Hydrogeological Implications of Slope and Land Use/Land Cover Distribution in Part of Southern, Nigeria

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ABSTRACT

The study focuses on the hydrogeological implications of slope and Land Use/Land Cover (LULC) distributions in the Aniocha and Oshimili regions of Nigeria. Understanding the spatial variations in these parameters is critical for effective groundwater management and sustainable land use planning in these areas. The aim is to assess the spatial distribution of slopes and LULC types and their impact on groundwater recharge and surface runoff in the study area. The study employs spatial analysis techniques to categorize slope data into five classes and LULC data into seven types for the years 2017 and 2023. The analysis covers Aniocha North, Aniocha South, Ika North, Ika South, Oshimili North, and Oshimili South. The slope analysis reveals that the largest area (1022.73 km²) falls within the 0-1.52° slope category, indicating predominantly flat terrain with high infiltration potential. The LULC analysis shows that in 2017, trees covered the most extensive area (2143.21 km²), which decreased to 1573.76 km² by 2023, indicating significant deforestation. Built areas expanded from 281.76 km² to 391.99 km², reflecting increased urbanization. Flat terrains (0-3.51°) are conducive to groundwater recharge due to their high infiltration rates, whereas steeper slopes (3.51-26.00°) exhibit higher runoff potential, impacting groundwater recharge negatively. The reduction in tree cover and expansion of built areas have significant hydrogeological implications. Deforestation reduces groundwater recharge potential, while urbanization increases surface runoff, potentially leading to flooding and reduced groundwater levels. The study highlights the need for integrated land and water management strategies to balance development with environmental sustainability. Protecting and managing flat areas for groundwater recharge, implementing soil conservation in steeper regions, and promoting sustainable agricultural practices are essential. Urban planning should incorporate green infrastructure to mitigate the impacts of increased impervious surfaces. This study provides a comprehensive analysis of slope and LULC changes over time and their hydrogeological implications, offering valuable insights for sustainable land and water resource management in the Aniocha and Oshimili regions.

Keywords: Groundwater recharge, Hydrogeology, Slope distribution, Urbanization

INTRODUCTION

Hydrogeology, the study of the distribution and movement of groundwater in the soil and rocks of the Earth's crust, is profoundly influenced by slope and land use/land cover (LULC) distribution (Quillet et al., 2017). These factors are integral in determining the infiltration, recharge, and flow of groundwater, which are essential for water resource management, environmental sustainability, and urban planning. Understanding the hydrogeological implications of slope and LULC is critical, particularly in regions experiencing rapid urbanization and agricultural expansion (Sertel et al., 2019).

Slope, the gradient or steepness of the land, significantly affects water infiltration and surface runoff. Steeper slopes generally lead to increased runoff and reduced infiltration, as water moves more quickly over the surface, leaving less time for it to percolate into the soil (Igwe & Una, 2019). This can result in decreased groundwater recharge and increased surface water flow, which can lead to erosion and sediment transport. Conversely, gentle slopes tend to facilitate greater infiltration, enhancing groundwater recharge and supporting more stable hydrogeological conditions (Ibeh, 2020).

Steep slopes are more susceptible to erosion due to the higher velocity of surface runoff. Erosion can remove the topsoil, which is crucial for water retention and infiltration, thereby reducing the land's capacity to recharge groundwater (Egbueri & Igwe, 2020). The transported sediments can clog waterways and reduce the permeability of soils in lower-lying areas, further impacting groundwater recharge.

Slope also influences soil moisture distribution, which in turn affects vegetation cover. On steeper slopes, the rapid runoff can lead to drier conditions, limiting vegetation growth. In contrast, gentle slopes with better water retention can support denser vegetation, which can enhance soil stability and promote higher infiltration rates through root systems (Baartman et al., 2018).

Urbanization typically involves the conversion of natural landscapes into impervious surfaces such as roads, buildings, and parking lots. This transformation drastically reduces the land's natural infiltration capacity, leading to increased surface runoff and reduced groundwater recharge (Khalil et al., 2021). Urban areas often require engineered drainage systems to manage the excess runoff, which can alter natural water flow patterns and impact local hydrogeology.

Agricultural activities can significantly alter the hydrogeological balance through irrigation, land leveling, and soil compaction. Irrigation can increase groundwater recharge in some areas but may also lead to waterlogging and salinization if not managed properly (Talabi et al., 2020). Land leveling, commonly practiced in agriculture, can alter natural slopes and drainage patterns, affecting water infiltration and runoff dynamics. Soil compaction from heavy machinery reduces soil permeability, further impacting groundwater recharge (Ogungbade et al., 2022).

