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Assessment of urbanization impacts on soil erosion and groundwater recharge in Enugu, Southeastern Nigeria

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Abstract

The study of Land Use and Land Cover (LULC) in Enugu, southeastern Nigeria, is crucial for understanding its effects on erosion and groundwater recharge. Different LULC types, coupled with varying slope gradients and soil types, create a complex interaction that influences soil stability and water infiltration in the region. This research aims to assess the distribution of LULC types, slope gradients, and soil types in Enugu, and to evaluate their impacts on erosion rates and groundwater recharge potential. Data for LULC, slope gradients, and soil types were collected and analyzed to determine their spatial distribution and characteristics. The study employed GIS techniques to map these variables and assess their interactions. Erosion potential and groundwater recharge capacity were evaluated based on the characteristics of the LULC types, slopes, and soils. The analysis revealed that trees cover the largest area (3709.74 km^2), playing a significant role in stabilizing the soil and reducing erosion through their extensive root systems and canopy cover. Rangeland (2631.81 km^2) also contributes to soil stability, although less effectively than forested areas. Crops (192.40 km^2) have mixed impacts on erosion depending on agricultural practices. Built areas (1162.69 km^2) present challenges due to impervious surfaces, which increase surface runoff and reduce groundwater recharge. Slope gradients were found to correlate with erosion processes and groundwater dynamics. Gentle slopes (0 - 1.81 degrees) cover 1870.15 km^2 and facilitate infiltration, enhancing groundwater recharge. Moderate slopes (1.81 - 4.06 degrees), covering 3275.46 km^2, are more prone to erosion, while steeper slopes (4.06 - 11.73 degrees) covering 2176.54 km^2 experience accelerated runoff and increased erosion rates. The steepest slopes (11.73 - 44.06 degrees) are the most erosion-prone areas, requiring significant intervention. The soil analysis showed that Dystric Nitosols (4052.80 km^2) with the lowest K-factor (0.0178) are least prone to erosion and have high infiltration capacity, making them beneficial for groundwater recharge. Plinthic Acrisols (2732.53 km^2) and Ferric Acrisols (102.36 km^2) exhibit moderate erosion susceptibility. Dystric Fluvisols (793.92 km^2) with the highest K-factor (0.0223) are highly erosion-prone. Gleysols (20.69 km^2) have low to moderate erosion susceptibility. The interplay between LULC types, slope gradients, and soil types significantly influences erosion and groundwater recharge in Enugu. The study highlights the need for targeted land management practices, such as afforestation, contour farming, terracing, and the use of cover crops to mitigate erosion and enhance groundwater recharge. This research provides a comprehensive analysis of the relationships between LULC, slope gradients, and soil types in Enugu, offering valuable insights for developing effective land management strategies to address erosion and groundwater recharge challenges.

Keywords: Slope Gradient; Soil Types; Vegetation Cover; Impervious Surfaces

1. Introduction

Land use and land cover (LULC) changes are significant drivers of environmental processes, directly influencing soil erosion and groundwater recharge. The rapid pace of urbanization, deforestation, agricultural expansion, and other anthropogenic activities has led to significant alterations in the natural landscape (Khalil et al., 2021; Pal et al., 2021).

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These changes affect the hydrological cycle, soil stability, and overall ecosystem health, making it imperative to understand and manage their impacts.

LULC refers to the human modification of natural environments into built environments such as fields, pastures, and settlements. These modifications significantly affect ecological processes and hydrological systems (Pham et al., 2020). Urban areas with impervious surfaces such as roads and buildings prevent water infiltration into the soil, reducing groundwater recharge and increasing surface runoff (Mahmoud et al., 2016). Conversely, forested areas promote water infiltration, reduce surface runoff, and contribute to groundwater recharge.

The significance of LULC changes extends beyond hydrological impacts. They influence soil erosion rates, sediment transport, and deposition processes. Soil erosion, driven by water and wind, is a natural process exacerbated by human activities. Deforestation, improper agricultural practices, and construction activities can accelerate soil erosion, leading to loss of fertile topsoil, reduced agricultural productivity, and increased sedimentation in water bodies (Amah et al., 2020).

Soil erosion is a critical environmental issue that affects both natural and human systems. The detachment and transportation of soil particles by water, wind, or gravity can lead to severe land degradation (Emeh & Igwe, 2017). Several factors influence soil erosion, including soil type, land slope, vegetation cover, and land management practices. LULC changes significantly impact these factors, altering the erosion rates (Onwudike, 2015).

Forested areas, with their dense vegetation cover and root systems, are effective in stabilizing soil and reducing erosion. The vegetation intercepts rainfall, reducing its kinetic energy, and the roots bind the soil particles together. In contrast, deforested areas are highly susceptible to erosion as the protective vegetation cover is removed (Iwara, 2014). Agricultural lands, depending on the crops grown and farming practices, can also be prone to erosion. Practices such as overgrazing, monoculture, and lack of soil conservation measures can accelerate soil erosion (Sedano et al., 2019).

Groundwater recharge is the process through which water infiltrates the ground and replenishes aquifers. It is a crucial component of the hydrological cycle, ensuring the availability of freshwater for various uses (Akinfaderin et al., 2019). The rate of groundwater recharge depends on several factors, including precipitation, soil characteristics, vegetation cover, and land use practices. Changes in LULC can significantly alter these factors, affecting the recharge rates (Oji & Ezekwe, 2019).

Natural landscapes, such as forests and grasslands, with their permeable soils and vegetation cover, facilitate groundwater recharge. The vegetation slows down the surface runoff, allowing more time for water to infiltrate the soil (Ogungbade et al., 2022). In contrast, urban areas with impervious surfaces inhibit water infiltration, reducing groundwater recharge. Agricultural practices, depending on the methods used, can either promote or hinder groundwater recharge. Practices such as contour farming and terracing can enhance infiltration, while excessive irrigation and use of heavy machinery can compact the soil, reducing its permeability (Pasquier et al., 2022).

