Urbanization and Deforestation Impacts on Geomorphology and Land Use Patterns in Enugu State, Southeastern Nigeria

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Abstract
The study examines Land Use and Land Cover (LULC) changes and their implications in Enugu North, Enugu South, Nkanu East, and Nkanu West LGAs, Enugu State, southeastern Nigeria, between 2017 and 2023. The aim is to assess the impact of these changes on the environment and to understand the influence of slope on land use suitability. The methodology involved analyzing satellite imagery and topographical data to classify LULC types and calculate slope ranges. The results show a significant reduction in tree cover from 565.99 km² to 432.48 km² and an increase in built-up areas from 204.51 km² to 328.73 km². Rangeland expanded from 456.40 km² to 504.03 km², while agricultural lands decreased from 97.70 km² to 60.77 km². Water bodies and flooded vegetation also declined slightly. The discussion highlights the environmental implications of these changes, such as deforestation, urbanization, and shifts in agricultural and grazing activities. The predominance of gentle slopes (0° to 4.17°) suggests suitability for various land uses, while steeper slopes (above 4.17°) present challenges for agriculture and construction. The study emphasizes the need for sustainable land management practices to balance urban growth with environmental conservation. The significant reduction in tree cover and increase in built-up areas underscore the impact of rapid urbanization and land conversion in the region. The findings highlight the importance of integrating slope analysis into land use planning to mitigate erosion risks and promote sustainable development. This study provides valuable insights for policymakers and planners in managing land resources effectively. This research uniquely combines LULC change analysis with slope dynamics to provide a comprehensive understanding of land use patterns and their environmental implications in a rapidly urbanizing region.

Keywords: *Land Use, Land Cover, Slope Analysis, Urbanization, Deforestation, Enugu State, Environmental Management*

1. Introduction

Geomorphology, the study of landforms and the processes that shape them, reveals the dynamic nature of Earth's surface. Landforms, such as mountains, valleys, plains, and plateaus, result from a combination of tectonic activities, erosion, weathering, and deposition (Gardner, 2020; Brandolini et al., 2021). These characteristics vary widely across different regions, influencing the soil type, drainage patterns, and vegetation. Mountainous areas, shaped by tectonic uplift and volcanic activity, exhibit steep slopes, rugged terrain, and often have thin, less fertile soils (Onderdonk et al., 2022). In contrast, river valleys and coastal plains, shaped by fluvial and marine processes, tend to have more fertile soils, supporting diverse ecosystems and agricultural activities.

The geomorphological characteristics of a region significantly influence land use patterns. Fertile plains and river valleys, with their rich alluvial soils, are ideal for agriculture, supporting extensive farming activities. These areas often become population centers due to the availability of water and fertile land (Ayadiuno et al., 2022). Conversely, mountainous and hilly regions, with their rugged terrain and poor soils, are less suitable for agriculture but may support forestry, tourism, and mining activities. Coastal areas, with their access to the sea, often develop into major urban and industrial centers, benefiting from trade and transportation (Yang et al., 2022). However, the geomorphological stability of these areas, such as susceptibility to erosion or flooding, must be considered in planning and development to prevent land degradation and ensure sustainable land use (Olorunfemi et al., 2020).

Urbanization and deforestation profoundly impact geomorphological processes and landforms. Urbanization transforms natural landscapes into built environments, altering drainage patterns, increasing surface runoff, and often leading to soil erosion and sedimentation in water bodies (Onilude & Vaz, 2020). The construction of buildings, roads, and other infrastructure modifies the natural topography, sometimes resulting in increased landslide risks, particularly in hilly or mountainous regions. The impermeable surfaces of urban areas reduce groundwater recharge, affecting water availability and increasing flood risks (Ernest et al., 2023).

Deforestation, the removal of vegetation cover, exacerbates soil erosion as the protective layer of vegetation is stripped away. This leads to increased runoff and sedimentation in rivers and streams, altering their courses and sometimes causing flooding. Deforested areas are also more susceptible to landslides, as tree roots that help stabilize the soil are removed (Wajim, 2020). Moreover, the loss of forests can lead to the degradation of soil structure and fertility, impacting agricultural productivity.

Both urbanization and deforestation disrupt the natural geomorphological processes, often resulting in negative environmental consequences. Sustainable land management practices, such as reforestation, the creation of green spaces in urban areas, and careful planning of infrastructure development, are essential to mitigate these impacts (Jande et al., 2022). By understanding and respecting the geomorphological characteristics of a region, it is possible to develop land use patterns that balance human needs with environmental sustainability.

Geomorphology plays a crucial role in natural hazard management. Understanding the processes and factors that shape landforms can help predict and mitigate the impacts of natural disasters such as earthquakes, landslides, floods, and volcanic eruptions (Oloyede et al., 2022). Identifying areas prone to landslides based on slope stability, soil composition, and vegetation cover can inform land use planning and emergency preparedness. Similarly, recognizing floodplains and designing appropriate flood control measures, such as levees and retention basins, can reduce the risk of flooding and protect communities (Ozioko & Igwe, 2020).

Understanding these geomorphological responses to climate change is essential for developing adaptation strategies. Restoring natural vegetation can help stabilize soils and reduce erosion, while constructing resilient infrastructure can mitigate the impacts of extreme weather events (Okon et al., 2021). Effective climate adaptation requires integrating geomorphological knowledge into planning and policy-making processes.