Deforestation for agriculture, logging, or urban development can lead to land degradation, altering the natural hydrogeological processes. The removal of vegetation reduces the land's ability to retain water and increases the susceptibility to erosion (Espejo et al., 2018). This can decrease groundwater recharge and increase surface runoff, leading to a higher risk of floods and reduced availability of groundwater resources.

Wetlands play a crucial role in maintaining the hydrogeological balance by acting as natural sponges that absorb and slowly release water. The destruction or alteration of wetlands due to land development can significantly impact groundwater recharge and water quality (Oji & Ezekwe, 2019). Similarly, the presence of natural water bodies such as lakes and rivers can influence local hydrogeology by providing sources of recharge and acting as discharge points for groundwater.

The interaction between slope and LULC has a compounded effect on groundwater recharge. For instance, urbanization on steep slopes can exacerbate runoff and erosion, leading to significant reductions in groundwater recharge (Oke, 2020). Conversely, sustainable agricultural practices on gentle slopes can enhance infiltration and promote groundwater recharge.

Slope and LULC changes can also impact water quality. Increased runoff from urban and agricultural areas can carry pollutants, sediments, and nutrients into water bodies, degrading water quality. Steep slopes with poor vegetation cover can contribute to higher sediment loads in runoff, impacting both surface and groundwater quality (Sulamo et al., 2021).

Changes in slope and LULC can alter the natural hydrological cycle, influencing the frequency and severity of floods and droughts. Urbanization and deforestation on slopes can increase the risk of flash floods due to rapid runoff (Akbar et al., 2019). Conversely, the loss of wetlands and vegetation can reduce the land's ability to retain water, increasing the risk of drought during dry periods.

Urban planners can mitigate the hydrogeological impacts of slope and LULC by incorporating green infrastructure, such as permeable pavements, green roofs, and rain gardens, to enhance infiltration and reduce runoff (Simwanda et al., 2019). Managing slope stability through vegetation cover and erosion control measures is also crucial in maintaining hydrogeological balance in urban areas. Implementing sustainable agricultural practices, such as contour farming, terracing, and conservation tillage, can mitigate the negative impacts of slope and LULC changes on hydrogeology (Nebeokike et al., 2020). These practices help reduce runoff, increase infiltration, and maintain soil health, promoting sustainable groundwater recharge.

Protecting and restoring wetlands is essential for maintaining hydrogeological balance. Wetlands act as natural buffers that regulate water flow, enhance groundwater recharge, and improve water quality. Conservation efforts should focus on preventing wetland degradation and promoting their role in the hydrological cycle (Mason et al., 2021). Effective watershed management requires an integrated approach that considers the interplay between slope and LULC. Strategies should include reforestation, erosion control, sustainable land use planning, and the protection of natural water bodies (Pham et al., 2020). By managing the entire watershed, it is possible to enhance groundwater recharge, reduce flood risks, and improve water quality.

Research and Geology of Study Area

The study area encompassing Aniocha North, Aniocha South, Ika North, Ika South, Oshimili North, and Oshimili South is located in the South-South region of Nigeria. This area is characterized by diverse geological formations, significant hydrogeological resources, and varied land use patterns. Understanding the geology and hydrogeological conditions of this region is essential for effective water resource management, environmental planning, and sustainable development. The study area is approximately bounded by the following coordinates Latitude 6.00°N to 6.75°N and Longitude 6.15°E to 6.70°E as shown in Figure 1.

