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Original Article

Geospatial Analysis of Topography, Hydrology, and Land Use Dynamics in Owerri and Environs Region, Southeastern Nigeria

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Abstract - *The landscape of Ikeduru, Mbaitoli, Owerri Municipal, Owerri North, and Owerri West in Imo State, Nigeria, exhibits distinct topographical features ranging from gentle to steep slopes and varied drainage patterns. These traits influence land use patterns, hydrological processes, and environmental vulnerabilities. Understanding these dynamics is vital for sustainable land management and development in the region. This study intends to examine the topographical features, hydrological characteristics, and land use dynamics of the selected LGAs in Imo State, Nigeria, utilising slope analysis, drainage density evaluation, and land use/land cover change analysis. The study intends to provide insights into environmental vulnerabilities, identify places prone to erosion and flooding, and propose options for sustainable land use planning. The study indicated that the bulk of the studied region has gentle slopes (0-2.69 degrees), supporting agricultural operations and urban expansion but also increasing susceptibility to flooding. Steeper slopes (>4.22 degrees) are limited and prone to erosion and landslides, particularly in the southern and western portions. Drainage density research found moderate to very high-density zones influencing runoff management and erosion hazards. LULC study found significant declines in tree cover and increases in built-up areas between 2017 and 2023, demonstrating fast urbanization and its accompanying environmental implications. These findings underline the necessity for appropriate land management strategies to prevent erosion, flooding, and other environmental dangers. Strategies such as soil conservation measures, afforestation, and enhanced drainage systems are advised to support sustainable development and resilience in the researched LGAs. This study presents a complete assessment of the topographical, hydrological, and land use characteristics of Ikeduru, Mbaitoli, Owerri Municipal, Owerri North, and Owerri West in Imo State, Nigeria. The findings illustrate the changing nature of the landscape, underlining the significance of integrated land use planning and environmental protection methods. By recognising and managing these processes, policymakers and stakeholders can work towards sustainable development goals while conserving natural resources and avoiding environmental threats. By combining these methodologies, the study gives a complete knowledge of landscape dynamics and their implications for sustainable land management. The insights collected led to the creation of targeted strategies for managing environmental risks and fostering resilience in the face of urbanization and climate change consequences in Imo State, Nigeria.*

Keywords - *Drainage density, Hydrological network, Land cover change, Soil conservation.*

1. Introduction

Hydrological processes are greatly influenced by terrain or the physical features of the landscape [1]. The way water travels across and through the landscape is determined by the terrain's shape, slope, elevation, and aspect, which has an impact on surface runoff, infiltration, and groundwater recharge [2, 3]. Faster runoff from steeper slopes usually reduces the possibility of water infiltration and increases the risk of erosion and sediment transfer. On the other hand, areas that are level or have a gentle slope allow water to seep in and create wetlands and floodplains, which are essential for replenishing groundwater and preserving biological equilibrium [4]. The topography of Imo State, which ranges from steep uplands to level lowlands, affects the hydrological features of the area. The hilly regions of the state, which are primarily in the north and east, are characterised by high runoff and low infiltration, which frequently results in problems with erosion and sedimentation [5]. The state's lowland areas, especially those in the south and west, have greater rates of infiltration and are more likely to flood, especially during the rainy season. Changes in Land Use and Land Cover (LULC) have a significant effect on hydrological features. By changing surface runoff, groundwater, and evapotranspiration rates, vegetation cover, urbanisation, agriculture, and deforestation affect the natural hydrological cycle [6]. While urban areas, with their impermeable surfaces such as buildings and highways, increase runoff and decrease infiltration, forests and other vegetation often improve water infiltration and decrease surface runoff. Rapid agricultural and urbanisation growth in Imo State has drastically changed the area's natural LULC, which has an effect on the hydrology of the state. The process of transforming wetlands and forests into agricultural and urban areas has raised the risk of erosion and flooding, decreased infiltration, and increased surface runoff. Extensive land clearing and the use of agrochemicals are part of agricultural practices, especially in the state's central and northern regions. These activities have an impact on the quality of the soil and water [7, 8]. The expansion of impermeable surfaces brought about by the emergence of urban centres such as Owerri has intensified urban flooding and changed natural drainage patterns.

Geographic Information Systems (GIS) and Remote Sensing (RS) have become indispensable instruments for studying and controlling topography and hydrological features. RS entails the use of satellite or aircraft sensors to gather data on the Earth's surface over wide geographic and temporal scales, resulting in spatially continuous data. In contrast, GIS provides a framework for organising, evaluating, and displaying spatial data that makes it easier to integrate different data sources and create intricate maps and models [9].

For terrain study, RS and GIS are especially useful because they make it possible to create Digital Elevation Models (DEMs), which are essential for comprehending topography and how it affects hydrological processes. For the purpose of simulating surface runoff, erosion, and sediment movement, complete information on elevation, slope, and aspect is provided by DEMs [10]. RS data—such as multispectral and hyperspectral imagery—can be utilised in hydrological studies to track changes in soil moisture, vegetation health, and LULC, offering insights into the ways in which these variables influence hydrological features. Imo State's hydrological difficulties have been assessed and managed in large part thanks to the application of RS and GIS. Satellite imaging has been used in studies to map changes in LULC, track deforestation, and assess urban growth. This data is useful for hydrological modelling and water resource management [11]. Several geographic datasets, including soil maps, rainfall data, and DEMs, have been integrated using GIS to simulate surface runoff, identify flood-prone locations, and evaluate the danger of erosion. A thorough understanding of the spatiotemporal dynamics of topography and hydrological features is made possible by the combination of RS and GIS, which promotes sustainable land and water management techniques and well-informed decision-making. The significance of terrain analysis in comprehending hydrological processes has been emphasised in earlier research. Using DEMs to model surface runoff and soil erosion, Lu et al. [12] highlighted the impact of topography on these processes. Comegna et al. [13] provided evidence on the impact of elevation and slope on hydrological responses, specifically with the generation of runoff and erosion potential. In their discussion of the value of level ground in facilitating water penetration and groundwater recharge, Asiwaju-Bello et al. [14] emphasised the wetlands and floodplains' ecological relevance.

The effects of LULC on hydrology have also been the subject of much research. In their investigation of the effects of land conversion and deforestation on the hydrological cycle, Lopes et al. [15] focused on modifications to runoff, groundwater recharge, and evapotranspiration. The hydrological impacts of urbanisation were examined by De Albuquerque et al. [16], with a focus on the rise in impermeable surfaces and the ensuing effects on infiltration and runoff. According to Ukpai et al. [17], Imo State's urbanisation and agricultural practices have changed the hydrology of the area, causing problems with water quality, erosion, and sedimentation.

It is commonly known that RS and GIS are used in hydrological investigations. A review of RS technologies and their uses in environmental monitoring, including hydrology, was given by Olalekan et al. [18]. Falebita et al. [19] discuss how GIS may be used to manage and analyse spatial data, with a focus on how it can integrate different datasets to provide a whole environmental analysis. In order to comprehend hydrological processes related to topography, Chymyrov [20] emphasised the use of DEMs in terrain study and hydrological modelling. Egbueri and Igwe [21] discuss how to monitor vegetation and soil moisture using RS data, and they also show how these elements affect hydrology.

Studies by Okoli et al. [22] and Akaolisa et al. [23] in the context of Imo State have shown the value of RS and GIS in evaluating LULC changes and their hydrological ramifications. This research has produced useful information for managing water resources, detecting flood-prone areas, and modelling surface runoff. A thorough understanding of the spatiotemporal dynamics of the region's topography and hydrological features has been made possible by the combination of RS and GIS, supporting well-informed decision-making and sustainable management techniques.

In Southeastern Nigeria, there is a gap in the full understanding of topography, hydrology, and land use dynamics in Owerri and its environs, despite major developments in geospatial technologies. Previous research has looked at the implications of land use changes on water resources [6] and the effects of terrain on hydrological processes [1, 2, 3]. Nevertheless, there aren't many integrated studies that use GIS and RS to combine these elements. Understanding the dynamics of the environment and the management of water resources in Owerri, a rapidly urbanising context, is severely lacking due to the lack of research on the linkages between topography, land use changes, and hydrology.