Human activities significantly impact geomorphological processes and landforms. Agriculture, mining, and construction activities alter the natural topography and accelerate erosion. Plowing fields and removing vegetation for agriculture disturb the soil structure, making it more susceptible to erosion by wind and water (Adenle et al., 2020). Mining operations often involve the removal of large amounts of earth, creating artificial landforms and increasing the risk of landslides and soil erosion (Liman et al., 2021).

Construction activities, such as building roads, dams, and urban developments, modify the landscape and disrupt natural drainage patterns. This can lead to increased surface runoff, soil erosion, and sedimentation in rivers and streams. The construction of dams, in particular, alters sediment transport processes, trapping sediments that would naturally replenish downstream areas, leading to coastal erosion and changes in river morphology (Zhang et al., 2021). Human-induced climate change further exacerbates these impacts, as altered precipitation patterns and more frequent extreme weather events increase the rates of erosion, flooding, and other geomorphological processes. Mitigating these impacts requires sustainable land use practices that minimize disturbance to the natural landscape and consider the long-term consequences of human activities (Hassan et al., 2020).

Modern geomorphology employs a variety of techniques and tools to study landforms and processes. Remote sensing technologies, such as satellite imagery and aerial photography, provide valuable data for mapping and analyzing landforms on a large scale (Akinluyi et al., 2021). Geographic Information Systems (GIS) allow researchers to integrate and analyze spatial data, identifying patterns and relationships between different geomorphological features.

Geomorphology is crucial for environmental conservation efforts. By understanding the natural processes that shape the landscape, conservationists can develop strategies to protect and restore ecosystems. Restoring natural river channels and floodplains can improve water quality, enhance habitat diversity, and reduce flood risks (Oloyede et al., 2022). Protecting coastal areas from erosion and sea-level rise involves understanding sediment transport processes and designing appropriate shoreline management practices.

The study examines Land Use and Land Cover (LULC) changes and their implications in Enugu North, Enugu South, Nkanu East, and Nkanu West LGAs, located in Enugu State, southeastern Nigeria, between 2017 and 2023. The primary aim is to assess the environmental impact of these changes and to understand the influence of slope on land use suitability. By analyzing how alterations in land cover affect soil stability, water drainage, and vegetation patterns, the study seeks to provide insights into sustainable land management practices. This understanding is crucial for informed decision-making in agriculture, urban development, and conservation efforts, ensuring sustainable development and environmental protection.

2. Research Location and Geology

The study area spans four Local Government Areas (LGAs) in Enugu State, South-Eastern Nigeria: Enugu North, Enugu South, Nkanu East, and Nkanu West. Enugu State, located within the coordinates of approximately 6°30'N to 7°30'N latitude and 7°00'E to 7°45'E longitude, is a significant region in southeastern Nigeria, known for its rich cultural heritage and economic activities as shown in Figure 1. The state capital, Enugu, serves as a major urban center and a hub for political, commercial, and educational activities.