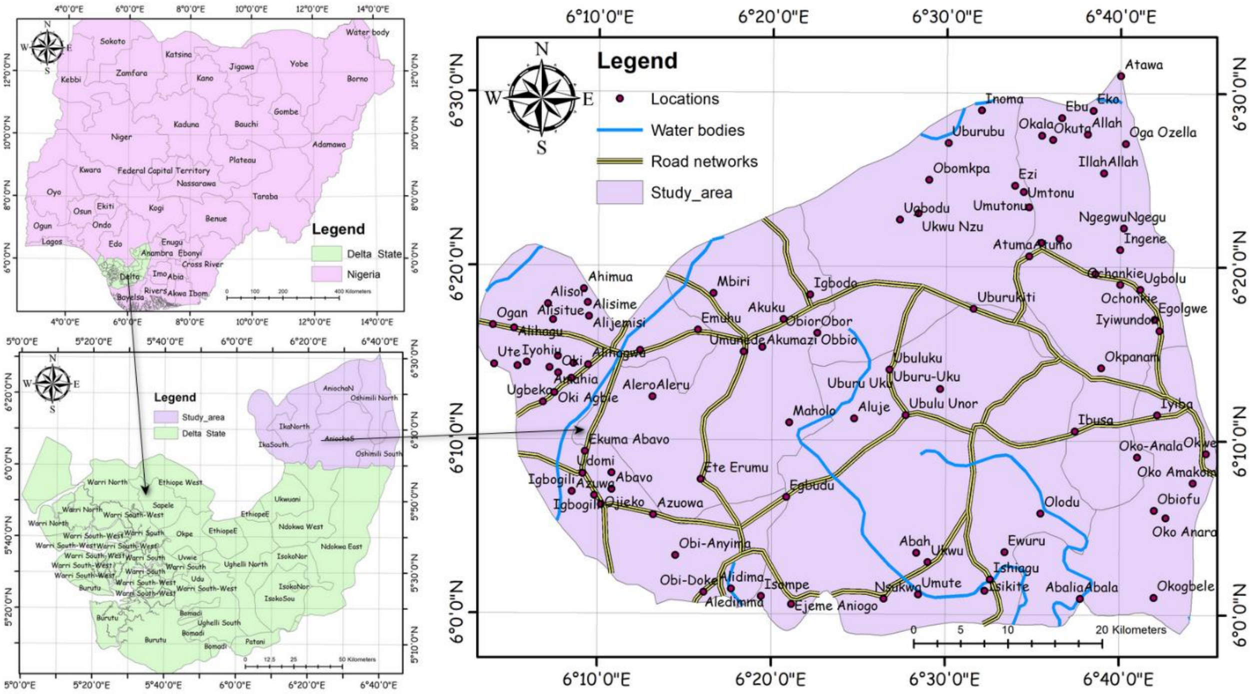

Figure 1 Map of the study area

The study area lies within the Nigerian Basement Complex, predominantly composed of Precambrian crystalline rocks such as granites, gneisses, and schists. These rocks are often deeply weathered and fractured, creating weathering profiles that extend several meters deep, with these zones being significant for groundwater storage and movement (Akinwumiju & Olorunfemi, 2019). In addition to the basement complex, parts of the study area, particularly towards the southern sections, are underlain by sedimentary formations of the Niger Delta Basin. These sedimentary sequences are composed of sandstones, shales, and clays. The sedimentary formations generally have higher porosity and permeability compared to the basement complex, making them favorable for groundwater storage and extraction (Falebita et al., 2020).

Groundwater in the study area occurs in both weathered basement rocks and sedimentary formations. The weathered basement aquifers are typically found at shallow depths and are recharged by direct infiltration of rainfall. These aquifers are generally discontinuous and localized, with groundwater availability depending on the thickness and extent of the weathered zone and the presence of fractures. In contrast, the sedimentary aquifers are more extensive and continuous. They are primarily recharged by rainfall and surface water bodies and can be found at varying depths, with deeper aquifers often being more prolific and less susceptible to seasonal fluctuations in water levels.

The study area is drained by several rivers and streams, including the Niger River, which flows along the western boundary of the area. These surface water bodies play a crucial role in the regional hydrology, providing sources of recharge for the aquifers and acting as natural discharge points for groundwater. The presence of wetlands and floodplains along these rivers also contributes to groundwater recharge and storage.

Agriculture is the predominant land use in the study area, with significant portions of the land being used for the cultivation of crops such as cassava, yams, maize, and oil palm. Agricultural practices can impact the hydrogeology of the region through irrigation, land clearing, and the use of agrochemicals. Irrigation can enhance groundwater recharge in some areas but may also lead to waterlogging and soil salinization if not managed properly.

Urban centers such as Asaba, the capital of Delta State, are experiencing rapid growth. Urbanization leads to the development of impervious surfaces such as roads, buildings, and parking lots, which reduce natural infiltration and increase surface runoff. This can decrease groundwater recharge and alter natural water flow patterns, impacting local hydrogeology.

The combination of steep slopes and deforestation in some parts of the study area has led to increased soil erosion and sedimentation in rivers and streams. Erosion not only degrades soil quality but also impacts water quality and the storage capacity of surface water bodies. Additionally, agricultural runoff containing fertilizers and pesticides, as well as industrial and domestic waste, can contaminate both surface and groundwater resources. Ensuring sustainable land use practices and effective waste management is crucial to protect the water quality in the region.

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:

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

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:

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

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

Spatial Distribution of Slope in the Study Area

The spatial distribution of slope within the study area, encompassing the regions of Aniocha North, Aniocha South, Ika North, Ika South, Oshimili North, and Oshimili South, reveals a varied topography with significant implications for hydrogeological and geophysical investigations. The slope data is categorized into five distinct classes: 0 - 1.52°, 1.52 - 1.98°, 1.98 - 3.51°, 3.51 - 8.66°, and 8.66 - 26.00° as shown in Table 2 and Figure 2.

