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Integrated geological and geomorphological analysis for sustainable land use planning in the Abia Region of southeastern Nigeria

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Abstract

The study focuses on the slope and soil characteristics of the Aba North, Aba South, Oboma Ngwa, and Ugwunagbo regions in southeastern Nigeria. Understanding these characteristics is crucial for determining land suitability, identifying erosion-prone areas, and informing sustainable land use practices. The primary aim of this study is to analyze the slope distribution and soil types to assess their implications for erosion risk and land management strategies in the study area. Soil types were classified into Dystric Nitosols and Xanthic Ferralsols, with their erodibility assessed using the K-Factor. Geographic Information System (GIS) techniques were used to map the spatial distribution of slopes and soil types. The slope analysis revealed that the majority of the area consists of flat to gently sloping terrain, with 198.81 km^2 in the 1.77 - 3.15 degrees range and 175.80 km^2 in the 0 - 1.37 degrees range. These areas are suitable for agriculture and urban development due to their stability. Moderate slopes (3.15 - 7.77 degrees) covered 86.38 km^2, while steep slopes (7.77 - 23.33 degrees) covered 2.42 km^2. Dystric Nitosols covered 42.07 km^2 with a lower K-Factor of 0.0178, indicating low erodibility, while Xanthic Ferralsols covered 505.60 km^2 with a higher K-Factor of 0.0187. The findings suggest that flat to gently sloping areas are ideal for development and agriculture due to their lower erosion risk. However, moderate and steep slopes require careful management to prevent erosion. The dominance of Xanthic Ferralsols, which are more erodible, necessitates targeted conservation strategies to maintain soil fertility and minimize land degradation. This study highlights the critical role of slope and soil analysis in informing land use planning and erosion risk management. Integrating these insights into land management practices is essential to enhance agricultural productivity and ensure sustainable development in the region. This research provides a comprehensive analysis of the terrain and soil characteristics of the study area, offering valuable insights for policymakers and land managers to develop effective soil conservation and land use strategies. The study underscores the importance of utilizing slope and soil data to inform sustainable land management and mitigate erosion risks.

Keywords: K-Factor; Landforms; Sedimentary structures; Soil conservation

1. Introduction

Sustainable land use planning is essential for balancing human development and environmental conservation. As urbanization, agriculture, and industrial activities expand, the need to utilize land resources judiciously becomes more pressing. Integrated geological and geomorphological analysis offers a robust framework for informing land use decisions, ensuring that they are sustainable and environmentally sound (Chen, 2019; Rodríguez et al., 2021).

Geological and geomorphological studies provide critical insights into the earth's surface and subsurface conditions, which are fundamental to understanding land suitability and potential hazards (Gbadebo et al., 2021). These analyses help in identifying areas prone to natural disasters such as landslides, earthquakes, and floods, thereby guiding the development away from vulnerable zones. Moreover, they play a pivotal role in resource management, identifying areas rich in minerals, groundwater, and other georesources essential for sustainable development (Gbadebo et al., 2018).

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Geological analysis involves the study of the earth's materials, including rocks, minerals, and soils, and the processes that shape them over time. Lithological mapping, which identifies and maps different rock types and their spatial distribution, is crucial for construction projects, as the type of bedrock can influence the stability and suitability of foundations (Igwe & Umbugadu, 2020). Structural geology examines the deformation of rocks and the forces that cause them, such as tectonic movements. Understanding fault lines, folds, and fractures is vital for assessing seismic risk and planning earthquake-resistant infrastructure (Aka et al., 2022a). Geotechnical investigations analyze soil and rock properties to determine their strength, compressibility, and permeability, which are essential for designing stable structures, from buildings to dams (Aka et al., 2022b). Hydrogeology investigates groundwater systems, including aquifer characteristics; recharge rates, and contamination risks. Groundwater is a critical resource for drinking water, agriculture, and industry, making its sustainable management a priority (Hassan et al., 2019).

Geomorphology focuses on the study of landforms and the processes that create and modify them. Topographic mapping, which creates detailed maps of the terrain to understand elevation changes, slope gradients, and drainage patterns, is fundamental for planning infrastructure, agricultural activities, and urban development (Amatulli et al., 2018). Erosion and sedimentation studies examine how water, wind, and ice transport and deposit sediments. Understanding these processes helps mitigate soil erosion, manage sediment loads in rivers, and protect against coastal erosion. Landform classification categorizes different types of landforms, such as mountains, valleys, plains, and plateaus, aiding in identifying suitable areas for various land uses, from agriculture to recreation (Scheingross et al., 2020). Hazard assessment identifies geomorphological hazards like landslides, avalanches, and volcanic eruptions. These assessments are crucial for disaster risk reduction and ensuring the safety of communities.