The processes of soil erosion and groundwater recharge are interconnected and influenced by LULC changes. Soil erosion affects the soil structure and its ability to absorb and retain water, impacting groundwater recharge. The removal of topsoil reduces the soil's permeability, hindering water infiltration (Tumsa, 2023). Moreover, the sediment carried by erosion can clog water bodies and reduce their storage capacity, further affecting groundwater recharge.

Conversely, changes in groundwater recharge can influence soil erosion. Reduced groundwater recharge can lower the water table, affecting the soil moisture content and its cohesion. Dry soils are more prone to erosion as they lack the moisture necessary to bind the soil particles together (Ibeh, 2020). Thus, understanding the interplay between soil erosion and groundwater recharge is essential for effective land management and conservation practices.

Urbanization is one of the most significant LULC changes affecting erosion and groundwater recharge. The expansion of urban areas results in the creation of impervious surfaces, which prevent water infiltration and increase surface runoff. This not only reduces groundwater recharge but also increases the potential for soil erosion (Ijioma, 2021). The increased runoff can carry large amounts of sediment, leading to sedimentation in water bodies and reduced water quality.

Agricultural expansion also significantly impacts soil erosion and groundwater recharge. The conversion of natural landscapes into agricultural lands often involves the removal of vegetation, which exposes the soil to erosion. Moreover, certain agricultural practices, such as plowing and the use of heavy machinery, can compact the soil, reducing its permeability and thus groundwater recharge (Garg et al., 2021). However, sustainable agricultural practices, such as conservation tillage, crop rotation, and agroforestry, can mitigate these impacts by enhancing soil structure and promoting water infiltration.

Deforestation, driven by logging, agriculture, and urban expansion, is another major LULC change affecting erosion and groundwater recharge. The removal of trees and vegetation disrupts the soil structure and increases its susceptibility to erosion (Amaechi et al., 2023). The loss of vegetation cover reduces the interception of rainfall, increasing surface runoff and reducing groundwater recharge. Reforestation and afforestation efforts can help mitigate these impacts by restoring vegetation cover and enhancing soil stability (Duku & Hein, 2021).

Climate change adds another layer of complexity to the interactions between LULC changes, soil erosion, and groundwater recharge (Aladejana et al., 2020). Changes in temperature and precipitation patterns can influence the hydrological cycle, affecting both erosion rates and recharge processes. Increased rainfall intensity can exacerbate soil erosion, while prolonged droughts can reduce groundwater recharge (Nnaji et al., 2021).

The impacts of climate change on LULC changes are also significant. Climate change can alter the suitability of land for various uses, leading to shifts in agricultural practices, urban expansion, and forest management. These changes, in turn, affect soil erosion and groundwater recharge dynamics (Koko et al., 2021). Understanding the combined effects of climate change and LULC changes is crucial for developing adaptive land management strategies that enhance resilience to environmental changes.

Soil conservation measures, such as terracing, contour farming, and the use of cover crops, can significantly reduce soil erosion and enhance groundwater recharge. Sustainable agricultural practices, including crop rotation, agroforestry, and conservation tillage, can improve soil structure and promote water infiltration. Reforestation and afforestation efforts can restore vegetation cover, stabilize soils, and enhance groundwater recharge (Kayode et al., 2022). Urban planning that incorporates green infrastructure, such as permeable pavements, green roofs, and rain gardens, can mitigate the impacts of urbanization on soil erosion and groundwater recharge. These practices promote water infiltration, reduce surface runoff, and enhance the resilience of urban areas to environmental changes (Dipeolu & Ibem, 2020).

The study of LULC impacts on erosion and groundwater recharge is critical for understanding and managing the complex interactions between human activities and environmental processes. By examining the effects of various LULC changes on soil erosion and groundwater recharge, this study aims to provide insights into sustainable land management practices that enhance environmental resilience and ensure the availability of essential ecosystem services. Addressing the challenges posed by LULC changes requires an integrated approach that considers the interconnectedness of soil, water, and vegetation, and promotes practices that balance human needs with ecological sustainability.

2. Research Area

2.1. Location of Study

The study area is located in southeastern Nigeria, within the Anambra Basin, encompassing coordinates approximately between 6°50' to 7°10'N and 7°15' to 7°35'E. This region is known for its diverse geological formations and significant groundwater resources. Access to water bodies is essential for local communities and agricultural activities, with the Anambra River and its tributaries being the primary sources of water for domestic, agricultural, and industrial purposes (Figure 1, study area map).

