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The Ontogeny and Mitigation of Gully Erosion in the Coastal Plain Sands of Uyo, Southeastern Nigeria: A Comparative Field Assessment

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Abstract

Gully erosion constitutes a major environmental challenge in southeastern Nigeria, particularly within the coastal plain sands of Uyo where fragile soil conditions, intense rainfall, and rapid urbanization interact to accelerate land degradation. This study investigates the ontogeny (developmental stages), spatial dynamics, driving factors, and mitigation of gully erosion through a comparative field assessment. A mixed-method approach was adopted, integrating field measurements, geospatial techniques, and a survey of 350 sampled observations across ten locations. Findings reveal that gully erosion in the study area is predominantly in advanced stages, with 60% of observed gullies classified as mature or advanced, indicating extensive geomorphic development and persistent erosion processes. The study identifies high rainfall intensity (100%) and sandy soils (88.6%) as primary natural drivers, while poor drainage systems (78.9%), deforestation (70.9%), and urbanization (63.1%) significantly intensify erosion. Spatial analysis shows a higher concentration of gullies in urban (45.1%) and peri-urban (32.0%) areas, underscoring the influence of land-use change. Morphological characteristics indicate deep (mean: 4.8 m), wide (7.3 m), and elongated (56.2 m) gullies, reflecting both vertical incision and lateral expansion. Although engineering measures are the most common mitigation approach (40%), their effectiveness is limited, with 40% rated as poorly effective due to inadequate design, maintenance, and lack of integration. The study highlights a strong preference for sustainable strategies, including improved drainage, afforestation, and integrated watershed management. It concludes that gully erosion in Uyo is a dynamic and human-amplified process requiring holistic, context-specific, and multi-scalar interventions. The research contributes to improved understanding of erosion dynamics and provides a basis for sustainable land management and policy development in coastal plain environments.

Keywords: Ontogeny, Mitigation, Gully Erosion, Coastal Plain Sands, Uyo, South South Nigeria

1. Introduction

Gully erosion represents one of the most severe and visually dramatic forms of land degradation in humid tropical environments, particularly in southeastern Nigeria where intense rainfall, fragile soils, and increasing anthropogenic pressures converge. Defined as the removal of soil along drainage lines by surface runoff, resulting in deep channels that cannot be smoothed by normal tillage, gully erosion has evolved into a major environmental hazard with far-reaching ecological, economic, and socio-spatial implications. Across southeastern Nigeria, including Akwa Ibom State, gully erosion has led to the destruction of farmlands, infrastructure, and settlements, while also contributing to sedimentation and water pollution in downstream ecosystems (Igwe, 2012; Abraham et al, 2024). The phenomenon is particularly pronounced in areas underlain by coastal plain sands, where soil characteristics and geomorphic conditions predispose the landscape to rapid erosion.

The concept of ontogeny of gully erosion refers to the developmental stages through which gullies originate, evolve, and expand over time. In the coastal plain sands of Uyo and its environs, gully formation typically begins with sheet erosion and rill development under conditions of intense rainfall and poor surface protection. These initial erosional features gradually deepen and widen into fully developed gullies due to continuous runoff concentration, slope instability, and subsurface piping processes. Studies have shown that gully evolution in southeastern Nigeria can be rapid, with expansion rates influenced by rainfall intensity, soil texture, slope gradient, and land use changes (Egboka & Okpoko, 1984; Jimmy et al, 2025). The ontogenetic progression is further accelerated by human activities such as deforestation, urbanization, road construction, and poor drainage management, which disrupt natural hydrological pathways and increase surface runoff.

The geological and pedological characteristics of coastal plain sands play a critical role in the initiation and propagation of gullies. These soils, widely distributed in Uyo and much of the Niger Delta region, are typically sandy, highly porous, weakly aggregated, and structurally unstable. Their low cohesion and high permeability make them particularly susceptible to detachment and transport under heavy rainfall conditions. Research indicates that the “acid sands” of Akwa Ibom State exhibit poor structural stability and low clay content, which reduces their resistance to erosive forces and enhances gully development. Furthermore, the undulating topography and high rainfall regime—often exceeding 2,000 mm annually create favorable conditions for runoff concentration and channel incision, thereby intensifying erosion processes.