The integration of geological and geomorphological data provides a comprehensive understanding of the landscape, facilitating informed land use planning. This integration involves geospatial analysis, utilizing Geographic Information Systems (GIS) to overlay geological and geomorphological data on maps. GIS technology allows for the visualization and analysis of spatial relationships, helping planners make data-driven decisions (Van Ngo Thi & Nguyen, 2019). Remote sensing employs satellite imagery and aerial photography to gather data on landforms, vegetation, and land use changes. Remote sensing provides a large-scale perspective and can monitor changes over time. Field surveys conduct on-the-ground investigations to validate and complement remote sensing and geospatial data, providing detailed, site-specific information that is often not visible in remote sensing data (Onyia et al., 2018). Modeling and simulation develop models to simulate geological and geomorphological processes, such as erosion, sediment transport, and groundwater flow. These models predict future scenarios and assess the impacts of different land use strategies.

The insights gained from integrated geological and geomorphological analysis are applied in various aspects of sustainable land use planning. Urban planning identifies safe and stable areas for urban development, minimizing the risk of natural hazards, and optimizing land use. Planners can design cities that are resilient to earthquakes, floods, and landslides while preserving natural landscapes (Sikakwe, 2020). Agricultural development determines soil suitability for different crops, manages irrigation systems, and prevents soil degradation. Sustainable agricultural practices ensure long-term productivity and environmental health. Infrastructure development designs roads, bridges, dams, and other infrastructure with consideration of geological and geomorphological conditions (Rowland & Ebuka, 2024). This ensures the longevity and safety of structures and reduces maintenance costs. Resource management locates and manages mineral resources, groundwater, and other georesources sustainably. Efficient resource extraction and usage minimize environmental impact and promote economic development (Ukpai, 2020). Environmental conservation protects natural habitats, preserves biodiversity, and restores degraded landscapes. Geomorphological insights guide the rehabilitation of eroded areas and the creation of conservation zones. Disaster risk reduction implements measures to reduce the impact of natural disasters, such as constructing flood defenses, stabilizing slopes, and creating early warning systems (Duque et al., 2021). Preparedness and mitigation strategies save lives and reduce economic losses.

Integrated geological and geomorphological analysis is a cornerstone of sustainable land use planning. By understanding the earth's surface and subsurface conditions, planners can make informed decisions that promote development while protecting the environment (Akter et al., 2018). This approach is essential for creating resilient communities, ensuring resource sustainability, and mitigating the impacts of natural disasters. The application of these analyses leads to more effective and sustainable land use strategies, benefiting both current and future generations.

The aim of the study is to analyze the slope distribution and soil types in the Aba North, Aba South, Oboma Ngwa, and Ugwunagbo regions in southeastern Nigeria. The primary objective is to assess the implications of these characteristics for erosion risk and land management strategies. By classifying soil types into Dystric Nitosols and Xanthic Ferralsols and evaluating their erodibility using the K-Factor, the study aims to determine land suitability, identify erosion-prone areas, and inform sustainable land use practices. Utilizing Geographic Information System (GIS) techniques, the study maps the spatial distribution of slopes and soil types, revealing that the majority of the area consists of flat to gently sloping terrain, which is suitable for agriculture and urban development. The research highlights the importance of integrating slope and soil data into land management practices to enhance agricultural productivity and ensure sustainable development, providing valuable insights for policymakers and land managers to develop effective soil conservation and land use strategies.

2. Research Location and Geology of Study area

Located in the southeastern region of Nigeria, Abia State features a diverse array of geological and geographical characteristics. This study focuses on the specific areas of Aba North, Aba South, Oboma Ngwa, and Ugwunagbo, each presenting unique features and challenges relevant to geological research and environmental management. The coordinate for the study area as shown in Figure 1 is approximately 5.12414° N latitude and 7.36667° E longitude, providing a central reference point within the region.

