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Research paper

Evaluating the geological and soil characteristics influencing landslide susceptibility in Anambra state, Nigeria

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Abstract

This study investigates soil erodibility in three Local Government Areas (LGAs) within Anambra State, Nigeria—Ekwusigo, Ihiala, and Ogbaru—situated in the lower Niger River Basin prone to frequent and severe flooding. The aim is to assess geological and soil characteristics influencing landslide susceptibility. The methodology involves identifying and characterizing soil types, calculating the Soil Erodibility Factor (K) using empirical formulas, and mapping erosion susceptibility. Data from the Soil Map of the World (version 3.6) were used, corrected for accuracy, and integrated into geographic projections. Analysis included William's equation to calculate K factors based on soil properties such as sand, silt, clay, and organic matter content. Results highlight diverse geological formations: Ameki Group (34.24%), Benin Formation (0.26%), Ogwashi-Asaba Formation (1.59%), River Niger (1.86%), Sands, Gravels, and Clay (42.36%), and Sombreiro Warri Deltaic Plain (19.69%). Soil types identified include Dystric Nitosols (K = 0.0178) covering 449.11 km² and Gleysols (K = 0.0189) covering 283.95 km², each exhibiting unique erosion susceptibilities. Gleysols are characterized by poor drainage and high-water retention, posing higher landslide risks during heavy rainfall compared to Dystric Nitosols. The correlation between K factors and hydrological data, showing Gleysols as more vulnerable to landslides in wet conditions. Recommendations include targeted erosion control measures like terracing, vegetative buffers, and improved drainage systems for high-risk zones. Maintaining vegetative cover and implementing sustainable land management practices are crucial for mitigating erosion and landslide risks. This study provides a detailed understanding of geological and soil factors affecting landslide susceptibility in Anambra State. It underscores the need for tailored soil conservation and landslide mitigation strategies aligned with specific geological formations and soil types, contributing to sustainable land management practices in flood-prone regions.

Keywords: *Dystric Nitosols; Geological formations; Gleysols; Soil erodibility .*

1. Introduction

Soil erosion is one of the most pressing environmental challenges faced by many regions around the world. It is a process where the topsoil, which is rich in nutrients and organic matter, is worn away by natural forces such as water, wind, and ice, as well as human activities (Ahmad et al., 2020). This loss of topsoil can have severe repercussions on agricultural productivity, water quality, and overall ecosystem health.

The topsoil layer is vital for plant growth because it contains the majority of the soil's organic matter and nutrients. When this layer is eroded, the remaining soil may lack sufficient nutrients, making it difficult for crops to thrive (Guo et al., 2021). This can lead to reduced agricultural yields, affecting food security and the livelihoods of farmers. In many developing regions, including parts of Nigeria, where agriculture forms the backbone of the economy, the impact of soil erosion on crop production can be particularly devastating. Farmers in these areas often rely on the same land for multiple growing seasons, making the preservation of soil health critical for sustainable agriculture (Ahmad et al., 2020; Ayadiuno et al., 2021). Without the protective cover of vegetation or the rich organic content of topsoil, the land becomes less fertile over time, and farmers may need to invest in expensive fertilizers and soil amendments to maintain productivity, which can be economically unfeasible for many.

As soil particles are carried away by runoff, they often enter water bodies such as rivers, lakes, and reservoirs. This sedimentation can reduce the water quality by increasing turbidity, which impacts aquatic life and ecosystems. Increased turbidity reduces the amount of sunlight that penetrates the water, which can affect the growth of aquatic plants and the overall health of the aquatic ecosystem (Touma et al., 2020; Wang et al., 2021). Eroded soil can carry with it pesticides, fertilizers, and other pollutants that further degrade water quality. This pollution can have downstream effects, harming fisheries, reducing biodiversity, and affecting the quality of water available for human consumption and recreational activities (Rehm et al., 2021).

