration rates and disrupt the water cycle, affecting local and regional water availability.

Land Use and Land Cover (LULC) analysis involves the classification and mapping of land surfaces into categories such as forests, agricultural lands, urban areas, and water bodies. This analysis is crucial for understanding the spatial and temporal dynamics of land cover changes and their implications for hydrological processes (Nwacholundu et al., 2021; Koko et al., 2022). LULC data can be derived from various sources, including satellite imagery, aerial photography, and ground surveys. Advances in remote sensing and Geographic Information Systems (GIS) have significantly enhanced the accuracy and efficiency of LULC analysis, enabling detailed monitoring of land cover changes over large areas and extended periods (Wang & Maduako, 2018).

Changes in LULC can have profound impacts on hydrological processes. For example, the conversion of forests to agricultural land can increase surface runoff and reduce soil moisture retention, leading to changes in river discharge and groundwater levels (Chaemiso et al., 2021). Urbanization often leads to the creation of impervious surfaces such as roads and buildings, which can disrupt natural drainage patterns, increase flood risks, and degrade water quality due to increased surface runoff carrying pollutants (Shao et al., 2019). Agricultural practices, particularly those involving irrigation and the use of fertilizers, can alter evapotranspiration rates and affect both the quantity and quality of water resources (Okechukwu & Mbajiorgu, 2020).

Integrating LULC analysis into water resource management strategies is essential for addressing the challenges posed by hydrological changes (Näschen et al., 2019). By providing a detailed understanding of land cover dynamics, LULC analysis can inform the development of policies and practices aimed at sustainable land and water use. Identifying areas where deforestation is contributing to reduced water availability can help target reforestation efforts to restore hydrological balance. Similarly, understanding the impacts of urbanization on local hydrology can guide the implementation of green infrastructure solutions, such as permeable pavements and green roofs, to mitigate flood risks and enhance groundwater recharge (Aladejana et al., 2018).

Numerous case studies worldwide demonstrate the value of LULC analysis in water resource management. In the Amazon Basin, LULC changes due to deforestation have been linked to alterations in the regional water cycle, affecting rainfall patterns and river flows (Levy et al., 2018; Ruiz-Vásquez et al., 2020; Lopes et al., 2021). LULC analysis in this context has been critical for developing conservation strategies to preserve the region's hydrological stability. Similarly, in urban areas like Beijing, China, LULC analysis has been used to assess the impacts of rapid urbanization on local water resources, informing the development of sustainable urban planning practices (Li et al., 2018; Guo et al., 2021).

While LULC analysis offers significant benefits, it also presents challenges. Ensuring the accuracy of LULC data, particularly in regions with rapid and complex land cover changes, can be difficult. Integrating LULC data with hydrological models requires sophisticated analytical techniques and a comprehensive understanding of local hydrological processes (Olorunfemi et al., 2018; Koko et al., 2022). Future advancements in remote sensing technology, machine learning algorithms, and data integration methods are expected to address these challenges, enhancing the capability of LULC analysis to support sustainable water resource management.

The interplay between hydrological changes and water resource management is complex and multifaceted, influenced by a myriad of factors including land use and land cover changes. LULC analysis provides a powerful tool for understanding these dynamics, offering critical insights that can inform sustainable water management practices (Wang et al., 2018; Gabiri et al., 2019). As the pressures on water resources continue to grow, leveraging LULC analysis will be essential for ensuring the resilience and sustainability of water systems in the face of ongoing environmental and socio-economic changes (Martin, 2021). By integrating LULC insights into water management strategies, policymakers and practitioners can develop more effective and adaptive approaches to managing this vital resource.

The aim of this study is to analyze the land use and land cover (LULC) changes between 2017 and 2023 in Ezza North, Ezza South, Abakalik, and Ikwo Local Government Areas (LGAs) in Enugu State, southeastern Nigeria. By leveraging satellite imagery and Geographic Information System (GIS) techniques, the study seeks to identify and quantify shifts in various land cover types, including built-up areas, tree cover, croplands, rangelands, flooded vegetation, bare ground, and water bodies. The study aims to assess the environmental, economic, and social implications of these changes, particularly focusing on the impacts of urbanization, deforestation, and agricultural expansion. The findings will inform policy recommendations for sustainable land management practices, aiming to balance development needs with environmental conservation to ensure long-term ecological and economic stability in the region.

2. Research Location and Geology

The study area encompasses Ezza North, Ezza South, Abakalik, and Ikwo Local Government Areas (LGAs) located in Enugu State, southeastern Nigeria. This region is distinguished by its diverse geological formations and significant hydrological features, making it an excellent case for examining land use and land cover (LULC) changes and their geological and environmental impacts.

Geographically, the study area is positioned between latitudes 6.1°N and 6.5°N and longitudes 7.8°E and 8.3°E. It benefits from a well-developed network of major roads, which provides easy access to different parts of the region as shown in Figure 1. The Abakaliki-Enugu Expressway, a key arterial road, runs through the area, connecting the capital city of Enugu with the northern parts of the state. Several state and local roads enhance intra-regional connectivity, supporting economic activities and influencing land use patterns due to the higher development pressures near these roads.