Table 2: Slope Distribution in the Study Area

Slope (degree)	Area (km²)
0 - 1.52	1022.73
1.52 - 1.98	389.95
1.98 - 3.51	1048.44
3.51 - 8.66	669.05
8.66 - 26.00	44.57

The largest area, covering 1022.73 km², falls within the 0 - 1.52° slope category, indicating predominantly flat terrain. This flatness is typically associated with low runoff potential, which could lead to increased infiltration rates, thereby enhancing groundwater recharge potential. This finding is crucial for the hydrogeological assessment as areas with minimal slopes are often targeted for groundwater exploration due to their high infiltration capacity.

The next significant slope category is 1.98 - 3.51°, covering 1048.44 km². These moderately sloping areas may exhibit moderate runoff, which can influence both surface and subsurface water distribution. Such slopes can facilitate the movement of water towards lower areas, potentially affecting the distribution and accumulation of groundwater resources.

The areas with slopes between 3.51 - 8.66° and 1.52 - 1.98° cover 669.05 km² and 389.95 km², respectively. These regions represent transitional zones where both surface runoff and infiltration processes are balanced.

These slopes can contribute to the variability in groundwater recharge and distribution, necessitating detailed geophysical surveys to understand the subsurface conditions better.

The steepest slopes, ranging from 8.66 - 26.00°, cover only 44.57 km². These areas are characterized by high runoff potential and lower infiltration rates. Steep slopes are less favorable for groundwater recharge but can significantly influence surface water flow and erosion processes. The minimal area under this category suggests that steep terrains are not a dominant feature within the study area.

The varying slopes within the study area have significant hydrogeological implications. Flat to moderately sloping areas (0 - 3.51°) are conducive to groundwater recharge due to their high infiltration potential.

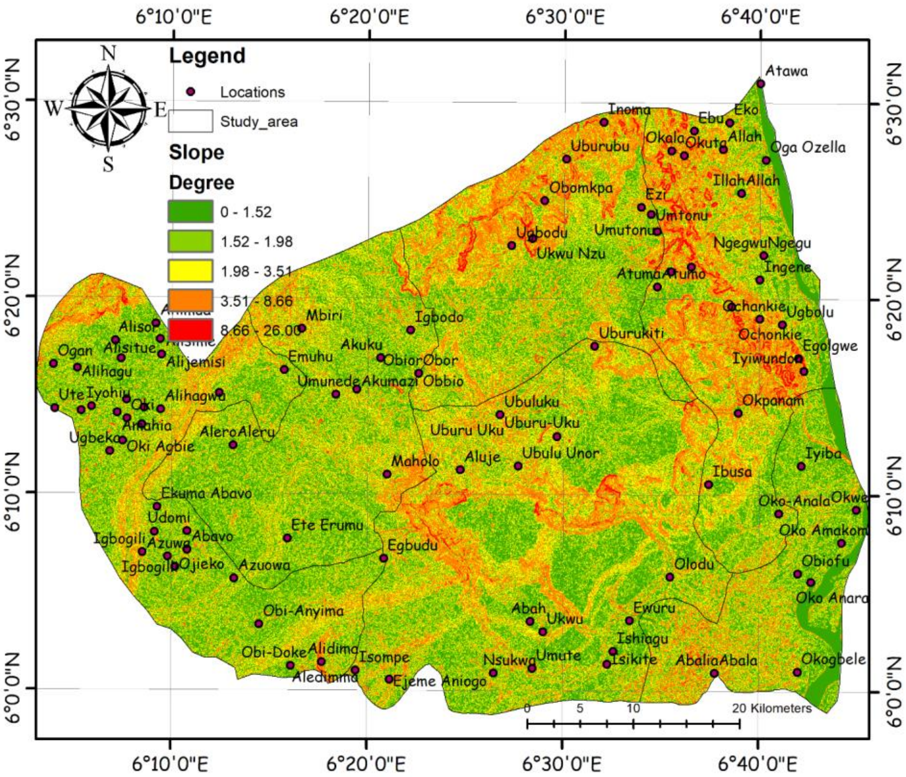

Figure 2: Slope Distribution Map of the Study Area

Steeper areas (3.51 - 26.00°), although limited in extent, are important for understanding surface water dynamics and potential erosion issues. In contrast, steeper regions may benefit from seismic surveys to understand subsurface layering and potential groundwater barriers.

Spatial Distribution of LULC 2017 in the Study Area

The spatial distribution of Land Use and Land Cover (LULC) within the study area, which encompasses Aniocha North, Aniocha South, Ika North, Ika South, Oshimili North, and Oshimili South, provides critical insights into the region's environmental and hydrogeological dynamics. The LULC data for 2017 is categorized into several types: Water, Trees, Flooded Vegetation, Crops, Built Area, Bare Ground, and Rangeland as shown Table 3 and Figure 3.