The loss of nutrient-rich topsoil can lead to the degradation of habitats, affecting plant and animal species that depend on healthy soil for food and shelter. Erosion can also lead to the formation of gullies and other landforms that can alter the landscape, changing drainage patterns and further impacting ecosystems (Seabloom et al., 2021). In severe cases, land that has been heavily eroded may become barren and unproductive, leading to desertification. Desertification is a particularly severe form of land degradation where fertile land becomes desert, typically as a result of drought, deforestation, or inappropriate agriculture (Azare et al., 2020). This process not only reduces the land's productivity but also contributes to the displacement of human populations and the loss of biodiversity.

Given these widespread impacts, understanding soil erodibility, or the susceptibility of soil to erosion, is essential for effective land management and conservation strategies. Soil erodibility is influenced by several factors, including soil texture, structure, organic matter content, and permeability. Soil texture refers to the proportion of sand, silt, and clay particles, with each type having different susceptibility to erosion (Songu et al., 2021; Luo et al., 2022). Sandy soils are more prone to wind erosion, while clayey soils might be more resistant to water erosion due to their cohesiveness. Organic matter content enhances soil structure and porosity, making the soil more resistant to erosion. By assessing these factors, land managers can identify areas at high risk of erosion and implement measures to protect and restore vulnerable soils (Nebeokike et al., 2020; Amah et al., 2020). Such measures may include planting cover crops, practicing no-till farming, constructing terraces, and creating buffer strips along waterways to reduce runoff and sedimentation.

Moreover, technological advances such as geographic information systems (GIS) and remote sensing can aid in monitoring and managing soil erosion. These tools allow for the mapping of erosion-prone areas, the assessment of erosion rates, and the evaluation of the effectiveness of soil conservation practices (Achasov et al., 2021). Public awareness and education about the importance of soil conservation can also play a crucial role in mitigating soil erosion. Engaging local communities in sustainable land management practices and promoting policies that support soil health can contribute to long-term environmental sustainability (Ukabiala et al., 2021).

Addressing soil erosion requires a multifaceted approach that combines scientific knowledge, technological innovation, community involvement, and policy support. By understanding the factors that contribute to soil erodibility and implementing effective conservation strategies, it is possible to mitigate the adverse effects of soil erosion and protect the vital topsoil that sustains agricultural productivity, water quality, and ecosystem health (Nebeokike et al., 2020; Amah et al., 2021).

This study focuses on analyzing soil erodibility in three Local Government Areas (LGAs) in Anambra State, Nigeria: Ekwusigo, Ihiala, and Ogbaru. These areas are particularly vulnerable to flooding due to their location within the lower Niger River Basin. The basin's topography, soil types, and climatic conditions contribute to frequent and severe flooding events, which exacerbate soil erosion. This study aims to evaluate the geological and soil characteristics that influence landslide susceptibility in Anambra State, Nigeria, focusing on Ekwusigo, Ihiala, and Ogbaru LGAs. It involves identifying and characterizing predominant soil types, calculating the Soil Erodibility Factor (K) using empirical formulas, and mapping areas with varying erosion susceptibilities. By correlating soil erodibility data with hydrological and climatic information, the study will analyze landslide risks and provide recommendations for soil conservation and landslide mitigation tailored to the specific conditions of the study area.

2. Location and geology of the study area

The study focuses on three Local Government Areas (LGAs) in Anambra State, Nigeria: Ekwusigo, Ihiala, and Ogbaru, as shown in Figure 1. These areas lie within the lower Niger River Basin, making them particularly vulnerable to flooding due to their soil types and geographical positioning.

