Temporal Analysis of Land Use, Land Cover, and Slope Variation in Rivers State, Nigeria: A Study from 2017 to 2023

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ABSTRACT

The landscape of Rivers State, South South, Nigeria, has been undergoing significant transformations over the past years, driven by various socio-economic and environmental factors. Monitoring these changes is crucial for sustainable development and resource management. This study focuses on analyzing the temporal variations in land use and land cover (LULC) from 2017 to 2023, along with evaluating slope variations using Digital Elevation Model (DEM) data. The primary aim of this study is to understand the spatial-temporal dynamics of LULC and slope variations in the study area, providing insights into landscape transformations and their implications for sustainable development. The study utilizes DEM data and satellite imagery to perform a detailed analysis of slope variations and LULC changes over the specified period. The slope data is categorized into five distinct classes, while the LULC analysis identifies changes in categories such as water bodies, tree cover, flooded vegetation, cropland, built-up areas, bare ground, and rangeland. The slope analysis reveals that the majority of the study area has low to moderate slopes, with the largest area (599.58 km²) falling within the 1.76 to 3.13 degrees range. LULC analysis shows a significant decrease in tree cover from 1189.98 km² in 2017 to 1030.59 km² in 2023, a substantial increase in built-up areas from 271.40 km² to 346.22 km², and a notable rise in cropland from 51.06 km² to 103.27 km². Water bodies increased from 23.91 km² to 28.48 km², while flooded vegetation slightly decreased from 98.90 km² to 88.45 km². Bare ground significantly decreased from 5.64 km² to 0.43 km², indicating successful land rehabilitation efforts. Rangeland also increased from 48.56 km² to 91.95 km². The predominance of gentle slopes in the study area facilitates diverse land use practices, particularly agriculture and urban development. However, the expansion of built-up areas and the decrease in tree cover suggest ongoing deforestation and urban sprawl, necessitating effective land use planning and conservation strategies. The increase in cropland reflects agricultural intensification, while the significant reduction in bare ground highlights successful land restoration efforts. The study provides a comprehensive understanding of the topographic and LULC dynamics in Rivers State, underscoring the need for integrated land management approaches. The findings emphasize the importance of balancing development with environmental conservation to ensure sustainable use of resources. This study offers a detailed temporal analysis of LULC and slope variations in Rivers State, providing valuable insights into landscape dynamics and their implications for sustainable development. The use of DEM data for slope analysis combined with LULC monitoring over six years provides a robust framework for understanding environmental changes and informing policy decisions.

Keywords: Digital Elevation Model (DEM), Rivers State, Nigeria, Slope Variation, Sustainable Development, Temporal Analysis

INTRODUCTION

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

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

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

Temporal analysis involves studying how LULC and slope variations change over time and understanding their impacts on hydrology. This analysis is crucial for understanding the spatial and temporal dynamics of land cover changes and their implications for hydrological processes (Nwacholundu et al., 2021). By examining data from different time periods, researchers can identify trends, patterns, and rates of change in land cover and slope, providing insights into how these factors influence water resources.

LULC data can be derived from various sources, including satellite imagery, aerial photography, and ground surveys. Advances in remote sensing and Geographic Information Systems (GIS) have significantly enhanced the accuracy and efficiency of LULC analysis, enabling detailed monitoring of land cover changes over large areas and extended periods (Wang & Maduako, 2018). These technologies allow for the precise mapping of land cover and slope variations, facilitating the analysis of temporal changes and their impacts on hydrological processes.

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

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

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

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

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

The aim of this study is to analyze the changes in land use and land cover from 2017 to 2023 and to evaluate the slope variations using Digital Elevation Model (DEM) data in part of Rivers State, South South, Nigeria. This research intends to understand the spatial-temporal dynamics in the study area, providing insights into landscape transformations and their implications for sustainable development and resource management.