Rapid urbanisation and agricultural growth in Owerri and the adjacent areas have resulted in notable changes to the patterns of land use. These alterations have an impact on hydrological processes such as surface runoff, infiltration, and groundwater recharge, together with the area's variable topography. Nevertheless, a thorough understanding of these intricate connections is hampered by a lack of integrated geospatial analysis. By applying RS and GIS technologies to examine the spatiotemporal dynamics of topography, hydrological, and land use changes in Owerri and its surroundings, this study seeks to close this gap. The results will offer vital information for the sustainable management of the region's water and land resources.

RS and GIS-based spatiotemporal analysis of topography and hydrological features provides a holistic framework for comprehending and controlling the intricate relationships between land and water resources. This strategy is especially beneficial in Imo State, Nigeria, due to the variety of land uses and hydrological issues that are present there. This project intends to promote sustainable land and water management practices by providing extensive insights into the region's terrain and hydrological dynamics by utilising the capabilities of RS and GIS [24]. The results of this study will add to the body of information regarding the interactions among hydrological features, terrain, and LULC changes, which will help shape environmental management policy and decision-making processes. Using remote sensing and GIS technology, this study aims to examine the changes in land use and cover over a six-year period in selected Local Government Areas (LGAs) of Imo State, Nigeria, as well as the spatial distribution of slope and drainage density. In order to facilitate efficient land management and planning, this study will evaluate the geological and environmental effects of these changes.

2. Location and Geology of Study Area

The study area encompasses five regions within Imo State, Nigeria: Ikeduru, Mbaitoli, Owerri Municipal, Owerri North, and Owerri West. These regions are part of the southeastern part of Nigeria, characterized by a mix of urban, peri-urban, and rural settings. The geographical coordinates of the study area range approximately from latitude 5°22'30"N to 5°36'15"N and longitude 6°50'00"E to 7°08'45"E.Ikeduru is located in the central part of Imo State, bordered by Mbaitoli to the south and Owerri North to the west. This area features a mix of agricultural land, forests, and emerging urban areas. Mbaitoli lies to the southwest of Owerri Municipal and borders Ikeduru to the north. It is predominantly agricultural, with significant areas dedicated to farming and rural settlements. Owerri Municipal, the heart of Imo State, serves as the administrative and commercial hub [23]. It is highly urbanized, with extensive infrastructure, commercial establishments, and residential areas. Owerri North, located north of Owerri Municipal, combines urban and rural characteristics with growing residential developments and agricultural land. Owerri West, positioned to the west of Owerri Municipal, features a blend of peri-urban and rural landscapes, including agricultural activities and expanding residential zones [23]. The location map of the study area is depicted in Figure 1, which includes Figure 1a (map of Nigeria), Figure 1b (map of Imo State), and Figure 1c (DEM of the study area).

The geology of the study area in Imo State is defined by a combination of sedimentary formations, tectonic features, and stratigraphic sequences that have evolved over geological time. The region's geology influences its terrain, hydrological characteristics, and land use patterns, making it crucial for understanding the spatiotemporal dynamics of the area. The tectonic history of this basin is closely linked to the opening of the South Atlantic Ocean and the breakup of the Gondwana supercontinent during the Cretaceous period [22]. The basin's development involved several tectonic phases, including rifting, subsidence, and sedimentation.

The primary tectonic features influencing the Imo State include the Benue Trough and the Anambra Basin. The Benue Trough, an intracontinental rift, extends in a northeast-southwest direction and plays a crucial role in regional tectonics. The Anambra Basin, to the northwest of the study area, is a subsiding basin that has accumulated significant sedimentary deposits over time [25]. The tectonic activity in the region has led to the formation of several fault systems and structural features. These tectonic processes have influenced the deposition and deformation of sedimentary layers, contributing to the complex geological framework of Imo State [26].

The stratigraphy of Imo State consists of a sequence of sedimentary formations ranging from the Cretaceous to the Tertiary periods. The major stratigraphic units in the study area include the Nkporo Formation, which represents the oldest sedimentary unit in the study area, dating back to the Late Cretaceous. It consists primarily of shales, sandstones, and siltstones deposited in a marine environment [27]. Overlying the Nkporo Formation is the Mamu Formation, characterized by alternating layers of sandstones, shales, and coal beds. This unit was deposited in a deltaic to shallow marine environment during the Maastrichtian stage of the Late Cretaceous. The Ajali Sandstone is a prominent stratigraphic unit composed mainly of coarse-grained sandstones with minor shale interbeds deposited in a fluvial to deltaic environment during the Maastrichtian stage.

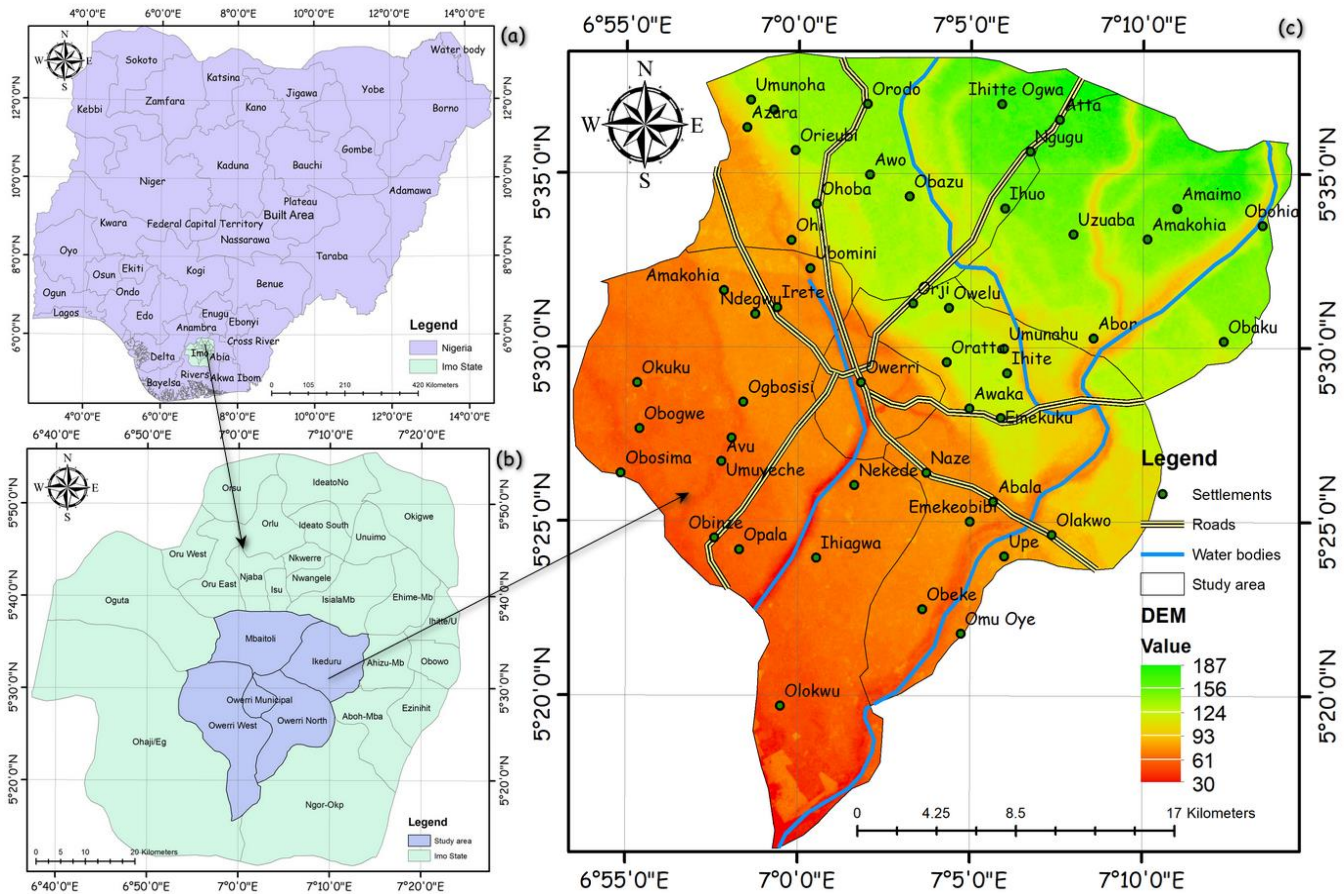

Fig. 1 Map of DEM of the study area with Imo state and Nigeria

The Nsukka Formation consists of sandstones, shales, and coal beds, representing a transition from deltaic to shallow marine depositional environments during the Paleocene [28]. Overlying the Nsukka Formation is the Imo Shale, predominantly composed of dark gray to black shales with minor sandstones and siltstones, deposited in a marine environment during the Paleocene to Eocene. The Ameki Formation consists of sandstones, shales, and limestones, representing a mix of marine and continental depositional environments during the Eocene. Lastly, the Ogwashi-Asaba Formation is characterized by lignites, clays, and sands, representing a transition from marine to continental environments during the Oligocene to Miocene [29].