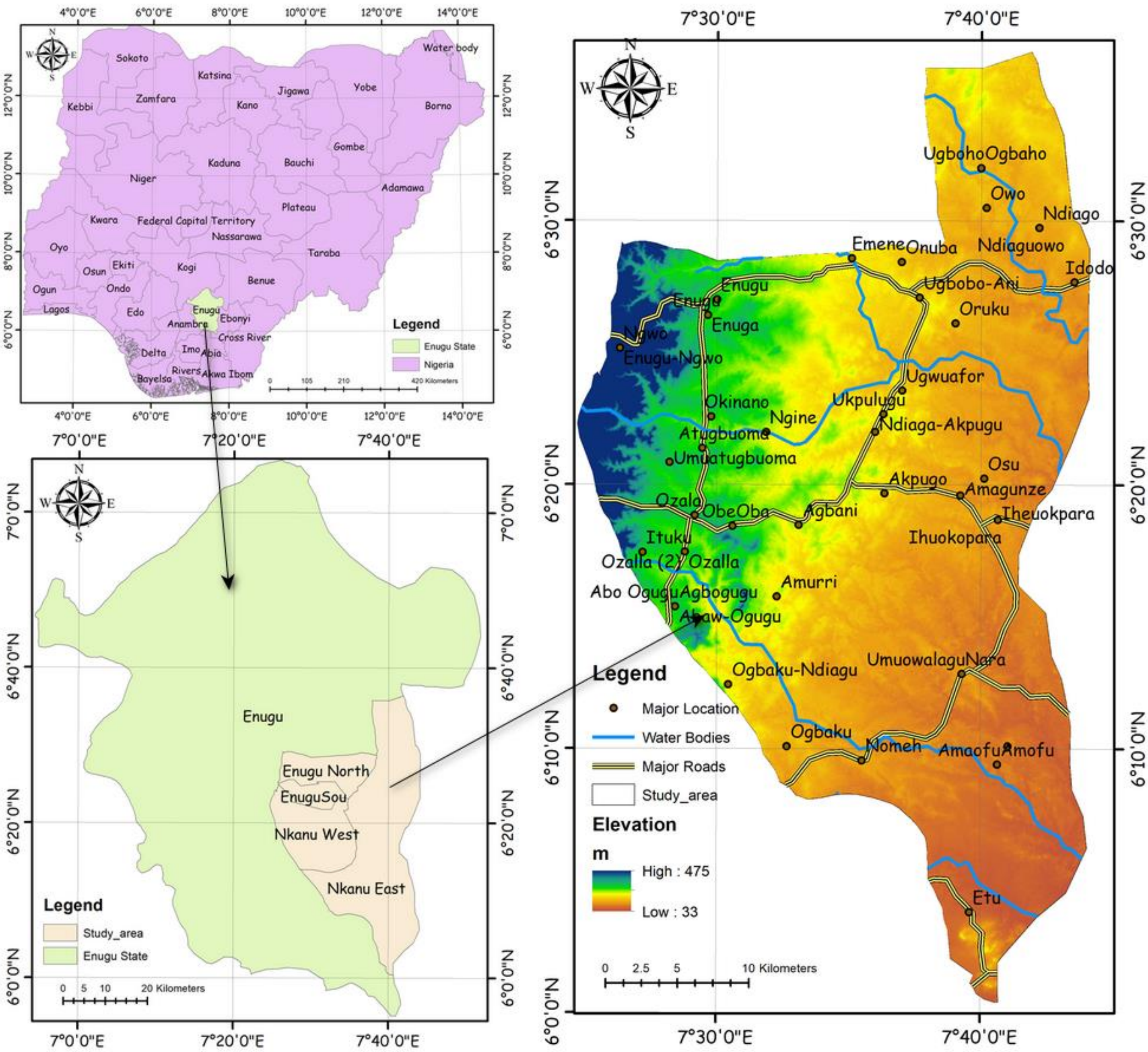

Figure 1: Map of Nigeria, Enugu State and elevation of the study area

Accessibility to these LGAs is facilitated by a network of major roads and highways that connect Enugu to other parts of Nigeria. The Enugu-Port Harcourt Expressway and the Enugu-Onitsha Expressway are crucial for regional connectivity, linking the state to major cities such as Port Harcourt and Onitsha. Additionally, local roads within the LGAs provide access to various communities and are essential for the movement of people and goods. The Akanu Ibiam International Airport, located in Enugu, further enhances accessibility, offering both domestic and international flights.

The geology of Enugu State is predominantly characterized by sedimentary rock formations, which are part of the Anambra Basin. This basin is one of Nigeria's major geological structures, known for its rich deposits of coal and other minerals (Olayiwola et al., 2020). The study area lies within the Anambra Basin, which is composed mainly of Cretaceous to Tertiary sediments. The primary geological formations include the Nkporo Shale, Mamu Formation, Ajali Sandstone, and Nsukka Formation.

Nkporo Shale is primarily composed of dark grey shales, siltstones, and occasional sandstones. It is the oldest of the formations and serves as a significant source rock for hydrocarbon generation. Overlying the Nkporo Shale, the Mamu Formation consists of alternating layers of sandstones, shales, and coal seams. This formation is economically significant due to its coal deposits, which have historically been mined in the Enugu area (Olayiwola et al., 2020). Characterized by its white to yellowish sandstones, the Ajali Sandstone is known for its high permeability and serves as a major aquifer in the region. It is crucial for groundwater resources. The youngest formation in the study area, the Nsukka Formation, comprises sandstones, shales, and coal beds. Like the Mamu Formation, it has economic importance due to its coal deposits (Ezim & Obiadi, 2021).

The topography of the study area varies significantly, with elevations ranging from 33 to 475 meters above sea level. This variation in elevation contributes to the diverse landscape, which includes rolling hills, valleys, and flat plains. The higher elevations are predominantly found in the northern and central parts of the study area, while the lower elevations are more common in the southern parts.

Several rivers and streams traverse the study area, contributing to its hydrogeological characteristics. The Ekulu River is one of the prominent water bodies, flowing through parts of Enugu North and Enugu South. This river is vital for the local ecosystem and serves as a source of water for domestic and agricultural purposes (Butu et al., 2020). Other smaller streams and tributaries crisscross the region, providing additional water resources and influencing the groundwater recharge.

3. Methodology

3.1 Data Acquisition

The analysis employs remote sensing (RS) and GIS technologies to assess the geological and environmental impacts of these changes, which can aid in effective land management and planning. Various spatial and non-spatial data were acquired for this purpose, as summarized in Table 1.

Table 1: Data 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, which 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, 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 preprocessed satellite images were classified into different LULC categories using supervised classification techniques. Training samples representing various land cover types (e.g., vegetation, water, urban areas) were collected, and a maximum likelihood classifier was applied to classify the images. The classification accuracy was assessed using ground truth data and accuracy metrics such as the Kappa coefficient.

3.2.2 DEM Processing

The SRTM DEM data were processed to derive slope and drainage density. The slope was calculated using the slope tool in ArcGIS, which computes the maximum rate of change in elevation for each DEM cell (Okoli et al., 2024). Drainage density was calculated by delineating the drainage network from the DEM using the hydrology toolset in ArcGIS, which includes flow direction, flow accumulation, and stream network delineation.

3.2.3 Change Detection

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

3.3 Data Analysis

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

3.3.1 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:

$$S = arctan\left(\frac{\Delta z}{d}\right) \times \frac{180}{\pi} \qquad 2$$

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.

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:

$$\Delta LULC = LULC_{2023} - LULC_{2017} \qquad 3$$

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.

4. Results and Discussions

4.1 Slope map

Slope analysis is a critical aspect of geomorphological studies, influencing factors such as erosion, runoff, and land use suitability. In this study, the slope range and corresponding area coverage for the research area in Enugu, southeastern Nigeria, are presented in Table 1. The slope data is categorized into five classes, ranging from 0° to 41.83°.

