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Impact of land cover, soil type and topography on groundwater resources in Ebonyi State, Southeastern, Nigeria

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Abstract

Understanding the interplay between land use, topography, and soil properties is crucial for effective groundwater management. Ebonyi State, Nigeria, exhibits diverse land cover types, slope variations, and soil characteristics, all influencing groundwater dynamics. This study aims to analyze these factors to inform sustainable groundwater management practices. The primary aim is to assess the spatial distribution of land use/land cover (LULC), slope, and soil types in Ebonyi State and their implications for groundwater recharge, availability, and quality. The study employs geospatial analysis techniques to map and quantify LULC, slope, and soil types across Ebonyi State. Data were collected from satellite imagery, topographic maps, and soil surveys. The analysis involved classifying land cover types, calculating slope gradients, and determining soil erodibility (K-factor). The LULC analysis revealed that rangeland is the dominant land cover type, covering 4223.89 km^2, indicating extensive grazing activities. Forested areas, covering 812.81 km^2, play a significant role in groundwater recharge through enhanced infiltration. Agricultural lands (754.11 km^2) suggest considerable groundwater extraction for irrigation. Urban areas (374.07 km^2) pose challenges for groundwater recharge due to increased surface runoff. Water bodies and flooded vegetation, though covering smaller areas, contribute positively to groundwater recharge. The slope analysis showed that gentle slopes (0 - 1.49 degrees) dominate, favoring groundwater recharge. Steeper slopes exhibit higher runoff rates, reducing recharge potential. The soil analysis identified four main soil types: Ferric Acrisols, Gleysols, Dystric Gleysols, and Dystric Nitosols. Dystric Nitosols, covering the largest area, are well-drained and suitable for groundwater recharge, while Gleysols and Dystric Gleysols present drainage challenges. The extensive rangeland and forested areas enhance groundwater recharge, while urbanization reduces it. Gentle slopes support recharge, but steeper slopes require erosion control measures. Dystric Nitosols are favorable for groundwater recharge, but Ferric Acrisols and Gleysols need targeted management to mitigate erosion and improve drainage. Effective groundwater management in Ebonyi State requires a nuanced understanding of LULC, slope, and soil types. Rangeland and forested areas should be preserved for their recharge benefits, while urban expansion needs careful planning. Soil conservation and sustainable agricultural practices are essential to enhance groundwater recharge and maintain water quality. To ensure sustainable groundwater management, implement erosion control measures in Ferric Acrisols, effective drainage systems for Gleysols, and promote sustainable agricultural practices in Dystric Nitosols to enhance soil structure and groundwater recharge.

Keywords: Ecological Impact; Geospatial Analysis; Land Use; Terrain Analysis; Water Quality

1. Introduction

Groundwater resources play a pivotal role in sustaining life, supporting ecosystems, and driving socio-economic development. In many parts of the world, particularly in arid and semi-arid regions, groundwater is often the primary source of fresh water for domestic, agricultural, and industrial uses (Adagunodo et al., 2018; Abdulrazzaq et al., 2020). Nigeria, with its diverse climatic and geographical conditions, is no exception. The country relies heavily on groundwater to meet the needs of its growing population and to support its agricultural sector, which is a cornerstone

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of its economy (Eduvie & Garba, 2021). However, the availability and quality of groundwater are influenced by a myriad of factors, including land cover, soil type, and topography (Igwe et al., 2020). Understanding these factors and their interplay is crucial for the sustainable management of groundwater resources.

Groundwater is a critical component of the hydrological cycle, serving as a reservoir that can buffer against periods of drought and supply water during times when surface water resources are scarce. It is estimated that about one-third of the world's population relies on groundwater for drinking water, and in some regions, this dependence is even greater (Adebayo et al., 2021). In Nigeria, groundwater is particularly important in rural areas where surface water sources may be limited or contaminated. Moreover, groundwater is less susceptible to pollution compared to surface water, making it a relatively safer source of drinking water (Yusuf & Abiye, 2019). The strategic importance of groundwater in ensuring water security cannot be overstated.

Land cover refers to the physical material on the surface of the earth, including vegetation, urban infrastructure, water bodies, and bare soil. It plays a significant role in the hydrological cycle by influencing the infiltration, evaporation, and runoff processes (Oyedele, 2019). Vegetated areas, for instance, tend to have higher infiltration rates compared to urban areas covered with impervious surfaces such as concrete and asphalt. This is because vegetation can enhance soil structure and promote the percolation of water into the ground, thereby recharging groundwater aquifers (Karnatz et al., 2019). Conversely, urbanization often leads to increased surface runoff and reduced groundwater recharge due to the prevalence of impervious surfaces. Changes in land cover, whether due to natural processes or human activities, can therefore have profound impacts on groundwater availability and quality (Khalil et al., 2021).

Soil type is another crucial factor that affects groundwater resources. Soils vary widely in their physical and chemical properties, which influence their capacity to absorb and transmit water (Omorogieva & Imasuen, 2018). Sandy soils, for example, have high permeability and allow water to infiltrate quickly, facilitating groundwater recharge (Oke et al., 2018). On the other hand, clayey soils have low permeability and tend to retain water on the surface, reducing the potential for groundwater recharge. Additionally, the chemical composition of soils can affect the quality of groundwater. For instance, soils rich in organic matter can enhance the natural filtration of contaminants, thereby improving groundwater quality (Omorogieva & Imasuen, 2018). Understanding the distribution and properties of different soil types is essential for assessing groundwater recharge rates and developing effective groundwater management strategies.