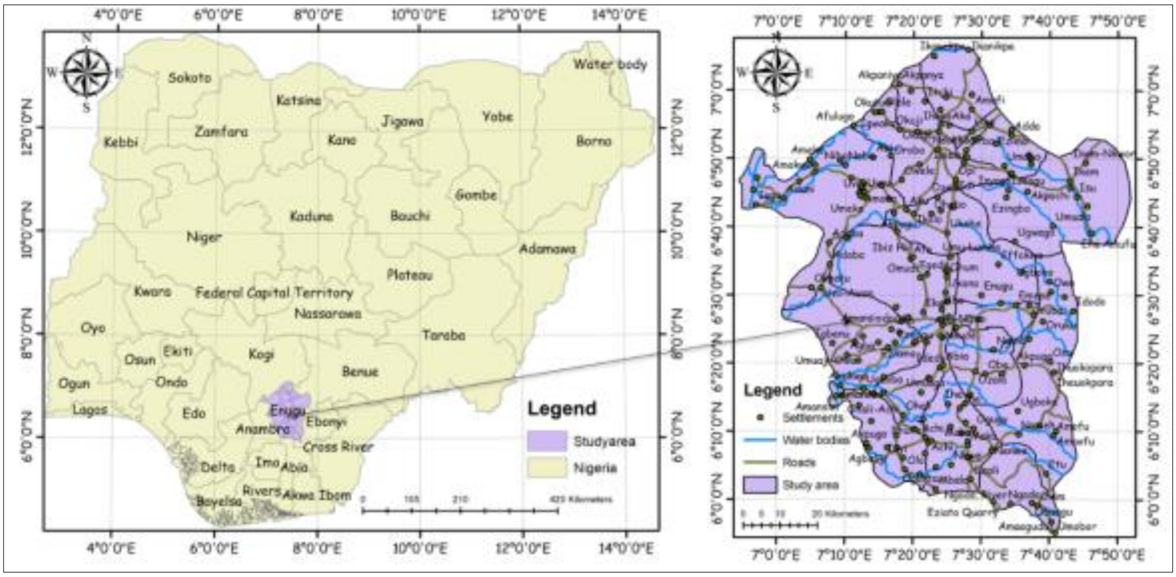

Figure 1 Map of the Study Area Showing Major Water Bodies and Road Networks

The area is well-connected by a network of roads, including major highways such as the Enugu-Onitsha Expressway and several state roads. These roads are crucial for the transportation of goods and services, playing a vital role in the socio-economic development of the region.

The climate in the study area is tropical, featuring two main seasons: the rainy season from April to October, and the dry season from November to March. The mean annual rainfall ranges from 1,500 mm to 2,000 mm, with the heaviest rainfall occurring in July and September. Temperatures remain relatively high throughout the year, averaging between 25°C and 30°C, and humidity levels are particularly elevated during the rainy season.

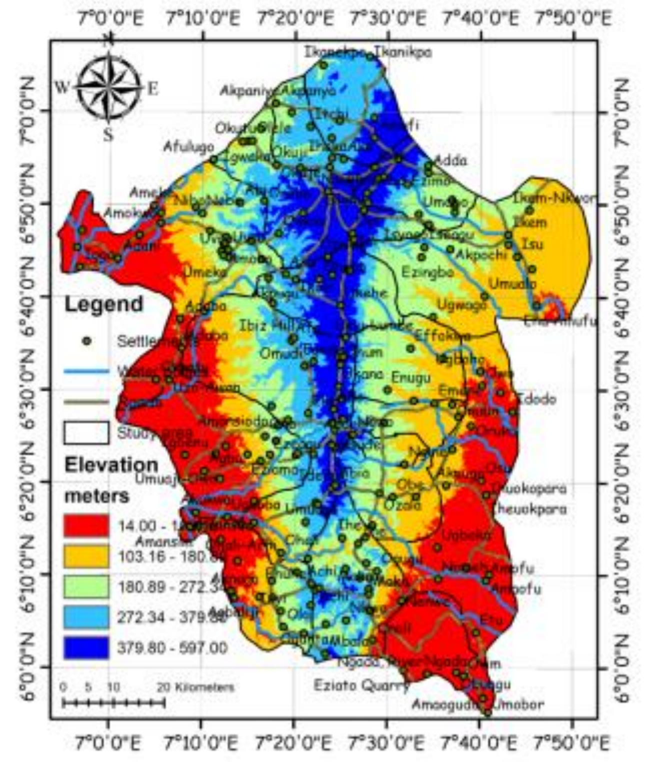

Figure 2 Elevation Map of the Study Area

Topographically, the study area is varied, ranging from lowland regions along river valleys to higher altitudes on escarpments. The terrain is generally undulating, with some areas presenting steep slopes and ridges. The variation in elevation provides insights into the hydrological characteristics and groundwater potential of the region (Figure 2, elevation of the study).

2.2. Geology of the Study Area

The geology of the study area is complex and reflects the diverse lithological units that characterize the Anambra Basin. One of the key formations is the Awgu Group, predominantly composed of black shale, siltstone, and sandstone. The black shale units are rich in organic matter, serving as potential hydrocarbon source rocks, while the siltstone and sandstone layers vary in grain size and are important aquifers (Aitalokhai et al., 2020).

Another significant geological feature is the clay and shale with limestone intercalations, characterized by alternating layers of clay, shale, and fossiliferous limestone. These formations contribute significantly to groundwater recharge and storage. The region features coal, shale, and limestone formations, where coal seams are interbedded with shale and limestone layers. These coal seams are of economic importance, while the accompanying shale and limestone influence the hydrogeological properties of the formation (Aitalokhai et al., 2020).