Table 1: Slope Range and Area Coverage in the Study Area

Slope Range (°)	Area (km^2)
0 - 1.85	378.04
1.85 - 2.31	133.98
2.31 - 4.17	484.41
4.17 - 11.65	286.50
11.65 - 41.83	39.47

The slope distribution indicates a predominance of gentle slopes within the study area. The largest portion of the area (484.41 km^2) falls within the 2.31° to 4.17° slope range, accounting for 37.3% of the total area. This is followed by the 0° to 1.85° slope range, covering 378.04 km^2, which represents 29.1% of the area. The slope range of 4.17° to 11.65° covers 286.50 km^2 (22.1%), while the 1.85° to 2.31° range accounts for 133.98 km^2 (10.3%). The steepest slopes, ranging from 11.65° to 41.83°, cover the smallest area of 39.47 km^2, making up just 3.0% of the total area.

The predominance of gentle slopes (0° to 4.17°) suggests that the study area is generally characterized by low relief, which is typical of sedimentary basins. The flat to gently undulating terrain is conducive to various land uses, including agriculture, urban development, and infrastructure projects. However, the presence of steeper slopes (above 4.17°) in some parts of the area indicates potential zones of increased erosion risk and challenges for construction.

The spatial variation in slope within the study area is significant for groundwater management, soil conservation, and urban planning. Gentle slopes, which dominate the region, are typically associated with lower runoff velocities and higher infiltration rates, favoring groundwater recharge. Conversely, steeper slopes are likely to have higher runoff rates, leading to soil erosion and reduced infiltration (Abdullateef et al., 2021). This spatial variability must be considered in sustainable land management practices.

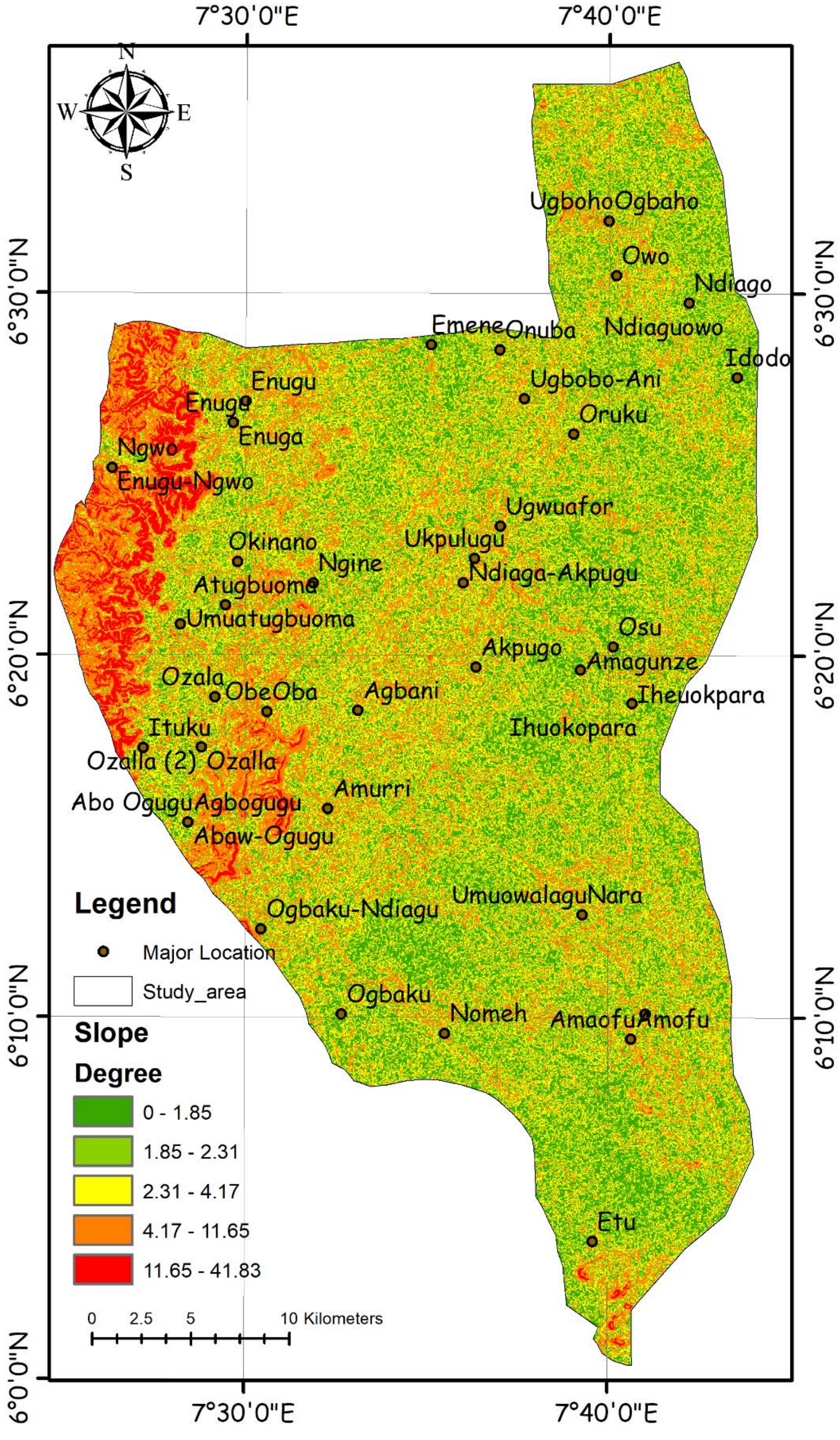

Figure 2: Spatial Distribution of Slope in the Study Area

The spatial distribution of slopes (Figure 2) reveals distinct patterns across the study area. The central and northern parts predominantly exhibit gentle slopes, which are indicative of the broader sedimentary plains within the Anambra Basin. These areas are likely to have favorable conditions for agriculture due to the reduced risk of erosion and higher soil moisture retention. In contrast, the southern and southwestern regions show a higher prevalence of steeper slopes. These areas are associated with more rugged terrain, likely influenced by underlying geological structures such as fault lines and escarpments. The increased slope steepness in these regions suggests a need for targeted soil conservation measures and careful planning for any development projects to mitigate erosion risks.