Research Area and Geology

The Local Government Areas (LGAs) of Emuoha, Ikwerre, and Obio Akpor, located in Rivers State, South-South Nigeria, are areas of significant geological interest. Positioned between latitudes 4°45'N to 5°15'N and longitudes 6°45'E to 7°15'E, these regions encompass a blend of urban and rural landscapes as shown in Figure 1. The geology of these areas is crucial for understanding their natural resources, particularly their hydrocarbon potential and groundwater systems.

The geology of Emuoha, Ikwerre, and Obio Akpor is shaped by their location within the Niger Delta Basin, renowned for its extensive petroleum and natural gas reserves. The region's geological formations are primarily sedimentary, indicative of the deltaic depositional environment. The stratigraphy of this area includes the Benin Formation, Agbada Formation, and Akata Formation, each with unique lithological characteristics and geological significance.

The Benin Formation, dating from the Miocene to the present, is predominantly composed of continental sands and gravels with minor clay intercalations. This formation is the most extensive and youngest unit in the Niger Delta Basin, characterized by high porosity and permeability, making it a significant aquifer system for groundwater extraction.

The Agbada Formation, ranging from the Eocene to Miocene, consists of alternating sequences of sandstones and shales. The upper sections of this formation are more sandstone-rich, while the lower sections contain more shale. This formation is crucial for hydrocarbon exploration, as it contains the majority of the petroleum reservoirs in the Niger Delta. The sandstones within the Agbada Formation have excellent reservoir properties, making them ideal for oil and gas accumulation.

The Akata Formation, spanning from the Paleocene to the present, is primarily composed of marine shales with occasional sandstones and siltstones. This formation serves as the main source rock for hydrocarbons in the Niger Delta. The thick shale sequences are essential for generating and expelling hydrocarbons, playing a vital role in the region's hydrocarbon system.

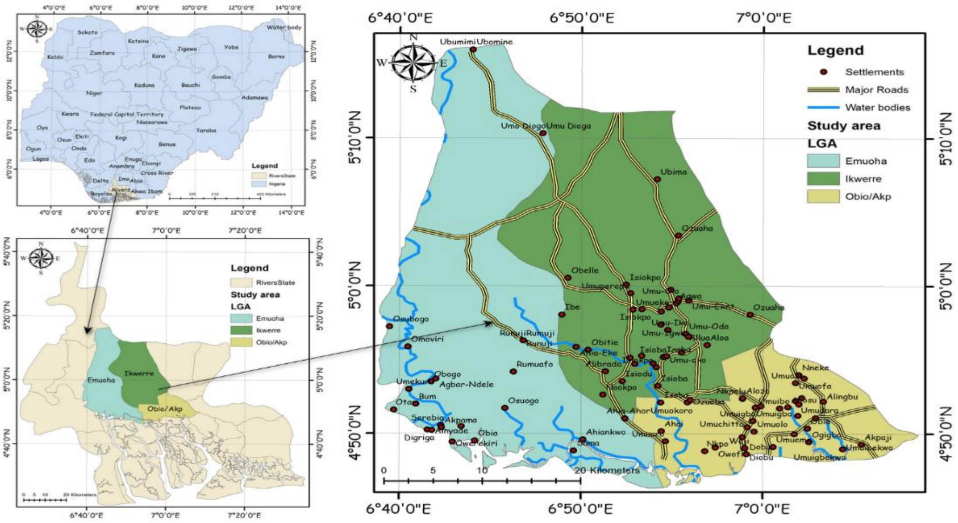

Figure 1: Map of the study area

The hydrogeology of Emuoha, Ikwerre, and Obio Akpor is significantly influenced by the Benin Formation, which serves as the primary aquifer in the region. Groundwater is found at varying depths, typically within the upper 100 meters, where the sands and gravels provide substantial storage and transmissivity. The region benefits from abundant groundwater resources due to the high porosity and permeability of the Benin Formation sands. The quality of groundwater is generally good, making it suitable for domestic, agricultural, and industrial uses. However, some areas may experience contamination from human activities and industrial operations.