Table 3: LULC Distribution in the Study Area (2017)

LULC Type	Area (km²)
Water	46.39
Trees	2143.21

Flooded Vegetation	2.12
Crops	137.37
Built Area	281.76
Bare Ground	12.29
Rangeland	559.73

The most extensive LULC type in the study area is Trees, covering 2143.21 km². This significant forested area indicates a substantial presence of natural vegetation, which plays a crucial role in maintaining ecological balance and influencing hydrogeological processes. Forested areas are known for their high infiltration rates and groundwater recharge potential due to the dense root systems and organic matter that enhance soil permeability. Moreover, these areas act as natural water reservoirs, helping to regulate the hydrological cycle.

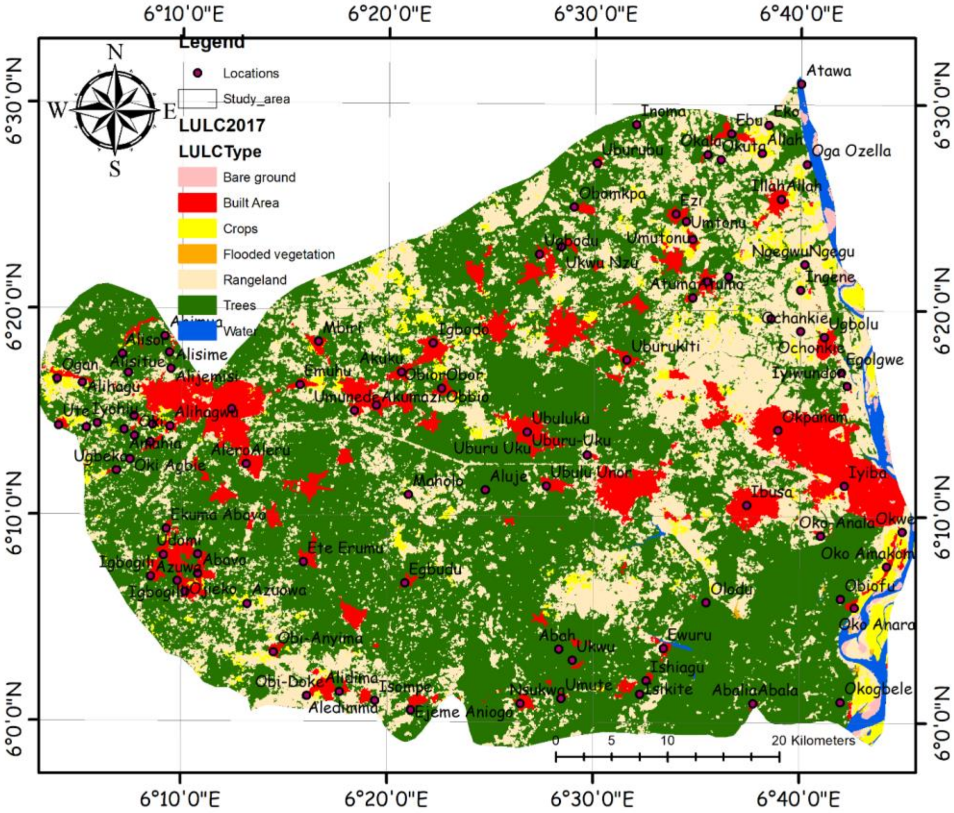

Figure 3: LULC Map of the Study Area in 2017

Rangeland covers 559.73 km², representing a significant portion of the study area. Rangelands, typically characterized by natural grasses and shrubs, have moderate infiltration rates and can support groundwater recharge, albeit less efficiently than forested areas. These areas also serve as grazing lands, which can impact the soil structure and influence water infiltration dynamics.

The Built Area category encompasses 281.76 km², highlighting the extent of urbanization and infrastructural development within the study area. Urban areas generally have low infiltration rates due to impervious surfaces such as roads, buildings, and pavements, leading to increased surface runoff and reduced groundwater recharge. This can cause localized flooding and strain on urban drainage systems, necessitating careful urban planning and sustainable water management practices.

Agricultural lands, classified under Crops, cover 137.37 km². Cropland areas are critical for food production but can also significantly impact the hydrogeological regime. Agricultural practices, including irrigation, pesticide use, and soil management, influence groundwater recharge and quality. Effective agricultural practices that promote soil health and water conservation can enhance groundwater recharge and sustainability.

Water bodies, including rivers, lakes, and ponds, cover 46.39 km². These water bodies are crucial for maintaining regional hydrology and providing essential resources for domestic, agricultural, and industrial use. Water bodies also contribute to groundwater recharge, especially in areas where surface water interacts with the subsurface aquifers.