4.2 Land Use/Land Cover Analysis for 2017

Understanding the Land Use and Land Cover (LULC) dynamics is crucial for environmental management and planning, especially in a region that comprises both urban and rural areas like the LGAs of Enugu North, Enugu South, Nkanu East, and Nkanu West in Enugu State, southeastern Nigeria. This section presents a detailed analysis of the LULC types in the study area based on the 2017 data. Table 2 provides the LULC types and their respective area coverage.

Table 2: Land Use and Land Cover (LULC) Types and Area Coverage in the Study Area

LULC Type (2017)	Area (km²)
Water	1.91
Trees	565.99
Flooded vegetation	0.69
Crops	97.70
Built Area	204.51
Bare ground	0.49
Rangeland	456.40

The LULC analysis indicates that the predominant land cover type in the study area is trees, covering 565.99 km², which constitutes approximately 40.2% of the total area. This extensive coverage of trees suggests that a significant portion of the study area is forested, which is typical of the tropical rainforest zone of southeastern Nigeria. Rangeland is the second most extensive LULC type, covering 456.40 km², or about 32.4% of the total area. This implies that a considerable portion of the land is used for grazing and pasture.

Built areas, including both urban and peri-urban regions, account for 204.51 km², making up 14.5% of the total land cover. The presence of substantial built-up areas highlights the level of urbanization within the LGAs, particularly in Enugu North and Enugu South, which encompass the city of Enugu. Agricultural land, categorized under crops, covers 97.70 km², representing 6.9% of the area, indicating the importance of agriculture to the local economy.

Water bodies, including rivers, lakes, and reservoirs, cover a relatively small area of 1.91 km², which is about 0.14% of the total area. Flooded vegetation, which includes wetlands and areas temporarily inundated by water, covers 0.69 km² (0.05%). Bare ground, which represents areas with little to no vegetation, covers the smallest area of 0.49 km², or 0.03% of the total land cover.

The distribution of LULC types reveals significant insights into the land use patterns and ecological characteristics of the study area. The large expanse of forested areas (trees) reflects the region's natural vegetation and the presence of protected areas or forest reserves. These forested areas are crucial for biodiversity conservation, carbon sequestration, and maintaining the ecological balance.

The substantial rangeland coverage indicates the importance of livestock farming and pastoral activities in the region. Rangelands provide essential resources for grazing animals and are vital for the livelihoods of rural communities (Abba et al., 2021). However, the management of these rangelands is crucial to prevent overgrazing, land degradation, and loss of biodiversity. The notable proportion of built-up areas underscores the urbanization trend within the study area, particularly around the city of Enugu. Urban expansion has implications for land use planning, infrastructure development, and environmental sustainability. The increase in built-up areas often leads to habitat fragmentation, increased surface runoff, and potential challenges related to waste management and urban heat island effects.

Agricultural land (crops) plays a significant role in the local economy, providing food security and livelihoods for many residents. Sustainable agricultural practices are necessary to enhance productivity while minimizing environmental impacts such as soil erosion, water pollution, and loss of soil fertility.

The relatively small coverage of water bodies and flooded vegetation indicates limited aquatic and wetland habitats within the study area. These areas are vital for water resources, supporting biodiversity, and providing ecosystem services such as flood regulation and water purification.