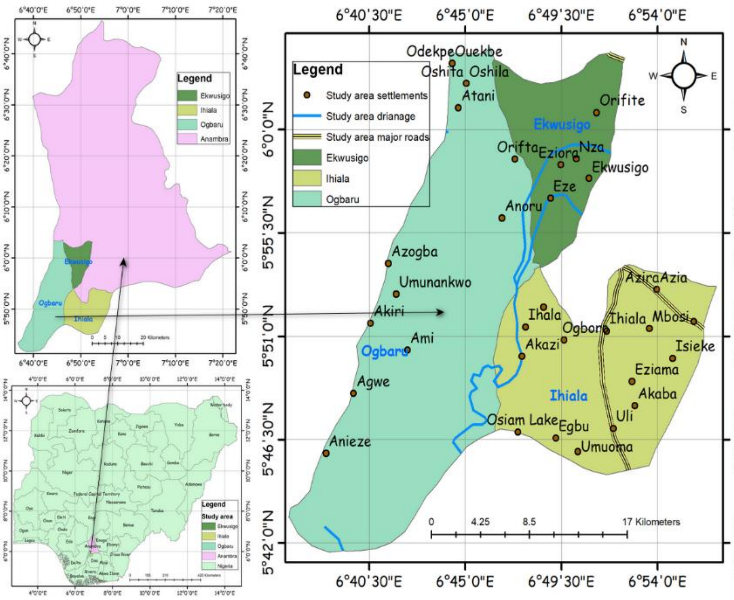

Fig. 1: Map of Nigeria, Anambra, and the Study Area.

Located approximately between latitudes 6°00'00"N and 6°10'00"N and longitudes 6°50'00"E and 7°00'00"E, Ekwusigo LGA features predominantly low-lying terrain with flat and gently undulating landscapes. The soil composition here is mainly alluvial, characterized by sandy loam and clay. These soil types significantly influence drainage and water infiltration rates, contributing to the area's susceptibility to flooding, especially during the rainy season. The high sand content aids in rapid water infiltration, while the clay components can retain water, leading to surface runoff and flooding (Aigbadon et al., 2021).

Positioned approximately between latitudes 5°50'00"N and 5°59'00"N and longitudes 6°50'00"E and 6°59'00"E, Ihiala LGA shares similar topographical features with Ekwusigo, including low-lying plains and minor undulations. The geology of Ihiala is marked by sedimentary formations predominantly composed of shale, sandstone, and siltstone. These geological features result in soil types that have varying drainage capabilities. Shale and siltstone tend to reduce permeability, leading to higher surface runoff during heavy rains, which increases flood risk. Seasonal rainfall variations combined with these geological structures contribute to periodic flooding in the region (Omietimi et al., 2021).

Situated approximately between latitudes 5°50'00"N and 6°00'00"N and longitudes 6°40'00"E and 6°50'00"E, Ogbaru LGA lies along the banks of the Niger River. This location makes Ogbaru highly susceptible to riverine flooding. The terrain in Ogbaru is predominantly flat and low-lying, with extensive floodplains. The soil in this area consists largely of alluvial deposits from the Niger River, including sand, silt, and clay (Omietimi et al., 2021). These soils are highly fertile but also flood-prone. The sandy components allow for some drainage, but the high silt and clay content can cause water retention, exacerbating flood conditions when the river levels rise.

The geological setting of the study area falls within the larger Anambra Basin, a significant geological formation in southeastern Nigeria. This Cretaceous sedimentary basin includes sequences like the Nkporo Shale, Mamu Formation, Ajali Sandstone, and Imo Shale (Faboya et al., 2020). These formations exhibit varying permeability and porosity, which influence groundwater movement and surface water dynamics. The Ajali Sandstone is highly permeable, allowing significant groundwater recharge, while the Nkporo Shale is less permeable, affecting surface runoff patterns (Wali et al., 2020; Ukpai et al., 2021).

3. Materials and methods

This study utilized multiple datasets to conduct comprehensive analyses and modeling tasks. The soil type data was sourced from the digitized Soil Map of the World, version 3.6, which was initially published between 1974 and 1978 and subsequently updated to January 1994. This map, produced by the Food and Agriculture Organization (FAO), offers a comprehensive global representation of soil types at a 1:5,000,000 scale. The dataset was meticulously corrected for database and digitized map errors to ensure accuracy (Adewumi 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 (Adewumi et al., 2023). The digital database was maintained in a Geographic projection, ensuring global compatibility and ease of integration with other spatial data.