Bare Ground, covering 12.29 km², represents areas with minimal vegetation cover. These regions are prone to erosion and have lower infiltration rates, affecting groundwater recharge negatively. Soil erosion in bare ground areas can lead to sedimentation in water bodies, impacting water quality and aquatic ecosystems.

Flooded Vegetation, although covering a small area of 2.12 km², plays a unique role in the landscape. These areas, often associated with wetlands, are crucial for biodiversity and act as natural water filters. Wetlands have high water retention capabilities, contributing to groundwater recharge and acting as buffers during flood events.

The diverse LULC distribution in the study area has significant hydrogeological and environmental implications. Forested areas (Trees) and rangelands provide substantial groundwater recharge potential, essential for maintaining regional water balance. However, the expanding Built Area poses challenges for groundwater recharge due to increased impervious surfaces. Integrating green infrastructure, such as permeable pavements and urban green spaces, can mitigate these impacts and enhance urban water management.

Agricultural lands (Crops) require sustainable practices to ensure groundwater recharge and protect water quality. Implementing conservation agriculture techniques, such as cover cropping and reduced tillage, can improve soil health and water infiltration.

Water bodies and flooded vegetation areas are critical for maintaining hydrological balance and supporting biodiversity. Protecting these areas from pollution and over-extraction is vital for long-term sustainability.

Spatial Distribution of LULC 2023 in the Study Area

The spatial distribution of Land Use and Land Cover (LULC) within the study area, comprising Aniocha North, Aniocha South, Ika North, Ika South, Oshimili North, and Oshimili South, reveals significant changes and patterns in land utilization. The LULC data for 2023 is categorized into seven types: Water, Trees, Flooded Vegetation, Crops, Built Area, Bare Ground, and Rangeland as shown Table 4 and Figure 4.

Table 4: LULC Distribution in the Study Area (2023)

LULC Type	Area (km²)
Water	47.95
Trees	1573.76
Flooded Vegetation	1.10
Crops	158.10
Built Area	391.99
Bare Ground	9.18
Rangeland	1000.77

The Trees category, covering 1573.76 km², is the largest land cover type but shows a reduction from previous years, indicating deforestation or land conversion. Forested areas are crucial for maintaining ecological balance and groundwater recharge due to their high infiltration rates. The reduction in tree cover could impact the region's hydrogeological conditions, potentially reducing groundwater recharge rates and altering local climate patterns.

Rangeland covers 1000.77 km², making it the second-largest LULC type. Rangelands, typically consisting of grasses and shrubs, support moderate infiltration rates, contributing to groundwater recharge. The extensive coverage of rangeland suggests significant potential for sustainable grazing and moderate water recharge, essential for maintaining the hydrological cycle.