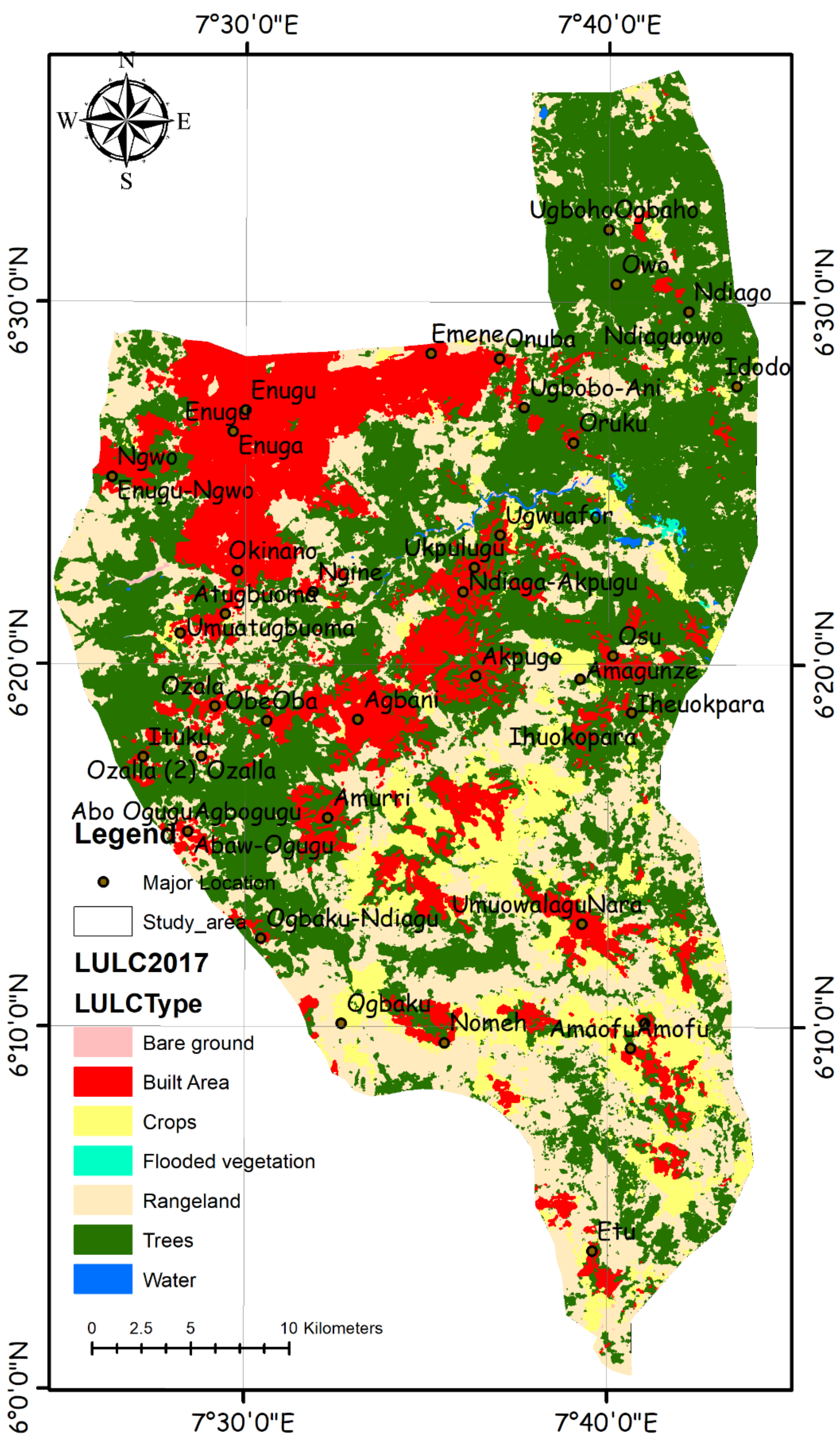

Figure 3: Spatial Distribution of LULC Types in the Study Area

The spatial distribution of LULC types varies across the study area, reflecting the interplay between natural and human factors. Figure 3 illustrates the spatial variation in LULC within the study area. The central and northern parts, encompassing Enugu North and Enugu South, are predominantly urbanized with significant built-up areas. These areas are characterized by dense human settlements, commercial activities, and infrastructure development.

In contrast, the southern and eastern parts, covering Nkanu East and Nkanu West, are more rural with extensive forested areas and rangelands. These regions exhibit lower population densities and are more reliant on agriculture and livestock farming. The presence of large forested areas in these LGAs highlights the importance of forest conservation and sustainable land management practices.

Water bodies and flooded vegetation are sparsely distributed, primarily located in low-lying areas and along river courses. These areas are essential for maintaining hydrological cycles and supporting aquatic ecosystems.

4.3 Land Use/Land Cover Analysis for 2023

Table 3 presents the LULC types and their respective area coverage for the year 2023. The LULC analysis reveals significant changes in land cover between the years leading up to 2023. Trees remain a substantial land cover type but have decreased significantly to 432.48 km², now accounting for approximately 30.7% of the total area. This reduction highlights ongoing deforestation and land conversion processes.

Table 2: Land Use and Land Cover (LULC) Types and Area Coverage in the Study Area

LULC Type (2023)	Area (km²)
Water	1.43
Trees	432.48
Flooded vegetation	0.10
Crops	60.77
Built Area	328.73
Bare ground	0.16
Rangeland	504.03

Rangeland, covering 504.03 km², represents the most extensive land cover, making up about 35.8% of the total area. This indicates an increase in rangeland, suggesting a shift towards more pastoral and grazing activities, possibly due to agricultural expansion or reforestation efforts on previously deforested lands.

Built areas have expanded significantly to 328.73 km², representing 23.3% of the total land cover. This substantial increase underscores the rapid urbanization occurring in the region, particularly around the urban centers of Enugu North and Enugu South.

Crops now cover 60.77 km², which is 4.3% of the area. This reduction in agricultural land could be attributed to the expansion of built-up areas and changes in land use priorities. Water bodies have also decreased slightly to 1.43 km² (0.1%), while flooded vegetation and bare ground cover 0.10 km² and 0.16 km², respectively, each representing less than 0.1% of the total area.

The LULC changes from 2017 to 2023 reflect significant trends in land use dynamics within the study area. The notable reduction in forested areas (trees) is a cause for concern, as it suggests increased deforestation, likely driven by urban expansion, agricultural land conversion, and possibly illegal logging activities. This reduction in forest cover has implications for biodiversity conservation, carbon sequestration, and local climate regulation.

The increase in rangeland suggests a shift towards more extensive livestock farming and grazing practices. While this can support rural livelihoods, it also requires sustainable management to prevent overgrazing, soil degradation, and loss of biodiversity. The substantial increase in built-up areas highlights the ongoing urbanization and infrastructure development in the region (Onanuga et al., 2021). This urban expansion, while beneficial for economic growth and modernization, brings challenges such as habitat fragmentation, increased surface runoff, and pressure on local resources and services.

The reduction in agricultural land (crops) indicates a possible shift in land use priorities, potentially due to urban encroachment and changes in agricultural practices. This trend underscores the need for integrated land use planning to balance urban development with agricultural productivity and food security.