Topography, or the shape and features of the land surface, influences the movement and distribution of water in the landscape. Sloped areas tend to facilitate surface runoff, while flat areas promote infiltration and groundwater recharge (Olofinlade et al., 2018). Topographical features such as hills, valleys, and plains can create variations in hydraulic head, driving the flow of groundwater. In addition, topography can affect the distribution of vegetation and soil types, further influencing groundwater dynamics (Aladejana & Fagbohun, 2018). For example, low-lying areas with dense vegetation and permeable soils are often favorable for groundwater recharge. Understanding the topographical characteristics of a region is therefore important for predicting groundwater flow patterns and identifying potential recharge zones.

The impact of land cover, soil type, and topography on groundwater resources is not isolated; rather, these factors interact in complex ways to influence the quantity and quality of groundwater. A region with permeable soils and gentle slopes may experience high groundwater recharge rates, but this potential can be compromised if the land cover is dominated by impervious surfaces. Similarly, the beneficial effects of vegetation on groundwater recharge can be negated by steep slopes that promote rapid runoff (Yenehun et al., 2020). Effective groundwater management therefore requires a holistic understanding of these interactions and the ability to integrate multiple factors into decision-making processes.

The sustainable management of groundwater resources in Nigeria faces several challenges. Rapid urbanization, agricultural expansion, and climate change are some of the key drivers of land cover changes that can adversely affect groundwater recharge. The heterogeneity of soil types and topographical features adds complexity to groundwater management. However, these challenges also present opportunities for innovation and improvement. Advances in remote sensing and geographic information systems (GIS) provide powerful tools for mapping and monitoring land cover, soil, and topography at high resolutions (Andualem & Demeke, 2019; Arunbose et al., 2021). These technologies can enhance our understanding of groundwater dynamics and support the development of targeted management strategies.

This study is expected to contribute to the body of knowledge on groundwater management by providing insights into the relationships between land cover, soil type, topography, and groundwater resources. The findings will be valuable for policymakers, water resource managers, and environmental planners in developing strategies for sustainable groundwater management. By enhancing our understanding of the factors that influence groundwater dynamics, this study will support efforts to ensure water security and promote the sustainable development of Nigeria's water resources. Groundwater is an invaluable resource that requires careful management to ensure its sustainability. The impact of land cover, soil type, and topography on groundwater resources is complex and multifaceted, necessitating a comprehensive and integrated approach to study and manage these interactions. This study aims to provide a detailed examination of these factors and their effects on groundwater in Nigeria, contributing to the development of effective management practices that can safeguard this vital resource for future generations.

2. Research Area and Geology of the Study

The study area is situated in Ebonyi State, located in the southeastern region of Nigeria. This area spans approximately between latitudes 6° 13' N and 6° 51' N, and longitudes 7° 30' E and 8° 30' E, encompassing a diverse and complex geological landscape that significantly influences the region's soil properties and erosion susceptibility as shown in Figure 1.

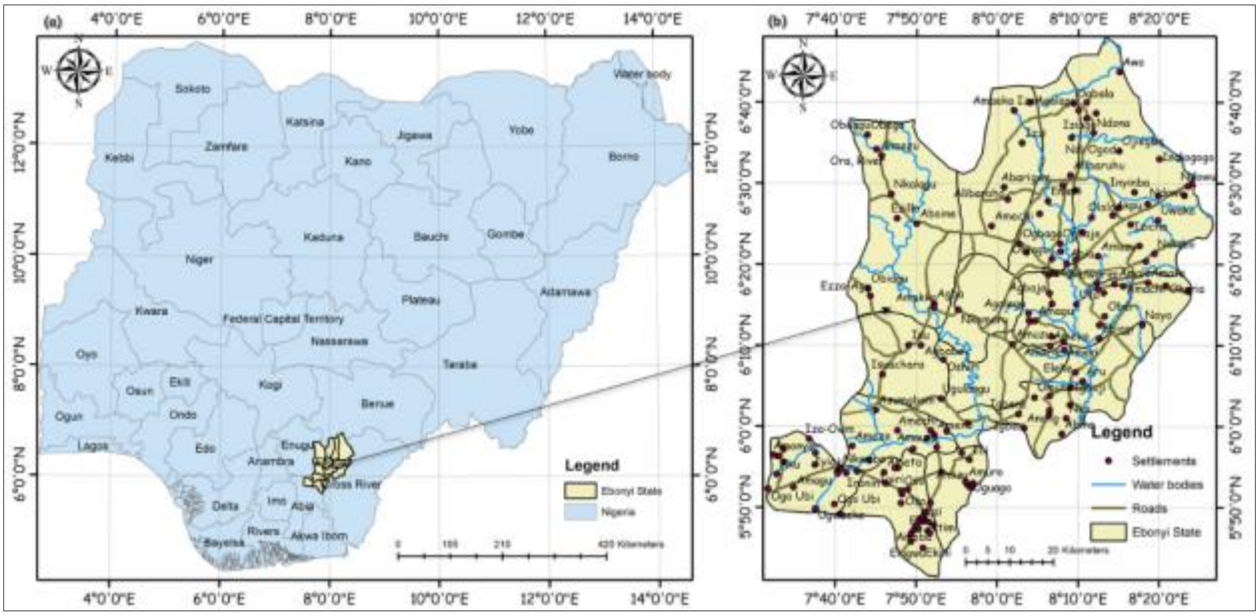

Figure 1 Map of the Study Area in Ebonyi State, Southeastern Nigeria

Ebonyi State is well connected through a network of roads and rivers, facilitating accessibility for transportation and commerce. Major roads traverse the state, linking it to neighboring regions and enhancing connectivity to urban centers. The Cross River, one of the principal rivers in the area, flows through parts of Ebonyi, providing essential water resources for agricultural, domestic, and industrial use. This network of rivers and roads plays a crucial role in the socioeconomic development of the state.