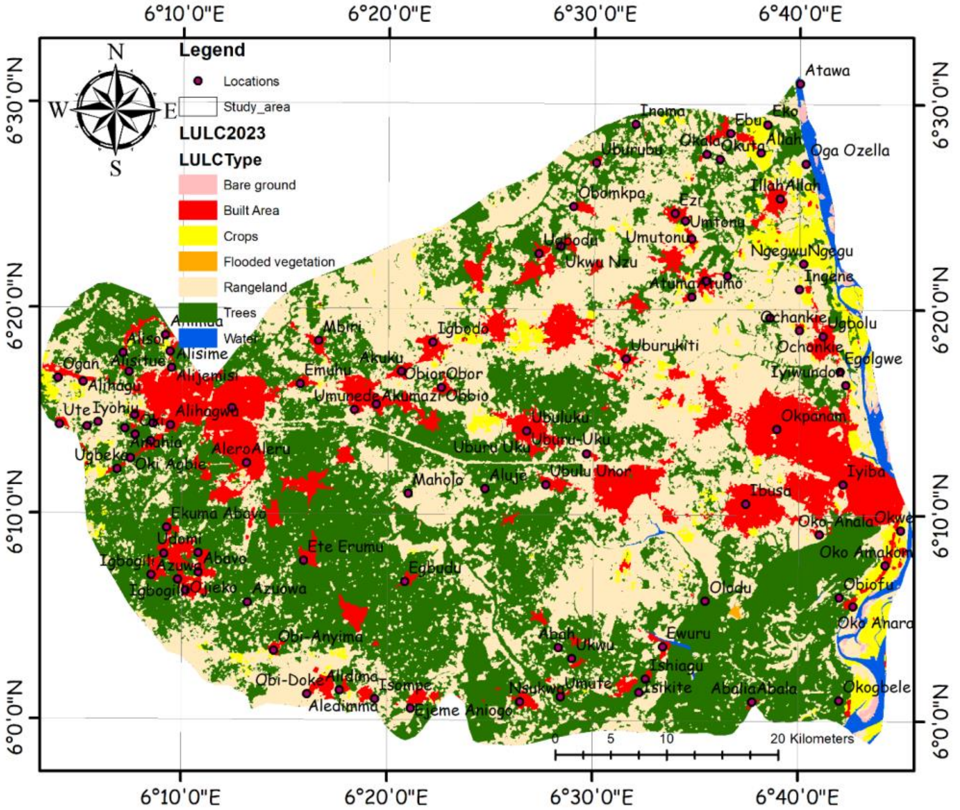

Figure 4: LULC Map of the Study Area in 2023

The Built Area category encompasses 391.99 km², reflecting a notable increase in urbanization and infrastructural development. Urban areas generally have low infiltration rates due to impervious surfaces, leading to increased surface runoff and decreased groundwater recharge. The growth in built-up areas necessitates effective urban planning and the incorporation of green infrastructure to mitigate the negative impacts on groundwater resources and manage surface water runoff.

Agricultural lands, under the Crops category, cover 158.10 km². This increase in cropland highlights the importance of agriculture in the region. Agricultural practices significantly influence groundwater recharge and quality. Sustainable farming practices, such as efficient irrigation and soil conservation, are essential to maximize groundwater recharge and maintain water quality.

Water bodies, including rivers, lakes, and ponds, cover 47.95 km². These water bodies play a critical role in the regional hydrology by providing essential resources for domestic, agricultural, and industrial use. They also contribute to groundwater recharge, especially in areas where surface water interacts with subsurface aquifers.

Bare Ground, covering 9.18 km², represents areas with minimal vegetation. These regions are prone to erosion and have lower infiltration rates, negatively impacting groundwater recharge. Managing these areas to reduce erosion and increase vegetation cover can enhance their water retention and recharge capabilities.

Flooded Vegetation, covering a small area of 1.10 km², plays a unique role in the landscape. These areas, often wetlands, are crucial for biodiversity and act as natural water filters. Wetlands have high water retention capabilities, contributing significantly to groundwater recharge and acting as buffers during flood events.

The LULC distribution within the study area has several hydrogeological and environmental implications. The reduction in tree cover (Trees) poses a challenge for groundwater recharge and ecological balance. Forest conservation and reforestation efforts are critical to restoring these areas' groundwater recharge potential and ecological health.

The significant increase in Built Area indicates urban sprawl, which reduces natural infiltration and increases surface runoff. Integrating green infrastructure, such as permeable pavements and urban green spaces, can help mitigate these impacts by enhancing urban water management and promoting groundwater recharge.

The expansion of agricultural lands (Crops) emphasizes the need for sustainable farming practices. Techniques like crop rotation, conservation tillage, and efficient irrigation can improve soil health and water infiltration, thereby supporting groundwater recharge.

Water bodies and wetlands (Flooded Vegetation) are vital for maintaining hydrological balance and supporting biodiversity. Protecting these areas from pollution and over-extraction is essential for long-term sustainability. Efforts to preserve and restore wetlands can enhance their role in groundwater recharge and flood mitigation.

Impacts on Groundwater Recharge and Surface Runoff

The analysis of spatial distribution of slope and Land Use and Land Cover (LULC) types within the study area, which includes Aniocha North, Aniocha South, Ika North, Ika South, Oshimili North, and Oshimili South, reveals significant insights into the region's hydrogeological and environmental dynamics. These insights are crucial for developing effective land and water management strategies, and they have several implications for sustainable development.

The slope data indicates that a substantial portion of the study area (1022.73 km²) has gentle slopes ranging from 0 to 1.52 degrees, which are conducive to groundwater recharge due to low runoff and high infiltration rates. These flat areas are essential for groundwater sustainability, especially in regions facing water scarcity. Protecting and managing these areas to enhance infiltration can significantly contribute to maintaining groundwater levels.

Conversely, areas with steeper slopes (3.51 - 26.00 degrees) are more prone to surface runoff and erosion, which reduces groundwater recharge potential. These regions require soil conservation measures, such as terracing and vegetation cover, to reduce erosion and enhance water retention.

The increase in built-up areas from 2017 to 2023, particularly the expansion to 391.99 km², poses a significant challenge for groundwater recharge due to the prevalence of impervious surfaces. Urban areas typically have reduced infiltration rates, leading to higher surface runoff and potential flooding. Implementing green infrastructure solutions, such as permeable pavements, green roofs, and urban green spaces, can help mitigate these impacts by enhancing water infiltration and reducing runoff.

The expansion of cropland from 137.37 km² to 158.10 km² highlights the growing importance of agriculture in the region. Sustainable agricultural practices, such as efficient irrigation, crop rotation, and conservation tillage, are critical to maintaining soil health and enhancing water infiltration. These practices can improve groundwater recharge and ensure the long-term sustainability of water resources.