These stratigraphic units reflect the complex depositional history of the region, influenced by changes in sea level, tectonics, and sediment supply. The geology map of Imo State, shown in Figure 2, illustrates the distribution of these stratigraphic units and tectonic features. This map provides a visual representation of the geological framework, highlighting the spatial relationships between different formations and structural elements.The geology of the study area has significant implications for its terrain and hydrological characteristics. The varying lithology and structural features influence the topography, soil properties, and drainage patterns, affecting surface runoff, infiltration, and groundwater recharge. For instance, the sandy formations, such as the Ajali Sandstone, typically exhibit higher permeability and porosity, facilitating groundwater recharge and influencing the distribution of aquifers [21]. Conversely, the shale-dominated formations, like the Imo Shale, tend to have lower permeability, affecting surface runoff and contributing to the formation of wetlands and floodplains. The tectonic features, including faults and folds, also play a crucial role in controlling groundwater flow and the distribution of aquifers. These structural elements can act as barriers or conduits for groundwater movement, influencing the hydrological characteristics of the region.

3. Materials and Methods

3.1. Data Acquisition

This study aims to analyze the spatial distribution of slope and drainage density, along with the LULC changes over six years in selected LGAs of Imo State, Nigeria, using 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.

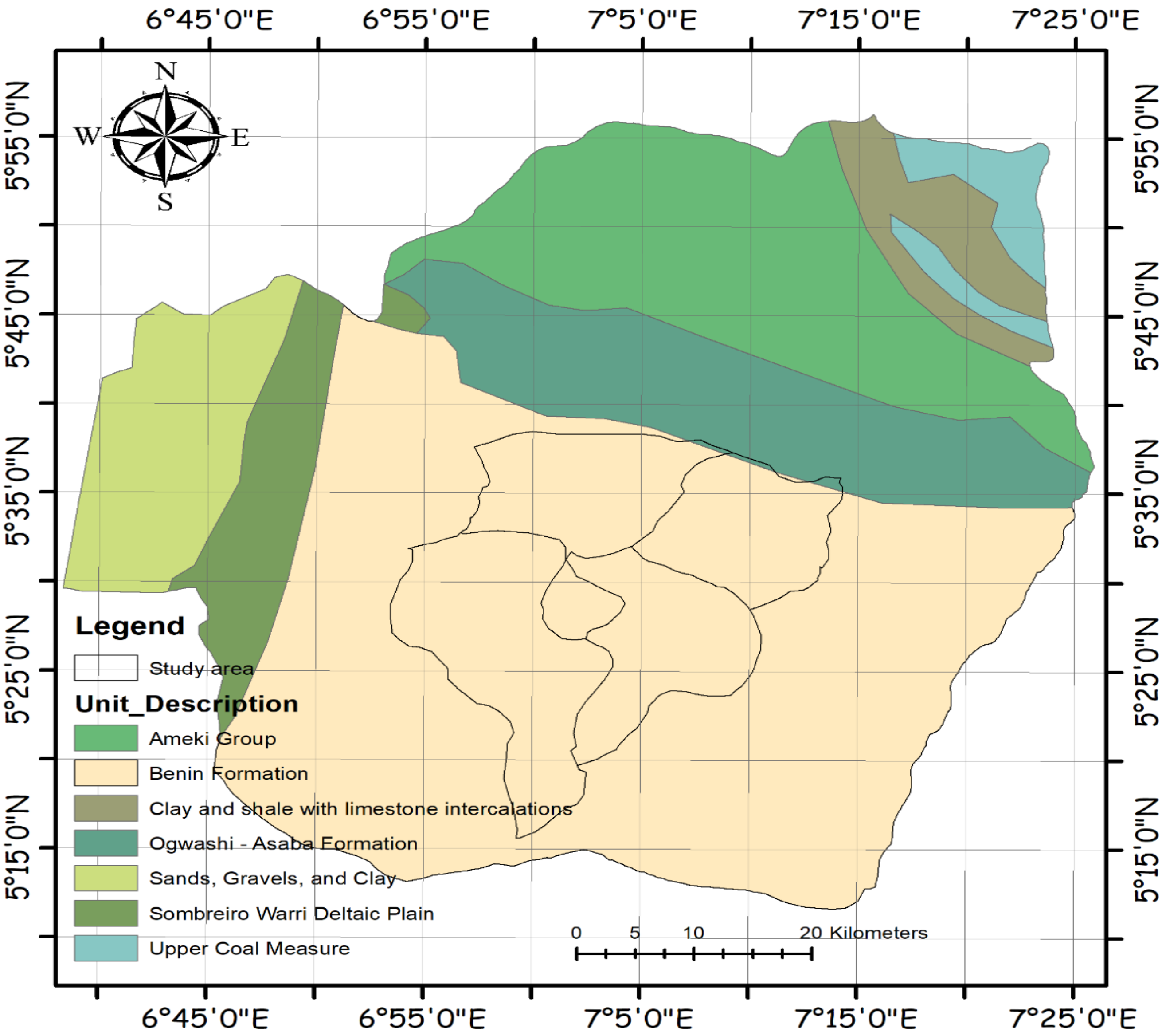

Fig. 2 Geology of Imo state

Table 1. Data type and source used

Data Type	Source
Satellite Imagery	Earth Explorer
LULC Data	Earth Explorer
SRTM Elevation Data	Earth Explorer

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 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, such as vegetation, water, and urban areas, were meticulously collected. A maximum likelihood classifier, known for its statistical robustness, was then applied to classify the images [30]. This classifier assigns each pixel to the class with the highest probability based on the statistical distribution of the training samples. The classification accuracy was rigorously assessed using ground truth data, which involved collecting real-world observations that correspond to the satellite imagery. Accuracy metrics such as the Kappa coefficient, overall accuracy, producer's accuracy, and user's accuracy were utilized to evaluate the performance of the classification. The Kappa coefficient, in particular, provides a measure of agreement between the classified image and the ground truth data, correcting for the agreement that could occur by chance [30]. High Kappa values indicate a strong agreement, suggesting the classification process was successful in accurately depicting the LULC categories. This comprehensive approach ensures that the classified images are reliable for subsequent analysis and applications in environmental monitoring and resource management.

3.2.2. DEM Processing

The SRTM DEM data were processed to derive slope and drainage density using ArcGIS. Slope calculation was performed with the slope tool, which determines the maximum rate of elevation change for each DEM cell [31]. Drainage density was derived by delineating the drainage network from the DEM using the hydrology toolset in ArcGIS. This process involved computing flow direction, flow accumulation, and stream network delineation. By analyzing these parameters, researchers can better understand the terrain's influence on hydrological processes and water resource management.