Table 1: The Details of the Datasets Used in this Study are Summarized

Parameters	Data Source	Year	Resolution (m)	Sources
Soil type	Digitized Soil Map of the World (version 3.6)	Published between 1974-1978; updated to January 1994	1:5,000,000 scale	FAO

These 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 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 (Amah et al., 2020; Yang et al., 2021). 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. Soils with high permeability, high organic matter content, and good structure tend to resist erosion better than those with high silt content (Yu et al., 2020). 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:

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

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

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

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

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

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 K Factor 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 (Rosskopf et al., 2020; Alaboz et al., 2021). This approach supports sustainable land management practices and the preservation of soil resources.

The K Factor is a critical element in soil erosion models, providing insights into the inherent vulnerability of different soil types. This information guides conservation efforts aimed at protecting and managing soil resources effectively, ensuring long-term environmental sustainability.

4. Results and discussion

A detailed analysis of the geological formations in the study area, as represented in Table 2 and Figure 2, highlights the diversity of geological types and their spatial distribution, which are critical in assessing landslide risks. The geological formations in the study area consist of six distinct types: Ameki Group, Benin Formation, Ogwashi-Asaba Formation, River Niger, Sands, Gravels and Clay, and the Sombreiro Warri Deltaic Plain. Each of these formations has unique characteristics that influence soil properties and, consequently, landslide susceptibility.

Table 2: Geology Type of the Study Area

Gelology Type	Area (%)
Ameki Group	34.24
Benin Formation	0.26
Ogwashi - Asaba Formation	1.59
River Niger	1.86
Sands, Gravels and Clay	42.36
Sombreiro Warri Deltaic Plain	19.69

The Ameki Group, covering 34.24% of the study area, is characterized by sandy clays and clayey sands, which are moderately resistant to erosion. However, areas with significant clay content can become slippery and unstable when wet, increasing landslide risks, particularly during heavy rainfall. This formation's moderate permeability and variable soil composition necessitate detailed soil erodibility assessments to identify specific zones of high landslide susceptibility (Yao et al., 2020).

While the sandy components of the Ameki Group allow for moderate drainage, the clay fractions can retain water, leading to increased pore water pressure and reduced shear strength during intense rainfall. This dual nature requires targeted erosion control measures that address both the drainage and stability aspects of the soil.

Although the Benin Formation only constitutes 0.26% of the area, its high sand content and low cohesion can lead to rapid erosion and potential landslide activity, especially on steep slopes. The minimal area coverage suggests localized but potentially severe impacts where this formation is present. The sandy nature of the Benin Formation results in low water retention, leading to high runoff and erosion rates. Stabilization efforts in these areas might include the use of vegetative cover to increase soil cohesion and reduce surface runoff (Aladejana et al., 2018).

The Ogwashi-Asaba Formation, making up 1.59% of the study area, consists predominantly of lignite and sandy clays. These materials can be prone to erosion, particularly in the presence of water. The organic content in lignite can contribute to soil instability, increasing landslide susceptibility in these areas. Lignite's propensity to decompose and create voids in the soil structure further exacerbates instability issues. Effective management practices may include monitoring lignite-rich areas for signs of subsidence and implementing soil stabilization techniques (Hall et al., 2020).

The proximity to River Niger affects 1.86% of the study area and introduces unique challenges. The alluvial deposits along the riverbanks are highly susceptible to erosion and sediment transport, which can exacerbate landslide risks in adjacent areas. The dynamic nature of riverine environments necessitates continuous monitoring and adaptive management strategies. Flooding and riverbank erosion can lead to significant changes in landscape stability, requiring interventions such as riparian buffers and reinforced riverbanks to mitigate erosion (Egbinola et al., 2015; Okeke et al., 2020).

