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Geomorphological Characteristics Based on RS and GIS Analysis and Land Use/Land Cover Dynamics in Anambra State, Southeastern Nigeria

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Abstract

The geological and geomorphological characteristics of a region significantly influence its land use patterns and environmental management strategies. In Anambra State, Southeastern Nigeria, the interplay between slope dynamics and land use/land cover (LULC) is critical for sustainable development. This study aims to analyze the slope distribution and its implications on LULC in a part of Anambra State, providing insights into the region's suitability for various land uses and potential risks. The primary aim of this study is to evaluate the slope classes in the study area and their impact on LULC distribution. By examining the slope data and corresponding LULC types, the study aims to identify areas suitable for agriculture, urban development, and conservation, and propose sustainable management practices. The study employed a quantitative approach, utilizing Geographic Information System (GIS) tools to analyze slope and LULC data. The slope data were categorized into five classes: 0 - 1.26 degrees, 1.26 - 1.57 degrees, 1.57 - 2.84 degrees, 2.84 - 7.94 degrees, and 7.94 - 28.51 degrees. The LULC analysis was conducted for the years 2017 and 2023, classifying the land cover into seven types: water, trees, flooded vegetation, crops, built area, bare ground, and rangeland. Spatial distribution maps and area statistics were generated to understand the correlation between slope and LULC. The analysis revealed that the largest area, 236.13 km², falls within the 1.57 - 2.84 degrees slope range, indicating predominantly gently sloping terrain. Flat to nearly flat terrain (0 - 1.26 degrees) covers 179.03 km², while moderately steep terrain (2.84 - 7.94 degrees) accounts for 178.40 km². Steeper slopes (7.94 - 28.51 degrees) cover a minimal area of 9.42 km². The LULC analysis showed significant areas covered by trees (394.16 km² in 2017 and 336.84 km² in 2023) and built areas (134.43 km² in 2017 and 156.90 km² in 2023), reflecting ongoing urbanization. The predominance of gentle slopes (1.57 - 2.84 degrees) suggests that the region is well-suited for agriculture, urban development, and infrastructure projects due to minimal elevation changes and low erosion risk. Flat to nearly flat terrain (0 - 1.26 degrees) supports extensive agricultural activities and urban expansion. Moderately steep slopes (2.84 - 7.94 degrees) require soil conservation measures to prevent erosion and maintain soil fertility. Steep slopes (7.94 - 28.51 degrees) are best preserved as natural vegetation to stabilize the soil and prevent landslides. This study provides a comprehensive understanding of the geomorphological characteristics and their influence on land use in a part of Anambra State. By integrating slope and LULC data, it highlights the need for targeted soil conservation measures and sustainable land management practices. The findings can inform regional planning efforts, balancing development with environmental conservation to ensure long-term sustainability.

Keywords: *Slope analysis, Soil conservation, Urban development, Anambra State*

1. Introduction

The study of geomorphology, which encompasses the analysis of landforms and the processes that shape them, has experienced a significant transformation with the integration of Remote Sensing (RS) and Geographic Information Systems (GIS) technologies. These advanced tools provide detailed, multi-temporal, and spatially explicit data that enhance our understanding of Earth's surface dynamics (Adewole et al., 2019; Ibitoye, 2021). In recent decades, the application of RS and GIS in geomorphology has enabled more precise mapping and analysis of landforms, facilitating a deeper understanding of the complex interactions between geological processes and LULC changes (Abdullateef et al., 2021).

Remote Sensing, through satellite imagery and aerial photography, offers a synoptic view of large areas, capturing various spectral bands that reveal different surface characteristics. This technology is indispensable for identifying geomorphological features such as mountains, valleys, rivers, and coastal zones, as well as monitoring changes over time (Okeke et al., 2019). By providing continuous and consistent data, RS allows geomorphologists to detect patterns and anomalies in landform evolution and assess the impact of natural and anthropogenic factors on the landscape.

GIS complement RS by providing robust tools for spatial analysis, data integration, and visualization. GIS platforms enable the manipulation of RS data along with other spatial datasets, such as topographic maps, geological surveys, and climate records (Egbueri & Igwe, 2020). This integration facilitates a comprehensive analysis of geomorphological characteristics and processes, allowing researchers to model terrain attributes, calculate morphometric parameters, and simulate landscape evolution scenarios. The synergy between RS and GIS enhances the accuracy and efficiency of geomorphological studies, providing valuable insights into the mechanisms driving landform development and change.

LULC dynamics, which refer to the changes in the landscape due to natural processes and human activities, are closely linked to geomorphological processes. Changes in LULC, such as deforestation, urbanization, agriculture, and mining, can significantly alter geomorphological characteristics by influencing erosion rates, sediment transport, and hydrological cycles (Akaolisa et al., 2023). Conversely, geomorphological features and processes can constrain or facilitate certain land use practices. Understanding the reciprocal relationship between LULC dynamics and geomorphology is essential for sustainable land management and environmental planning (Sedano et al., 2019).