The intricate network of rivers and creeks in the region, which are part of the Niger Delta system, plays a crucial role in recharging the aquifers. The interaction between surface water and groundwater is complex but essential for maintaining the hydrological balance. This surface water-groundwater interaction ensures the sustainability of water resources, which are vital for the region’s socio-economic development.

The geological formations in Emuoha, Ikwerre, and Obio Akpor have significant environmental and economic importance. The Benin Formation, with its extensive aquifer systems, supports agriculture and provides essential water resources for domestic use. The fertile soils overlying the Benin Formation are ideal for agriculture, and the availability of groundwater for irrigation enhances agricultural productivity in the region.

The Agbada and Akata formations are critical for hydrocarbon exploration. The alternating sand and shale sequences in the Agbada Formation create excellent reservoir and seal conditions, essential for hydrocarbon accumulation. The Akata Formation, serving as the main source rock, generates and expels hydrocarbons, contributing to the region's status as a major oil and gas producer.

The LGAs of Emuoha, Ikwerre, and Obio Akpor in Rivers State are geologically significant areas within the Niger Delta Basin. The Benin, Agbada, and Akata formations play crucial roles in hydrocarbon exploration and groundwater availability. Understanding the geology and hydrogeology of these areas is essential for sustainable resource management and economic development. Detailed geological studies and continuous monitoring are vital for harnessing the region’s potential while mitigating environmental impacts. By leveraging the geological characteristics of Emuoha, Ikwerre, and Obio Akpor, policymakers and stakeholders can develop effective strategies for sustainable development and resource utilization.

METHODOLOGY

Data Acquisition

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

Table 1: Data Sources

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

The primary data sources include high-resolution satellite imagery obtained from the USGS Earth Explorer platform. This platform provides detailed views of LULC changes over the selected time period. Historical LULC data from the USGS classify land into categories such as agricultural land, forests, urban areas, and water bodies. Shuttle Radar Topography Mission (SRTM) elevation data provide a Digital Elevation Model (DEM) of the study area, essential for analyzing terrain features, including slope and drainage density (Akaolisa et al., 2023). Additional data, such as administrative boundaries, hydrological features, and geological maps, were obtained from local government sources and previous studies to support the analysis.

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.

LULC Classification

The preprocessing of satellite images involved radiometric and geometric corrections to ensure accuracy. Once preprocessed, the images were classified into different LULC categories using supervised classification techniques. Training samples representing various land cover types (e.g., vegetation, water, urban areas) were collected. A maximum likelihood classifier was applied to classify the images based on these training samples. The classification accuracy was assessed using ground truth data and accuracy metrics such as the Kappa coefficient, which measures the agreement between classified data and reference data.

DEM Processing

The SRTM DEM data were processed to derive slope and drainage density. The slope was calculated using the slope tool in ArcGIS, which computes the maximum rate of change in elevation for each DEM cell (Okoli et al., 2024). Drainage density was calculated by delineating the drainage network from the DEM using the hydrology toolset in ArcGIS. This toolset includes processes such as flow direction, flow accumulation, and stream network delineation. These analyses help in understanding the terrain and hydrological characteristics of the study area, which are crucial for environmental impact assessments.

Change Detection

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

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.

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:

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

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

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

LULC Change Analysis

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

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

where $LULC_{2023}$ and $LULC_{2017}$ represent the areas of each land cover type in 2023 and 2017, respectively. The changes were visualized using maps and statistical summaries to identify trends and patterns in land use dynamics. This analysis is critical for understanding the impacts of human activities on the environment and for developing strategies for sustainable land management.

Integration and Impact Assessment

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

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

RESULTS AND DISCUSSION

Slope Analysis

The slope analysis of the study area in part of Rivers State, South South, Nigeria, reveals a diverse range of slope categories, which significantly impact land use, land cover, and potential developmental activities. The slope data is categorized into five distinct classes, as shown in Table 2.

Table 2: Slope Distribution in the Study Area

Slope (Degree)	Area (Km²)
0 - 1.36	465.80
1.36 - 1.76	224.72
1.76 - 3.13	599.58
3.13 - 7.72	377.32
7.72 - 23.19	13.07

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In examining the slope categories, it becomes apparent that the majority of the study area is characterized by relatively low to moderate slopes. This has significant implications for various land use practices and environmental processes within the region.