The minimal changes in water bodies, flooded vegetation, and bare ground suggest relative stability in these land cover types, although their small coverage highlights their limited presence in the landscape.

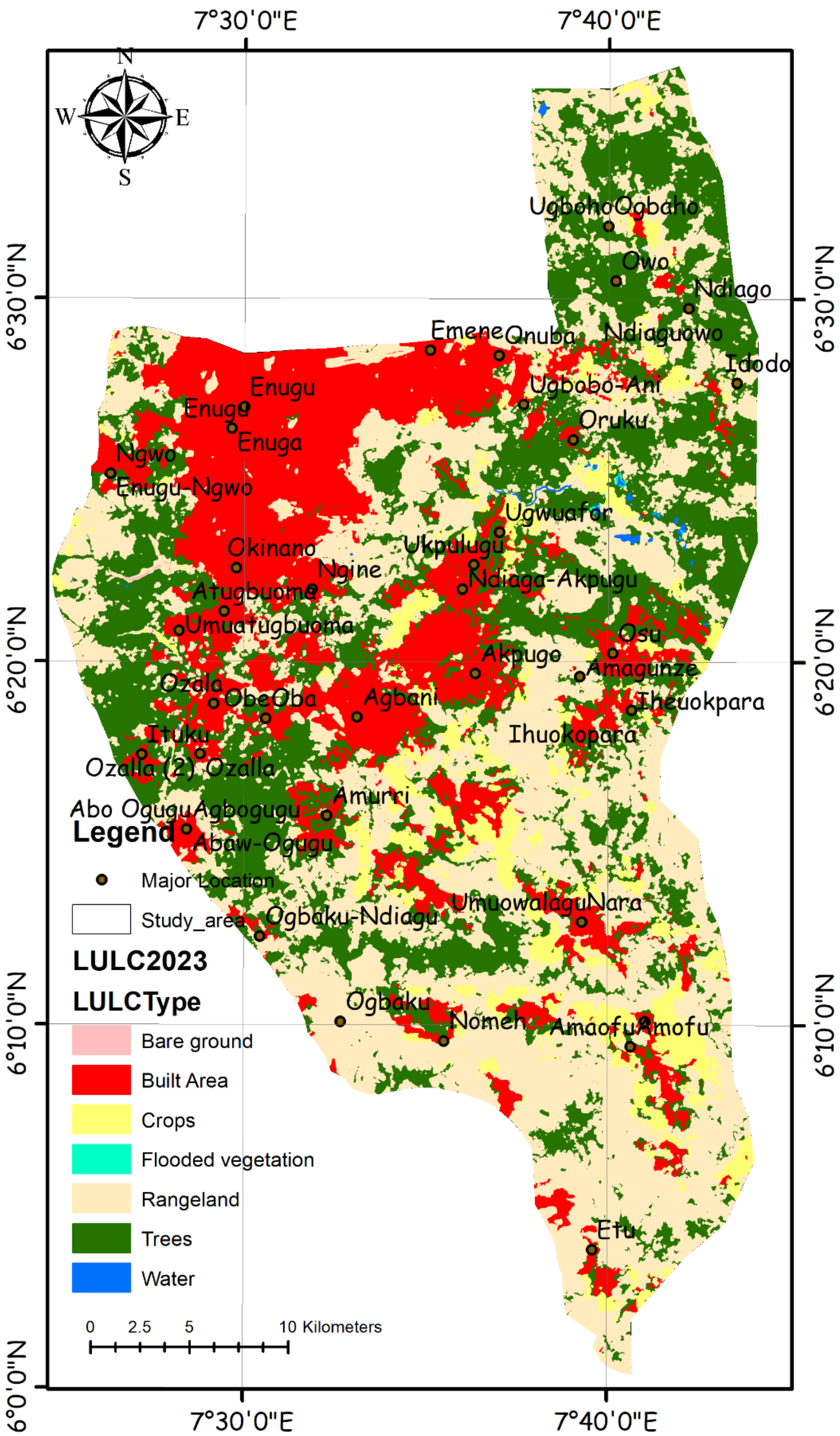

Figure 4: Spatial Distribution of LULC Types in the Study Area for 2023

The spatial distribution of LULC types in 2023 (Figure 4) reveals distinct patterns across the study area. The central and northern parts, encompassing Enugu North and Enugu South, are predominantly urbanized with significant built-up areas. These regions show dense human settlements, commercial activities, and extensive infrastructure development, reflecting the urbanization trend.

In contrast, the southern and eastern parts, covering Nkanu East and Nkanu West, are more rural with extensive rangelands and remaining forested areas. These regions exhibit lower population densities and are more reliant on pastoral and agricultural activities. The spatial variation underscores the diverse land use dynamics and the need for tailored land management strategies across different LGAs.

The limited presence of water bodies and flooded vegetation, primarily located in low-lying areas and along river courses, highlights the need for water resource management to support local communities and ecosystems.

4.4 Impacts of LULC Changes and Slope Dynamics

Between 2017 and 2023, the most notable change is the reduction in tree cover from 565.99 km² to 432.48 km². This decrease in forested areas indicates substantial deforestation, likely driven by expanding urban areas and increased demand for agricultural land. The loss of trees has profound implications for biodiversity, carbon sequestration, and the overall ecological balance of the region. Forests serve as critical habitats for numerous species and play a vital role in regulating the local climate and hydrological cycles. Deforestation, therefore, threatens biodiversity and disrupts these essential ecosystem services.