The integration of RS and GIS in studying LULC dynamics provides a powerful framework for monitoring and analyzing landscape changes. RS data, through time-series analysis, helps in detecting LULC changes and identifying trends and patterns over time (Rowland & Ebuka, 2024). GIS tools enable the spatial correlation of these changes with geomorphological features, revealing the underlying processes and drivers. The conversion of forested areas to agricultural land can be analyzed in the context of slope stability and soil erosion potential. Similarly, urban expansion can be examined concerning floodplain dynamics and river channel morphology (Igwe et al., 2020).

The analysis of geomorphological characteristics using RS and GIS also plays a vital role in natural hazard assessment and mitigation. Understanding the spatial distribution and evolution of landforms helps in identifying areas prone to hazards such as landslides, floods, and coastal erosion. By mapping and modeling these hazards, researchers can develop risk assessment frameworks and inform policy decisions for disaster risk reduction (Gbadebo et al., 2018; Roy et al., 2019). Moreover, the ability to monitor and predict geomorphological changes contributes to climate change adaptation strategies by identifying vulnerable areas and guiding land use planning.

The primary aim of this study is to evaluate the slope classes in the study area and their impact on LULC distribution. By thoroughly examining the slope data and corresponding LULC types, the research intends to identify areas suitable for agriculture, urban development, and conservation. Additionally, it aims to propose sustainable management practices to optimize land use while ensuring environmental sustainability.

2. Research Area

This research focuses on the geomorphological characteristics of Ihiala, Ogbaru, Onitsha North, and Onitsha South Local Government Areas (LGAs) in Anambra State, Southeastern Nigeria. The study area spans approximately between coordinates 5.815°N to 6.290°N latitude and 6.910°E to 7.190°E longitude as shown in Figure 1. The drainage system of the study area is influenced by the presence of several rivers, including the Niger River, which flows through Ogbaru LGA, and its tributaries. These rivers play a crucial role in the hydrology and land use patterns of the region. The road network, particularly in urban areas like Onitsha North and Onitsha South, is dense and serves as vital transportation corridors linking urban centers and rural settlements.

The study will explore the intricate relationship between rural and urban areas, highlighting how geomorphological features shape land use practices. Urban centers such as Onitsha North and South exhibit intensive development, contrasting with the more rural landscapes of Ihiala and Ogbaru, characterized by agricultural activities and natural vegetation cover. This research will provide valuable insights into sustainable land use planning, environmental management, and infrastructure development in the region.