The area with slopes ranging from 0 to 1.36 degrees covers 465.80 km², which represents a substantial portion of the study area. This category indicates nearly flat terrain, which is highly suitable for agricultural activities, settlement, and infrastructure development. The gentle slope minimizes the risk of soil erosion and makes it easier for construction and mechanized farming. The dominance of this slope class suggests that a significant part of the landscape is under minimal topographic constraint, thus offering extensive opportunities for various land uses without major engineering challenges.

Slopes ranging from 1.36 to 1.76 degrees cover 224.72 km² of the study area. While slightly steeper than the 0 - 1.36 degrees category, these slopes still represent gentle terrain conducive to similar uses. The slight increase in slope might require more attention to water drainage and soil conservation practices to prevent erosion, but overall, the land remains favorable for agricultural and developmental activities. This slope range may also support some forms of semi-intensive agriculture, where slight undulations in the landscape can aid in natural drainage.

The largest area, 599.58 km², falls within the slope range of 1.76 to 3.13 degrees. This moderate slope category suggests a landscape that is more varied and potentially more challenging for certain types of land use, especially extensive agriculture or large-scale infrastructure projects. However, these slopes can be advantageous for certain crops that benefit from better drainage and may also be suitable for terracing, a traditional method of farming on sloped land. The prevalence of this slope range indicates a need for more detailed land use planning to ensure sustainable development and to mitigate potential erosion.

The 3.13 to 7.72 degrees slope category encompasses 377.32 km². These steeper slopes are less suitable for large-scale agriculture but can be ideal for certain types of horticulture, viticulture, or forestry. The steeper terrain might also provide opportunities for recreational activities and conservation areas. However, development in these areas would require significant consideration of erosion control and water management. Engineering solutions for construction on these slopes would need to address stability and access issues.

The smallest area, 13.07 km², is characterized by slopes ranging from 7.72 to 23.19 degrees. These steep slopes are generally unsuitable for agriculture or conventional development without substantial modification and engineering intervention. These areas are most likely to be left in their natural state or used for purposes that do not require extensive alteration of the landscape, such as conservation, wildlife habitat, or certain types of recreation. The presence of these steep slopes, although minimal in area, highlights the importance of maintaining natural vegetation to prevent landslides and soil erosion.

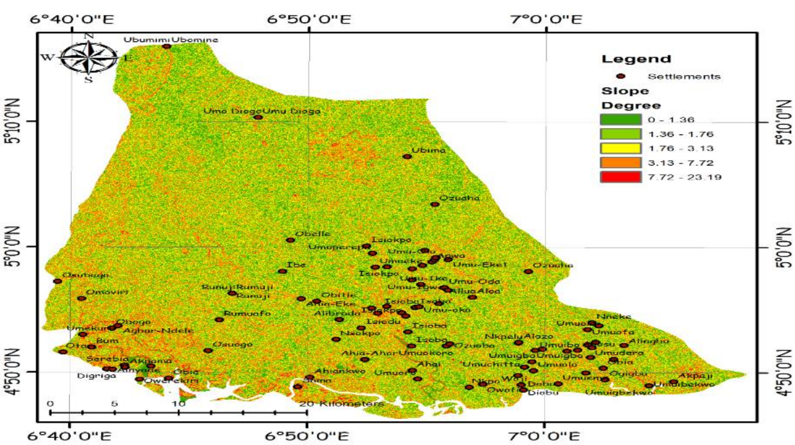

Figure 2: Slope Distribution Map of the Study Area

The slope analysis, as shown in Table 2 and Figure 2, provides a comprehensive understanding of the topographic variation within the study area. The predominance of gentle to moderate slopes indicates a landscape with significant potential for diverse land use applications, from agriculture to urban development. However, the presence of steeper slopes, although limited in extent, necessitates careful planning and management to prevent environmental degradation.