3.2.3. Change Detection

A change detection analysis was performed to analyze the changes in LULC over the six-year period. The classified LULC maps for 2017 and 2023 were compared using post-classification comparison techniques [32]. This method involves overlaying the LULC maps from both years and identifying areas of change. The differences in the extent of each land cover type between 2017 and 2023 were quantified to determine the specific changes in LULC. This comparison allows for a detailed assessment of how urbanization, deforestation, and other land use activities have altered the landscape over time, providing essential data for environmental management and planning.

3.3. Data Analysis

The data analysis phase integrated processed data to assess the spatial distribution of slope, drainage density, and LULC changes, along with their geological and environmental impacts. Analytical techniques and equations, such as slope gradient analysis, drainage density calculations, and LULC change detection, were employed. This integration facilitated a comprehensive understanding of the terrain's influence on hydrological processes and land use dynamics. The findings provided insights into how these factors interact to affect erosion, water infiltration, and environmental sustainability, supporting effective land management and planning.

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:

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

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. Once determined, the slope data were divided into many categories, such as flat, gentle, moderate, and high. These classifications are essential for analysing the distribution of different slope classes across the study area. For instance, flat terrain (0^o – 5^o) is generally good for agricultural and urban development, while steep locations (>30^o) may pose obstacles for construction and are prone to erosion.

The categorized slope data offer useful insights for land use planning, soil erosion risk, and watershed management. By recognising the terrain's features, decision-makers can implement suitable strategies for sustainable land management, ensuring the effective use of resources and minimizing environmental damage. This slope analysis is vital for the study area's full terrain appraisal, influencing numerous areas of development and conservation initiatives.

3.3.2. Drainage Density Analysis

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

$$D_d = \frac{L}{A} \tag{2}$$

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. A landscape that has a high drainage density and a high potential for surface runoff and erosion is characterised by this potential. In places that have rock or impermeable soil, scant vegetation, and steep slopes, this phenomenon is frequently observed. Such locations are particularly prone to flash floods and soil erosion due to the rapid movement of water across the surface. Conversely, low drainage density means better infiltration and groundwater recharge. This generally occurs in regions with permeable soil or rock, lush vegetation, and mild slopes. These conditions favor the percolation of water into the ground, boosting the availability of groundwater resources. Understanding drainage density is crucial for good watershed management, flood risk assessment, and soil conservation methods. High drainage density locations may require erosion control techniques and careful land use planning to limit runoff consequences. In contrast, low drainage density areas might focus on conserving recharge zones to sustain groundwater levels. This research aids in making educated decisions for sustainable water resource management and land development.

3.4. 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:

$$\Delta LULC = LULC_{2023} - LULC_{2017} \quad (3)$$

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. Through the utilisation of maps and data summaries, the alterations in land use and land cover were visualised, which enabled the discovery of patterns and trends in land use dynamics. For instance, a growth in the number of urban areas or agricultural land could be an indication of advancements in economic development or changes in the methods of land management. On the other hand, decreases in the amount of land covered by forests may indicate deforestation or the deterioration of land. The mapping of these changes serves to highlight the spatial distribution of land cover transformations as well as the magnitude of these changes. The statistical summaries provide supplementary insights into the percentage changes as well as the absolute areas that were impacted. The results of this research are essential for gaining an understanding of the effects that human activities have on the landscape and for developing strategies for the sustainable management of land. Examining changes in LULC allows policymakers and other stakeholders to have a better understanding of the environmental implications of these changes, which in turn helps them make decisions regarding urban planning, conservation, and resource management in order to guarantee that development is both balanced and sustainable.

3.5. Geological and Environmental Impact Assessment

The impacts of slope, drainage density, and LULC changes on the geology and environment were assessed by integrating spatial data using RS and GIS. Areas with steep slopes and high drainage density were identified as prone to erosion and landslides due to the increased velocity of surface runoff and reduced infiltration capacity. These geomorphological features exacerbate soil erosion and sediment transport, posing significant risks to the stability of the terrain and contributing to land degradation [33]. Changes in LULC were closely correlated with alterations in hydrological patterns. Urbanized areas showed increased surface runoff due to the proliferation of impervious surfaces, such as roads and buildings, which impede water infiltration. Conversely, deforested regions exhibited reduced infiltration, further disrupting natural water cycles and increasing the likelihood of flash floods and soil erosion [32].

The study highlighted how agricultural expansion, particularly in previously forested areas, led to habitat loss, soil degradation, and a decline in water quality, impacting local biodiversity and ecosystem services. The integration of RS and GIS technologies enabled a comprehensive analysis of the spatial distribution of slope, drainage density, and LULC changes in the selected LGAs of Imo State. By overlaying DEM data with LULC maps, researchers could identify critical areas requiring intervention to mitigate environmental degradation. This approach provided detailed insights into the environmental consequences of land use changes, such as the fragmentation of habitats, the increase in sediment load in water bodies, and the subsequent impact on water quality.The findings from this study will inform effective land management and planning strategies aimed at mitigating geological and environmental impacts.

By understanding the spatial dynamics of these factors, policymakers can develop targeted interventions to promote sustainable development, protect natural resources, and enhance the resilience of the region's ecosystems. This research underscores the importance of integrating geospatial technologies in environmental monitoring and resource management to address the challenges posed by rapid urbanization and land use changes.

4. Results and Discussion

4.1. Slope Analysis

The slope analysis of the study area revealed a varied topography with slopes ranging from 0 to 18.56 degrees. The distribution of slope classes across the study area is shown in Table 2, while the slope map is depicted in Figure 3. The majority of the study area has gentle slopes, with slopes ranging from 0 to 2.69 degrees, covering 84% of the total area. Steeper slopes, greater than 4.22 degrees, are limited and account for less than 6% of the total area.

Table 2. Slope distribution in the study area

Slope (degrees)	Area (Km²)
0 - 1.45	311.4119
1.45 - 2.69	328.3046
2.69 - 4.22	176.8251
4.22 - 6.55	70.2895
6.55 - 18.56	14.3838

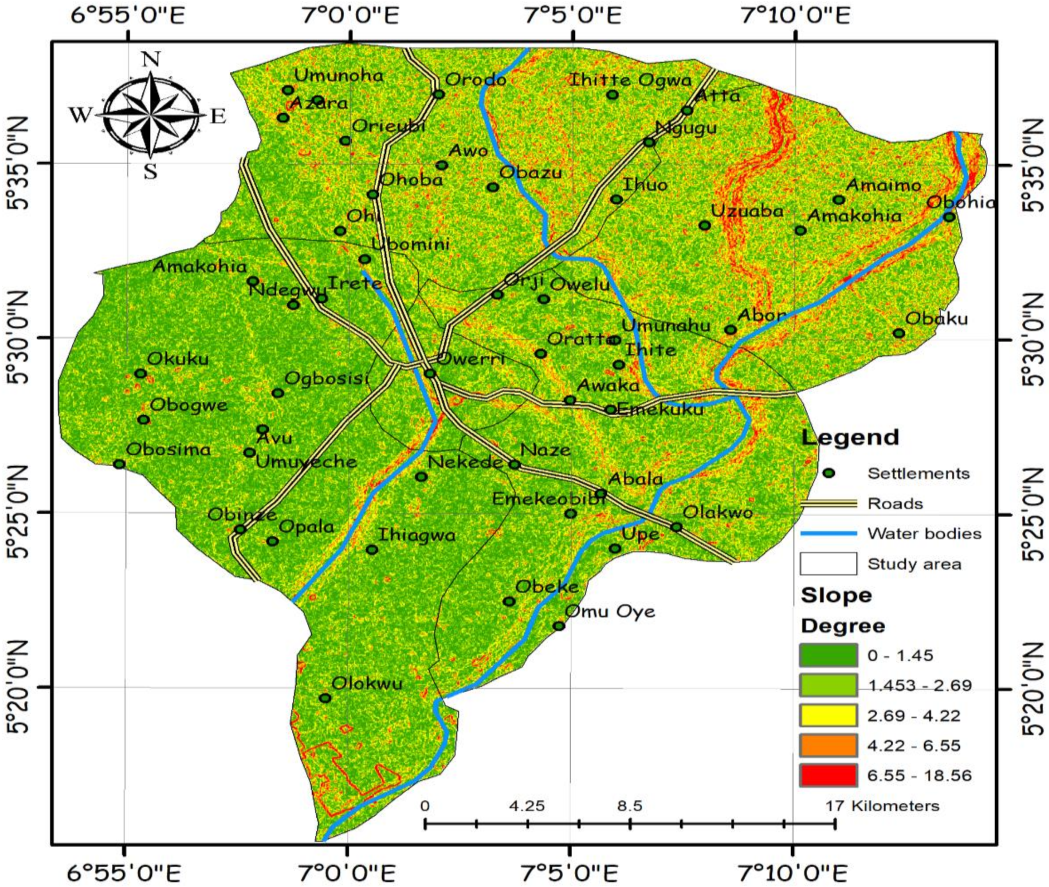

Fig. 3 Map of the slope of the study area

The gentle slopes (0 - 2.69 degrees) predominantly cover the central and northern parts of the study area, which are primarily used for agricultural activities and urban development. The relatively flat terrain in these regions facilitates construction and farming but also increases susceptibility to flooding and waterlogging, especially during heavy rainfall. Conversely, the steeper slopes (greater than 4.22 degrees) are mainly found in the southern and western parts of the study area.