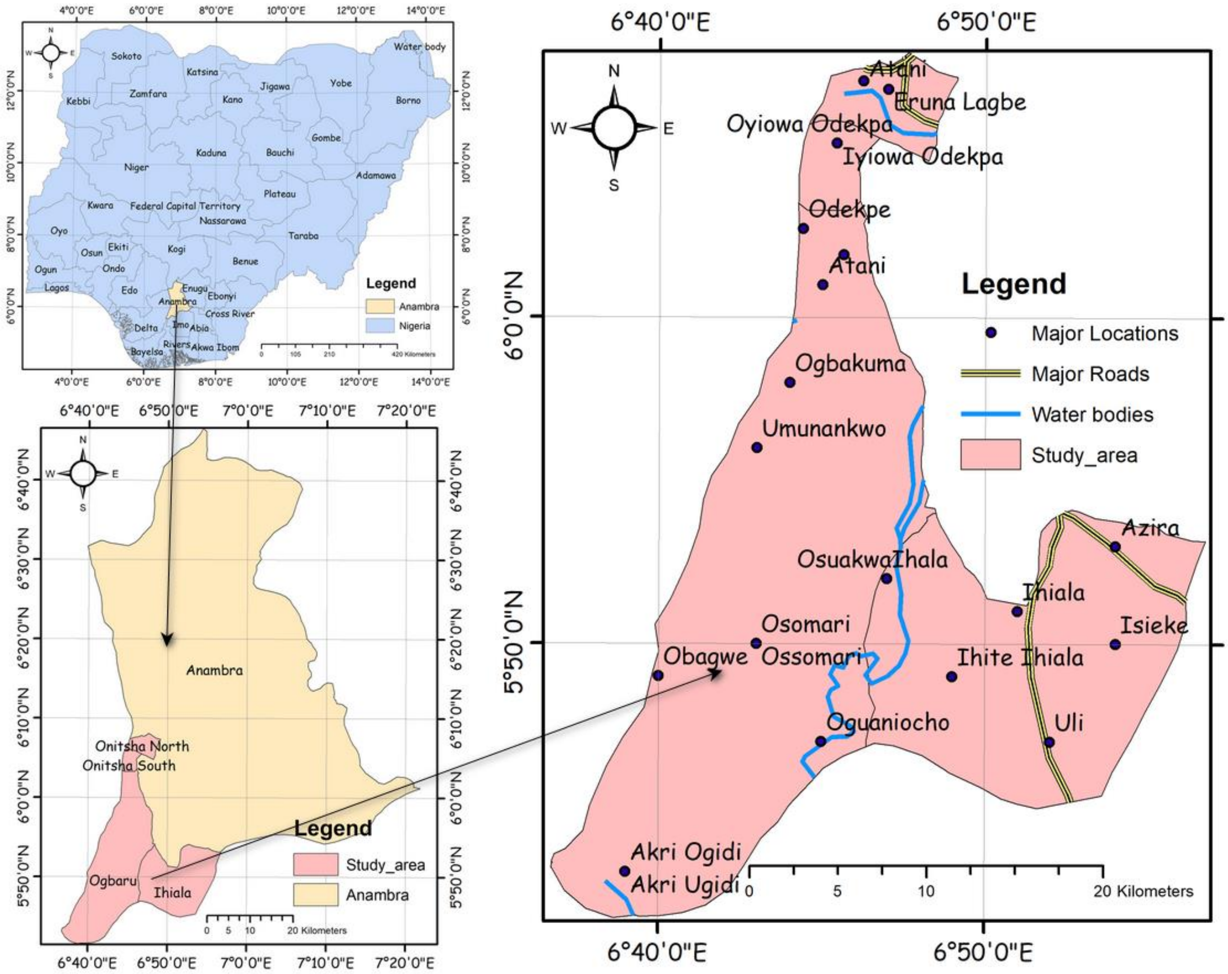

Figure 1: Map of Research area with Anambra state and Nigeria

The geological composition of the study area, illustrated in Figure 2, encompasses a rich variety of formations that significantly contribute to its distinctive landscape features. Among these formations are the Ameki Group and the Ogwashi-Asaba Formation, each with its unique characteristics and geological significance. The Ameki Group, known for its sedimentary deposits, plays a pivotal role in shaping the topography and soil composition of the study area (Ogbe & Osokpor, 2021). These sedimentary rocks, formed over millions of years, provide valuable insights into the geological history and evolution of the region. The Ogwashi-Asaba Formation, characterized by its geological diversity and stratigraphic complexity, further enriches the geological profile of the study area (De Andrade Caxito et al., 2020).

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. Additional data, such as administrative boundaries, hydrological features, and geological maps, were obtained from local government sources and previous studies to support the analysis.

3.2 Data Processing

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

3.2.1 LULC Classification

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

3.2.2 DEM Processing

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

3.2.3 Change Detection

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

3.3 Data Analysis

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

3.3.1 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:

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

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:

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

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.

4. Results and Discussions

4.1 Slope map

The slope data were categorized into five classes: 0 - 1.26 degrees, 1.26 - 1.57 degrees, 1.57 - 2.84 degrees, 2.84 - 7.94 degrees, and 7.94 - 28.51 degrees. Table 2 and Figure 2 illustrate the distribution of these slope classes across the study area.

The analysis reveals that the largest area, 236.13 km², falls within the 1.57 - 2.84 degrees slope range, indicating that the predominant terrain in the region is gently sloping. The next significant area, 179.03 km², consists of slopes ranging from 0 to 1.26 degrees, representing flat to nearly flat terrain. These areas are typically associated with minimal elevation change and are suitable for a variety of land uses. An area of 178.40 km² falls within the 2.84 - 7.94 degrees slope category, indicating moderately steep terrain. The area with slopes ranging from 1.26 to 1.57 degrees is 56.46 km², while the steepest slopes, ranging from 7.94 to 28.51 degrees, cover only 9.42 km².

Table 2: Area of Slope within the study area

Area (km^2)	Slope (^{o})
179.03	0 - 12.6
56.46	1.26 - 1.57
236.13	1.57 - 2.84
178.40	2.84 - 7.94
9.42	7.94 - 28.51

The spatial distribution of slope classes has significant implications for land use planning, agriculture, and environmental management in the study area. The dominance of gentle slopes (1.57 - 2.84 degrees) covering 236.13 km² (approximately 39.2% of the study area) suggests that the region is well-suited for various types of land use, including agriculture, urban development, and infrastructure projects. Gentle slopes generally offer good drainage, moderate runoff, and low erosion risk, making them ideal for farming activities and the construction of residential and commercial structures (Igwe & Una, 2019).