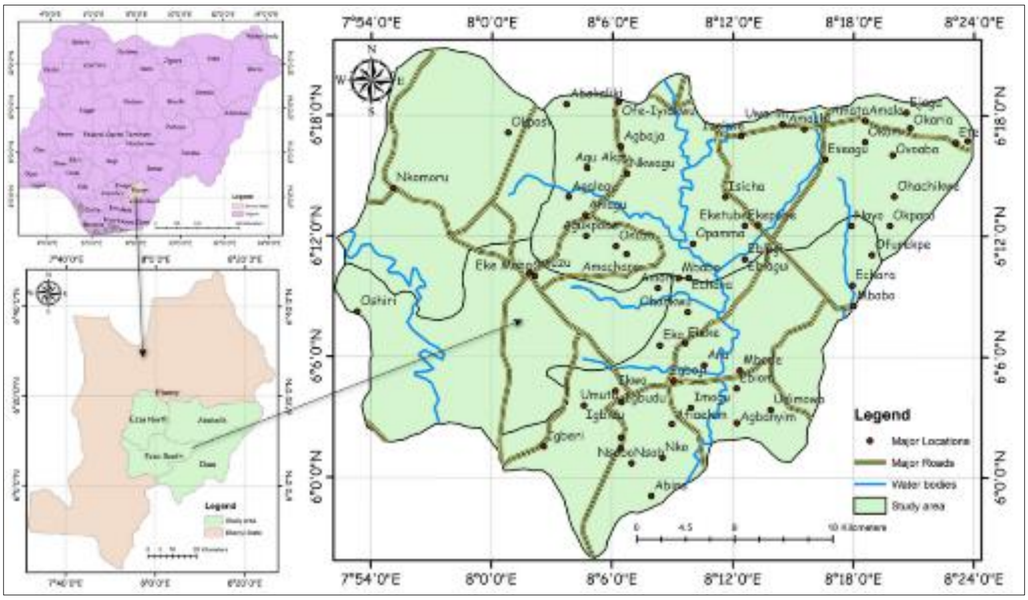

Figure 1 Map of the study area with major location, roads and water bodies

The drainage system in the study area is primarily influenced by the Cross River Basin, with several rivers and streams flowing through the region. Major rivers include the Ebonyi River, which passes through Abakaliki and serves as a significant water source for both agricultural and domestic use. Other important water bodies are the Iyiokwu River and the Ivo River, which contribute to the area's hydrological network. The drainage pattern is predominantly dendritic, characterized by a tree-like branching of rivers and streams, typical of regions with relatively uniform substrate and moderate to steep slopes, facilitating efficient water runoff. The high drainage density reflects the abundance of surface water features in the region.

Geologically, Ezza North, Ezza South, Abakaliki, and Ikwo LGAs form part of the Lower Benue Trough, a major structural feature in southeastern Nigeria. The Benue Trough is a rift basin filled with Cretaceous to Tertiary sediments. The most prominent geological unit in the region is the Abakaliki Shale Formation, consisting mainly of dark gray to black shales with occasional interbedded sandstones and limestone. These shales are rich in organic material, with significant hydrocarbon potential and notable for their lead-zinc mineralization (Salufu & Iyoha, 2019).

Overlying the Abakaliki Shale is the Eze-Aku Formation, which comprises predominantly marine sandstones, shales, and limestones, representing a deeper marine depositional environment. This formation is characterized by its fossiliferous content, including ammonites and other marine fossils. The Awgu Formation, composed of alternating layers of sandstone, shale, and limestone, represents a transition from marine to fluvial environments (Obasi & Selemo, 2018; Mode et al., 2021). It is marked by its varied lithology and fossil content, with coarse-grained, poorly sorted sandstones indicative of high-energy depositional settings. The youngest of the major formations in the study area is the Nkporo Formation, consisting of dark gray to black shales with interbedded sandstones and siltstones, representing a deltaic to shallow marine environment with high organic content and potential for hydrocarbon generation (Eze et al., 2020).

The soil types in the study area are predominantly lateritic, derived from the weathering of underlying shale and sandstone formations. These soils are typically red to reddish-brown, rich in iron and aluminum oxides, and generally fertile, supporting diverse agricultural activities. The topography is characterized by gently undulating terrain, with elevations ranging from 100 to 300 meters above sea level. The presence of shale formations influences the landscape, resulting in areas with relatively low relief and broad, flat valleys. In contrast, the sandstone ridges create more elevated and rugged terrain, particularly in areas underlain by the Eze-Aku and Awgu Formations (Dim et al., 2019). These topographical variations play a significant role in determining land use patterns and the distribution of vegetation.