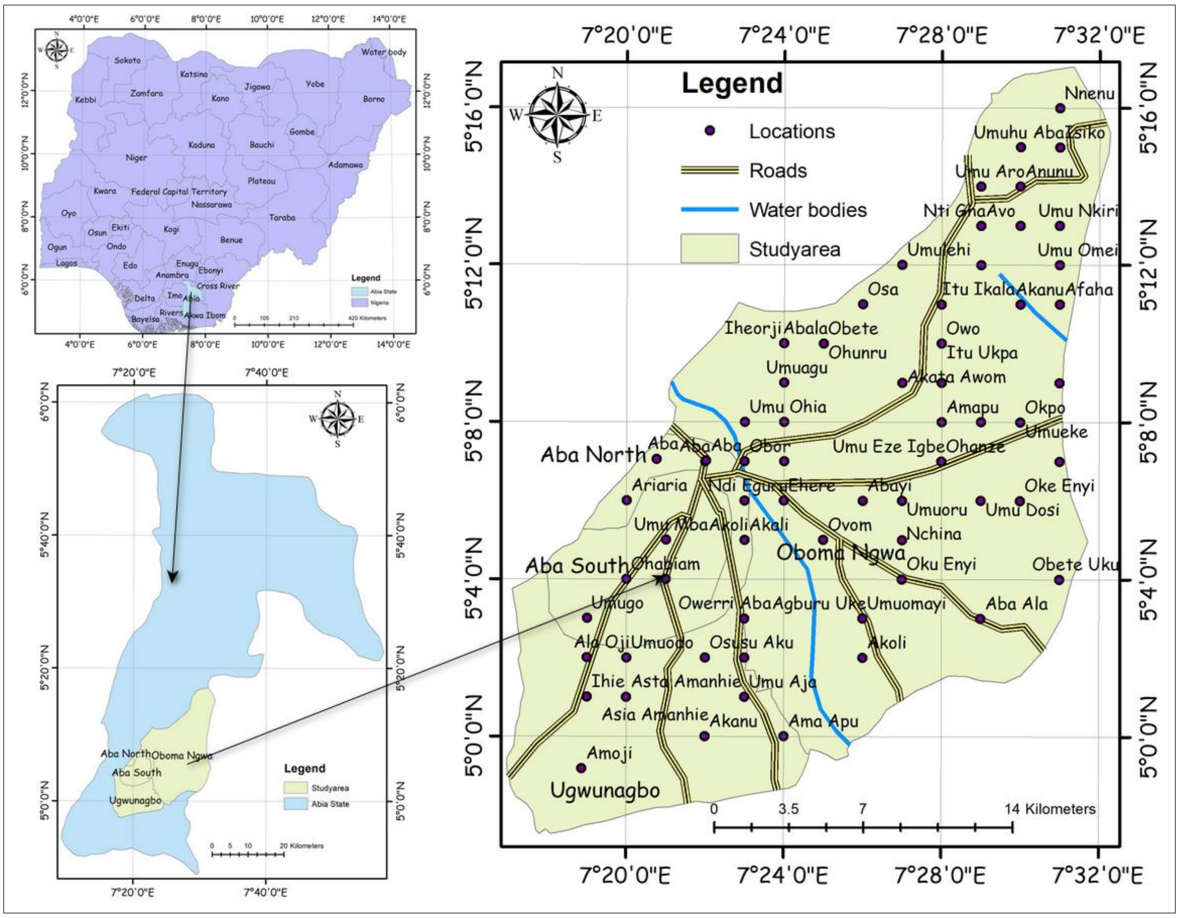

Figure 1 Map of Nigeria, Abia State and the Research Location

Aba North and Aba South are part of the larger city of Aba, a major urban center in Abia State. These areas are well-connected through a comprehensive network of roads, including the Enugu-Port Harcourt Expressway, which is a significant transportation corridor. This expressway facilitates the movement of goods and people, linking the city to other major urban centers in Nigeria. Public transportation within these areas is robust, with numerous buses, taxis, and motorcycle services available, ensuring easy access to various parts of the city.

Oboma Ngwa and Ugwunagbo, while less urbanized compared to Aba North and Aba South, still benefit from road networks that connect them to Aba and other neighboring towns. The quality of roads in these more rural areas can vary, with some roads being less maintained and challenging to navigate, especially during the rainy season. Despite these challenges, the overall connectivity of the region supports economic activities and mobility.

Water bodies in this region include several rivers and streams that contribute to the area's hydrology. The Aba River, a significant waterway, flows through the city of Aba, providing water resources for domestic and industrial use.

Additionally, numerous smaller streams and rivers crisscross Oboma Ngwa and Ugwunagbo, supporting agriculture and local water needs.

The topography of the study area is characterized by a mix of lowlands and gently rolling hills. Aba North and Aba South, being part of the urban center of Aba, generally lie in lowland areas with minimal elevation changes. The terrain is predominantly flat, which has facilitated urban development and infrastructure expansion.

Oboma Ngwa and Ugwunagbo present a more varied topography. These areas feature gently rolling hills and low-lying plains, with elevations ranging from approximately 50 to 200 meters above sea level. This variation in elevation contributes to diverse microenvironments and affects local climate and hydrology. The presence of hills influences drainage patterns and soil erosion processes, which are critical factors in agricultural practices and land management.

Aba North and Aba South are predominantly urban, characterized by dense residential, commercial, and industrial developments. Aba is a major commercial hub in southeastern Nigeria, known for its markets, manufacturing industries, and vibrant economic activities. The urban nature of these areas brings challenges related to infrastructure, waste management, and environmental pollution, which are key considerations for geologists and urban planners.