The elevation of Ebonyi State varies significantly, with altitudes ranging from approximately 100 meters to over 500 meters above sea level. The terrain is characterized by undulating hills and low-lying plains, contributing to varied microclimates and influencing land use patterns (Oli et al., 2020). Figure 2 illustrates the elevation distribution across the study area, highlighting the diverse topographical features that impact soil erosion and agricultural practices.

The climate of Ebonyi State is typically tropical, with distinct wet and dry seasons. The wet season extends from April to October, bringing substantial rainfall that can lead to increased soil erosion, especially in areas with steep slopes and poor vegetation cover. The dry season, from November to March, is characterized by lower humidity and reduced rainfall. The average annual temperature ranges from 27°C to 31°C, while annual rainfall varies between 1,500 mm and 2,000 mm. These weather conditions significantly affect soil moisture content, vegetation growth, and the overall erosion dynamics in the region.

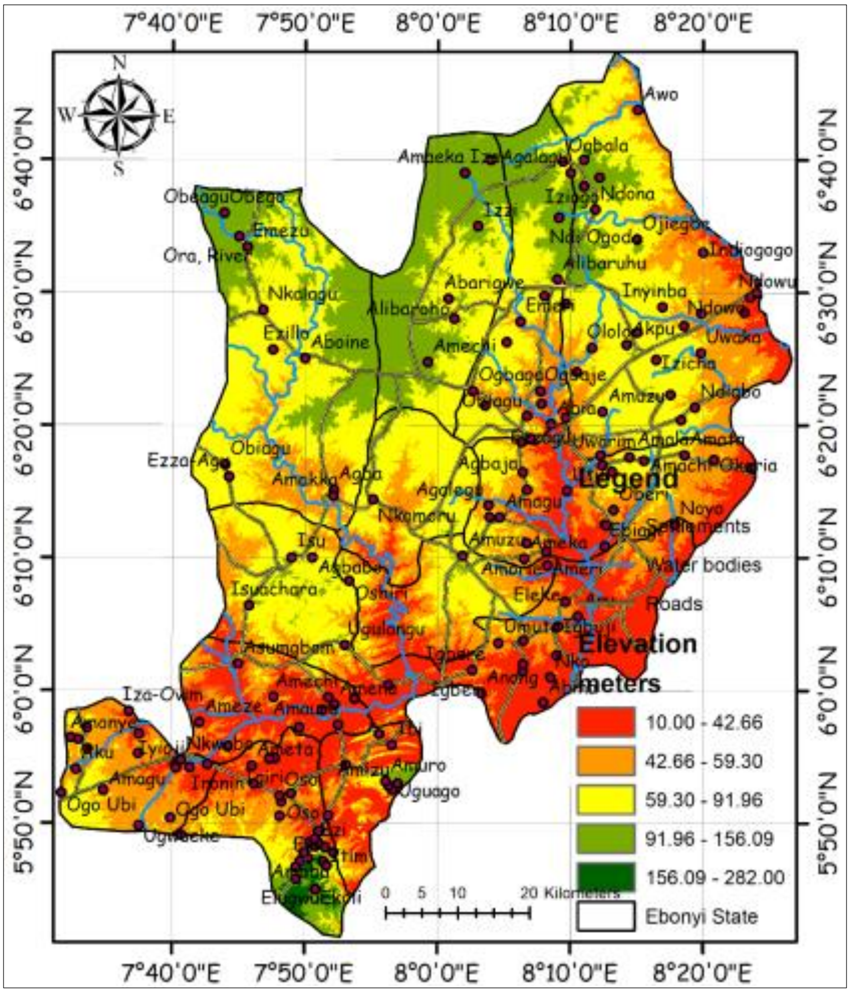

Figure 2 Elevation Map of the Study Area Highlighting Topographical Variations

The geology of Ebonyi State is predominantly composed of sedimentary formations and volcanic rocks, part of the larger Benue Trough, a significant geological structure in southeastern Nigeria. The major geological formations in the study area include the Awgu Group, characterized by black shales, siltstones, and sandstones (Onwe-Moses et al., 2019). These fine-grained sediments influence soil texture and erodibility. The black shales are rich in organic matter, contributing to the fertility of the soils, while the siltstones and sandstones offer varying degrees of permeability and stability (Ayadiuno et al., 2021). Figure 3 depicts the geological distribution within the study area, providing a detailed view of the different formations present.

In addition to the Awgu Group, the geology of Ebonyi State includes significant deposits of coal, shale, and limestone, which are interbedded in various formations. The Lower Coal Measures consist of coal seams interspersed with shales and limestones, contributing to the region's economic geology and affecting soil composition. These coal measures are essential for understanding the mineral wealth of the area and its influence on land use and soil management practices.