The study area holds considerable environmental and economic importance. The fertile soils and favorable climate conditions support extensive agricultural activities, including the cultivation of crops such as rice, yam, cassava, and maize. The presence of mineral resources, particularly lead and zinc, has historically contributed to the local economy through mining activities. The diverse geological formations also have implications for groundwater resources. Shale formations, with their low permeability, serve as aquitards, restricting groundwater flow and creating confined aquifers. In contrast, the sandstones act as aquifers, facilitating groundwater recharge and storage. Understanding these geological and hydrological characteristics is crucial for sustainable water resource management in the region.

Ezza North, Ezza South, Abakaliki, and Ikwo LGAs in Enugu State, southeastern Nigeria, present a complex and dynamic study area with diverse geological formations, significant hydrological features, and varied land use patterns. The integration of remote sensing and GIS technologies in this study provides valuable insights into the geological and environmental impacts of LULC changes, aiding in effective land management and planning. A detailed understanding of the region's geology, soil, topography, and drainage systems is essential for developing strategies that promote sustainable development and environmental conservation.

3. Methodology

3.1. Data Acquisition

To assess the geological and environmental impacts of land use and land cover (LULC) changes, this study employed remote sensing (RS) and Geographic Information System (GIS) technologies. These tools are crucial for effective land management and planning. The data acquisition process involved gathering various spatial and non-spatial data, as summarized in Table 1.

Table 1 Data Sources

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. This platform provides detailed views of LULC changes over the selected time period. Historical LULC data from the USGS classify land into categories such as agricultural land, forests, urban areas, and water bodies. Shuttle Radar Topography Mission (SRTM) elevation data provide a Digital Elevation Model (DEM) of the study area, essential for analyzing terrain features, including slope and drainage density (Akaolisa et al., 2023). 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 preprocessing of satellite images involved radiometric and geometric corrections to ensure accuracy. Once preprocessed, the 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. A maximum likelihood classifier was applied to classify the images based on these training samples. The classification accuracy was assessed using ground truth data and accuracy metrics such as the Kappa coefficient, which measures the agreement between classified data and reference data.

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 (Okoli et al., 2024). Drainage density was calculated by delineating the drainage network from the DEM using the hydrology toolset in ArcGIS. This toolset includes processes such as flow direction, flow accumulation, and stream network delineation. These analyses help in understanding the terrain and hydrological characteristics of the study area, which are crucial for environmental impact assessments.

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. This analysis helps in understanding the dynamics of land use changes and their potential impacts on the environment.

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. Slope Analysis

The slope data derived from the DEM were analyzed to understand the terrain characteristics of the study area. The slope (S) was calculated using the following equation:

$$S = arctan\left(\frac{\Delta z}{d}\right) \times \frac{180}{\pi} \qquad \text{...........1}$$

where Δz is the change in elevation, and d is the horizontal distance. The slope data were classified into categories (e.g., flat, gentle, moderate, steep) to assess the distribution of different slope classes across the study area.

The slope data were classified into categories such as flat, gentle, moderate, and steep to assess the distribution of different slope classes across the study area. This classification helps in understanding the terrain's suitability for various land uses and identifying areas prone to erosion or other geological hazards.

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:

$$\Delta LULC = LULC_{2023} - LULC_{2017} \text{............} 2$$

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. This analysis is critical for understanding the impacts of human activities on the environment and for developing strategies for sustainable land management.

3.4. Integration and Impact Assessment

The final phase of the methodology involved integrating all processed data to conduct a comprehensive assessment of the geological and environmental impacts of LULC changes. By overlaying slope, drainage density, and LULC change data, the study identified areas most affected by land use changes. These areas were further analyzed to understand the implications for soil stability, water resources, and habitat integrity.

The integration of spatial data allowed for a holistic view of the study area, facilitating the identification of critical zones that require conservation efforts or land management interventions. This comprehensive approach ensures that planning and management strategies are based on accurate, up-to-date information, ultimately aiding in the promotion of sustainable development and environmental conservation.

4. Results and discussion

4.1. Slope map

The slope analysis of the study area, covering Ezza North, Ezza South, Abakalik, and Ikwo LGAs in Enugu State, southeastern Nigeria, reveals a varied topography with significant implications for land use, soil erosion, and hydrological processes. The slope data, derived from the Digital Elevation Model (DEM), were categorized into five classes, as shown in Table 2.