In contrast, Oboma Ngwa and Ugwunagbo are primarily rural, with agriculture being the dominant economic activity. These areas are marked by extensive farmlands, small villages, and scattered settlements. The rural landscape supports a variety of crops, including cassava, yam, maize, and vegetables, which are vital for local food security and the economy. The rural character of these areas also implies fewer infrastructural developments and lower population densities compared to the urban centers.

The study area experiences a tropical rainforest climate, characterized by high humidity and significant rainfall throughout the year. The wet season typically spans from March to October, with peak rainfall occurring between June and September. During this period, heavy rains can lead to flooding, particularly in low-lying urban areas like Aba North and Aba South. The dry season, from November to February, is marked by lower humidity and reduced rainfall, providing a respite from the intense rains of the wet season.

Average annual temperatures in the region range from 24°C to 28°C, with minimal variation between seasons. The consistent warm temperatures and ample rainfall support lush vegetation and diverse ecosystems. However, these climatic conditions also pose challenges for infrastructure maintenance and agricultural productivity, as excessive rainfall can lead to soil erosion and waterlogging.

The geology of the study area is primarily influenced by the sedimentary formations of the Niger Delta Basin. The region is underlain by sedimentary rocks, including sandstones, shales, and clays, which were deposited during the Tertiary and Quaternary periods (YuShan et al., 2019). These sedimentary formations are rich in organic matter and have significant implications for groundwater resources and soil fertility.

In Aba North and Aba South, the urban environment has led to extensive alteration of the natural geological landscape. Urbanization has resulted in the paving over of natural surfaces, affecting groundwater recharge and increasing surface runoff. In Oboma Ngwa and Ugwunagbo, the geological formations play a crucial role in supporting agriculture and water resources. The presence of porous sandstones facilitates groundwater recharge, providing a reliable source of water for irrigation and domestic use.

3. Material 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. To ensure accuracy, the dataset was meticulously corrected for database and digitized map errors (Akaolisa et al., 2023).

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

(Akaolisa et al., 2023). The digital database was maintained in a Geographic projection, ensuring global compatibility and ease of integration with other spatial 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 (Igwe & Egbueri, 2018). 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 (Nebeokike et al., 2020). The K Factor was calculated using William's equation, which incorporates the following parameters:

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

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

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

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

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

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.

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 (Ayadiuno et al., 2021). 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.

3.4. Slope Analysis

The slope data derived from the Digital Elevation Model (DEM) were analyzed to understand the terrain characteristics of the study area. Slope (S) is a crucial factor in determining the topography and potential erosion risks. It was calculated using the following equation:

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

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.

Understanding slope distribution is essential for effective land management and planning. Flat and gentle slopes are generally more suitable for agriculture, urban development, and infrastructure projects due to their stability and ease of construction. Moderate slopes may require more careful planning and erosion control measures (Ozioko & Igwe, 2020). Steep slopes, however, pose significant challenges, as they are more susceptible to landslides and erosion, making them less suitable for most types of development without substantial engineering interventions.

This detailed slope analysis aids in identifying high-risk areas that may require targeted soil conservation practices, such as terracing, reforestation, or the construction of retaining walls. Additionally, the slope classification informs infrastructure development, ensuring that roads, buildings, and other structures are strategically placed to minimize geological risks and maximize land use efficiency (Fagbohun et al., 2016). By integrating slope data with other spatial datasets, such as soil type and land use, a comprehensive model of the study area's terrain can be developed, supporting sustainable land management and mitigating environmental hazards.

4. Results and discussion

4.1. Slope Distribution

The slope analysis of the study area, encompassing Aba North, Aba South, Oboma Ngwa, and Ugwunagbo, reveals significant variations in terrain characteristics. These variations are critical for understanding the region's suitability for different land uses and identifying areas prone to erosion or other geological hazards.

The slope data were classified into five categories: 0 - 1.37 degrees, 1.37 - 1.77 degrees, 1.77 - 3.15 degrees, 3.15 - 7.77 degrees, and 7.77 - 23.33 degrees. Table 1 presents the distribution of these slope classes across the study area.

Table 1 Slope Distribution in the Study Area

Slope (Degree)	**Area (Km^2)**
0 - 1.37	175.80
1.37 - 1.77	80.95
1.77 - 3.15	198.81
3.15 - 7.77	86.38
7.77 - 23.33	2.42

The slope classification indicates that the majority of the study area (approximately 198.82 km^2) falls within the 1.77 - 3.15 degrees slope range, followed by the 0 - 1.37 degrees range, covering around 175.80 km^2. These two categories together encompass a substantial portion of the terrain, suggesting predominantly flat to gently sloping land.