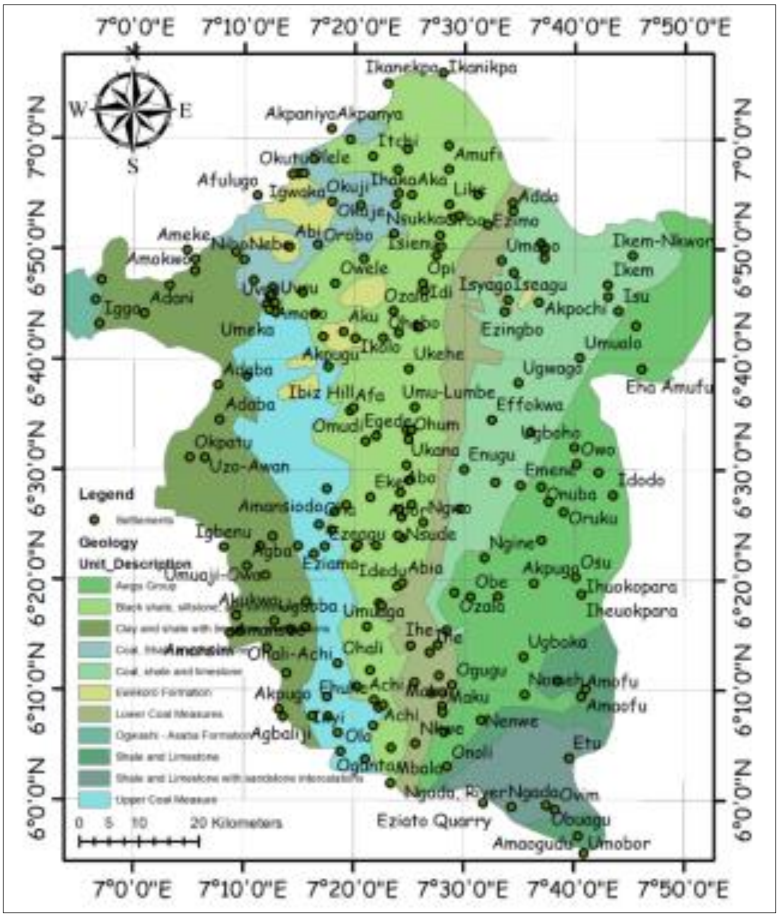

Figure 3 Geological Map of the Study Area

The study area also includes the Ewekoro Formation, primarily composed of limestone with minor shale and marl intercalations. This formation is notable for its hydrogeological properties and significance as an aquifer. The Lower Coal Measures, comprising coal seams, shale, and sandstone, are known for their economic coal deposits and their role in groundwater storage.

The Ogwashi-Asaba Formation, characterized by alternating layers of shale, sandstone, and lignite, is another important geological unit in the study area. This formation is significant for its lignite deposits and its role in groundwater recharge and flow (Overare et al., 2020). The region features thick sequences of shale interbedded with limestone layers, which act as confined aquifers and influence the permeability and porosity of the formation.

Furthermore, the geological diversity of the study area includes formations where shale and limestone are intercalated with sandstone. These alternating layers provide pathways for groundwater flow and influence the overall hydrogeological characteristics of the region. The Upper Coal Measures, with their interbedded coal seams, shale, and sandstone, are significant both for their coal resources and their impact on groundwater flow and storage (Overare et al., 2020).

The interplay between these different lithological units, as depicted in Figure 3 (Geology of the study), is crucial in determining the hydrogeological characteristics, groundwater availability, and quality in the study area. This geological diversity influences the aquifer properties, recharge rates, and the overall groundwater potential, making it a key factor in the region's water resource management.

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3. Materials and Methods

3.1. Data Sources and Preparation

This study leveraged a variety of datasets to conduct comprehensive analyses and modeling tasks. One of the primary sources of soil type data was the digitized Soil Map of the World, version 3.6. Initially published between 1974 and 1978 and subsequently updated to January 1994, this map was produced by the Food and Agriculture Organization (FAO). It offers a detailed global representation of soil types at a 1:5,000,000 scale (Adewumi et al., 2023). Ensuring accuracy, the dataset was meticulously corrected for database and digitized map errors.

To accommodate different geographic regions, the Americas utilized a bipolar oblique conformal projection, while other regions employed the Miller oblated stereographic projection. The updated map series included intersections with water-related features and revised country boundaries, enhancing the dataset's relevance for contemporary studies. The digital database was maintained in a Geographic projection, ensuring global compatibility and ease of integration with other spatial data.

The preparation of the data involved several crucial steps to ensure the reliability and consistency of the subsequent analyses. Initially, all datasets were converted to a common coordinate system, which is vital for accurate spatial analysis. The soil data was cross-referenced with topographic, land use, and climatic data to build a comprehensive database. Any discrepancies or errors in the data were identified and corrected during this phase. The data preparation process also involved the use of advanced GIS tools to enhance the spatial resolution and accuracy of the datasets, making them suitable for detailed analysis and modeling tasks.

3.2. Soil Erodibility Factor (K)

The Soil Erodibility Factor (K) is a crucial component in understanding soil erosion processes. It represents the susceptibility of soils to erosion, influenced by several soil properties, including texture, organic matter content, structure, and permeability. To calculate the K Factor, key soil properties such as the percentages of sand, silt, and clay, along with organic matter content and soil structure, were analyzed (Huang et al., 2022). Soils with high permeability, high organic matter content, and good structure tend to resist erosion better than those with high silt content. These properties were systematically measured and integrated into established empirical formulas to determine the K Factor.

The K Factor was calculated using William’s equation, which incorporates the following parameters:

$$K_{factor} = f_{sand} \times f_{clays} \times f_{orgc} \times f_{silt} \times 0.1317 \qquad \text{……….1}$$

Where

$$f_{sand} = \left(0.2 + 0.3exp\left[-0.256 \times M_{sand} \times \left(1 - \frac{M_{silt}}{100}\right)\right]\right) \qquad \text{………..2}$$

$$f_{clay} = \left(\frac{M_{silt}}{M_{clay}+M_{silt}}\right)^{0.3} \qquad \text{………..3}$$

$$f_{orgc} = \left(1 - \frac{0.0256orgc}{orgc+exp[3.72-2.95orgc]}\right) \qquad \text{……4}$$

$$f_{silt} = \left(1 - \frac{0.7\left(1-\frac{M_{sand}}{100}\right)}{\left(1-\frac{M_{sand}}{100}\right)+exp\left[-5.51+22.9\left(1-\frac{M_{sand}}{100}\right)\right]}\right) \qquad \ldots\ldots\ldots\ldots 5$$

By applying this equation, a comprehensive K Factor map was generated. This map highlights areas with varying levels of erosion susceptibility, serving as a valuable tool for soil conservation planning. The calculated K Factors were validated against field data to ensure their accuracy. This validation step was essential for confirming the reliability of the modeled K Factors.

The integration of these soil properties into the K Factor calculation provides a nuanced understanding of soil erodibility. Each component of the equation plays a critical role in determining the overall susceptibility of the soil to erosion (Huang et al., 2022). The sand factor f_{sand} accounts for the protective nature of sand particles in the soil matrix, while the clay factor f_{clay} considers the binding properties of clay particles. The organic carbon factor f_{orgc} reflects the soil's organic matter content, which enhances soil structure and water infiltration. Lastly, the silt factor f_{silt} addresses the vulnerability of fine particles to detachment and transport by water.