Land Use and Land Cover Analysis for 2017

The land use and land cover (LULC) analysis for 2017 in the study area, part of Rivers State, South South, Nigeria, reveals significant insights into the spatial distribution of various land cover types. Table 3 provides a detailed summary of the different LULC categories and their respective areas.

Table 3: Land Use and Land Cover (LULC) Distribution in 2017

LULC Type	Area (Km^2)
Water	23.91
Trees	1189.98
Flooded vegetation	98.90
Crops	51.06
Built Area	271.40
Bare ground	5.64
Rangeland	48.56

The dominant land cover type in 2017 was trees, covering an extensive area of 1189.98 km^2. This substantial forest cover indicates that a large portion of the study area is characterized by dense vegetation, which plays a crucial role in maintaining ecological balance, supporting biodiversity, and providing resources for local communities. The prevalence of tree cover also suggests that the area may have substantial carbon sequestration potential, which is significant for climate change mitigation efforts.

Water bodies occupied 23.91 km^2 of the study area. The presence of water bodies, although relatively limited in extent, is vital for supporting aquatic ecosystems and providing water resources for both human consumption and agricultural activities. These water bodies also contribute to the overall landscape diversity and are essential for maintaining hydrological balance within the region.

Flooded vegetation covered 98.90 km^2, indicating areas that are periodically or permanently inundated with water. This type of land cover is often associated with wetlands, which are critical for water filtration, flood control, and serving as habitats for various species of flora and fauna. The existence of such vegetation highlights the importance of wetland conservation in the study area, considering their ecological functions and benefits.

Crops occupied 51.06 km^2 of the study area. Agricultural activities are a significant component of land use, reflecting the region's dependence on farming for livelihoods and food security. The extent of cropland indicates the presence of arable land suitable for cultivation, although it also underscores the need for sustainable agricultural practices to prevent soil degradation and ensure long-term productivity.

Built-up areas covered 271.40 km^2, indicating the extent of urbanization and infrastructure development within the region. This significant built-up area reflects the level of urban expansion, industrial activities, and population density. The spread of built-up areas necessitates careful urban planning to balance development with environmental sustainability and to address potential issues such as habitat loss, pollution, and increased demand for resources.

Bare ground, which includes areas with little to no vegetation cover, accounted for 5.64 km^2. These areas might

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represent lands that have been cleared for construction, mining activities, or other human interventions. The presence of bare ground is often a concern as it can lead to increased soil erosion, reduced soil fertility, and loss of biodiversity. Effective land management practices are needed to rehabilitate these areas and restore their ecological functions.

Rangelands covered 48.56 km², providing grazing areas for livestock and supporting pastoral activities. Rangelands are essential for the livelihoods of pastoral communities and contribute to the agricultural economy. However, overgrazing and improper management can lead to land degradation, making it important to implement sustainable grazing practices to maintain the health of these ecosystems.