Flat to gently sloping areas (0 - 3.15 degrees) are generally more suitable for agriculture, urban development, and infrastructure projects due to their stability and ease of construction. These areas are less likely to experience severe erosion, making them ideal for such uses. The largest area falls within the 1.77 - 3.15 degrees range, indicating that this slope class offers the greatest potential for various land use activities (Table 1).

Moderate slopes (3.15 - 7.77 degrees) account for 86.39 km^2 of the study area. These regions may require more careful planning and erosion control measures, especially if they are to be used for agriculture or construction. While they present some challenges, they can still be utilized effectively with proper management practices.

Steep slopes (7.77 - 23.33 degrees), although covering only 2.43 km^2, pose significant challenges. These areas are more susceptible to landslides and erosion, making them less suitable for most types of development without substantial engineering interventions. Identifying these regions is crucial for risk assessment and implementing appropriate soil conservation measures.

Understanding the slope distribution is vital for assessing erosion susceptibility. Steeper slopes are more prone to erosion due to the gravitational pull on soil particles. Therefore, areas with slopes greater than 3.15 degrees should be closely monitored and managed to prevent soil degradation and loss. Figure 2 illustrates the slope distribution across the study area, highlighting regions with different erosion susceptibilities.

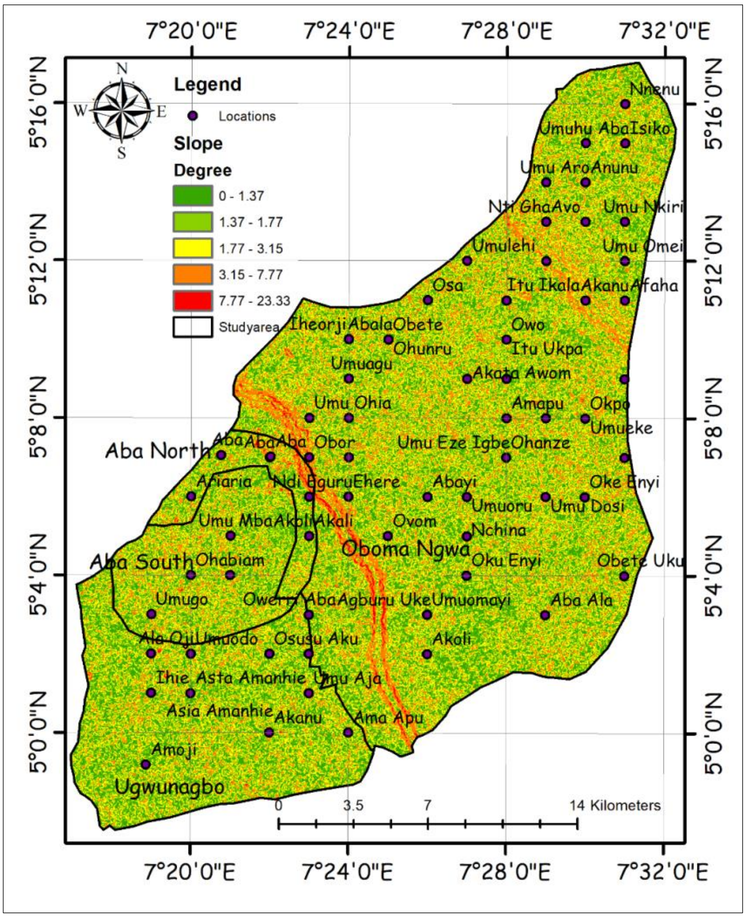

Figure 2 Slope Distribution Map of the Study Area

The slope distribution map (Figure 2) visually represents the spatial variation in terrain, aiding in the identification of high-risk areas. This map is a valuable tool for land managers and planners to develop effective soil conservation strategies.

Given the slope analysis, specific recommendations can be made to mitigate erosion risks and promote sustainable land use. In flat and gently sloping areas, maintaining vegetative cover and practicing crop rotation can help preserve soil structure and fertility. For moderate slopes, terracing and contour plowing are effective techniques to reduce surface runoff and soil erosion.

In steep slope regions, more intensive measures are required. Reforestation and the construction of retaining walls can stabilize the soil and prevent landslides. Additionally, restricting development in these areas can minimize human-induced erosion risks.

4.2. Assessment of Soil Types and Erodibility Factors

The soil types within the study area were classified into two main categories: Dystric Nitosols and Xanthic Ferralsols. These classifications are based on distinct physical and chemical characteristics that influence soil behavior, particularly their erodibility. Table 2 presents the area coverage and the corresponding soil erodibility factors (K-Factor) for these soil types. The K-Factor is crucial in assessing the susceptibility of soil particles to detachment and transport by rainfall and runoff, thereby indicating their potential for erosion. This information is essential for understanding the soil dynamics within the study area and is foundational for developing effective land management and conservation strategies.