The Upper Coal Measures also feature prominently in the geological landscape of Ebonyi State. These formations consist of younger sedimentary rocks, including coal, shale, and limestone with sandstone intercalations. These intercalated sandstone layers add complexity to the soil structure and impact its erosion susceptibility (Onwe-Moses et al., 2019). The presence of these varied geological materials necessitates detailed study to understand their role in soil conservation and erosion control.

Younger basaltic rocks are another important geological feature in the study area. These volcanic rocks, formed from ancient lava flows, are typically hard and resistant to weathering. They contribute to the topographical diversity of the region and influence soil formation processes. The basaltic rocks provide a source of essential minerals that enhance soil fertility but also present challenges for erosion control due to their rugged terrain (Onwe-Moses et al., 2019).

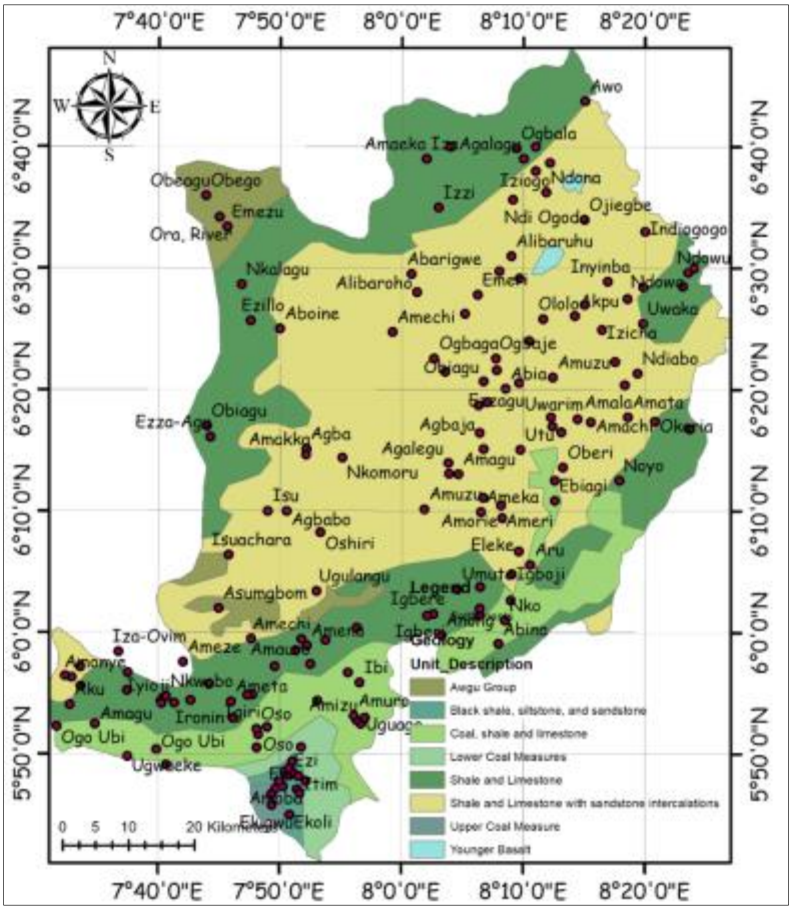

Figure 3 Geological Map of the Study Area Showing Key Formations

The varied geology of Ebonyi State, with its complex interplay of sedimentary and volcanic rocks, significantly impacts the region's soil characteristics. The presence of shale and limestone formations, along with sandstone intercalations, creates a diverse soil matrix that varies in texture, fertility, and erodibility (Onwe-Moses et al., 2019). These geological features must be carefully considered when developing soil conservation strategies and managing land use practices to mitigate erosion risks.

The integration of geological data with topographical and climatic information is crucial for comprehensive land management in Ebonyi State. Understanding the spatial distribution of different geological formations helps identify areas susceptible to erosion and informs the implementation of targeted soil conservation measures. This holistic approach ensures sustainable land use and the preservation of soil resources in the face of climatic and anthropogenic pressures.

3. Materials and Methods

3.1. Data Sources and Preparation

This study utilized multiple 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 comprehensive global representation of soil types at a 1:5,000,000 scale (Adewumi et al., 2023). To ensure 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.

To prepare the data for analysis, a series of preprocessing steps were undertaken. This included ensuring consistency in data formats, correcting any discrepancies, and integrating various spatial datasets. The data was then transformed into a common coordinate system to facilitate accurate spatial analysis. This preparation was crucial for ensuring that the subsequent analyses and models were based on reliable and consistent data.

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 (Amah et al., 2020). 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

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

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

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

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

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 then validated against field data to ensure their accuracy. This validation step was essential for confirming the reliability of the modeled K Factors (Igwe & Egbueri, 2018).

3.3. 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 (Nebeokike et al., 2020). 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.

3.3.1. 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:

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

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 (Mayomi et al., 2016). 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.

3.3.2. 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:

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

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. For instance, 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.

4. Results and Discussion

4.1. Analysis of Land Use/Land Cover Impact

The Land Use/Land Cover (LULC) analysis for Ebonyi State, Nigeria, as presented in Table 1, reveals significant insights into the spatial distribution of various land cover types in 2023. This analysis is crucial for understanding the potential impact on groundwater resources in the region.