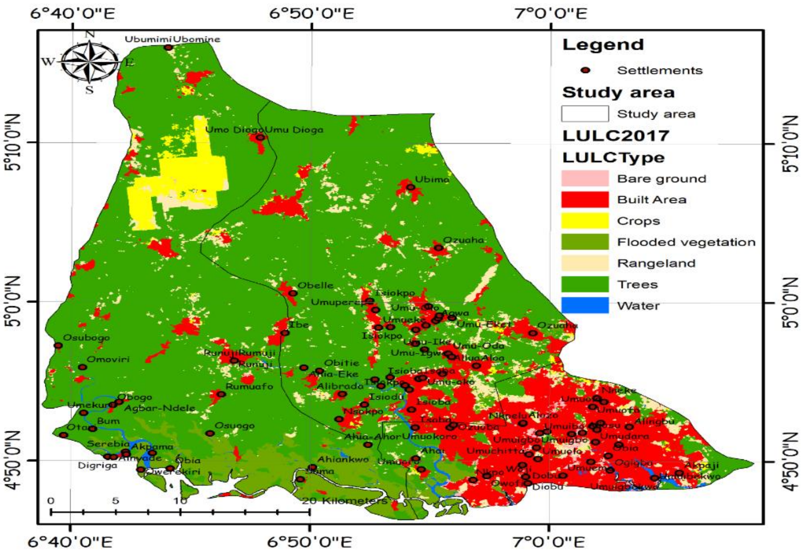

Figure 3: LULC Map of the Study Area in 2017

The land use and land cover distribution in 2017, as depicted in Table 3 and illustrated in Figure 3, reflects a complex mosaic of natural and human-modified landscapes. The dominance of tree cover and the presence of various other land cover types indicate a diverse environment with multiple land use practices. The findings emphasize the need for integrated land management approaches that consider the interplay between different land cover types and their associated ecological, economic, and social functions.

Land Use and Land Cover Analysis for 2023

The land use and land cover (LULC) analysis for 2023 in the study area of Rivers State, South South, Nigeria, provides insights into the evolving landscape and land management practices over the recent years. Table 34summarizes the distribution of different land cover types and their respective areas in 2023.

Table 4: Land Use and Land Cover (LULC) Distribution in 2023

LULC Type	Area (Km²)
Water	28.48
Trees	1030.59
Flooded vegetation	88.45
Crops	103.27
Built Area	346.22
Bare ground	0.43
Rangeland	91.95

The analysis reveals several key changes and trends in land use and land cover from 2017 to 2023. Comparing the current data with previous years provides a clear view of how the landscape has transformed.

Firstly, the area covered by water bodies has increased to 28.48 km² from 23.91 km². This 18.9% increase suggests possible changes in water management practices or natural hydrological dynamics in the region. The expansion of water bodies could be due to factors such as increased rainfall, the construction of reservoirs or water management infrastructure, or the natural expansion of wetlands. This increase in water coverage is significant for maintaining regional biodiversity and supporting aquatic ecosystems.

The tree cover has decreased from 1189.98 km² to 1030.59 km², marking a reduction of approximately 13.4%. This decline in forested area could be attributed to deforestation or land conversion for agricultural or urban development purposes. The reduction in tree cover has potential implications for biodiversity, carbon sequestration, and soil stabilization. It underscores the need for reforestation and conservation efforts to mitigate environmental impacts and preserve the ecological balance.

Flooded vegetation has decreased slightly from 98.90 km² to 88.45 km². This reduction of about 10.5% could indicate a change in the extent or frequency of flooding events or alterations in land management practices affecting wetland areas. Flooded vegetation plays a crucial role in water regulation and habitat provision for various species, and its decrease might affect local biodiversity and ecological functions.

The area dedicated to crops has increased from 51.06 km² to 103.27 km², more than doubling the cropland area. This significant increase reflects a possible expansion in agricultural activities, driven by growing food demands or changes in land use policies. While this expansion can enhance local agricultural productivity, it also raises concerns about potential impacts on soil quality, deforestation, and changes in water usage.

The built-up area has risen from 271.40 km² to 346.22 km², marking a notable increase of approximately 27.5%. This expansion indicates continued urbanization and infrastructural development in the region. The growth in built-up areas reflects increased human settlement and economic activity but also highlights the need for effective urban planning to manage the associated challenges such as habitat loss, increased pollution, and resource consumption.

Bare ground has decreased substantially from 5.64 km² to just 0.43 km². This dramatic reduction suggests successful rehabilitation or stabilization efforts in areas previously affected by human activities or natural disturbances. The minimal presence of bare ground is indicative of improved land management practices or natural recovery processes that have restored vegetative cover and soil integrity.

Rangeland has seen an increase from 48.56 km² to 91.95 km². This expansion could be related to changes in land management or an increase in pastoral activities. The growth in rangeland area supports the importance of grazing lands for livestock and pastoral communities but also necessitates sustainable grazing practices to prevent overgrazing and land degradation.

The land use and land cover data for 2023, as presented in Table 4 and illustrated in Figure 4, highlight significant shifts in the landscape over recent years. The increase in water bodies, built-up areas, and cropland, combined with the decrease in tree cover, reflects ongoing changes in human activity and land use priorities. These changes have various implications for environmental management, biodiversity conservation, and sustainable development.