Table 2 Slope Distribution in the Study Area

Slope Range (Degrees)	Area (km^2)
0 - 1.54	400.86
1.54 - 2.09	249.06
2.09 - 3.64	585.09
3.64 - 8.01	380.61
8.01 - 20.27	9.46

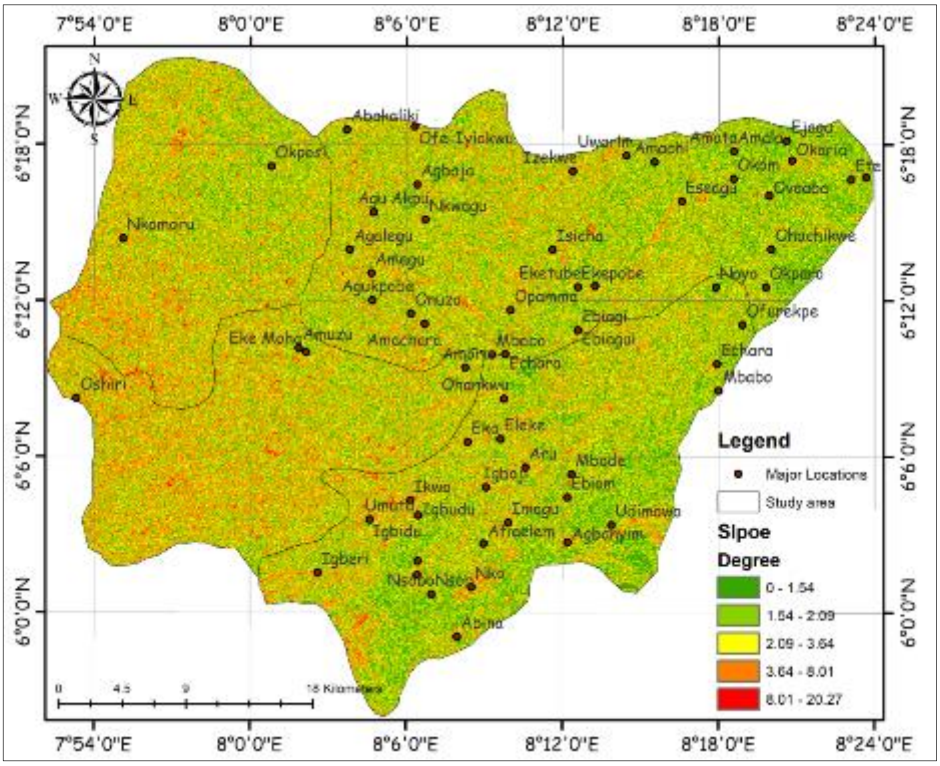

Figure 2 Slope Distribution Map of the Study Area

From the analysis presented in Table 2 and depicted in Figure 2, it is evident that the majority of the area falls within the 2.09 to 3.64-degree slope range, covering 585.09 km^2. This is followed by the 0 to 1.54-degree range with 400.86 km^2, the 3.64 to 8.01-degree range with 380.61 km^2, and the 1.54 to 2.09-degree range with 249.06 km^2. The smallest area, 9.46 km^2, is within the steepest slope range of 8.01 to 20.27 degrees.

The gentle slopes (0 - 1.54 degrees) are predominantly found in the central and northeastern parts of the study area. These regions are primarily used for agriculture due to their relatively flat terrain and fertile soils. The moderate slopes (1.54 - 3.64 degrees) are also suitable for agriculture but may require some soil conservation measures to prevent erosion. The steep slopes (3.64 - 20.27 degrees), although covering a smaller area, are significant for their potential to impact hydrological processes and soil stability. These areas are more prone to erosion and may require targeted land management practices to mitigate soil loss and maintain vegetation cover.

4.2. Land Use and Land Cover (LULC) Analysis 2017

The Land Use and Land Cover (LULC) analysis for the study area, encompassing Ezza North, Ezza South, Abakalik, and Ikwo LGAs in Enugu State, southeastern Nigeria, provides valuable insights into the distribution and extent of various land cover types as of 2017. The LULC data were categorized into seven classes: Water, Trees, Flooded Vegetation, Crops, Built Area, Bare Ground, and Rangeland. The distribution of these classes is summarized in Table 3 and illustrated in Figure 3.

Table 3 Land Use and Land Cover Distribution in 2017

LULC Type	**Area (km^2)**
Water	4.28
Trees	156.40
Flooded Vegetation	4.64
Crops	90.80
Built Area	16.84