This geological type is the most extensive, covering 42.36% of the area. The mixture of sands, gravels, and clays results in variable soil stability. Sands and gravels provide good drainage but low cohesion, whereas clays, while cohesive, can become unstable when saturated. This heterogeneity requires site-specific soil erodibility assessments to accurately map landslide risks. The variability in texture and composition within this formation means that different areas may require tailored erosion control strategies (Mwaniki et al., 2015).

Covering 19.69% of the study area, the Sombreiro Warri Deltaic Plain is characterized by deltaic deposits of fine sediments. These fine-grained soils are highly susceptible to erosion, particularly under heavy rainfall or rapid water flow conditions. The flat topography, coupled with fine sediment deposits, can lead to extensive sheet erosion and potential landslide events in areas with minor slopes (Tian et al., 2020). Given the fine sediment composition, these areas are prone to quick erosion during heavy rainfall, requiring strategies such as constructing check dams or silt traps to manage sediment flow and prevent erosion.

The soil types identified in the study area are Dystric Nitosols and Gleysols, each exhibiting different characteristics that influence their susceptibility to erosion and landslides. The Soil Erodibility Factor (K) for these soil types was calculated to understand their potential contribution to landslide risks.

Dystric Nitosols, covering an area of 449.11 km², have a K factor of 0.0178. These soils are characterized by their high iron and aluminum oxide content, which contributes to their stability and relatively low erodibility. The low K factor indicates that Dystric Nitosols are less susceptible to erosion compared to other soil types. However, their stability can be compromised in areas with steep slopes or where vegetation cover is removed, leading to increased erosion and landslide risks. In regions where Dystric Nitosols are prevalent, maintaining vegetative cover and implementing erosion control measures are crucial to preventing soil degradation and landslides.

Table 3: Area of Soil Type and Soil Erodibility Factor of the Study Area

Soil Type	K factor	Area (km^2)
Dystric Nitosols	0.0178	449.11
Gleysols	0.0189	283.95

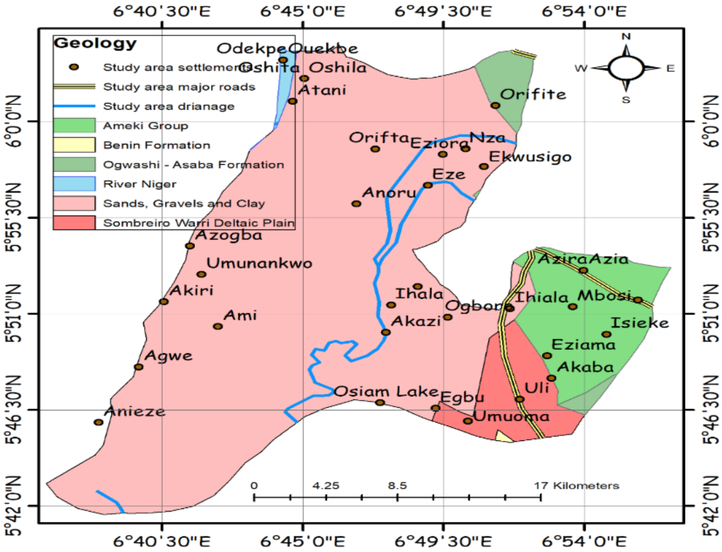

Fig. 2: Geology of the Study Area.

The Dystric Nitosols are typically found in upland areas with moderate to high slopes. These soils, although stable under normal conditions, can become prone to erosion if the vegetation cover is disturbed. The iron and aluminum oxides in Dystric Nitosols enhance soil aggregation and cohesion, reducing the likelihood of particle detachment. However, in the absence of protective vegetation, rainfall can directly impact the soil surface, dislodging particles and initiating erosion processes. Therefore, land management practices that preserve vegetation cover, such as agroforestry and conservation tillage, are essential in areas dominated by Dystric Nitosols.