The significant reduction in tree cover from 2143.21 km² in 2017 to 1573.76 km² in 2023 indicates ongoing deforestation. Forested areas are vital for maintaining biodiversity, soil stability, and hydrological balance. The loss of trees can lead to increased soil erosion, reduced groundwater recharge, and habitat loss. Reforestation and afforestation initiatives are essential to restore these areas, enhance ecological health, and improve groundwater recharge.

Wetlands and water bodies, although covering smaller areas, play a crucial role in maintaining hydrological balance and supporting biodiversity. The slight increase in water bodies from 46.39 km² to 47.95 km² is positive, but the reduction in flooded vegetation from 2.12 km² to 1.10 km² is concerning. Wetlands act as natural water filters and buffers during flood events, contributing to groundwater recharge and providing habitats for various species. Protecting and restoring wetlands is essential for maintaining these ecological functions and ensuring water quality.

The growth of built-up areas reflects ongoing urbanization and infrastructure development. Effective urban planning is necessary to balance development needs with environmental sustainability. Incorporating green spaces, sustainable drainage systems, and low-impact development practices can enhance urban resilience to climate change and support sustainable water management (Ahmad & Haie, 2018).

The increase in agricultural lands underscores the region's dependence on agriculture for economic development. Promoting sustainable agricultural practices can improve crop yields, enhance soil health, and ensure water security (Haruna et al., 2018). Policies that support farmers in adopting these practices, such as providing access to efficient irrigation technologies and training on soil conservation methods, are crucial for long-term agricultural sustainability.

The findings highlight the need for integrated land and water management strategies that consider the interdependencies between land use, slope, and water resources. Policies should promote sustainable land use practices, protect critical recharge areas, and manage urban growth to minimize environmental impacts.

Targeted conservation efforts are needed to protect forests, wetlands, and other critical ecosystems. Establishing protected areas, promoting reforestation, and implementing soil conservation measures can enhance ecological health and support sustainable water management.

The region's land use changes and hydrogeological dynamics must be considered in the context of climate change. Increasing temperatures and changing precipitation patterns can exacerbate water scarcity and impact land use. Adaptive management strategies that enhance resilience to climate change, such as improving water storage capacity and diversifying land use, are essential for sustainable development.

CONCLUSION

The analysis of the spatial distribution of slope and Land Use and Land Cover (LULC) within the study area, comprising Aniocha North, Aniocha South, Ika North, Ika South, Oshimili North, and Oshimili South, provides valuable insights into the region's hydrogeological and environmental dynamics. These findings are critical for developing effective land and water management strategies, ensuring sustainable development.

The study area's diverse LULC distribution and slope variations have significant hydrogeological and environmental implications. The reduction in tree cover poses a challenge for groundwater recharge and ecological balance. Forest conservation and reforestation efforts are critical to restoring these areas' groundwater recharge potential and ecological health.

The growth of built-up areas reflects ongoing urbanization and infrastructure development. Effective urban planning is necessary to balance development needs with environmental sustainability. Integrating green spaces, sustainable drainage systems, and low-impact development practices can enhance urban resilience to climate change and support sustainable water management.

The expansion of agricultural lands underscores the region's dependence on agriculture for economic development. Promoting sustainable agricultural practices can improve crop yields, enhance soil health, and ensure water security. Policies that support farmers in adopting these practices, such as providing access to efficient irrigation technologies and training on soil conservation methods, are crucial for long-term agricultural sustainability.

Protecting water bodies and wetlands from pollution and over-extraction is vital for long-term sustainability. Efforts to preserve and restore wetlands can enhance their role in groundwater recharge and flood mitigation.

The findings highlight the need for integrated land and water management strategies that consider the interdependencies between land use, slope, and water resources. Policies should promote sustainable land use practices, protect critical recharge areas, and manage urban growth to minimize environmental impacts. Targeted conservation efforts are needed to protect forests, wetlands, and other critical ecosystems. Establishing protected areas, promoting reforestation, and implementing soil conservation measures can enhance ecological health and support sustainable water management. The region's land use changes and hydrogeological dynamics must be considered in the context of climate change. Increasing temperatures and changing precipitation patterns can exacerbate water scarcity and impact land use. Adaptive management strategies that enhance resilience to climate change, such as improving water storage capacity and diversifying land use, are essential for sustainable development.

To address the identified issues, it is recommended to implement integrated land and water management strategies. Prioritize reforestation and afforestation initiatives to restore tree cover. Promote sustainable agricultural practices to improve soil health and water infiltration. Incorporate green infrastructure in urban planning to enhance groundwater recharge and manage surface runoff.

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