These areas are more prone to erosion and landslides, particularly during the rainy season. The predominance of gentle slopes in the central and northern regions supports the extensive agricultural activities and urban development observed. However, the susceptibility to flooding and waterlogging in these areas highlights the need for effective water management practices [34].

Implementing proper drainage systems and flood control measures will be essential to mitigate these risks. In contrast, the steeper slopes in the southern and western parts of the study area necessitate soil conservation measures to prevent erosion and landslides [35]. Afforestation and the construction of retaining walls can help stabilize these areas and reduce the risk of environmental hazards.

4.2. Drainage Density Analysis

The drainage density analysis of the study area revealed a complex and varied hydrological network indicative of diverse terrain and land cover characteristics. The distribution of drainage density across the study area is presented in Table 3, and the drainage density map is shown in Figure 4.

The majority of the study area falls within the moderate drainage density classes (53.10 - 159.32 km/km²), covering approximately 62% of the total area. These regions are characterized by a well-defined drainage network that facilitates effective runoff management and reduces the risk of flooding. However, the areas with very high drainage density (212.42 - 265.53 km/km²), although limited in extent, are critical as they indicate regions with steep slopes and high potential for erosion and rapid surface runoff.

Table 3. Drainage Density Distribution in the Study Area

Drainage Density (km/km²)	Area (km²)
0 - 53.10	134.2915
53.10 - 106.21	247.4317
106.21 - 159.32	277.2614
159.32 - 212.42	185.7404
212.42 - 265.53	60.2967

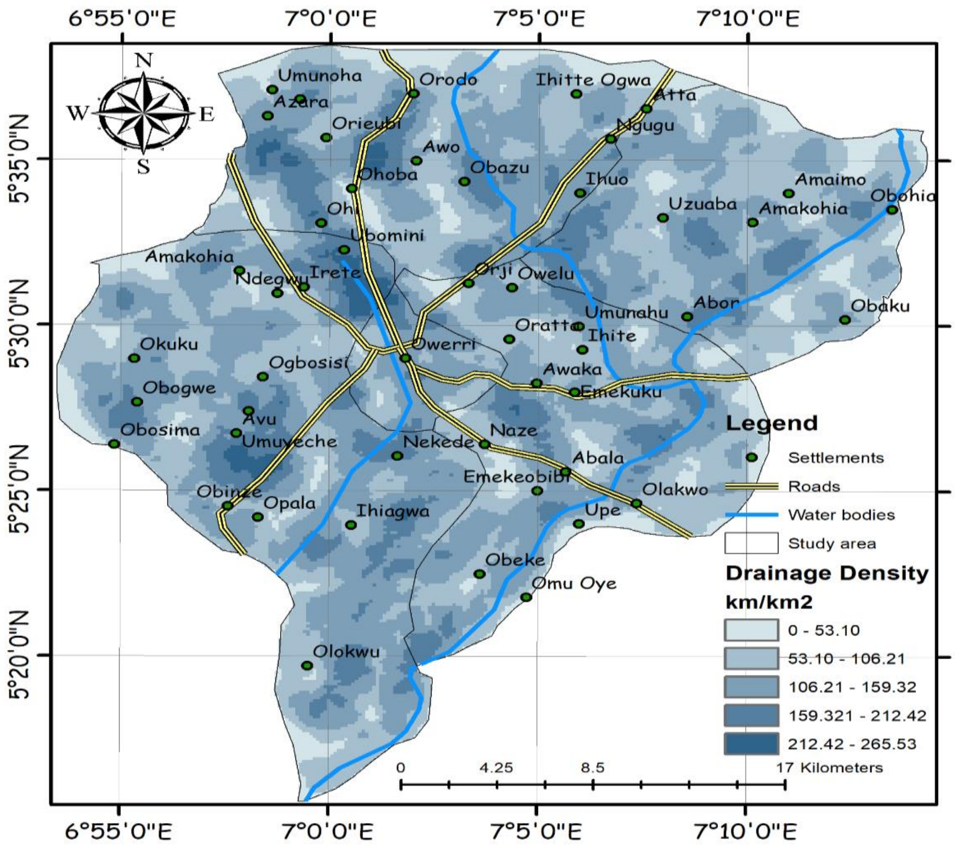

Fig. 4 Map of drainage density of the study area

Areas with low drainage density (0 - 53.10 km/km²) are predominantly flat or gently sloping regions, which are more prone to waterlogging and slower drainage. These areas are typically suitable for agricultural activities due to the availability of water and flat terrain. However, they may require effective drainage management to prevent crop damage from prolonged waterlogging.

The moderate drainage density zones (53.10 - 159.32 km/km²) strike a balance between surface runoff and infiltration, making them ideal for a mix of land uses, including agriculture, urban development, and forest cover. These regions benefit from moderate slopes that support both natural and managed drainage systems. High drainage density areas (159.32 - 212.42 km/km²) are often associated with steeper terrains, which are more susceptible to soil erosion and landslides, especially during heavy rainfall events. Proper soil conservation measures and vegetation cover are essential in these areas to mitigate the impacts of erosion. Very high drainage density zones (212.42 - 265.53 km/km²) are typically found in the most rugged parts of the study area.

These regions have a dense network of streams and rivers, leading to rapid runoff and significant erosion potential. These areas are less suitable for agriculture or urban development without substantial soil conservation and erosion control measures. The drainage density analysis provides crucial insights into the hydrological behavior of the study area. Understanding the distribution of drainage density helps in identifying regions that require specific management practices to mitigate environmental risks such as erosion, landslides, and waterlogging [11, 36]. By integrating drainage density data with slope and land use/land cover information, effective land management strategies can be developed to promote sustainable development in the selected LGAs of Imo State, Nigeria.

4.3. LULC Analysis for 2017

The LULC analysis for the year 2017 provides a comprehensive understanding of the distribution and extent of various land cover types within the study area. The distribution of LULC types is summarized in Table 4, while the LULC map for 2017 is shown in Figure 5.