The presence of flat to nearly flat terrain (0 - 1.26 degrees) across 179.03 km² (approximately 29.7% of the study area) further supports the potential for extensive agricultural activities and urban development. These areas are characterized by minimal slope, which facilitates the easy construction of buildings and roads, reduces the cost of land preparation, and minimizes the risk of soil erosion. This flat terrain is particularly advantageous for mechanized agriculture, where large, contiguous tracts of land are preferred for efficient farming operations.

In contrast, the moderately steep slopes (2.84 - 7.94 degrees), covering 178.40 km² (approximately 29.6% of the study area), present different challenges and opportunities. While these areas can still support agricultural activities, they are more susceptible to erosion, especially during heavy rainfall events. Soil conservation measures such as contour plowing, terracing, and the use of cover crops may be necessary to mitigate erosion and maintain soil fertility. These areas may also influence local hydrology by increasing surface runoff, which can lead to flooding downstream (Amah et al., 2021). Therefore, proper water management practices are essential to prevent negative impacts on agricultural productivity and water quality.

The smaller area with slopes ranging from 1.26 to 1.57 degrees, covering 56.46 km² (approximately 9.4% of the study area), indicates a transition between flat and moderately steep terrain. These slopes are still relatively gentle but may require some soil conservation practices to prevent erosion. This slope class represents areas that could potentially support a mix of land uses, including agriculture and low-density residential development, without significant risk of environmental degradation.

The steepest slopes (7.94 - 28.51 degrees), covering only 9.42 km² (approximately 1.6% of the study area), are the most prone to erosion and landslides. Development in these areas is challenging due to the steep gradient, which increases construction costs and the risk of structural instability. These areas are typically best left under natural vegetation or managed as forested land to stabilize the soil and prevent erosion. Preserving these steep areas as natural landscapes also contributes to biodiversity conservation and the maintenance of ecosystem services, such as water regulation and carbon sequestration.

The quantitative analysis of slope distribution provides a comprehensive understanding of the geomorphological characteristics of the study area. The predominance of gentle slopes (1.57 - 2.84 degrees) and flat terrain (0 - 1.26 degrees) indicates favorable conditions for agriculture and development. However, the presence of moderately steep slopes (2.84 - 7.94 degrees) and steep terrain (7.94 - 28.51 degrees) highlights the need for targeted soil conservation measures and careful land management practices to prevent environmental degradation and ensure sustainable land use.

4.2 Land Use/Land Cover Analysis for 2017

The data, summarized in Table 3 and visualized in Figure 3, indicate significant areas covered by trees, built areas, rangeland, crops, water bodies, bare ground, and flooded vegetation.

Table 3: LULC 2017 Distribution in the Study Area

LULC Type 2017	Area (km²)
Water	27.02
Trees	394.16
Flooded vegetation	1.64
Crops	31.70
Built Area	134.43
Bare ground	5.00
Rangeland	70.17