Conversely, built-up areas increased significantly from 204.51 km² to 328.73 km², reflecting rapid urbanization, particularly in Enugu North and Enugu South. This urban expansion underscores the growing population and the corresponding need for housing, infrastructure, and services. However, unplanned urban growth can lead to environmental degradation, including increased surface runoff, flooding, and the urban heat island effect (Okafor et al., 2023). The increase in impervious surfaces associated with urban areas reduces groundwater recharge and exacerbates flood risks, especially in regions with steeper slopes.

The expansion of rangelands from 456.40 km² to 504.03 km² suggests a shift towards more extensive livestock farming and grazing activities. While rangelands are crucial for supporting pastoral livelihoods, their increase at the expense of forests and agricultural lands highlights a potential imbalance in land use. Sustainable management of these rangelands is essential to prevent overgrazing, soil erosion, and the degradation of vegetation cover, which can have long-term negative impacts on the land's productivity and ecological health.

Agricultural lands, categorized under crops, decreased from 97.70 km² to 60.77 km², indicating a reduction in the area dedicated to farming. This decline can be attributed to the encroachment of urban areas and possibly changing economic activities. The reduction in agricultural land raises concerns about food security and the livelihoods of rural communities. Balancing urban development with the preservation of agricultural zones is crucial to ensure food availability and economic stability.

Water bodies and flooded vegetation also showed minor decreases, reflecting their limited presence in the landscape. Water bodies, which decreased from 1.91 km² to 1.43 km², are essential for local hydrological cycles, providing water for domestic, agricultural, and industrial uses. The reduction in flooded vegetation, from 0.69 km² to 0.10 km², indicates a loss of wetland areas, which are vital for biodiversity, water purification, and flood regulation. The minimal changes in bare ground highlight its limited presence and suggest stability in this land cover type.

The influence of slope on these LULC changes is significant. The study area's topography, with slope ranges varying from 0° to 41.83°, affects land use suitability, erosion potential, and water runoff. The predominance of gentle slopes (0° to 4.17°), covering the majority of the area, is conducive to agriculture and urban development due to lower erosion risks and higher infiltration rates. These areas are likely where the expansion of built-up areas and rangelands has occurred. In contrast, steeper slopes (above 4.17°) are more prone to erosion and landslides, limiting their suitability for agriculture and construction. The presence of steeper slopes in certain parts of the study area necessitates careful land management practices to mitigate erosion and maintain soil stability.

5. Conclusion

The analysis of LULC changes and slope dynamics between 2017 and 2023 in Enugu North, Enugu South, Nkanu East, and Nkanu West LGAs reveals significant trends with profound environmental and socio-economic implications. The most notable change is the substantial reduction in tree cover from 565.99 km² to 432.48 km², indicating extensive deforestation driven by urban expansion and agricultural land conversion. This reduction in forested areas threatens biodiversity, disrupts carbon sequestration processes, and alters local climate and hydrological cycles, underscoring the urgent need for effective forest conservation strategies.

Simultaneously, built-up areas have expanded markedly from 204.51 km² to 328.73 km², reflecting rapid urbanization, especially in Enugu North and Enugu South. This urban growth is accompanied by increased surface runoff, reduced groundwater recharge, and heightened flood risks, particularly in regions with steeper slopes. Unplanned urban expansion poses significant environmental challenges, including habitat fragmentation and the urban heat island effect. Urban planning must integrate green infrastructure and sustainable practices to mitigate these adverse effects.

The expansion of rangelands from 456.40 km² to 504.03 km² indicates a shift towards more extensive livestock farming and grazing activities. While this can support rural livelihoods, it raises concerns about overgrazing, soil erosion, and vegetation degradation. Sustainable rangeland management practices are crucial to prevent long-term ecological damage and maintain the land's productivity.

Agricultural lands have decreased from 97.70 km² to 60.77 km², reflecting a shift in land use priorities, possibly due to urban encroachment and changing economic activities. This reduction in agricultural area raises concerns about food security and the livelihoods of rural communities. Balancing urban development with the preservation of agricultural zones is essential to ensure sustainable food production and economic stability.

Water bodies and flooded vegetation have shown minor decreases, with water bodies shrinking from 1.91 km² to 1.43 km² and flooded vegetation reducing from 0.69 km² to 0.10 km². These areas, although limited in coverage, are crucial for local hydrological cycles, water purification, and flood regulation. Maintaining and protecting these water bodies and wetland areas is vital for ecological balance and water resource management.

The influence of slope on LULC changes is significant. The predominance of gentle slopes (0° to 4.17°) in the study area is conducive to agriculture, urban development, and infrastructure projects due to lower erosion risks and higher infiltration rates. These areas are likely where the expansion of built-up areas and rangelands has occurred. In contrast, steeper slopes (above 4.17°) are more prone to erosion and landslides, limiting their suitability for agriculture and

construction. Effective land management practices must consider these topographical variations to mitigate erosion risks and promote sustainable development.
In summary, the findings highlight the dynamic interplay between urbanization, deforestation, and agricultural practices in shaping the land use patterns in Enugu State. The significant reduction in tree cover and the rapid increase in built-up areas underscore the need for integrated land use planning that balances development with environmental conservation. Slope analysis provides critical insights for mitigating erosion risks and guiding sustainable land management practices. Policymakers and planners must prioritize the conservation of forested areas, sustainable agricultural practices, and the integration of green infrastructure in urban planning to ensure a balanced and sustainable development trajectory for the region.

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