Table 1 LULC Distribution in Ebonyi State, 2023

LULC Type 2023	**Area (km^2)**
Water	15.36
Trees	812.81
Flooded vegetation	5.09
Crops	754.11
Built Area	374.07
Bare ground	0.44
Rangeland	4223.89

The dominant LULC type in Ebonyi State is rangeland, which covers an extensive area of 4223.89 km^2. This extensive coverage is likely indicative of the predominant use of land for grazing and pastoral activities. The large area of rangeland can have significant implications for groundwater recharge and sustainability, as these areas often allow for greater infiltration of rainwater compared to built-up areas or land under intensive agricultural use.

Trees cover 812.81 km^2, making up a substantial portion of the state's land cover. Forested areas play a critical role in maintaining the hydrological cycle, supporting groundwater recharge through enhanced infiltration and reduced surface runoff. The presence of trees is beneficial for groundwater sustainability, contributing to the maintenance of aquifers and overall water quality.

Agricultural land, classified as crops, accounts for 754.11 km^2 of the area. The significant agricultural activity suggests that groundwater extraction for irrigation might be considerable, which could impact the groundwater levels over time. Sustainable agricultural practices are essential to ensure that groundwater resources are not overexploited.

Built areas cover 374.07 km^2, indicating urbanization and infrastructure development. Urban areas typically reduce the permeability of the land surface, leading to increased surface runoff and decreased groundwater recharge. This urban expansion needs to be managed carefully to avoid adverse effects on groundwater availability.

Water bodies occupy 15.36 km^2, providing essential surface water resources that can contribute to groundwater recharge, particularly in regions where surface and groundwater systems are interconnected.

Flooded vegetation, although covering a relatively small area of 5.09 km^2, plays a crucial role in the local hydrology. These areas can act as natural reservoirs that store floodwaters and gradually release them, aiding in groundwater recharge.

The smallest land cover type, bare ground, occupies only 0.44 km^2. While its impact may be minimal due to its limited extent, bare ground areas are typically characterized by low infiltration rates and higher erosion potential, which can negatively affect groundwater recharge if not properly managed.

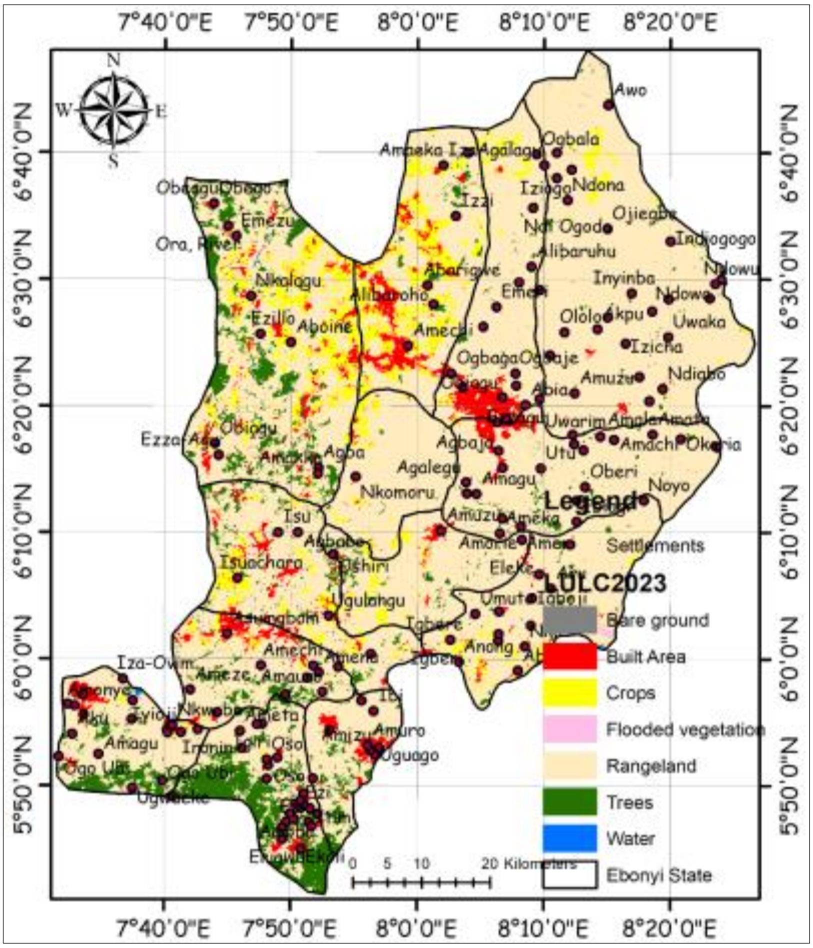

Figure 4 LULC Distribution Map of Ebonyi State, Nigeria (2023)

Figure 4 illustrates the spatial distribution of the various LULC types across Ebonyi State, derived from the data in Table 1. The map provides a visual representation of the extensive rangeland coverage, the significant areas occupied by trees and crops, and the distribution of built areas, water bodies, and other land cover types. This spatial analysis is essential for planning and implementing effective groundwater management strategies.

4.2. Implications of Slope Distribution

The slope of the terrain plays a critical role in determining groundwater recharge, runoff patterns, and overall water availability. In the context of Ebonyi State, Nigeria, the slope distribution data presented in Table 2 provides insights into how the terrain may influence groundwater dynamics.