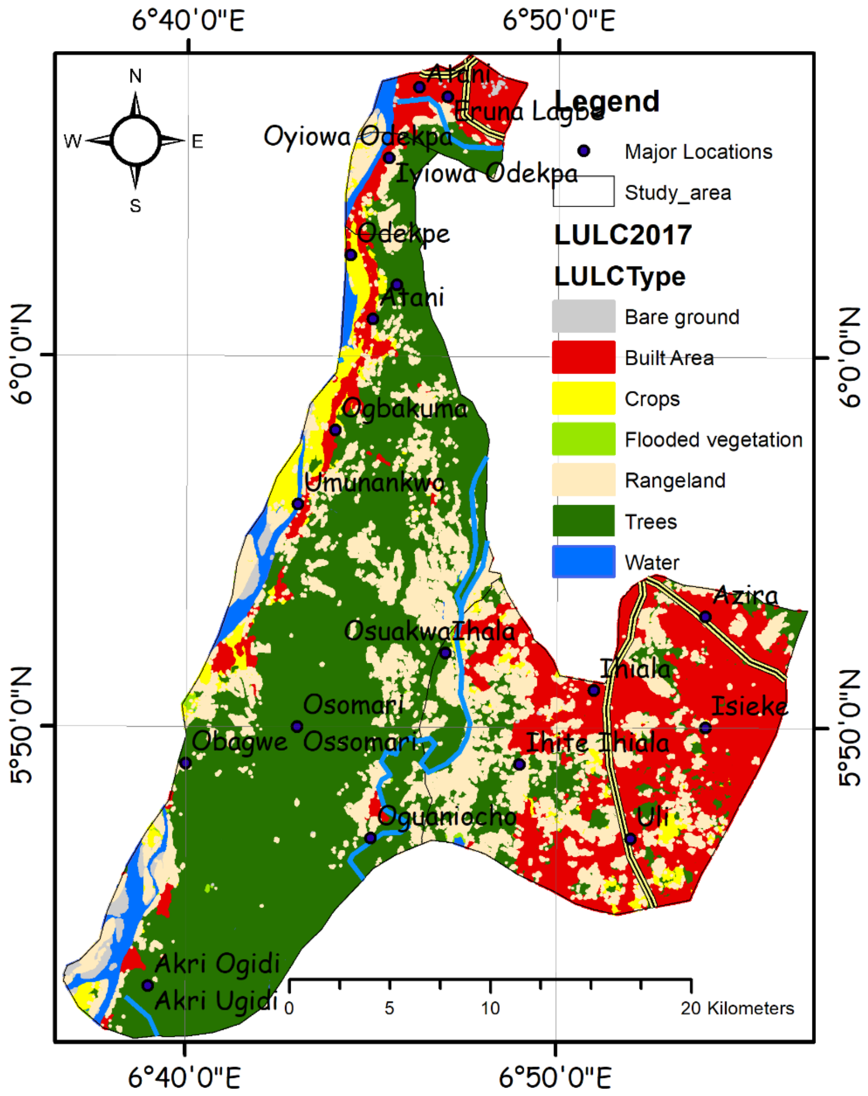

Figure 3: Spatial Distribution of LULC Types in the Study Area

The most extensive land cover type in the study area is trees, occupying 394.16 km². This significant tree coverage suggests that a large portion of the area remains under natural or semi-natural forest cover, which plays a crucial role in maintaining ecological balance, supporting biodiversity, and regulating the local climate. The presence of extensive tree cover also indicates potential areas for forestry activities and conservation efforts aimed at preserving natural habitats and protecting wildlife.

Built areas cover 134.43 km², reflecting the extent of urbanization and human settlement within the study area. This substantial built-up area signifies the region's development and infrastructural growth. The concentration of built areas highlights the need for effective urban planning and management strategies to ensure sustainable development, prevent urban sprawl, and mitigate the environmental impacts associated with urbanization, such as increased surface runoff, reduced groundwater recharge, and heat island effects (Simwanda et al., 2019).

Rangeland, covering 70.17 km², represents another significant land cover type. Rangelands are typically used for grazing livestock and can play an essential role in the local economy, especially in rural areas where agriculture and livestock rearing are predominant activities. The presence of substantial rangeland indicates areas where sustainable grazing practices can be implemented to prevent overgrazing, soil degradation, and loss of biodiversity. Effective management of these rangelands is crucial to maintaining their productivity and ecological health.

Crops cover 31.70 km² of the study area, highlighting the region's agricultural activities. Agricultural land use is vital for food production and local livelihoods. However, the relatively small area under crops compared to other land cover types suggests that agriculture might be concentrated in specific zones or that the region's agricultural practices are integrated with other land uses, such as agroforestry or mixed farming systems. Promoting sustainable agricultural practices, such as crop rotation, organic farming, and soil conservation techniques, can enhance food security and environmental sustainability.

Water bodies occupy 27.02 km², reflecting the presence of rivers, lakes, ponds, and other aquatic ecosystems within the study area. These water bodies are critical for maintaining local hydrology, supporting aquatic biodiversity, and providing water resources for domestic, agricultural, and industrial use. Protecting and managing these water resources is essential to prevent pollution, over-extraction, and habitat degradation, ensuring the availability of clean water for various uses(Hassan et al., 2019).

Bare ground, covering 5.00 km², indicates areas with little or no vegetation cover. These areas may include exposed soil, rocky terrain, or degraded lands. Bare ground can be highly susceptible to erosion, especially during heavy rainfall events, leading to soil loss and sedimentation in nearby water bodies. Implementing soil conservation measures, such as reforestation, afforestation, and erosion control practices, can help stabilize these areas and prevent further degradation.

Flooded vegetation, occupying the smallest area of 1.64 km², represents regions that are seasonally or permanently inundated with water, supporting specific plant species adapted to wet conditions. These areas can provide valuable ecosystem services, such as flood regulation, water filtration, and habitat for aquatic and semi-aquatic species. Conserving flooded vegetation is crucial for maintaining these ecosystem services and supporting biodiversity in wetland habitats.

The diverse LULC 2017 distribution within the study area highlights the need for an integrated land management approach that balances development, agricultural productivity, and environmental conservation. The dominance of tree cover and built areas underscores the importance of protecting natural forests while accommodating urban growth through sustainable planning practices. Enhancing green infrastructure within urban areas, such as parks, green roofs, and urban forests, can mitigate some of the adverse effects of urbanization and improve the quality of life for residents.