Table 4. LULC distribution in the study area (2017)

LULC Type 2017	Area (km²)
Water	2.872478
Trees	565.643467
Flooded Vegetation	1.844277
Crops	14.463834
Built Area	269.983987
Bare Ground	2.790668
Rangeland	47.599466

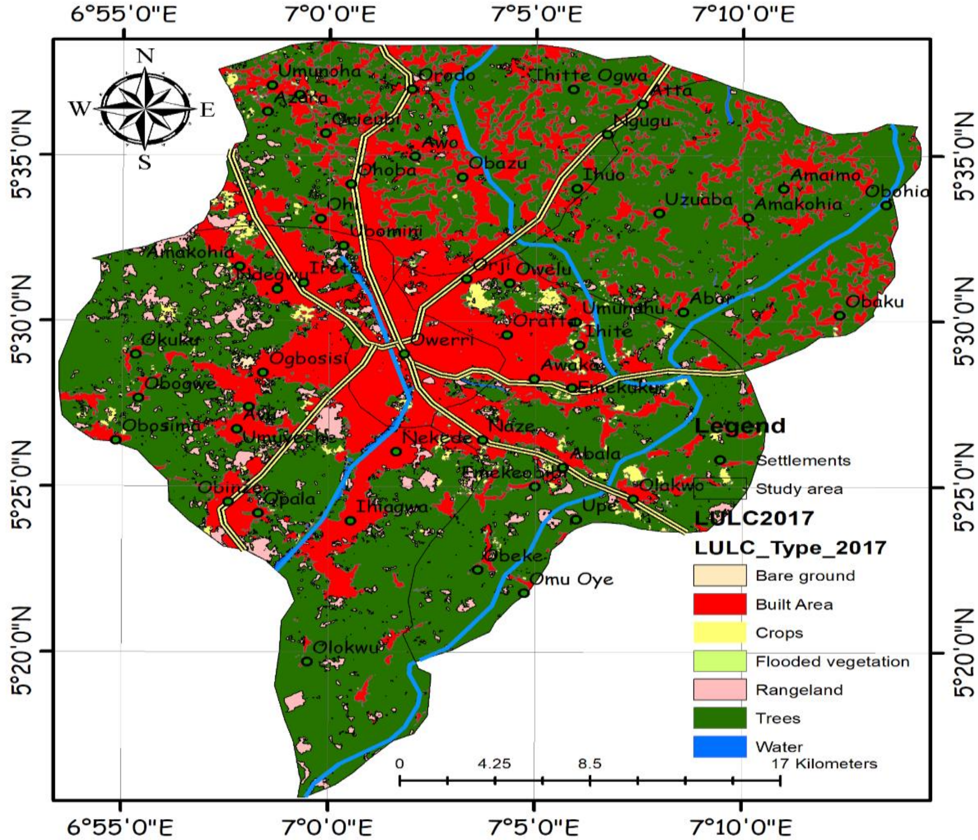

Fig. 4 LULC 2017 of the study area

The results indicate that tree cover is the predominant land cover type, accounting for approximately 565.64 km², which is a significant portion of the study area. Built-up areas are the second largest land cover type, covering 269.98 km². These areas include urban and peri-urban settlements, reflecting the extent of urbanization within the study area. Rangeland, primarily used for grazing and other extensive land uses, covers 47.60 km². Croplands, important for agricultural activities, occupy 14.46 km². Water bodies, flooded vegetation, and bare ground have relatively smaller extents, covering 2.87 km², 1.84 km², and 2.79 km², respectively.

The extensive tree cover of 565.64 km² within the research area highlights the presence of significant forested regions. These forests are crucial for preserving ecological equilibrium, biodiversity, and carbon sequestration. Forests play a crucial role in managing the local climate by lowering temperatures and sustaining humidity levels. They provide a home for a broad range of species, providing ecosystem functions such as water filtration and soil stabilization. The extensive tree cover works as a carbon sink, absorbing carbon dioxide from the atmosphere, which helps minimise the consequences of climate change. However, the huge presence of built-up regions, comprising 269.98 km², suggests significant urban expansion. This urbanization has important ramifications for land management and environmental sustainability. The rise in impermeable surfaces, such as roads and buildings, owing to urban expansion can exacerbate surface runoff. This not only limits groundwater recharge but also raises the risk of flooding. Moreover, urban areas often experience the urban heat island effect, where temperatures are greater than in adjacent rural areas due to human activity and infrastructure.

The comparatively tiny extent of cropland, which occupies 14.46 km², implies that agriculture, while present, is not the primary land use in the studied area. This has serious consequences for food security and rural livelihoods. Sustainable agricultural techniques are needed to optimize the utilisation of available land for crop production. Sustainable methods can assist in boosting agricultural yields and ensure long-term soil fertility, thereby improving food security and rural economies. Rangelands, comprising 47.60 km², are crucial for pastoral activity, providing grazing areas for animals. Effective management of these lands is necessary to prevent overgrazing, which can lead to soil degradation and desertification. Overgrazing reduces plant cover, exposing soil to erosion by wind and water, which in turn diminishes land productivity. Sustainable rangeland management strategies, such as rotational grazing and reseeding, can assist in sustaining the health of these ecosystems. Water bodies, occupying 2.87 km², and flooded vegetation, totalling 1.84 km², form vital aquatic habitats. These regions are crucial for water storage, flood management, and providing habitats for a range of aquatic organisms. Maintaining the health and integrity of water bodies is crucial for assuring the availability of water supplies and protecting biodiversity. Healthy aquatic ecosystems support fisheries, give recreational possibilities, and enhance the visual value of the environment.

The prevalence of bare terrain, covering 2.79 km², suggests areas devoid of significant vegetation cover. These locations are subject to erosion, land degradation, and diminished soil fertility. Bare land can occur from natural processes or human activity such as deforestation, overgrazing, or development. To offset these impacts, it is vital to employ soil conservation measures such as reforestation, erosion control structures, and sustainable land management methods. Understanding the spatial distribution and breadth of different land cover types provides useful insights into the land use dynamics and environmental conditions of the research area. The high amount of tree cover signifies a robust presence of natural vegetation, which is important for ecological stability. However, the vast extent of built-up regions underscores the issues associated with urban growth, such as habitat fragmentation, increasing pollution, and pressure on infrastructure and services. The analysis also underlines the necessity for integrated land use planning and management systems that balance the demands of urban development, agricultural productivity, and environmental conservation. Promoting sustainable agricultural methods, developing green infrastructure in urban areas, and implementing soil and water conservation measures can help alleviate the negative impacts of land use changes. Strategies such as these can increase ecological resilience, improve quality of life, and assure the sustainable use of natural resources. The LULC analysis for 2017 depicts a diversified terrain with significant forest cover, urban areas, and rangelands. These findings provide a baseline for monitoring future land use changes and assessing their impacts on the environment and local residents. By integrating LULC data with other spatial and environmental information, policymakers and land managers can make educated decisions to promote sustainable development and resilience in the study region. Such educated decision-making is vital for resolving the difficulties posed by urbanization and environmental change, ensuring that growth is balanced with the preservation of natural resources and ecosystem services.

4.4. LULC Analysis for 2023

The LULC analysis for the year 2023 reveals significant changes in the distribution and extent of various land cover types within the study area. The distribution of LULC types is summarized in Table 5, while the LULC map for 2023 is shown in Figure 6.

Table 5. LULC Distribution in the Study Area (2023)

LULC Type 2023	Area (km²)
Water	3.795949
Trees	440.382
Flooded Vegetation	0.153268
Crops	13.56778
Built Area	393.6246
Bare Ground	0.006444
Rangeland	53.67297

The area covered by trees has considerably dropped from 565.64 km² in 2017 to 440.38 km² in 2023. This loss in tree cover can be linked to deforestation and urban expansion. The decline in wooded areas has major implications for biodiversity, carbon sequestration, and ecosystem functions such as water management and soil stabilization. Forests are crucial habitats for a diverse range of species, and their removal can contribute to a decrease in biodiversity. Moreover, forests operate as large carbon sinks, absorbing carbon dioxide from the atmosphere and moderating climate change. The decline in forest cover undermines these functions, resulting in higher atmospheric carbon levels and aggravating climate change. Efforts to prevent deforestation and encourage regeneration are vital to maintaining ecological balance and assuring the sustainability of the region’s natural resources. Reforestation programs and policies that encourage sustainable land use practices are necessary to recover lost forest areas and increase their ecological services.

The area classed as built-up has expanded considerably from 269.98 km² in 2017 to 393.62 km² in 2023. This increase is suggestive of fast urbanization and infrastructure development. While urban growth can encourage economic development by providing housing, jobs, and services, it also offers significant environmental difficulties. Increased surface runoff due to the proliferation of impermeable surfaces, such as concrete and asphalt, can lead to higher risks of flooding. Additionally, the urban heat island effect, where urban regions experience greater temperatures than their rural surrounds, can occur from increased energy consumption and heat retention by buildings and pavement. Strategic urban planning is important to mitigate these problems. Incorporating green infrastructure, such as parks, green roofs, and permeable pavements, can assist in managing rainwater, minimise heat retention, and improve urban living conditions.