Table 2 Slope Distribution in Ebonyi State, 2023

Slope (degree)	Area (km^2)
0 - 1.49	1453.361
1.49 - 1.85	455.895
1.85 - 3.35	2385.330
3.35 - 9.66	1826.441
9.66 - 36.29	52.112

The slope categories indicate varying degrees of steepness across Ebonyi State, which in turn affects water movement and storage within the landscape.

The largest area of Ebonyi State, covering 1453.361 km^2, falls within the gentle slope category of 0 - 1.49 degrees. Gentle slopes favor groundwater recharge due to the slower movement of surface water, allowing more time for infiltration into the soil and underlying aquifers. This terrain is likely to have higher groundwater recharge rates, making it vital for maintaining groundwater levels. These areas are suitable for groundwater extraction and sustainable agricultural practices that rely on groundwater.

Moderate slopes, covering 455.895 km^2, also support groundwater recharge, although the infiltration rates might be slightly lower compared to gentler slopes. The moderate incline facilitates adequate infiltration while minimizing surface runoff, making these areas beneficial for groundwater recharge. Sustainable land management practices in these regions can enhance groundwater availability.

The most extensive area, 2385.330 km^2, falls within the moderately steep slope range of 1.85 - 3.35 degrees. These slopes can pose challenges for groundwater recharge due to increased runoff and reduced infiltration. However, they can still contribute to groundwater recharge if managed properly. Vegetation cover and soil conservation practices are essential in these areas to enhance infiltration and reduce erosion.

Steep slopes, covering 1826.441 km^2, are characterized by higher runoff rates and reduced infiltration, posing challenges for groundwater recharge. These areas are prone to soil erosion, which can further reduce the potential for groundwater recharge. Implementing erosion control measures and maintaining vegetation cover are crucial for mitigating the negative impacts of steep slopes on groundwater resources.

The smallest area, 52.112 km^2, falls within the very steep slope category of 9.66 - 36.29 degrees. These slopes have the highest runoff rates and the least potential for groundwater recharge. Water conservation and management practices in these areas are critical to prevent soil erosion and manage surface water runoff (Mayomi et al., 2016). These regions are less suitable for activities that rely heavily on groundwater due to their limited recharge capacity.

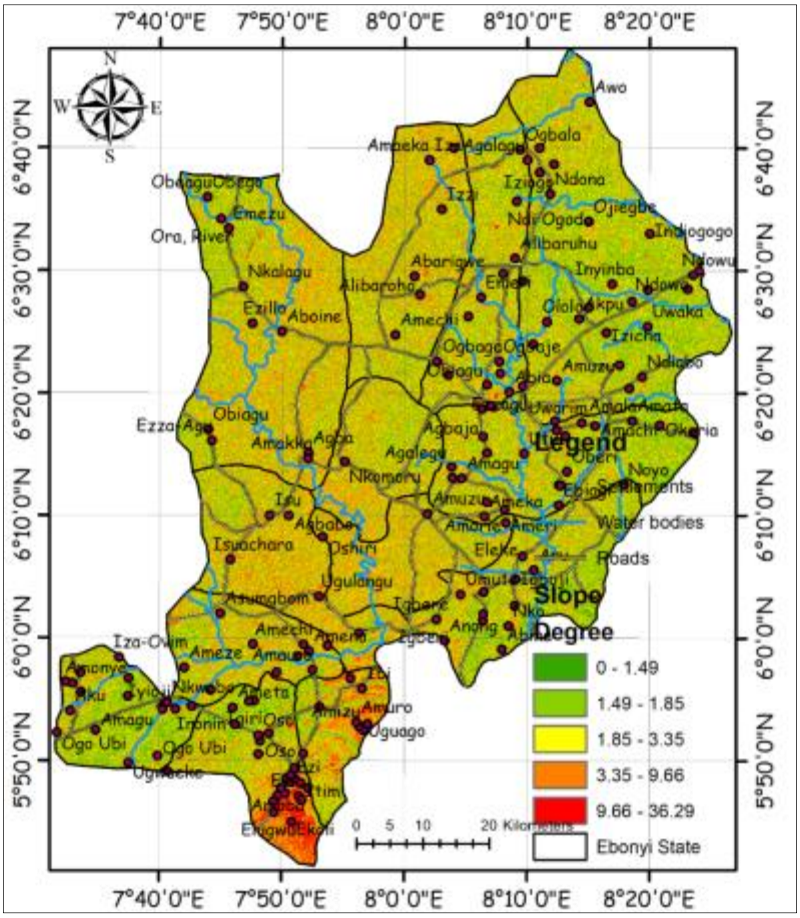

Figure 5 Slope Distribution Map of Ebonyi State, Nigeria (2023)

Figure 5, derived from Table 2, visually represents the distribution of slope categories across Ebonyi State. This map is instrumental in understanding the spatial variability of terrain steepness and its potential impact on groundwater recharge and availability.

4.3. Implications of Soil Type and Erodibility

Soil properties, including texture and erodibility, significantly influence groundwater recharge, availability, and quality. In Ebonyi State, Nigeria, understanding the distribution of soil types and their erodibility (K-factor) is essential for effective groundwater management. The data in Table 3 presents the prevalent soil types, their respective areas, and K-factors in Ebonyi State, providing insights into how these factors affect groundwater resources.