Agricultural land, although covering a smaller area, remains crucial for local food security and livelihoods. Encouraging sustainable agricultural practices and supporting small-scale farmers through training, access to resources, and market opportunities can enhance agricultural productivity and sustainability. Rangelands should be managed to support livestock production without degrading the land, ensuring long-term productivity and ecological balance.

Water bodies and flooded vegetation play essential roles in maintaining the local hydrology and supporting biodiversity. Protecting these areas from pollution, over-extraction, and habitat destruction is vital for sustaining water resources and the health of aquatic ecosystems (Idowu & Zhou, 2019). Implementing integrated watershed management practices can help safeguard these water resources and enhance their resilience to climate change and other environmental pressures.

4.3 Land Use/Land Cover Analysis for 2023

The data, as shown in Table 4 and visualized in Figure 5, provide a detailed understanding of the spatial distribution of these land cover types and their implications for land use planning, resource management, and environmental conservation.

Table 4: LULC Distribution in the Study Area for 2023

Area (km²)	LULC Type 2023
27.996	Water
336.840	Trees
0.141	Flooded vegetation
62.066	Crops
156.902	Built Area
4.388	Bare ground
75.780	Rangeland

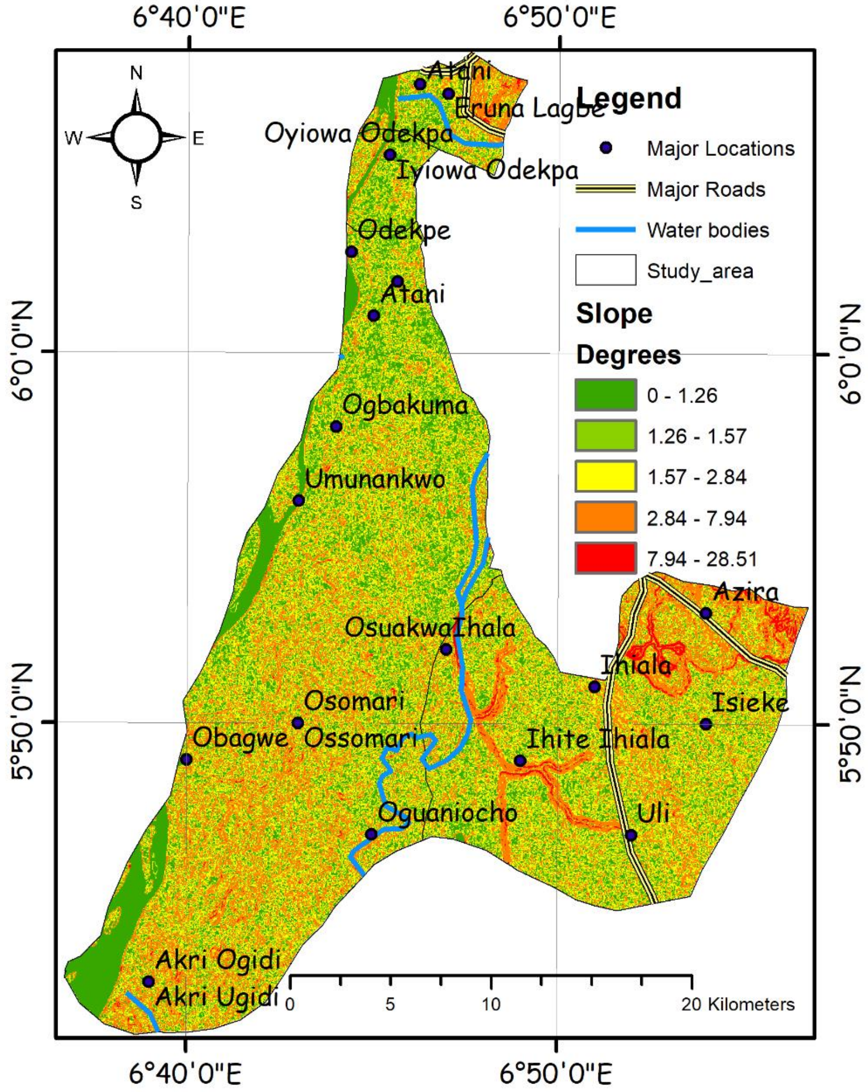

Figure 4: Spatial Distribution of LULC Types in the Study Area for 2023

The largest land cover type identified in the study area for 2023 is trees, which occupy 336.840 km². This significant tree cover indicates that a substantial portion of the region remains under natural or semi-natural forest, which is crucial for biodiversity conservation, carbon sequestration, and climate regulation. Forests play a vital role in maintaining ecological balance, providing habitat for numerous species, and supporting ecosystem services such as soil stabilization and water regulation (Onyia et al., 2018).