Bare Ground	4.30
Rangeland	1353.11

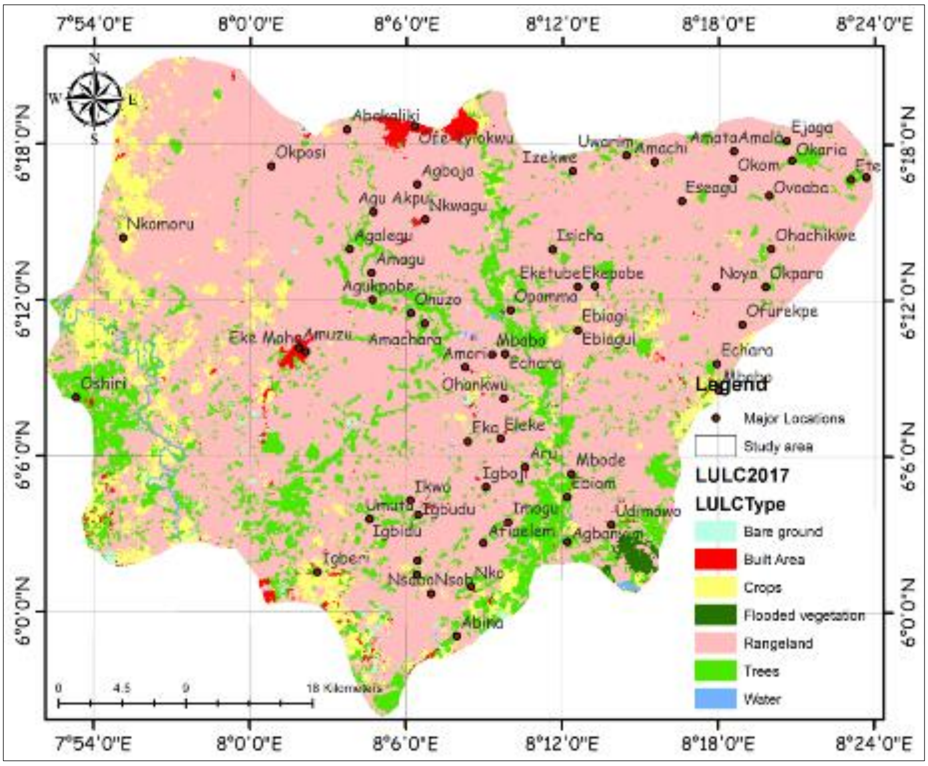

Figure 3 LULC Map of the Study Area in 2017

The LULC analysis reveals that Rangeland is the dominant land cover type, covering an extensive area of 1353.11 km^2. This class represents open land used for grazing and natural vegetation, which is prevalent in the region due to its suitability for pastoral activities and low-intensity agriculture. The extensive coverage of rangeland indicates a landscape predominantly influenced by extensive grazing practices and natural grasslands.

Trees cover the second-largest area, amounting to 156.40 km^2. This category includes forested areas and other regions with significant tree cover, reflecting the presence of natural forests and possibly plantations. The distribution of tree cover is crucial for maintaining ecological balance, supporting biodiversity, and providing essential ecosystem services such as carbon sequestration and soil stabilization.

Crops occupy 90.80 km^2, highlighting the importance of agriculture in the region. The cultivated areas are primarily used for the production of staple crops such as rice, yam, cassava, and maize. The distribution of cropland is influenced by factors such as soil fertility, availability of water for irrigation, and accessibility to markets.

Built Areas cover 16.84 km^2, representing urban and peri-urban developments, including residential, commercial, and industrial areas. The relatively small extent of built areas indicates that urbanization is still limited in the region, with most of the population engaged in rural and agricultural livelihoods.

Flooded Vegetation and Bare Ground cover 4.64 km^2 and 4.30 km^2, respectively. Flooded Vegetation includes areas periodically inundated with water, such as wetlands and riparian zones, which are vital for maintaining hydrological balance and supporting diverse aquatic and terrestrial species. Bare Ground represents areas with little to no vegetation cover, which may include exposed soils, rocky outcrops, and areas affected by erosion or land degradation.

Water bodies cover 4.28 km^2, including rivers, lakes, ponds, and other surface water features. The distribution of water bodies is essential for supporting domestic, agricultural, and industrial water needs, as well as maintaining ecological functions and biodiversity.

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

The Land Use and Land Cover (LULC) analysis for the study area in 2023, covering Ezza North, Ezza South, Abakalik, and Ikwo LGAs in Enugu State, southeastern Nigeria, presents significant changes compared to the LULC data from 2017. The updated LULC data, categorized into seven classes, are summarized in Table 4 and depicted in Figure 4.

Table 4 Land Use and Land Cover Distribution in 2023

LULC Type	Area (km^2)
Water	4.32
Trees	101.76
Flooded Vegetation	3.88
Crops	124.65
Built Area	66.54
Bare Ground	0.15
Rangeland	1329.08