Dystric Nitosols also exhibit a high clay content (43.6%), similar to Gleysols, indicating they are clayey soils with high water retention and low permeability. The sand content is slightly higher (37.3%) compared to Gleysols, which might contribute to better drainage than Gleysols but still retains significant moisture. Dystric Nitosols have a lower organic carbon content (1.5%). Although this indicates lower fertility compared to Gleysols, Dystric Nitosols are still relatively fertile soils. The lower organic matter might result in less nutrient availability and poorer soil structure compared to Gleysols.

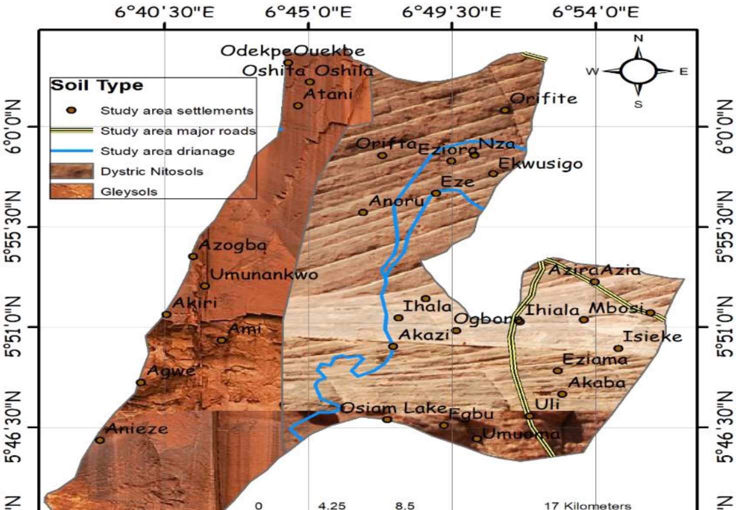

Fig. 3: Soil Type of the Study Area.

Gleysols cover 283.95 km² of the study area and have a K factor of 0.0189. These soils are typically found in poorly drained areas with high groundwater tables, which makes them more prone to waterlogging and erosion. The slightly higher K factor of Gleysols compared to Dystric Nitosols suggests a greater susceptibility to erosion, particularly during heavy rainfall events. Waterlogged conditions can weaken soil structure, increasing the likelihood of landslides in these areas. Effective drainage management and the use of soil stabilization techniques are essential to mitigate landslide risks in areas dominated by Gleysols.

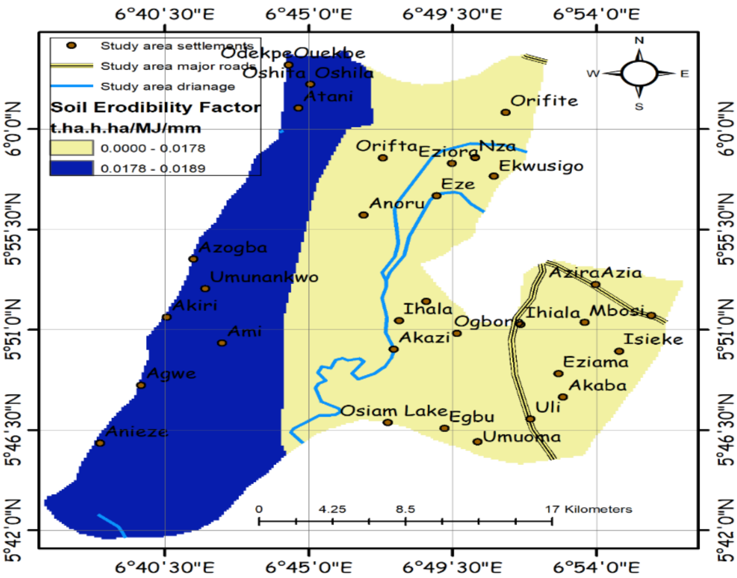

Fig. 4: Soil Type of the Study Area.