Implications of Slope and Land Use/Land Cover Changes

The interplay between topography and land use/land cover (LULC) dynamics is critical in understanding environmental processes, managing natural resources, and planning sustainable development. In the study area within part of Rivers State, South South, Nigeria, the analysis of slope categories and LULC types over 2017 and 2023 provides valuable insights into the landscape's evolution and its implications for various ecological and socio-economic factors. This section examines the implications of slope data in conjunction with LULC changes, focusing on their impact on land management, agricultural practices, urban development, and environmental conservation.

The slope data indicates a predominance of low to moderate slopes in the study area, with significant implications for land use patterns and environmental processes.

The LULC data for 2017 and 2023 reflect significant changes in land use patterns, including increases in built-up areas and cropland, and decreases in tree cover and flooded vegetation.

The distribution of slope categories in the study area indicates that a large portion of the land (465.80 km²) falls within the 0 - 1.36 degrees range. This nearly flat terrain is highly suitable for agricultural activities, settlement, and infrastructure development, as evidenced by the substantial increase in built-up areas from 271.40 km² in 2017 to 346.22 km² in 2023 (Table 3). The gentle slopes minimize the risk of soil erosion and make it easier to implement mechanized farming and construction projects.

However, the expansion of built-up areas also raises concerns about habitat loss and environmental degradation. The reduction in tree cover from 1189.98 km² in 2017 to 1030.59 km² in 2023 (Table 2 and Table 3) suggests ongoing deforestation, likely driven by urban expansion and agricultural development. This trend highlights the need for effective land use planning and conservation strategies to balance development with ecological preservation.

Moderate slopes (1.76 - 3.13 degrees) cover the largest area (599.58 km²) in the study region. These slopes are suitable for a range of land uses, including agriculture, forestry, and some forms of development. The increase in cropland from 51.06 km² in 2017 to 103.27 km² in 2023 (Table 2 and Table 3) indicates an intensification of agricultural activities, likely facilitated by these moderate slopes. While agricultural expansion can enhance food security and economic growth, it also necessitates the adoption of sustainable practices to prevent soil degradation, erosion, and loss of biodiversity.

Steeper slopes (3.13 - 7.72 degrees and 7.72 - 23.19 degrees) are less suitable for extensive agriculture and development due to the higher risk of erosion and landslides. The limited area of steep slopes (13.07 km²) in the study area suggests that these regions are less impacted by human activities. However, they are crucial for maintaining ecological functions such as water regulation and habitat provision. The slight decrease in flooded vegetation from 98.90 km² in 2017 to 88.45 km² in 2023 (Table 2 and Table 3) may indicate changes in wetland areas, which are often associated with these steeper, ecologically sensitive zones.

The analysis of slope categories and LULC changes reveals important implications for agricultural practices in the study area. The increase in cropland, particularly on gentle to moderate slopes, underscores the region's agricultural potential. However, the reduction in tree cover and the expansion of built-up areas indicate potential conflicts between agricultural development and environmental conservation.

Sustainable agricultural practices are essential to mitigate the impacts of land conversion on soil health and ecosystem services. Techniques such as contour farming, terracing, and agroforestry can enhance soil stability and reduce erosion on sloped lands. Additionally, maintaining buffer zones of natural vegetation around agricultural fields can help preserve biodiversity and water quality.

The significant presence of water bodies (23.91 km² in 2017 and 28.48 km² in 2023) also supports irrigation and aquaculture, which are vital for agricultural productivity in the region. However, the management of water resources must be carefully planned to prevent over-extraction and ensure long-term sustainability. The slight increase in water bodies indicates potential improvements in water management practices or natural hydrological changes, which could benefit agricultural activities.

The expansion of built-up areas, particularly on gentle slopes, reflects the ongoing urbanization and infrastructure development in the study area. This growth presents both opportunities and challenges for sustainable urban planning. The increase in built-up areas from 271.40 km² in 2017 to 346.22 km² in 2023 (Table 2 and Table 3) indicates a rising demand for housing, industrial facilities, and transportation infrastructure.