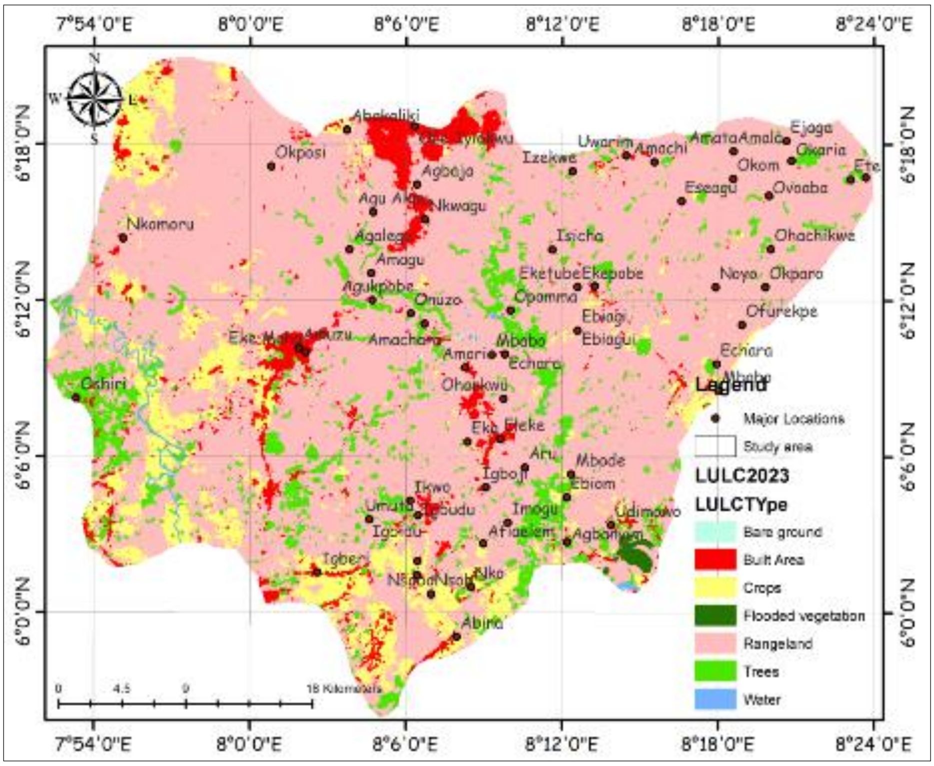

Figure 4 LULC Map of the Study Area in 2023

The analysis reveals noticeable changes in the distribution of LULC types over the six-year period. The most significant change is observed in the Built Area category, which increased substantially from 16.84 km^2 in 2017 to 66.54 km^2 in 2023. This increase reflects a rapid urbanization trend in the region, likely driven by population growth and economic development. The expansion of built areas has implications for land use planning, infrastructure development, and environmental management, as it often leads to increased pressure on natural resources and the environment (Rowland & Ebuka, 2024).

The area covered by Trees decreased significantly from 156.40 km^2 in 2017 to 101.76 km^2 in 2023. This reduction indicates a loss of forested areas, which could be attributed to deforestation, agricultural expansion, and urban encroachment. The loss of tree cover is concerning as it impacts biodiversity, carbon sequestration, and ecosystem services such as soil stabilization and water regulation. The conservation of remaining forested areas and reforestation initiatives are critical to mitigate these impacts (Lal, 2019).

Crops saw a notable increase from 90.80 km^2 in 2017 to 124.65 km^2 in 2023, indicating an expansion of agricultural activities. This expansion is likely due to increased demand for food production to support the growing population. While the increase in agricultural land can boost food security and local economies, it also poses challenges related to soil degradation, water resource management, and sustainable farming practices. Implementing sustainable agricultural practices, such as crop rotation, conservation tillage, and integrated pest management, is essential to balance productivity and environmental health (Patin et al., 2018).

Rangeland remains the dominant land cover type, although its area decreased slightly from 1353.11 km^2 in 2017 to 1329.08 km^2 in 2023. The reduction in rangeland area may be due to its conversion to other land uses, particularly agriculture and built-up areas. Sustainable management of rangelands is crucial to prevent overgrazing, land degradation, and biodiversity loss. Practices such as rotational grazing, pasture restoration, and agroforestry can enhance the resilience and productivity of rangelands.

The areas covered by Flooded Vegetation and Bare Ground also experienced changes. Flooded Vegetation decreased from 4.64 km^2 to 3.88 km^2, which might be due to changes in hydrological regimes, land use changes, or climate variability affecting wetland areas. Maintaining and restoring wetland ecosystems is vital for biodiversity, water purification, and flood mitigation. Bare Ground, significantly reduced from 4.30 km^2 to just 0.15 km^2, indicates either reclamation or re-vegetation efforts. While the reduction in bare ground is positive, it is essential to ensure that reclaimed areas are managed sustainably to prevent erosion and land degradation.

Water bodies showed a slight increase from 4.28 km^2 in 2017 to 4.32 km^2 in 2023. This stable water coverage is crucial for supporting domestic, agricultural, and industrial water needs, as well as maintaining ecological functions and biodiversity. Continued monitoring and management of water resources are necessary to ensure their sustainable use and to address any emerging challenges related to water quality and availability.

4.4. Implications of Changes in LULC between 2017 and 2023, and the Influence of Slope

The comparison of LULC data from 2017 and 2023 for Ezza North, Ezza South, Abakalik, and Ikwo LGAs in Enugu State, southeastern Nigeria, reveals significant shifts in land use and cover. These changes have profound implications for the region's environmental, economic, and social dynamics.

One of the most striking changes is the increase in built-up areas from 16.84 km^2 in 2017 to 66.54 km^2 in 2023. This expansion, likely driven by population growth and economic development, indicates a trend towards urbanization. The increase in urban areas typically leads to a higher demand for infrastructure, services, and housing. However, rapid urbanization can also bring about challenges such as inadequate waste management, increased air and water pollution, and higher demand for resources.