3.2.1. Data Analysis and Modeling

The datasets were instrumental in various analyses and modeling tasks conducted in the study, providing a robust foundation for evaluating land use patterns and soil characteristics. The digitized Soil Map of the World, version 3.6, was crucial in identifying soil types across the study region. The map's global scale and detailed representation allowed for precise analysis of soil properties and their impact on erosion.

By integrating the soil type data with other spatial datasets, such as topography, land use, and climatic variables, a comprehensive model of soil erosion susceptibility was developed. The K Factor map was a key output of this modeling effort, providing detailed insights into the spatial distribution of soil erodibility. This map is instrumental in identifying regions prone to erosion, allowing for targeted soil conservation measures. By understanding the spatial distribution of soil erodibility, land managers and planners can develop effective strategies to mitigate erosion risks. This approach supports sustainable land management practices and the preservation of soil resources.

The process of integrating various datasets involved advanced spatial analysis techniques using Geographic Information Systems (GIS). The spatial data layers were overlaid and analyzed to identify patterns and relationships between different variables. Areas with steep slopes, high rainfall, and vulnerable soil types were identified as high-risk zones for erosion. These zones were prioritized for further analysis and intervention.

3.3. Slope Analysis

The slope data derived from the Digital Elevation Model (DEM) were analyzed to understand the terrain characteristics of the study area. The slope (S) was calculated using the following equation:

$$S = arctan\left(\frac{\Delta z}{d}\right) \times \frac{180}{\pi} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 6$$

where Δz is the change in elevation, and d is the horizontal distance. 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.

The slope analysis provided a detailed understanding of the topographic variations within the study area. This information was critical for assessing erosion risks, as areas with steeper slopes are generally more susceptible to erosion. By correlating slope data with soil type and land use, the study was able to identify high-risk areas and recommend appropriate soil conservation measures.

The slope classification involved dividing the study area into different categories based on the degree of slope (Zhao et al., 2022). Each category was analyzed to determine its potential impact on soil erosion. Areas with steep slopes were identified as having a higher risk of erosion due to the increased gravitational force acting on soil particles. These areas were targeted for specific soil conservation practices such as terracing, contour plowing, and reforestation.

3.4. Land Use and Land Cover (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:

$$\Delta LULC = LULC_{2023} - LULC_{2017} \quad \ldots\ldots\ldots\ldots\ldots 7$$

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.

The LULC change analysis revealed significant shifts in land use patterns over the study period. These changes were closely examined to determine their impact on soil erosion. Areas that experienced deforestation or urbanization were found to have higher erosion rates due to the loss of vegetation cover and increased surface runoff. By identifying these trends, the study provided valuable insights into the relationship between land use changes and soil erosion.

The analysis of LULC changes involved the use of remote sensing data and satellite imagery. These data sources provided high-resolution images that were analyzed to detect changes in land cover over time. Advanced image processing techniques, such as classification algorithms and change detection methods, were used to accurately identify and quantify the changes in land use. The results were then validated with ground truth data to ensure their accuracy.

4. Results and Discussion

4.1. Land Use and Land Cover (LULC) 2023 Analysis

The study of the Land Use and Land Cover (LULC) 2023 in Enugu, southeastern Nigeria, reveals diverse categories, each with significant implications for erosion and groundwater recharge. Table 1 summarizes the LULC data, which highlights the predominant land cover types in the region.

Table 1 Land Use and Land Cover (LULC) in Enugu, Southeastern Nigeria

LULC Type 2023	Area (km^2)
Water	4.61
Trees	3709.74
Flooded vegetation	0.72
Crops	192.40
Built Area	1162.69
Bare ground	0.26
Rangeland	2631.81

The distribution of LULC types (Figure 4) significantly impacts both erosion and groundwater dynamics in the region. Trees, which cover the largest area (3709.74 km^2), play a crucial role in stabilizing the soil and reducing erosion rates. The extensive root systems of trees help anchor the soil, preventing it from being easily washed away by rainfall. Moreover, the canopy cover provided by trees reduces the impact of raindrops on the soil surface, further minimizing erosion.

Rangeland, covering 2631.81 km^2, also contributes to soil stability but to a lesser extent compared to forested areas. The vegetation in rangelands can help protect the soil surface, though the protection is less comprehensive than that offered by dense tree cover. Crops, covering 192.40 km^2, have a mixed impact on erosion. While they can help stabilize the soil during their growth periods, certain agricultural practices, such as tillage, can increase erosion rates if not managed properly.