Effective urban planning must consider the implications of slope and LULC changes to minimize environmental impacts and enhance the quality of life for residents. Integrating green spaces, implementing sustainable building practices, and ensuring efficient land use are critical for managing urban growth. Additionally, preserving areas with significant ecological value, such as forests and wetlands, can mitigate the environmental footprint of urban expansion.

The reduction in bare ground from 5.64 km² in 2017 to 0.43 km² in 2023 suggests successful land rehabilitation efforts, possibly through reforestation or restoration projects. These efforts are crucial for improving soil health, reducing erosion, and enhancing the overall resilience of the landscape.

The analysis of slope and LULC data underscores the importance of environmental conservation in the study area. The reduction in tree cover and flooded vegetation highlights the need for proactive conservation strategies to protect critical habitats and ecosystem services. Forest conservation, wetland protection, and sustainable land management practices are essential for maintaining biodiversity, regulating water cycles, and mitigating climate change.

The presence of rangeland, which increased from 48.56 km² in 2017 to 91.95 km² in 2023 (Table 2 and Table 3), indicates the importance of pastoral activities in the region. Sustainable grazing practices are necessary to prevent overgrazing and land degradation, ensuring that rangelands continue to provide valuable ecosystem services.

CONCLUSION

The study "Temporal Analysis of Land Use, Land Cover, and Slope Variation in Rivers State, Nigeria: A Study from 2017 to 2023" has revealed significant changes in the landscape over the past six years. The analysis of slope variations and land use/land cover (LULC) dynamics in the study area provides a comprehensive understanding of the region's topographical and environmental transformations.

The slope distribution within the study area is predominantly characterized by gentle to moderate slopes. Slopes ranging from 0 to 1.36 degrees cover the largest area (465.80 km²), indicating a terrain highly suitable for agriculture, settlement, and infrastructure development. The gentle slopes minimize soil erosion risks and facilitate mechanized farming and construction. Moderate slopes (1.76 to 3.13 degrees), which cover 599.58 km², present more varied topography. While suitable for a range of land uses, these slopes necessitate detailed land use planning to prevent erosion and ensure sustainable development. Steeper slopes (3.13 to 7.72 degrees and 7.72 to 23.19 degrees) are limited in extent (13.07 km²) and generally unsuitable for extensive agriculture or development without substantial modification. These areas are crucial for ecological functions like water regulation and habitat provision, highlighting the importance of maintaining natural vegetation to prevent landslides and soil erosion.

There has been a significant increase in built-up areas, expanding from 271.40 km² in 2017 to 346.22 km² in 2023, reflecting ongoing urbanization and infrastructure development. This growth underscores the need for effective urban planning to balance development with environmental sustainability. Tree cover has decreased from 1189.98 km² in 2017 to 1030.59 km² in 2023, indicating deforestation likely driven by urban expansion and agricultural development. This reduction in forested areas poses risks to biodiversity, carbon sequestration, and soil stabilization. Agricultural activities have expanded, with cropland increasing from 51.06 km² to 103.27 km². This reflects an intensification of agricultural practices, which, while beneficial for food security, necessitates sustainable practices to prevent soil degradation and loss of biodiversity. Water bodies have increased from 23.91 km² to 28.48 km², suggesting improvements in water management or natural hydrological changes. This expansion is significant for maintaining biodiversity and supporting agricultural irrigation. Rangelands have increased from 48.56 km² to 91.95 km², indicating the importance of pastoral activities in the region. Sustainable grazing practices are essential to prevent overgrazing and land degradation. The presence of bare ground has dramatically reduced from 5.64 km² to 0.43 km², suggesting successful land rehabilitation efforts, possibly through reforestation or restoration projects.

For sustainable development in the study area, integrate land management with conservation, enhance urban planning to include green spaces, promote reforestation, and continuously monitor land use and slope changes for informed policy decisions.

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