Table 3 Soil Types and Erodibility in Ebonyi State, 2023

Soil Type	Area (km^2)	K-Factor (t·ha·h·ha/MJ/mm)
Ferric Acrisols	780.52	0.0193
Gleysols	26.41	0.0189
Dystric Gleysols	43.65	0.0179
Dystric Nitosols	5335.25	0.0178

Ferric Acrisols cover 780.52 km^2 of Ebonyi State and have a K-factor of 0.0193. Acrisols are typically composed of sandy to loamy sand textures with high iron content, which gives them a reddish color. These soils are often well-drained but can be prone to erosion due to their sandy nature and low organic matter content. The relatively high K-factor indicates moderate susceptibility to erosion. In terms of groundwater, the well-drained nature of Ferric Acrisols can facilitate infiltration, enhancing groundwater recharge (Nebeokike et al., 2020). However, their susceptibility to erosion can lead to the loss of topsoil, potentially affecting the quality of infiltrating water.

Gleysols, occupying 26.41 km², have a K-factor of 0.0189. These soils are typically found in areas with poor drainage and are often waterlogged. Gleysols are characterized by a high clay content, which reduces permeability and slows down water infiltration. The lower K-factor indicates a lower susceptibility to erosion compared to Acrisols. The waterlogged nature of Gleysols can limit groundwater recharge, as water tends to remain on the surface or in the upper soil layers. Effective drainage management is crucial in these areas to improve groundwater recharge potential (Igwe & Egbueri, 2018).

Dystric Gleysols cover 43.65 km² and have a K-factor of 0.0179. Similar to Gleysols, these soils are poorly drained and often found in low-lying areas. Dystric Gleysols have a higher organic matter content and a mix of clay and silt, which can improve water retention but reduce infiltration rates. The lower K-factor suggests a lower erosion risk. These soils' poor drainage properties can hinder groundwater recharge, making it essential to implement strategies that enhance infiltration and reduce surface water stagnation.

The largest soil type in Ebonyi State, Dystric Nitosols, covers 5335.25 km² with a K-factor of 0.0178. Nitosols are deep, well-drained soils with a high clay content and good structure, often found on hilly or undulating terrain. Their structure and composition make them less prone to erosion, as indicated by the low K-factor. Dystric Nitosols are highly fertile and capable of retaining water, which supports groundwater recharge (Igwe & Egbueri, 2018). The well-drained nature and good structure of these soils make them ideal for sustainable agricultural practices that rely on groundwater.

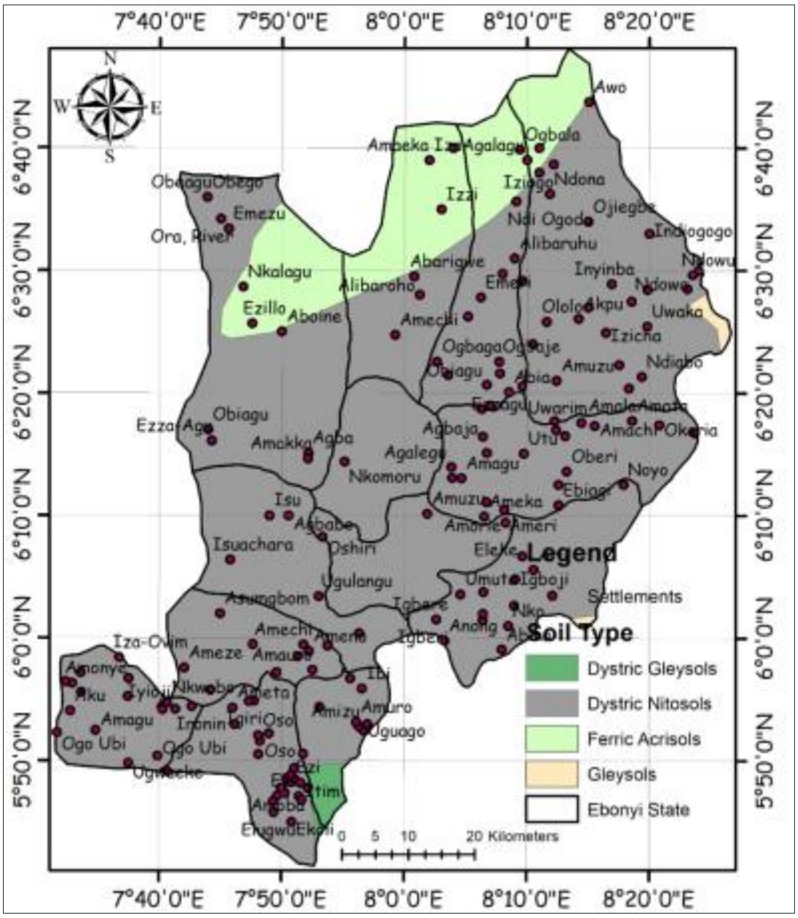

Figure 6 Soil Type Distribution in Ebonyi State, Nigeria (2023)

Figure 6 illustrates the spatial distribution of different soil types across Ebonyi State, highlighting the extensive coverage of Dystric Nitosols and the scattered presence of other soil types.