Table 2 Soil Types and Erodibility Factors

Soil Type	Area (km^2)	K_Factor (t.ha.h.ha/MJ/mm)
Dystric Nitosols	42.07	0.0178
Xanthic Ferralsols	505.60	0.0187

Dystric Nitosols cover an area of approximately 42.07 km^2, representing a minor portion of the study area. These soils are typically deep, well-drained, and have a fine-textured profile, which contributes to their relatively low erodibility factor (K-Factor = 0.0178). The low K-Factor indicates that Dystric Nitosols are less susceptible to erosion, which can be attributed to their stable structure and high organic matter content.

Xanthic Ferralsols dominate the study area, covering approximately 505.60 km^2. These soils are highly weathered, characterized by a yellowish-brown color, and typically have a loamy to clayey texture. The K-Factor for Xanthic Ferralsols is slightly higher (0.0187) than that of Dystric Nitosols, suggesting a marginally greater susceptibility to erosion. This increased erodibility may be due to the lower organic matter content and weaker aggregate stability in these soils compared to Nitosols.

4.2.1. Soil Erodibility

The erodibility of soils is a critical factor influencing land degradation and agricultural productivity. In this study, the erodibility of the soil types was assessed using the K-Factor, which quantifies the susceptibility of soil particles to detachment and transport by rainfall and runoff.