Gleysols are prevalent in low-lying areas and depressions where water accumulates. The high moisture content of Gleysols can lead to the development of gleyic properties, such as the reduction of iron and manganese oxides, which can adversely affect soil structure. When saturated, these soils lose their cohesion and become more susceptible to mechanical disturbances and erosion (Ma et al., 2020). Consequently, areas with Gleysols require interventions to improve drainage and reduce waterlogging. Techniques such as subsurface drainage, raised bed farming, and the installation of diversion channels can help manage excess water and enhance soil stability.

Gleysols have a significant clay content (42.7%), making them clayey soils. The high clay percentage suggests these soils have high water retention capacity, low permeability, and might be prone to waterlogging. The moderate sand content (31.8%) provides some drainage but not enough to prevent water stagnation. Gleysols have a higher organic carbon content (2.8%) compared to Dystric Nitosols. This higher OC percentage indicates better soil fertility and a higher potential for supporting plant growth. The higher organic matter also helps improve soil structure and water-holding capacity, which is beneficial in clay-rich soils.

The analysis of soil erodibility was complemented by correlating the K factors with hydrological and climatic data to better understand landslide susceptibility. The study area experiences significant seasonal rainfall, which impacts soil moisture levels and erosion rates. High-intensity rainfall events, common in the region, exacerbate erosion, particularly in areas with high K factors. The correlation analysis revealed that regions with Gleysols, due to their higher K factor and poor drainage, are more vulnerable to landslides during heavy rainfall. In contrast, areas with Dystric Nitosols showed lower erosion rates but still presented risks in steep or deforested areas.

Seasonal variations in rainfall patterns significantly influence the hydrological dynamics of the study area. During the rainy season, intense and prolonged precipitation events can lead to rapid saturation of the soil, particularly in areas with Gleysols. The increased water content reduces soil cohesion and enhances the likelihood of slope failures and landslides. In contrast, the relatively stable Dystric Nitosols exhibit lower erosion rates but remain susceptible to landslides in regions where vegetation cover is inadequate or slopes are steep. Using the K factors and spatial distribution data, erosion susceptibility maps were created to identify high-risk areas. Figures 3 and 4 illustrate the distribution of soil types and their corresponding erosion susceptibilities. These maps are instrumental in visualizing areas where targeted soil conservation and landslide mitigation measures are needed.

High-risk zones, particularly those with Gleysols, are identified for immediate intervention. These areas are prioritized for the implementation of erosion control measures such as the construction of terraces, the establishment of vegetative buffer zones, and the improvement of drainage systems to manage surface runoff and reduce waterlogging.

The erosion susceptibility maps provide a visual representation of the spatial variability in soil erosion risk across the study area. By overlaying soil type data with topographic and climatic information, the maps highlight regions that require urgent attention and intervention. Areas with steep slopes, poor drainage, and high K factors are marked as high-risk zones (Alaboz et al., 2021; Aslam et al., 2021). In these areas, the construction of terraces can help reduce slope gradients and control runoff, while vegetative buffer zones can trap sediments and stabilize the soil. Additionally, improving drainage infrastructure in regions with Gleysols can mitigate waterlogging and enhance soil stability.

Maintaining vegetative cover is critical in reducing soil erosion and enhancing slope stability. Deep-rooted plants and trees can anchor the soil, preventing detachment and movement of soil particles. Implementing agroforestry systems and reforestation projects can help restore vegetative cover in deforested areas and reduce landslide risks. Effective drainage management is crucial in areas with Gleysols to prevent waterlogging and enhance soil stability. Installing subsurface drainage systems, constructing diversion channels, and using raised bed farming techniques can help manage excess water and reduce the likelihood of landslides.

Terracing and contour plowing are effective soil conservation practices for sloped areas. By creating level platforms along the contours of slopes, terracing reduces the speed and volume of surface runoff, minimizing soil erosion (Didoné et al., 2021). Contour plowing involves tilling the soil along the natural contours of the land, creating ridges that slow down water flow and promote water infiltration.