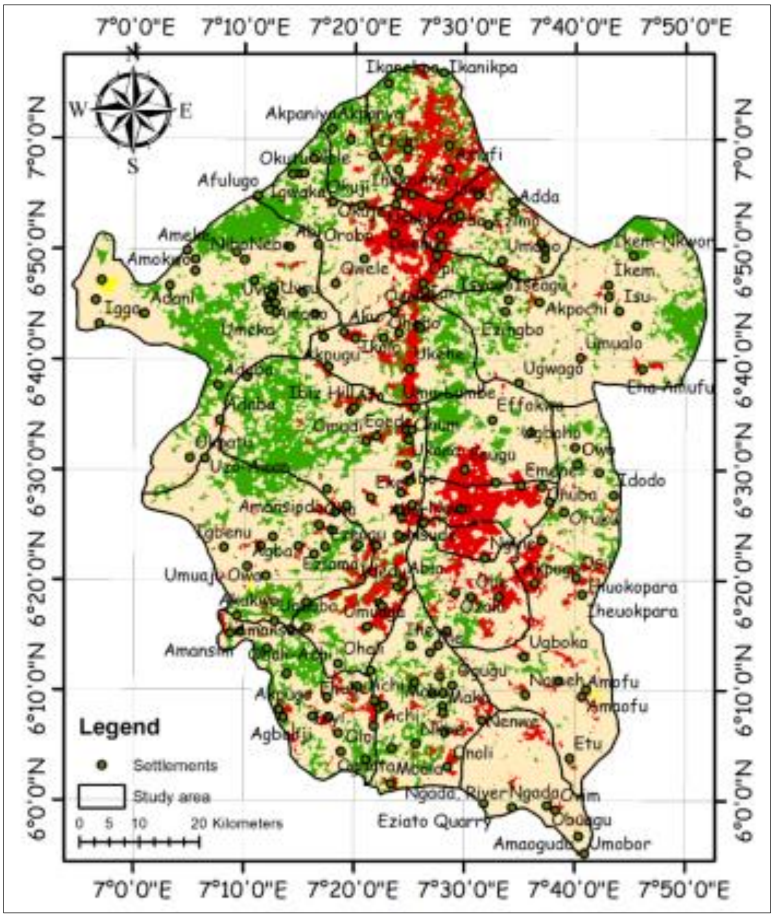

Figure 4 Spatial distribution of LULC 2023 in the study area

The built area, accounting for 1162.69 km^2, presents a significant challenge for both erosion and groundwater recharge. Impervious surfaces, such as roads and buildings, prevent water infiltration, leading to increased surface runoff and reduced groundwater recharge. The lack of vegetation in built areas means there is little to prevent soil erosion. The small areas covered by water (4.61 km^2), flooded vegetation (0.72 km^2), and bare ground (0.26 km^2) also play specific roles. Water bodies and flooded vegetation can act as groundwater recharge zones, whereas bare ground is highly susceptible to erosion due to the lack of protective vegetation cover.

4.2. Slope Analysis

Slope is another critical factor influencing erosion and groundwater recharge. Table 2 presents the distribution of slope degrees across Enugu, southeastern Nigeria.

Table 2 Slope Distribution in Enugu, Southeastern Nigeria

Slope (Degree)	Area (km^2)
0 - 1.81	1870.15
1.81 - 2.24	640.69
2.24 - 4.06	2634.77
4.06 - 11.73	2176.54
11.73 - 44.06	367.37

The slope distribution (Figure 5) has a direct correlation with erosion processes and groundwater dynamics. Gentle slopes (0 - 1.81 degrees), covering 1870.15 km^2, typically experience lower erosion rates because water tends to infiltrate rather than run off. This enhances groundwater recharge, making these areas crucial for maintaining the water table.

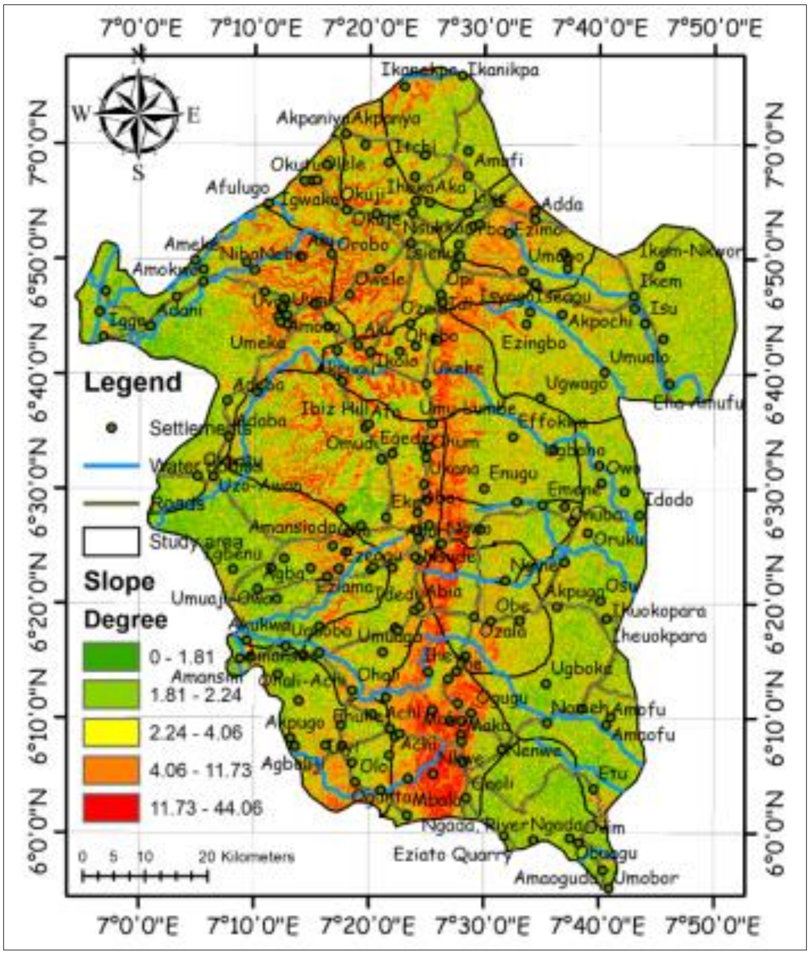

Figure 5 Spatial map of slope within the study area

Moderate slopes (1.81 - 4.06 degrees), encompassing 3275.46 km^2, are more susceptible to erosion compared to gentle slopes. While they still allow for some infiltration, the increased gradient can lead to more significant surface runoff, especially during heavy rainfall events. The balance between infiltration and runoff in these areas is delicate, and proper land management practices are essential to mitigate erosion.

Steeper slopes (4.06 - 11.73 degrees) covering 2176.54 km^2 are highly prone to erosion. The increased gradient accelerates water runoff, reducing infiltration and increasing soil erosion. These areas require significant intervention to manage erosion and prevent soil loss. The steepest slopes (11.73 - 44.06 degrees), although covering the smallest area (367.37 km^2), are the most erosion-prone. The high gradient leads to rapid water runoff, minimal infiltration, and severe soil erosion. These areas are critical points for implementing erosion control measures such as terracing, vegetation cover, and retaining walls to prevent significant soil loss and promote groundwater recharge.

The interplay between LULC types and slope gradients significantly influences both erosion and groundwater recharge in Enugu. The extensive tree cover and rangeland areas provide substantial protection against erosion while facilitating groundwater recharge through increased infiltration. However, the built areas and agricultural lands present challenges due to reduced infiltration and increased surface runoff.