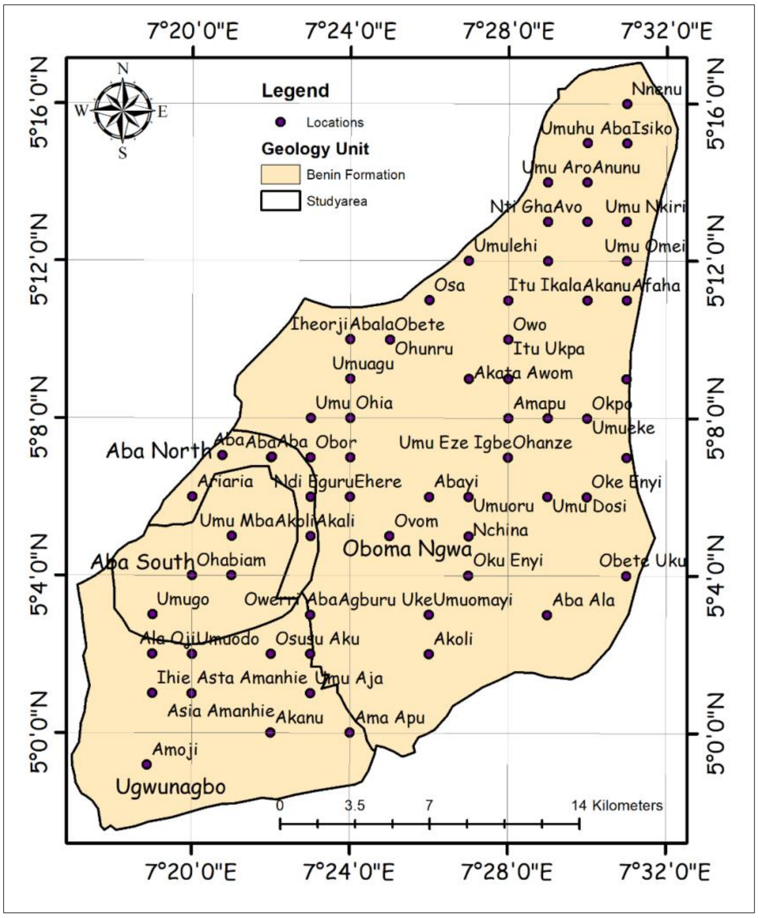

Figure 3 Geological Map of the Study Area

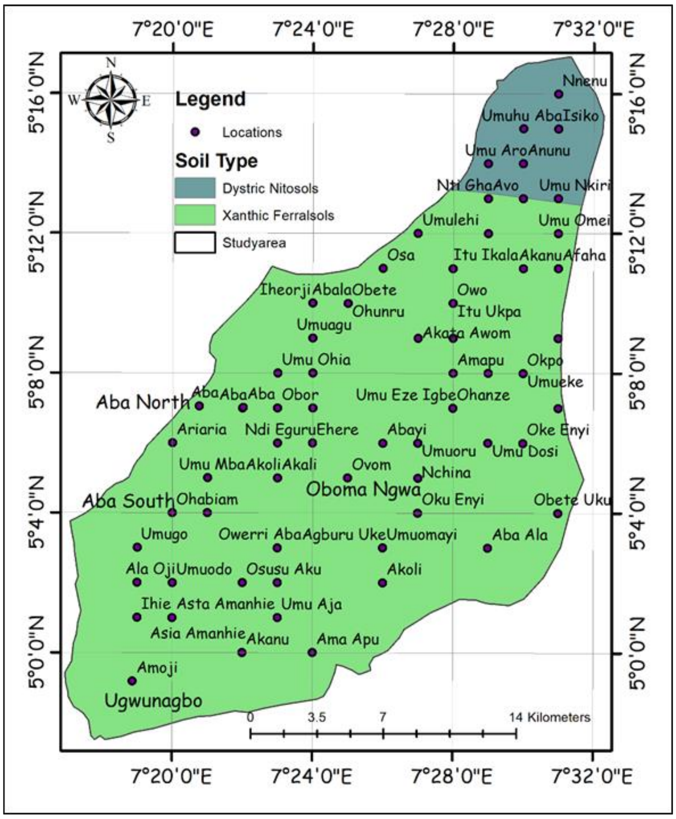

Figure 4 Soil Type Distribution Map

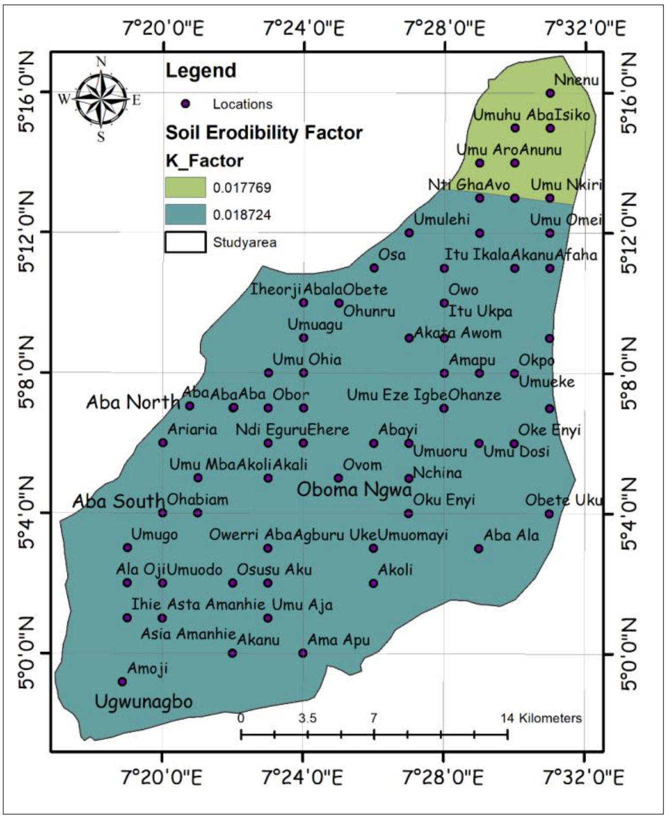

Figure 5 Soil Erodibility Factor Map

The variation in K-Factor values across the study area reflects the inherent differences in soil properties and their implications for land management. Dystric Nitosols, with their lower erodibility, are better suited for agricultural practices that require minimal soil disturbance, such as conservation tillage. On the other hand, Xanthic Ferralsols, with a higher K-Factor, require more careful management to prevent soil erosion, especially in areas with steep slopes or intense rainfall events.

The dominance of Xanthic Ferralsols in the study area indicates a need for targeted soil conservation strategies to mitigate erosion risks. Practices such as contour farming, cover cropping, and the establishment of buffer strips can be effective in reducing soil loss and maintaining soil fertility. Additionally, understanding the spatial distribution of soil types and their erodibility can inform land-use planning and the sustainable management of natural resources.

The findings from this study have significant implications for land use and management in the study area. The geological and soil characteristics should be considered when planning agricultural activities, infrastructure development, and environmental conservation efforts. The Benin Formation's sandy deposits may pose challenges for construction due to potential instability, necessitating engineering solutions to ensure safe and sustainable development.

4.3. Implications of Soil and Slope Analysis

The soil and slope characteristics of the study area have significant implications for land use, agricultural productivity, and environmental management. The study area, which is predominantly composed of Xanthic Ferralsols and Dystric Nitosols, presents diverse challenges and opportunities based on the distribution and properties of these soils.

The presence of Dystric Nitosols and Xanthic Ferralsols, with their respective K-Factors of 0.017769 and 0.018724, indicates varying susceptibilities to erosion. Xanthic Ferralsols, which cover the majority of the area (505.60 km^2), have a slightly higher erodibility factor, which may affect soil fertility and agricultural yield. This characteristic necessitates careful soil management practices to minimize erosion, particularly in areas with intensive agriculture. Techniques such as mulching, crop rotation, and the use of cover crops can help maintain soil structure and reduce runoff.