Community awareness and training programs are essential for promoting sustainable land management practices. Educating farmers and local communities about the benefits of soil conservation and the techniques to maintain soil health can foster a culture of environmental stewardship and reduce landslide risks. Regular monitoring and the establishment of early warning systems can provide timely information about soil moisture levels, erosion rates, and landslide occurrences. Monitoring stations equipped with sensors can collect real-time data on soil conditions, enabling prompt interventions and reducing the impact of landslides.

5. Conclusion

The geological formations in the study area exhibit considerable diversity, which is crucial in assessing landslide risks. The Ameki Group, covering 34.24% of the area, is characterized by sandy clays and clayey sands with moderate erosion resistance. However, significant clay content can increase landslide risk during heavy rainfall due to water retention and increased pore water pressure. The Benin Formation, constituting only 0.26% of the area, is predominantly sandy with low cohesion, making it prone to rapid erosion and landslides, especially on steep slopes. The Ogwashi-Asaba Formation, covering 1.59% of the area, consists of lignite and sandy clays, which are prone to erosion. The organic content in lignite contributes to soil instability, increasing landslide susceptibility.

Proximity to the River Niger affects 1.86% of the area, with alluvial deposits along the riverbanks being highly susceptible to erosion and sediment transport, exacerbating landslide risks. The Sands, Gravels, and Clay formation, covering 42.36% of the area, shows variable soil stability. Sands and gravels provide good drainage but low cohesion, while clays can become unstable when saturated. The Sombreiro Warri Deltaic Plain, covering 19.69% of the area, consists of deltaic deposits of fine sediments that are highly erodible, particularly under heavy rainfall or rapid water flow conditions.

The study area contains two predominant soil types: Dystric Nitosols and Gleysols, each with distinct characteristics influencing erosion and landslide susceptibility. Dystric Nitosols, with a K factor of 0.0178 and covering 449.11 km², are found in upland areas with moderate to high slopes. These soils are relatively stable due to high iron and aluminum oxide content, which enhances soil aggregation and cohesion. However, disturbances in vegetation cover can increase erosion and landslide risks. Maintaining vegetative cover and implementing erosion control measures are crucial to preventing soil degradation in areas with Dystric Nitosols.

Gleysols, with a K factor of 0.0189 and covering 283.95 km², are typically found in poorly drained areas. These soils have high water retention and low permeability, making them prone to waterlogging and erosion. Effective drainage management and soil stabilization techniques are essential to mitigate landslide risks in areas dominated by Gleysols.

The region experiences significant seasonal rainfall, impacting soil moisture levels and erosion rates. High-intensity rainfall events exacerbate erosion, particularly in areas with high K factors. The correlation analysis revealed that regions with Gleysols are more vulnerable to landslides during heavy rainfall, while areas with Dystric Nitosols, though less susceptible to erosion, present risks in steep or deforested areas.

In terms of soil conservation and landslide mitigation, high-risk zones, particularly those with Gleysols, should be prioritized for intervention. Erosion control measures, such as terracing, vegetative buffer zones, and improved drainage systems, are essential. Maintaining vegetative cover is critical for reducing soil erosion and enhancing slope stability. Implementing agroforestry and reforestation projects can help restore vegetative cover in deforested areas. Effective drainage management, including subsurface drainage systems and diversion channels, is crucial in areas with Gleysols to prevent waterlogging.

Terracing and contour plowing are effective soil conservation practices for sloped areas, reducing surface runoff and minimizing soil erosion. Community awareness and training programs on sustainable land management practices are essential for promoting environmental stewardship and reducing landslide risks. Regular monitoring and the establishment of early warning systems can provide timely information on soil conditions, enabling prompt interventions and reducing the impact of landslides.

This study provides a comprehensive understanding of the geological and soil factors influencing landslide susceptibility in the study area. The findings underscore the importance of targeted soil conservation and landslide mitigation measures tailored to the specific conditions of each geological formation and soil type.

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