The amount of rangeland has expanded slightly from 47.60 km² in 2017 to 53.67 km² in 2023. This increase shows a likely shift in land use practices, either due to changes in agricultural regulations or the need for more grazing land. Effective management of rangelands is vital to prevent overgrazing, which can lead to soil degradation and desertification. Overgrazing reduces vegetation cover, leaving the soil more prone to erosion by wind and water.

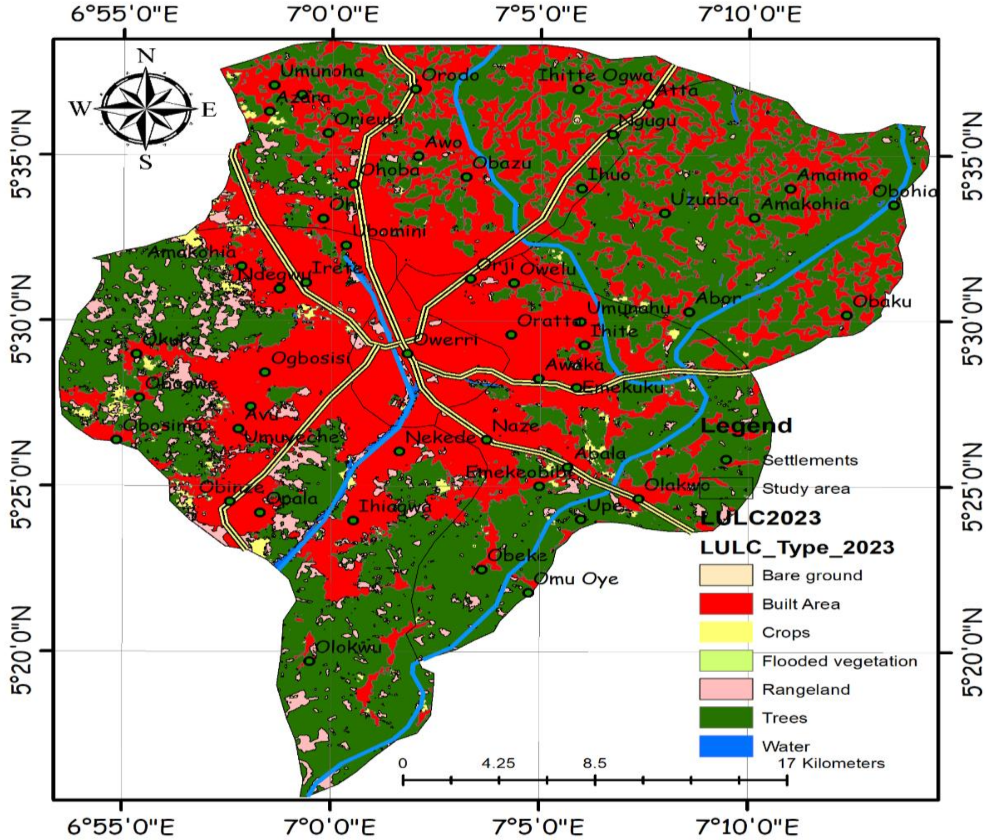

Fig. 5 LULC 2023 of the study area

Sustainable rangeland management strategies, such as rotational grazing and the introduction of drought-resistant forage species, can help sustain the health and productivity of these lands. The area covered by water bodies has expanded from 2.87 km² in 2017 to 3.80 km² in 2023. This increase may result from better water management methods, the construction of additional reservoirs, or natural changes in the hydrological cycle. Water bodies play a significant role in the environment, supporting aquatic ecosystems, providing water for home and agricultural use, and affording recreational opportunities. Preserving and managing water bodies is crucial for assuring water availability, sustaining biodiversity, and supporting human activities. Efforts to safeguard water sources from pollution and over-extraction are necessary to sustain their ecological and economic value. The area dedicated to crops has slightly dropped from 14.46 km² in 2017 to 13.57 km² in 2023. This loss could be attributed to the conversion of agricultural land to urban areas or changes in agricultural practices. Ensuring food security and promoting sustainable farming practices are crucial for the well-being of the population and the economy. Practices such as crop rotation, organic farming, and the use of efficient irrigation systems can help preserve soil fertility, reduce environmental impacts, and boost agricultural yields. The area of flooded vegetation has fallen from 1.84 km² in 2017 to 0.15 km² in 2023, while the area of bare ground has severely reduced from 2.79 km² to 0.006 km². The large reduction in bare ground reflects successful soil stabilization operations or land cover alterations that have boosted vegetation cover. Techniques such as reforestation, afforestation, and the introduction of cover crops can successfully minimise soil erosion and boost land productivity. The decrease in flooded vegetation may imply improved drainage and flood control methods, reducing the extent of waterlogged areas. Effective water management methods, including the development of drainage systems and the deployment of flood control measures, are vital to prevent waterlogging and safeguard agricultural lands and human settlements. Understanding these land cover changes provides vital insights into the land use dynamics and environmental conditions of the research area. The data illustrates the persistent problems of balancing urban growth with environmental sustainability and the necessity for integrated land use planning. By supporting sustainable practices across multiple land uses, policymakers and land managers may promote the resilience of the landscape, ensure the sustainable use of natural resources, and improve the quality of life for local communities. The considerable changes in LULC from 2017 to 2023 emphasise the dynamic nature of land use and its repercussions for the environment and society. The loss in tree cover and the increase in built-up areas underline the need for sustainable land management approaches. Policymakers and land managers must reconcile the need for urban growth with the requirement to conserve natural habitats and maintain ecosystem services [37]. The growth in water bodies and rangelands shows some good improvements in land use practices. However, the general trend towards urbanization offers issues that require integrated approaches to land use planning. Enhancing green infrastructure, fostering reforestation, and adopting sustainable agriculture methods are critical initiatives to ensure that land use changes contribute to long-term environmental sustainability and resilience [37].

The LULC analysis for 2023 provides vital insights into the continuous changes in land cover within the research region. These findings are significant for influencing land use planning and management methods that aim to promote sustainable development while reducing the negative impacts of urbanization and deforestation. By identifying and managing these land cover changes, stakeholders may better manage the region's natural resources and guarantee a balanced approach to development and conservation.

4.5. LULC Change Analysis

The analysis of the change in LULC between the years 2017 and 2023 reveals significant shifts in a variety of land cover types within the study area. These changes are detailed in Table 6, which displays the details of the specific transformations that occurred between the various land use categories and the area changes that occurred in square kilometres for each category. The most notable shift identified in the land use and land cover (LULC) analysis is the conversion of tree-covered areas to built-up areas, covering 103.34 km². This suggests major urban growth at the expense of forested regions. The repercussions of this change are varied, including the loss of biodiversity, decline in carbon sequestration, and increased surface runoff, which can lead to flooding. Forests are crucial for maintaining ecological equilibrium, as they provide a home for various species and act as significant carbon sinks, absorbing carbon dioxide from the atmosphere.

Table 6. LULC Change in the Study Area

Change LULC	Area Change (km²)
Trees - Built Area	103.34152
Trees - Rangeland	36.106853
Rangeland - Trees	16.863032
Rangeland - Built Area	13.427411
Trees - Crops	7.971651
Crops - Built Area	6.30129
Crops - Trees	4.140295
Rangeland - Crops	2.977693
Bare Ground - Built Area	2.432178
Crops - Rangeland	1.702521
Built Area - Trees	1.586789
Flooded Vegetation - Built Area	1.397414
Built Area - Rangeland	1.287238

The elimination of forested areas undermines these functions, resulting in increasing carbon levels in the atmosphere, exacerbating climate change, and causing a decline in wildlife numbers owing to habitat loss. Urban expansion also contributes to the urban heat island effect, which elevates local temperatures and changes the microclimate, making cities hotter than their rural equivalents. The transfer of 36.11 km² of tree cover to rangeland shows a shift towards agricultural or grazing activities. This trend may be driven by the desire for greater grazing land owing to livestock farming. While rangeland can still provide certain ecological benefits, such as feeding specific types of species and conserving soil structure, the removal of trees diminishes overall forest cover. This disrupts wildlife habitats and lowers ecological functions such as water management and soil stabilization. Rangelands, if not managed properly, can lead to overgrazing, soil degradation, and desertification, further complicating environmental concerns.