In contrast, Dystric Nitosols, which cover a smaller area (42.07 km^2), are more stable and less prone to erosion. Their lower K-Factor suggests they can support agricultural activities with minimal soil loss, making them ideal for crops that require stable soil conditions. However, the limited coverage of Nitosols means that their benefits are confined to specific areas, requiring targeted land management strategies.

The slope analysis reveals that the majority of the study area has gentle slopes, with 455.57 km^2 (comprising slope ranges 0-1.37° and 1.37-1.77°) categorized as flat to gently undulating. These areas are well-suited for agriculture and infrastructure development due to their ease of access and reduced risk of erosion.

However, areas with moderate to steep slopes (1.77-7.77°) cover a significant portion of the landscape (285.21 km^2). These areas pose a greater risk of erosion, particularly where Xanthic Ferralsols dominate. Soil conservation measures, such as terracing and contour plowing, should be implemented to prevent soil degradation and promote sustainable land use.

The steepest slopes (7.77-23.33°), though covering a small area (2.43 km^2), require particular attention. These areas are highly susceptible to erosion and should be preserved as natural vegetation or used for controlled activities that do not disturb the soil structure. Reforestation and the establishment of vegetative buffer zones can be effective strategies to stabilize these slopes.

The combined analysis of soil types and slopes underscores the importance of integrated land management practices in the study area. Policymakers and land managers must prioritize soil conservation strategies to enhance agricultural productivity and prevent land degradation. Understanding the spatial distribution of soil types and slopes allows for informed decisions regarding land use planning, infrastructure development, and environmental conservation.

5. Conclusion

This study highlights significant findings regarding the soil and slope characteristics of the study area, encompassing Aba North, Aba South, Oboma Ngwa, and Ugwunagbo in southeastern Nigeria. The region's terrain and soil composition play a crucial role in determining suitable land uses and identifying areas at risk of erosion or other geological hazards.

The slope analysis reveals that the majority of the study area comprises flat to gently sloping terrain, with 175.80 km^2 falling within the 0 - 1.37 degrees range and 198.81 km^2 within the 1.77 - 3.15 degrees range. These slopes are ideal for agricultural activities, urban development, and infrastructure projects due to their stability and reduced risk of erosion. However, moderate slopes (3.15 - 7.77 degrees) covering 86.38 km^2 and steep slopes (7.77 - 23.33 degrees) occupying 2.42 km^2 present challenges that require careful planning and management.

The study of soil types reveals that the region is predominantly covered by Xanthic Ferralsols (505.60 km^2), which are highly weathered and exhibit a loamy to clayey texture. With a higher K-Factor of 0.0187, these soils are more susceptible to erosion compared to the less extensive Dystric Nitosols (42.07 km^2), which have a lower K-Factor of 0.0178 and exhibit greater stability due to their fine texture and high organic matter content.

These findings underscore the need for targeted soil management strategies to mitigate erosion risks and enhance agricultural productivity. In areas dominated by Xanthic Ferralsols, practices such as mulching, crop rotation, and cover cropping can help maintain soil structure and fertility. Additionally, contour farming and the establishment of buffer strips can reduce soil loss and promote sustainable land use.

The slope analysis further emphasizes the importance of tailored land management practices. In flat and gently sloping areas, maintaining vegetative cover and practicing crop rotation are effective measures to preserve soil structure and fertility. For moderate slopes, techniques like terracing and contour plowing are recommended to reduce surface runoff and prevent soil erosion. In regions with steep slopes, more intensive measures such as reforestation and the construction of retaining walls are necessary to stabilize the soil and prevent landslides. Moreover, restricting development in these areas can minimize human-induced erosion risks and protect natural resources.

The study also highlights the importance of integrating geological and soil data in land use planning and infrastructure development. The sandy deposits of the Benin Formation, which characterize the region, pose challenges for construction due to potential instability. Engineering solutions and careful planning are essential to ensure safe and sustainable development.

Overall, this study provides valuable insights into the soil and slope dynamics of the study area, offering a foundation for effective land management and conservation strategies. Policymakers, land managers, and stakeholders must prioritize soil conservation measures and adopt sustainable land use practices to prevent land degradation and promote agricultural productivity. By understanding the spatial distribution of soil types and slopes, stakeholders can make informed decisions to ensure the long-term sustainability and resilience of the region's natural resources.

In conclusion, the findings of this study underscore the critical role of geology and soil characteristics in shaping land use practices and environmental management in the study area. By implementing targeted strategies and prioritizing soil conservation, stakeholders can mitigate erosion risks, enhance agricultural productivity, and promote the sustainable use of land resources.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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