Built areas cover 156.902 km², reflecting extensive urbanization and infrastructure development. The expansion of built areas signifies the region's ongoing development and the growth of human settlements. This trend underscores the importance of sustainable urban planning and management to address challenges associated with urban sprawl, such as increased surface runoff, reduced green spaces, and potential impacts on local microclimates. Effective urban planning should incorporate green infrastructure, zoning regulations, and sustainable building practices to mitigate these challenges.

Rangeland occupies 75.780 km², representing areas primarily used for grazing livestock. Rangelands are essential for supporting the livelihoods of rural communities that depend on livestock farming. Sustainable management practices, such as rotational grazing and the maintenance of native vegetation, are crucial to prevent overgrazing, soil degradation, and loss of biodiversity. Rangelands also serve as critical habitats for various wildlife species and play a role in maintaining ecological connectivity across the landscape.

Crops cover 62.066 km², indicating the extent of agricultural activities within the study area. Agriculture is a vital sector for local food security and the economy. The presence of cultivated land suggests the importance of promoting sustainable agricultural practices to enhance productivity while minimizing environmental impacts. Practices such as crop rotation, conservation tillage, and the use of organic fertilizers can improve soil health, reduce erosion, and enhance resilience to climate change.

Water bodies, including rivers, lakes, and ponds, occupy 27.996 km². These aquatic ecosystems are crucial for maintaining local hydrology, supporting biodiversity, and providing water resources for domestic, agricultural, and industrial use. Protecting and managing these water bodies is essential to prevent pollution, over-extraction, and habitat degradation. Integrated watershed management approaches can help maintain water quality and ensure the sustainability of water resources.

Bare ground covers 4.388 km², indicating areas with little or no vegetation. These areas may be characterized by exposed soil, rocky terrain, or degraded land. Bare ground is highly susceptible to erosion, especially during heavy rainfall events, which can lead to significant soil loss and sedimentation in nearby water bodies. Reclamation and revegetation efforts, such as planting native vegetation and implementing erosion control measures, are necessary to stabilize these areas and prevent further environmental degradation.

Flooded vegetation, occupying 0.141 km², represents regions that are seasonally or permanently inundated with water, supporting specific plant species adapted to wet conditions. Although this is the smallest land cover type in the study area, flooded vegetation provides valuable ecosystem services, including flood regulation, water filtration, and habitat for aquatic and semi-aquatic species. Conserving these areas is critical for maintaining their ecological functions and supporting biodiversity in wetland habitats.

The spatial distribution of LULC types in 2023 highlights the dynamic and diverse nature of the study area. The predominance of tree cover suggests a strong natural component in the landscape, which is beneficial for ecological stability and environmental health. However, the significant extent of built areas and agricultural land points to ongoing development and land use changes that require careful management to balance economic growth with environmental sustainability.

4.4 Geological Implications of Slope and Land Use/Land Cover Dynamics

The spatial distribution of slopes and LULC types provides critical insights into the region's suitability for various land uses, potential risks, and opportunities for sustainable development. The slope data reveal a landscape predominantly characterized by gentle slopes. Areas with slopes between 1.57 - 2.84 degrees are the most extensive, covering 236.13 km², followed by areas with slopes from 0 - 1.26 degrees, which cover 179.03 km². These gentle slopes are generally conducive to agriculture, urban development, and infrastructure projects due to their minimal elevation changes, which reduce the risk of soil erosion and construction challenges. The significant coverage of gentle slopes correlates with the extensive areas of trees (336.84 km² in 2023 and 394.16 km² in previous years), indicating that forested regions are located on stable, low-gradient terrain. This stability is crucial for maintaining forest health, supporting biodiversity, and providing ecosystem services such as carbon sequestration and soil stabilization.

Built areas, which cover 156.902 km² in 2023, are also predominantly situated on gentle to moderate slopes. Urban expansion in these areas is facilitated by the favorable topography, which supports the construction of buildings and infrastructure with lower risk of landslides and reduced engineering costs (Igwe & Umbugadu, 2020). However, the increase in built areas from previous years (134.43 km²) highlights the need for sustainable urban planning to manage urban sprawl and its environmental impacts. Proper planning is essential to mitigate issues such as increased surface runoff, reduced groundwater recharge, and the heat island effect.

Agricultural activities, represented by crops covering 62.066 km² in 2023, are primarily located on flat to gently sloping terrain. This distribution is advantageous for farming, as gentle slopes facilitate mechanized agriculture, improve water retention, and minimize soil erosion. The increase in agricultural land from previous years (31.70 km²) indicates a growing emphasis on food production. Sustainable farming practices, such as crop rotation, conservation tillage, and organic farming, should be promoted to maintain soil fertility and environmental health.