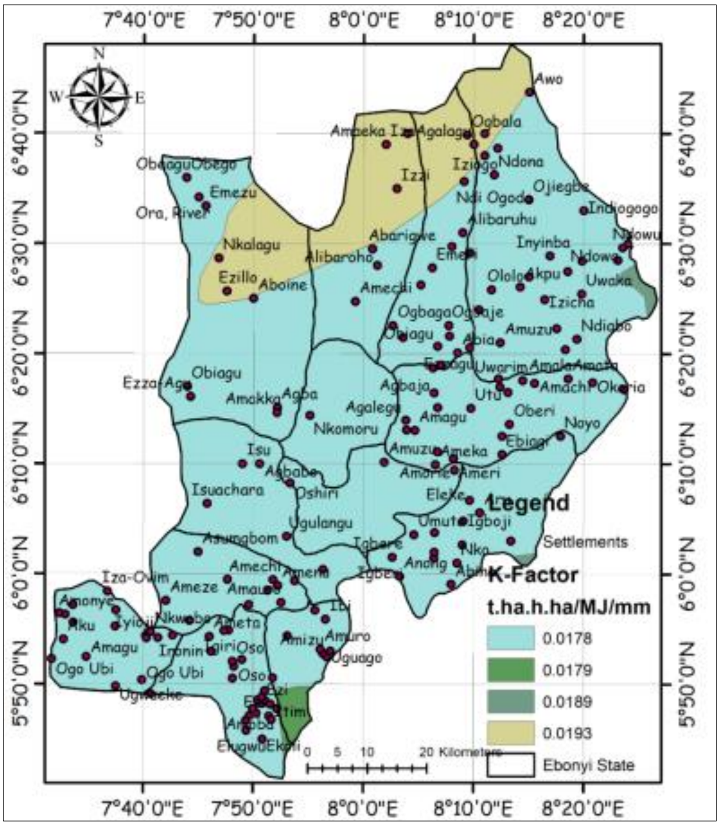

Figure 7 Soil Erodibility (K-Factor) in Ebonyi State, Nigeria (2023)

Figure 7 represents the K-factor distribution, indicating areas susceptible to soil erosion. This map is crucial for identifying regions that require soil conservation measures to maintain groundwater quality and recharge rates.

Understanding the distribution of soil types and their erodibility is vital for effective groundwater management in Ebonyi State. The extensive coverage of Dystric Nitosols, with their favorable properties for groundwater recharge, suggests that these areas can support sustainable groundwater use. However, the presence of Ferric Acrisols and Gleysols, with their higher erosion risks and poor drainage, respectively, indicates the need for targeted management practices. In areas dominated by Ferric Acrisols, implementing erosion control measures such as cover crops, contour plowing, and maintaining vegetation cover can reduce soil loss and improve groundwater infiltration. Similarly, managing waterlogged areas with Gleysols and Dystric Gleysols requires effective drainage systems to enhance infiltration and prevent surface water stagnation.

Dystric Nitosols, with their high fertility and good drainage, are suitable for agricultural activities. Promoting sustainable farming practices that enhance soil structure and organic matter content can further improve groundwater recharge rates. Crop rotation, reduced tillage, and organic amendments are practices that can benefit both soil health and groundwater resources.

5. Conclusion

The comprehensive analysis of Land Use/Land Cover (LULC), slope, and soil types in Ebonyi State, Nigeria, offers vital insights into their implications for groundwater resources. The key findings from this study highlight the intricate interplay between land cover, topography, soil properties, and groundwater dynamics, providing a foundation for effective groundwater management strategies.

The analysis of land cover in 2023 reveals that rangeland is the predominant type in Ebonyi State, covering a substantial portion of the area. This extensive rangeland indicates significant use of land for grazing and pastoral activities, which positively impacts groundwater recharge due to higher infiltration rates. Forested areas also make up a considerable portion of the land cover and play a critical role in enhancing groundwater recharge through improved infiltration and reduced runoff. Agricultural lands indicate substantial groundwater extraction for irrigation, necessitating sustainable practices to avoid overexploitation. Built-up areas pose challenges for groundwater recharge due to reduced land permeability and increased runoff. Water bodies contribute to surface water resources that can enhance groundwater recharge, while flooded vegetation acts as natural reservoirs aiding in gradual water release and infiltration. The minimal area covered by bare ground presents a negligible impact on groundwater recharge.

The slope analysis categorizes the terrain into various classes, with the largest area falling within the gentle slope category. These gentle slopes favor groundwater recharge by allowing slow surface water movement, enhancing infiltration into aquifers. Moderate slopes also support recharge, though at slightly reduced rates. The most extensive slope category presents moderate challenges for recharge due to increased runoff. Steeper slopes exhibit higher runoff rates and reduced infiltration, necessitating erosion control measures. The smallest area with very steep slopes has the least potential for groundwater recharge, highlighting the need for water conservation practices.

The soil analysis identifies four primary soil types: Ferric Acrisols, Gleysols, Dystric Gleysols, and Dystric Nitosols. Ferric Acrisols are sandy to loamy with moderate erodibility, facilitating good infiltration but requiring erosion control. Gleysols and Dystric Gleysols are poorly drained, with higher clay content and lower erodibility, but hinder groundwater recharge due to waterlogging. Dystric Nitosols, with high clay content and good structure, are less prone to erosion and highly suitable for groundwater recharge, making them ideal for sustainable agricultural practices.

To ensure sustainable groundwater management in Ebonyi State, it is recommended to implement targeted land management practices. These include erosion control measures in areas with Ferric Acrisols, effective drainage systems for Gleysols and Dystric Gleysols, and promoting sustainable agricultural practices in regions dominated by Dystric Nitosols to enhance soil structure and groundwater recharge. These strategies will help maintain groundwater levels and support long-term water security in the region.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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