The expansion of built areas often comes at the expense of natural and agricultural lands, leading to habitat loss and fragmentation, which can severely impact biodiversity. Urbanization can also alter local climate conditions through the urban heat island effect, where increased concrete and asphalt surfaces lead to higher temperatures in urban areas compared to rural surroundings.

The area covered by trees decreased significantly from 156.40 km^2 in 2017 to 101.76 km^2 in 2023. This reduction suggests considerable deforestation, which is often driven by the need for agricultural land and urban development. The loss of forest cover can have several adverse effects, including reduced carbon sequestration capacity, leading to higher atmospheric CO_2 levels and contributing to climate change (Song et al., 2018). Deforestation can also lead to soil erosion, as tree roots that bind the soil are removed. This loss of soil structure can increase the susceptibility of the land to landslides, particularly on steeper slopes. Moreover, forests play a crucial role in regulating the hydrological cycle by facilitating groundwater recharge and maintaining stream flow. Their loss can result in altered hydrological regimes, potentially increasing the frequency and severity of floods and droughts (Scheidl et al., 2020).

Crops expanded from 90.80 km^2 in 2017 to 124.65 km^2 in 2023, reflecting an increase in agricultural activities. This expansion is essential for supporting the growing population and enhancing food security. However, agricultural expansion needs to be managed sustainably to prevent soil degradation, depletion of water resources, and loss of biodiversity. Sustainable agricultural practices, such as crop rotation, conservation tillage, and integrated pest management, are crucial to maintaining soil fertility and productivity. Agroforestry practices, which integrate trees and shrubs into agricultural landscapes, can help mitigate some negative impacts of agricultural expansion by enhancing biodiversity, improving soil health, and sequestering carbon (Ai et al., 2018).

Rangeland remains the dominant land cover type, although its area decreased slightly from 1353.11 km² in 2017 to 1329.08 km² in 2023. Rangelands are critical for pastoral activities and maintaining natural grasslands. However, their management is essential to prevent overgrazing, which can lead to soil degradation and loss of vegetation cover. Implementing sustainable grazing practices, such as rotational grazing and pasture restoration, can enhance the resilience and productivity of rangelands. These practices help maintain soil health, promote biodiversity, and support the livelihoods of local communities reliant on pastoralism.

The areas covered by Flooded Vegetation and Bare Ground experienced reductions. Flooded Vegetation decreased from 4.64 km² to 3.88 km², likely due to changes in hydrological regimes or land use. Wetlands are vital for maintaining hydrological balance, supporting diverse species, and providing ecosystem services such as water purification and flood mitigation. Their decline can reduce these benefits and increase the vulnerability of the region to floods and water shortages. Bare Ground reduced significantly from 4.30 km² to 0.15 km², indicating successful reclamation or re-vegetation efforts. While this reduction is positive, ensuring sustainable land management practices in these reclaimed areas is crucial to prevent erosion and maintain soil stability. Water bodies showed a slight increase from 4.28 km² in 2017 to 4.32 km² in 2023, which is essential for supporting domestic, agricultural, and industrial water needs. Proper management of these water resources is necessary to maintain their availability and quality.

The slope analysis of the study area, derived from the Digital Elevation Model (DEM), reveals a varied topography with significant implications for land use, soil erosion, and hydrological processes. The analysis shows that the majority of the area falls within the 2.09 to 3.64-degree slope range, covering 585.09 km². This is followed by the 0 to 1.54-degree range with 400.86 km², the 3.64 to 8.01-degree range with 380.61 km², and the 1.54 to 2.09-degree range with 249.06 km². The smallest area, 9.46 km², is within the steepest slope range of 8.01 to 20.27 degrees.

The gentle slopes (0 - 1.54 degrees) are predominantly found in the central and northeastern parts of the study area. These regions are primarily used for agriculture due to their relatively flat terrain and fertile soils. Gentle slopes are suitable for various agricultural activities, including crop cultivation and livestock grazing, as they minimize the risk of soil erosion and facilitate easier mechanization.

The moderate slopes (1.54 - 3.64 degrees) are also suitable for agriculture but may require soil conservation measures to prevent erosion. These areas are often used for terraced farming, which helps reduce soil loss and manage water runoff. Implementing soil conservation practices, such as contour plowing and the establishment of vegetative buffers, can enhance the sustainability of agricultural activities on moderate slopes.

The steep slopes (3.64 - 20.27 degrees), although covering a smaller area, are significant for their potential to impact hydrological processes and soil stability. These areas are more prone to erosion due to the higher gradient, which increases the velocity of water runoff. Land use on steep slopes should be carefully managed to prevent soil erosion, landslides, and degradation of water quality. Forested areas on steep slopes play a critical role in stabilizing the soil and reducing erosion. The loss of trees in these areas, as observed in the LULC changes, can exacerbate erosion and increase the risk of landslides. Reforestation and the maintenance of vegetation cover are essential strategies for mitigating these risks and ensuring slope stability.