Rangeland, which covers 75.780 km² in 2023, is found on a mix of gentle and moderate slopes. These areas are suitable for grazing livestock, providing essential resources for rural communities. Sustainable rangeland management practices, such as rotational grazing and maintaining native vegetation, are necessary to prevent overgrazing and soil degradation.

Water bodies, including rivers, lakes, and ponds, cover 27.996 km² in 2023. These aquatic ecosystems are crucial for maintaining local hydrology, supporting biodiversity, and providing water resources for various uses. The relatively stable area of water bodies (27.02 km² in previous years) suggests effective management and conservation efforts. Protecting these water bodies from pollution and over-extraction is essential to ensure their sustainability.

Flooded vegetation, although occupying a small area (0.141 km² in 2023), represents critical wetland habitats that provide flood regulation, water filtration, and habitat for aquatic species. The slight increase from previous years (1.64 km²) indicates the need for continued conservation efforts to protect these valuable ecosystems.

Bare ground, covering 4.388 km² in 2023, and 5.00 km² in previous years, indicates areas with minimal vegetation, which are susceptible to erosion. Reclamation and revegetation efforts are necessary to stabilize these areas and prevent further degradation.

The integration of slope and LULC data reveals a landscape well-suited for diverse land uses, including forestry, agriculture, and urban development, while highlighting the need for sustainable management practices. Gentle slopes facilitate various land uses, while steeper areas require careful management to prevent erosion and environmental degradation. The data underscore the importance of balancing development with conservation to ensure the long-term sustainability of the region's natural resources and ecosystem services.

5. Conclusion

The comprehensive analysis of slope and LULC data in the study area reveals significant insights into the geomorphological characteristics and their implications for sustainable development and environmental management. The slope data were classified into five categories: 0-1.26 degrees, 1.26-1.57 degrees, 1.57-2.84 degrees, 2.84-7.94 degrees, and 7.94-28.51 degrees. The predominant slope class is 1.57-2.84 degrees, covering 236.13 km², which indicates that the region's terrain is mostly gently sloping.

Flat to nearly flat terrain (0-1.26 degrees) encompasses 179.03 km², which is also substantial. These areas are associated with minimal elevation changes and are highly suitable for diverse land uses, including agriculture and urban development. These areas benefit from easy construction, low preparation costs, and minimal erosion risk, making them ideal for mechanized agriculture and extensive urban development.

Moderately steep slopes (2.84-7.94 degrees), covering 178.40 km², pose challenges such as erosion susceptibility, especially during heavy rainfall. However, with appropriate soil conservation measures like contour plowing, terracing, and cover crops, these areas can still support agriculture. Proper water management practices are also crucial to prevent flooding downstream and maintain agricultural productivity and water quality.

The 1.26-1.57 degrees slope class, covering 56.46 km², serves as a transition between flat and moderately steep terrain. These areas are relatively gentle and can support mixed land uses, including agriculture and low-density residential development, with some soil conservation efforts.

The steepest slopes (7.94-28.51 degrees), covering 9.42 km², are highly prone to erosion and landslides. Development in these areas is challenging and costly due to the steep gradient. These areas are best managed as natural vegetation or forested land to stabilize soil and prevent erosion, contributing to biodiversity conservation and ecosystem services like water regulation and carbon sequestration.

The LULC data from 2017 and 2023 provide a detailed view of land cover changes and their implications. In 2017, trees covered 394.16 km², built areas covered 134.43 km², rangeland covered 70.17 km², and crops covered 31.70 km². By 2023, tree cover had decreased to 336.84 km², built areas had increased to 156.90 km², rangeland had expanded to 75.78 km², and crop areas had grown to 62.07 km².

The extensive tree cover in both years highlights the importance of maintaining ecological balance, supporting biodiversity, and regulating the local climate. The reduction in tree cover indicates potential deforestation or land conversion, emphasizing the need for conservation efforts.

The increase in built areas reflects urbanization and human settlement expansion. This trend underscores the importance of effective urban planning and management strategies to prevent urban sprawl and mitigate the environmental impacts of urbanization.

Rangeland expansion indicates a growing reliance on grazing livestock, necessitating sustainable management practices to prevent overgrazing, soil degradation, and biodiversity loss. The significant increase in crop areas from 31.70 km² to 62.07 km² highlights the region's agricultural activities and the need for sustainable agricultural practices to enhance food security and environmental sustainability.

Other land cover types, such as water bodies, bare ground, and flooded vegetation, play essential roles in maintaining local hydrology, supporting biodiversity, and providing water resources for various uses.

In conclusion, the slope and LULC data analysis provides critical insights for sustainable land use planning and environmental management in the study area. The findings highlight areas suitable for agriculture, urban development, and conservation while emphasizing the need for targeted soil conservation measures and careful land management practices to prevent environmental degradation and ensure sustainable development.

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