The change of 16.86 km² of rangeland to tree cover reflects a good trend towards reforestation or natural forest regeneration. This modification can promote biodiversity, improve carbon storage, and contribute to soil and water conservation. Reforestation activities are vital for repairing damaged lands and minimising the impacts of climate change. Trees not only store carbon but also promote soil health by avoiding erosion and improving nutrient content. Additionally, forests play a critical role in regulating the water cycle, controlling groundwater levels, and assuring the supply of clean water for various uses.

The change of 13.43 km² of rangeland to built-up areas demonstrates ongoing urbanization and infrastructure development. This change limits accessible grazing space and may lead to tensions between urban growth and agricultural needs. Managing urban growth responsibly is vital to balance development with the preservation of rural lands. Integrating green spaces into urban areas and promoting vertical farming and urban agriculture can help reduce some of the stresses on rural agricultural lands while delivering fresh products to urban inhabitants. The change of 7.97 km² of tree cover to agriculture shows an increase in agricultural activities. This change may be driven by the desire to boost food production, but it also leads to deforestation and loss of natural habitats. Sustainable farming techniques and agroforestry can help alleviate these impacts by integrating trees into agricultural landscapes. Agroforestry strategies, such as growing trees alongside crops, can increase soil health, minimise erosion, and enhance biodiversity, providing a more resilient agricultural system. The transformation of 6.30 km² of cropland to built-up regions reflects urban expansion into agricultural fields. This tendency offers issues for food security and rural livelihoods, demanding initiatives to protect prime agricultural land from urban sprawl. Ensuring that urban growth does not impair agricultural production is vital for sustaining a steady food supply. Strategies such as zoning rules and incentives for urban agriculture can assist in safeguarding agricultural lands from being turned into built-up areas. The conversion of 4.14 km² of cropland to tree cover reflects initiatives towards afforestation or changes in land use policies encouraging forest restoration. This shift enhances natural equilibrium and facilitates sustainable land management. Afforestation programs can repair degraded lands, promote biodiversity, and enhance ecosystem services such as carbon sequestration and water management. Effective land use regulations that support forest conservation and restoration can create a more balanced and sustainable landscape.

The shift of 2.98 km² of rangeland to farmland demonstrates a rise in agricultural operations, likely driven by the need for more arable land. This development underlines the necessity of sustainable farming practices to maintain soil health and prevent land degradation. Practices such as crop rotation, conservation tillage, and the use of cover crops can help preserve soil fertility, prevent erosion, and boost agricultural productivity, assuring long-term sustainability. The conversion of 2.43 km² of bare terrain to built-up areas suggests development in previously unusable or degraded lands. This adjustment can minimise erosion and enhance land use efficiency but requires careful planning to avoid environmental deterioration. Ensuring that new developments use sustainable practices, such as green building techniques and low-impact development, can help limit environmental impacts and create more sustainable communities.

The transfer of 1.70 km² of farmland to rangeland may represent changes in land use priorities or farming techniques. Maintaining a balance between crop output and grazing space is crucial for food security and ecosystem health. Diversifying land use and using integrated land management strategies can assist in optimizing land productivity and supporting both agriculture and pastoral activities.

The transfer of 1.59 km² of built-up areas to tree cover reflects a tiny but positive change, either due to urban greening initiatives or abandoned developments reverting to natural vegetation. Such modifications promote urban biodiversity and enhance green spaces. Urban greening projects, such as planting trees along streets and building parks and green roofs, can bring several benefits, including minimising the urban heat island effect, increasing air quality, and raising the quality of life for people.

The conversion of 1.40 km² of flooded vegetation to built-up areas emphasises the pressure on wetland ecosystems from urban growth. Wetlands provide critical ecological services, including flood regulation, water purification, and habitat for numerous species. Their disappearance can have major environmental effects, such as increased flooding, water pollution, and loss of biodiversity. Protecting and restoring wetlands through regulations and conservation activities is vital for keeping these unique ecosystems.

The shift of 1.29 km² of built-up areas to rangeland may suggest land abandonment or repurposing of urban areas for large land uses. This tendency can aid ecological restoration but requires monitoring to guarantee sustainable land use practices. Repurposing abandoned urban areas for green spaces, communal gardens, or wildlife habitats can boost urban biodiversity and create more resilient and sustainable cities. The LULC change analysis illustrates the dynamic land use transitions in the study area, driven by urbanization, agricultural growth, and environmental control activities. The large loss of tree cover to built-up areas underscores the need for conservation and sustainable urban design approaches to balance development with ecological preservation. Policymakers and land managers can encourage sustainable land use practices and offset the negative environmental impacts of rapid development by implementing targeted measures. Understanding these land use shifts provides vital insights into the environmental and socio-economic aspects of the research area. By integrating LULC data with other spatial and environmental information, decision-makers can make educated choices to promote sustainable development, safeguard natural resources, and enhance the resilience of the landscape. Sustainable land management strategies, such as reforestation, agroforestry, and urban greening, can assist in alleviating the impacts of land use changes, guaranteeing a balanced and sustainable future for the region.

5. Conclusion

The study area, encompassing varied terrain across Ikeduru, Mbaitoli, Owerri Municipal, Owerri North, and Owerri West in Imo State, Nigeria, exhibits diverse slope characteristics and hydrological patterns that significantly influence environmental dynamics and human activities. Predominantly, 84% of the area features gentle slopes between 0 and 2.69 degrees, concentrated in the central and northern regions. These slopes facilitate agricultural activities and urban development but increase susceptibility to flooding and waterlogging during heavy rainfall. Conversely, steeper slopes exceeding 4.22 degrees cover less than 6% of the area, primarily in the southern and western parts, posing risks of erosion and landslides during the rainy season. Effective soil conservation measures, such as afforestation and retaining walls, are crucial to stabilize these regions and mitigate environmental hazards. The drainage density analysis revealed distinct hydrological patterns. Moderate drainage density zones (53.10 - 159.32 km/km²), covering about 62% of the area, facilitate effective runoff management, reducing flooding risk. Higher drainage density areas (159.32 - 265.53 km/km²) indicate more rapid runoff and erosion potential, especially in steeper terrains. Understanding these dynamics is essential for implementing sustainable water management practices. The LULC analysis between 2017 and 2023 highlighted significant changes. Tree cover decreased from 565.64 km² to 440.38 km², reflecting deforestation and urban expansion. This decline impacts biodiversity, carbon sequestration, and ecosystem services. Built-up areas increased from 269.98 km² to 393.62 km², indicating rapid urbanization with implications for increased surface runoff and urban heat island effects. Rangeland slightly increased, suggesting shifts in land use practices that require careful management to prevent degradation. Water bodies also expanded, emphasizing the importance of maintaining aquatic ecosystems and water availability. The study underscores the need for integrated land use planning and sustainable management strategies to balance developmental pressures with environmental conservation in the United States. Effective measures to manage slope stability, water resources, and land cover changes are essential for fostering resilient and sustainable landscapes amidst ongoing urbanization and environmental challenges. Integrating slope, drainage density, and LULC data provides valuable insights for effective land use planning and management. By understanding the spatial distribution and extent of different land cover types, stakeholders can make informed decisions to promote sustainable development and resilience in Imo State, Nigeria. Policymakers and land managers must balance urban development demands with preserving natural habitats and maintaining ecosystem services. Strategies such as promoting sustainable agricultural practices, enhancing green infrastructure in urban areas, and implementing soil and water conservation measures are crucial for mitigating the negative impacts of land use changes.

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