Steeper slopes exacerbate erosion, particularly in areas with insufficient vegetation cover. The combination of built areas on steep slopes poses a dual threat of increased erosion and decreased groundwater recharge. Conversely, flatter areas with tree cover or rangeland are beneficial for maintaining soil stability and enhancing groundwater recharge.

4.3. Soil Types and Erosion Susceptibility

In Enugu, southeastern Nigeria, the distribution of soil types plays a crucial role in determining both the region's erosion potential and its groundwater recharge capacity. The soil types, their areas, and their K-factors, which indicate soil erodibility, are summarized in Table 3.

Table 3 Soil Types and Erodibility in Enugu, Southeastern Nigeria

Soil Type	Area (km^2)	K-Factor (t.ha.h.ha/MJ/mm)
Ferric Acrisols	102.36	0.0193
Plinthic Acrisols	2732.53	0.0192
Gleysols	20.69	0.0189
Dystric Fluvisols	793.92	0.0223
Dystric Nitosols	4052.80	0.0178

The extensive coverage of Dystric Nitosols (4052.80 km^2) in the region has significant implications for erosion control and groundwater recharge. With the lowest K-factor (0.0178) among the soil types, Dystric Nitosols are less prone to erosion. This low erodibility enhances soil stability, which is beneficial for both agriculture and natural vegetation. Furthermore, the higher infiltration capacity of Dystric Nitosols supports effective groundwater recharge, ensuring that rainwater percolates into the soil rather than running off and causing erosion.

Plinthic Acrisols, covering 2732.53 km^2, have a slightly higher K-factor (0.0192) than Dystric Nitosols, indicating a moderate susceptibility to erosion. These soils are often found in areas with periodic waterlogging, which can affect their stability and erodibility. Proper land management practices, such as maintaining vegetation cover and avoiding intensive agricultural activities on these soils, can mitigate erosion risks.

Ferric Acrisols, with an area of 102.36 km^2 and a K-factor of 0.0193, also exhibit moderate erosion susceptibility. These soils, characterized by iron-rich horizons, require careful management to prevent soil degradation. Practices such as contour farming, terracing, and afforestation can help reduce erosion on Ferric Acrisols, thereby preserving soil health and promoting groundwater recharge.

Dystric Fluvisols, occupying 793.92 km^2, have the highest K-factor (0.0223), making them the most erosion-prone soil type in the study area. These alluvial soils, typically found along river valleys, are highly susceptible to erosion due to their loose structure and location in areas with high water flow. Implementing erosion control measures, such as riparian buffers and cover crops, is essential to reduce soil loss and maintain the ecological health of river systems. Enhancing the stability of Dystric Fluvisols also supports groundwater recharge by reducing surface runoff.

Gleysols, although covering a small area (20.69 km^2), have a K-factor of 0.0189, indicating low to moderate erosion susceptibility. These waterlogged soils are often found in depressions and low-lying areas. Managing water levels and maintaining vegetation cover can help reduce erosion and support groundwater recharge in areas with Gleysols.

The soil types in Enugu significantly influence groundwater recharge rates. Dystric Nitosols, with their low erodibility and high infiltration capacity, are particularly beneficial for groundwater recharge. The extensive coverage of these soils means that a substantial portion of the region has the potential to support effective groundwater replenishment. Ensuring that land management practices enhance the infiltration capacity of these soils is crucial for maintaining groundwater resources.

Plinthic Acrisols, with their moderate erosion susceptibility, can also contribute to groundwater recharge if managed properly. Avoiding intensive land use and maintaining vegetation cover are key strategies to enhance the recharge potential of these soils. Ferric Acrisols, with similar characteristics, require similar management practices to support groundwater recharge while preventing erosion. The high erosion susceptibility of Dystric Fluvisols poses a challenge for groundwater recharge. The loose structure of these soils and their location in high water flow areas mean that much of the rainwater can be lost as surface runoff rather than infiltrating the soil. Implementing erosion control measures and enhancing soil structure are critical for improving the recharge potential of Dystric Fluvisols.