The varied topography of the study area also influences hydrological processes. Steep slopes contribute to faster runoff, which can lead to flash floods and reduced groundwater recharge. Conversely, gentle slopes promote infiltration and groundwater recharge, supporting the availability of water resources. Effective watershed management practices, such as the construction of check dams and the restoration of riparian buffers, can help regulate water flow, reduce erosion, and enhance groundwater recharge. These practices are vital for maintaining the hydrological balance and ensuring sustainable water resources in the region.

5. Conclusion

One of the most striking changes is the increase in built-up areas from 16.84 km² in 2017 to 66.54 km² in 2023. This expansion, likely driven by population growth and economic development, indicates a trend towards urbanization. The increase in urban areas typically leads to a higher demand for infrastructure, services, and housing. However, rapid urbanization can also bring about challenges such as inadequate waste management, increased air and water pollution, and higher demand for resources. The expansion of built areas often comes at the expense of natural and agricultural lands, leading to habitat loss and fragmentation, which can severely impact biodiversity. Urbanization can also alter local climate conditions through the urban heat island effect, where increased concrete and asphalt surfaces lead to higher temperatures in urban areas compared to rural surroundings.

The area covered by trees decreased significantly from 156.40 km^2 in 2017 to 101.76 km^2 in 2023. This reduction suggests considerable deforestation, which is often driven by the need for agricultural land and urban development. The loss of forest cover can have several adverse effects, including reduced carbon sequestration capacity, leading to higher atmospheric CO_2 levels and contributing to climate change. Deforestation can also lead to soil erosion, as tree roots that bind the soil are removed. This loss of soil structure can increase the susceptibility of the land to landslides, particularly on steeper slopes. Moreover, forests play a crucial role in regulating the hydrological cycle by facilitating groundwater recharge and maintaining stream flow. Their loss can result in altered hydrological regimes, potentially increasing the frequency and severity of floods and droughts.

This expansion is essential for supporting the growing population and enhancing food security. However, agricultural expansion needs to be managed sustainably to prevent soil degradation, depletion of water resources, and loss of biodiversity. Sustainable agricultural practices, such as crop rotation, conservation tillage, and integrated pest management, are crucial to maintaining soil fertility and productivity. Implementing sustainable grazing practices, such as rotational grazing and pasture restoration, can enhance the resilience and productivity of rangelands. These practices help maintain soil health, promote biodiversity, and support the livelihoods of local communities reliant on pastoralism.

Wetlands are vital for maintaining hydrological balance, supporting diverse species, and providing ecosystem services such as water purification and flood mitigation. Their decline can reduce these benefits and increase the vulnerability of the region to floods and water shortages. Bare Ground reduced significantly from 4.30 km^2 to 0.15 km^2, indicating successful reclamation or re-vegetation efforts. While this reduction is positive, ensuring sustainable land management practices in these reclaimed areas is crucial to prevent erosion and maintain soil stability. Water bodies showed a slight increase from 4.28 km^2 in 2017 to 4.32 km^2 in 2023, which is essential for supporting domestic, agricultural, and industrial water needs. Proper management of these water resources is necessary to maintain their availability and quality.

The gentle slopes (0 - 1.54 degrees) are predominantly found in the central and northeastern parts of the study area. These regions are primarily used for agriculture due to their relatively flat terrain and fertile soils. Gentle slopes are suitable for various agricultural activities, including crop cultivation and livestock grazing, as they minimize the risk of soil erosion and facilitate easier mechanization. The moderate slopes (1.54 - 3.64 degrees) are also suitable for agriculture but may require soil conservation measures to prevent erosion. These areas are often used for terraced farming, which helps reduce soil loss and manage water runoff. Implementing soil conservation practices, such as contour plowing and the establishment of vegetative buffers, can enhance the sustainability of agricultural activities on moderate slopes. The steep slopes (3.64 - 20.27 degrees), although covering a smaller area, are significant for their potential to impact hydrological processes and soil stability. These areas are more prone to erosion due to the higher gradient, which increases the velocity of water runoff. Land use on steep slopes should be carefully managed to prevent soil erosion, landslides, and degradation of water quality. Forested areas on steep slopes play a critical role in stabilizing the soil and reducing erosion. The loss of trees in these areas, as observed in the LULC changes, can exacerbate erosion and increase the risk of landslides. Reforestation and the maintenance of vegetation cover are essential strategies for mitigating these risks and ensuring slope stability.

The varied topography of the study area also influences hydrological processes. Steep slopes contribute to faster runoff, which can lead to flash floods and reduced groundwater recharge. Conversely, gentle slopes promote infiltration and groundwater recharge, supporting the availability of water resources. Effective watershed management practices, such as the construction of check dams and the restoration of riparian buffers, can help regulate water flow, reduce erosion, and enhance groundwater recharge. These practices are vital for maintaining the hydrological balance and ensuring sustainable water resources in the region.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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