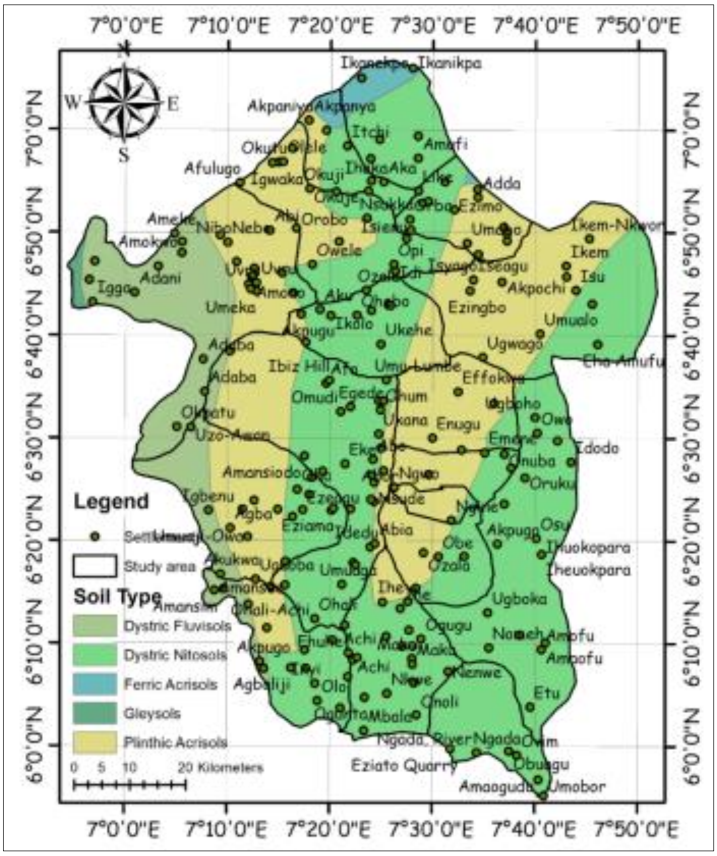

Figure 6 Distribution of Soil Types in Enugu, Southeastern Nigeria

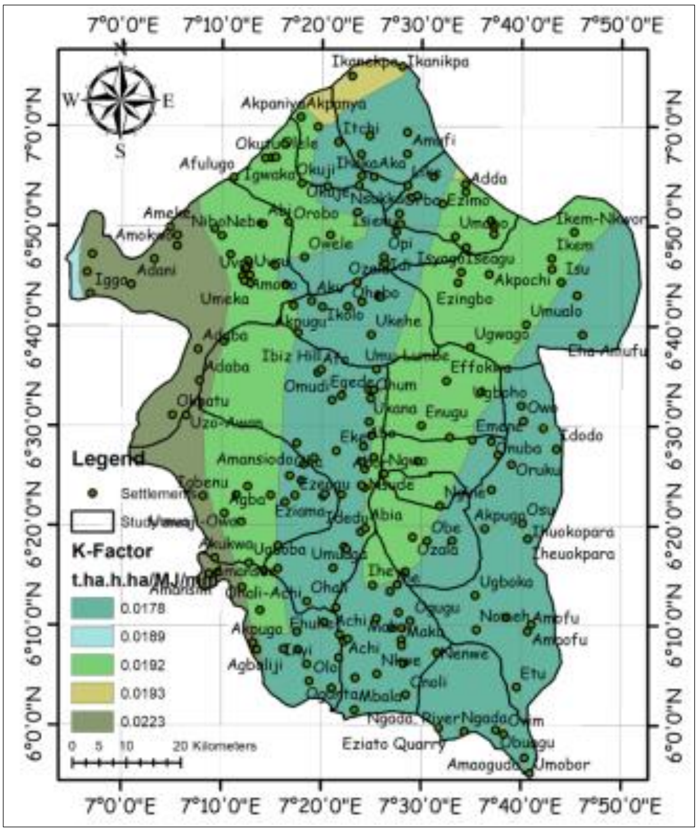

Figure 7 Soil Erodibility (K-Factor) in Enugu, Southeastern Nigeria

Gleysols, despite their small area, play a role in local groundwater dynamics. Managing water levels and vegetation cover in areas with Gleysols can support groundwater recharge by enhancing infiltration and reducing surface runoff.

Figures 6 and 7 illustrate the spatial distribution of soil types and their respective K-factors across Enugu. These visual representations are essential for understanding the area's most susceptible to erosion and those with the highest potential for groundwater recharge. By identifying these critical areas, land management strategies can be tailored to address specific soil and erosion challenges.

The analysis of soil types and their erodibility in Enugu, southeastern Nigeria, highlights the need for targeted land management practices to mitigate erosion and enhance groundwater recharge. The extensive coverage of Dystric Nitosols, with their low erodibility and high infiltration capacity, presents a significant opportunity for effective groundwater management. However, the moderate to high erosion susceptibility of other soil types, particularly Dystric Fluvisols, necessitates the implementation of erosion control measures to prevent soil loss and enhance water infiltration.

Land management practices such as afforestation, contour farming, terracing, and the use of cover crops can significantly reduce erosion risks and promote soil stability. These practices not only protect the soil but also enhance groundwater recharge by increasing the infiltration capacity of the land. In areas with high erosion susceptibility, such as those with Dystric Fluvisols, specific interventions like riparian buffers and erosion control structures are essential to prevent soil degradation and maintain ecological balance.

5. Conclusion

The study of Land Use and Land Cover (LULC) in Enugu, southeastern Nigeria, reveals a complex interplay between land cover types, slope gradients, and soil types, each significantly influencing erosion and groundwater recharge. Trees, which dominate the landscape, are vital for soil stabilization and reducing erosion through their extensive root systems and canopy cover. Rangelands also contribute to soil stability, though to a lesser extent. Crops present a dual impact; while they can stabilize soil during growth, agricultural practices like tillage can exacerbate erosion. Built areas, with their impervious surfaces, pose significant challenges by increasing surface runoff and reducing groundwater recharge.

The slope gradient distribution further impacts erosion and groundwater dynamics. Gentle slopes facilitate water infiltration and enhance groundwater recharge, whereas moderate and steeper slopes are more prone to erosion due to increased runoff. Steeper slopes, especially those without sufficient vegetation cover, require targeted erosion control measures to prevent significant soil loss and to enhance water infiltration.

Soil types in Enugu also play a critical role in determining erosion potential and groundwater recharge capacity. Dystric Nitosols, covering the largest area, exhibit the lowest erodibility, making them less prone to erosion and highly beneficial for groundwater recharge due to their high infiltration capacity. Plinthic Acrisols and Ferric Acrisols, with moderate erosion susceptibility, require careful management to prevent degradation and to promote infiltration. Dystric Fluvisols, being the most erosion-prone, necessitate rigorous erosion control measures to maintain soil stability and support groundwater recharge. Gleysols, though covering a small area, require water management and vegetation cover to reduce erosion and enhance groundwater recharge.

The extensive coverage of Dystric Nitosols provides a substantial opportunity for effective groundwater management in Enugu. Proper land management practices, such as afforestation, contour farming, and terracing, are essential to mitigate erosion and to enhance the infiltration capacity of these soils. However, the erosion susceptibility of other soil types, particularly Dystric Fluvisols, highlights the need for targeted interventions like riparian buffers and cover crops to prevent soil loss and to improve groundwater recharge.

The diverse LULC types, varied slope gradients, and different soil types in Enugu collectively influence the region's erosion and groundwater recharge dynamics. Effective land management practices tailored to these specific conditions are crucial to mitigate erosion risks and to enhance groundwater resources in the region. Implement targeted land management practices such as afforestation, contour farming, and the use of cover crops to mitigate erosion and enhance groundwater recharge, especially in areas with high erosion susceptibility like Dystric Fluvisols.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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