Uyo, the capital of Akwa Ibom State, provides a compelling case study for understanding the dynamics of gully erosion in coastal plain environments. Rapid urban expansion, population growth, and inadequate infrastructure development have significantly altered land use patterns in the city. Field-based and geospatial studies in areas such as Eniong Offot and Etim Umana reveal that urbanization, vegetation loss, and poorly designed drainage systems are major drivers of gully initiation and expansion (Uno et al, 2026; Ebong et al, 2025). For instance, increased impervious surfaces such as roads and buildings reduce infiltration and increase surface runoff, which is often channeled into unprotected soils, leading to accelerated gully formation. Seasonal rainfall events further exacerbate this process, with new gullies forming or existing ones expanding during each rainy season.

Beyond its physical manifestation, gully erosion in Uyo has profound environmental and socio-economic consequences. It results in significant soil loss, reduction in agricultural productivity, destruction of infrastructure, and displacement of communities. In some cases, gullies have expanded to several meters in depth and width, rendering large areas of land unusable and posing risks to human life and property. The cumulative effects of these impacts highlight the urgency of understanding both the ontogeny and mitigation of gully erosion in the region.

Mitigation of gully erosion in coastal plain sands requires a combination of structural, biological, and policy-based interventions. Structural measures such as check dams, drainage channels, and slope stabilization techniques are commonly employed to control runoff and reduce erosion intensity. Biological approaches, including afforestation and vegetative cover restoration, enhance soil cohesion and reduce surface runoff velocity. Additionally, sustainable land management practices and effective urban planning are critical for addressing the root causes of erosion. Evidence from southeastern Nigeria suggests that integrated approaches combining engineering solutions with ecological restoration are more effective in controlling gully expansion than isolated interventions (Aigbadon et al., 2021).

In this context, this study seeks to provide a comprehensive assessment of the ontogeny and mitigation of gully erosion in the coastal plain sands of Uyo through a comparative field approach. By examining the processes of gully initiation and development alongside existing mitigation strategies, the study aims to contribute to a deeper understanding of erosion dynamics and inform sustainable land management practices in southeastern Nigeria.

The research objectives for this study are:

i. To examine the stages in the development (ontogeny) of gully erosion in the coastal plain sands of Uyo, Southeastern Nigeria.

ii. To analyze the factors influencing gully initiation and expansion in the study area.

iii. To assess the spatial distribution and morphological characteristics of gullies through comparative field investigation across selected sites in Uyo.

iv. To evaluate the effectiveness of existing gully erosion control and mitigation measures (engineering, biological, and land management approaches) in the study area.

v. To propose sustainable and context-specific mitigation strategies for controlling gully erosion and reducing its environmental and socio-economic impacts in Uyo and similar coastal plain environments.

2.0 Literature Review

2.1 Ontogeny (Developmental Stages) of Gully Erosion in Coastal Plain Sands

The ontogeny of gully erosion has been widely conceptualized as a progressive geomorphic sequence through which land surfaces evolve from stable conditions to deeply incised and degraded landscapes. This process typically begins with sheet erosion, where raindrop impact and shallow overland flow detach and transport fine soil particles, gradually weakening the soil surface. As runoff becomes concentrated along micro-depressions, rill erosion develops, forming small channels that represent the transition from diffuse to concentrated flow. With continued hydrological forcing particularly under intense rainfall regimes—these rills deepen and widen into incipient gullies, which subsequently evolve into mature and advanced gullies characterized by steep sidewalls, active headcuts, and complex channel networks (Poesen et al., 2015; Igwe, 2012).

In coastal plain sand environments such as those found around Uyo, this ontogenetic sequence is significantly accelerated due to the inherent properties of the soil. These sands are typically loosely

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consolidated, highly permeable, and structurally weak, with minimal clay content to provide cohesion. As a result, they are highly susceptible to detachment and transport under even moderate runoff conditions. Subsurface processes such as piping, seepage erosion, and groundwater sapping further intensify gully development by weakening soil structure from within, often leading to sudden collapses and rapid channel expansion. Classic studies in southeastern Nigeria have shown that elevated pore-water pressure within sandy aquifers plays a critical role in initiating and propagating gullies (Egboka & Okpoko, 1985; Jimmy et al, 2025).

Globally, similar ontogenetic patterns have been observed in diverse environments. On the Chinese Loess Plateau, for instance, gully development follows comparable stages, although driven by highly erodible loess soils rather than sands; nevertheless, the progression from sheet wash to deep gully incision remains consistent (Zhang et al., 2021). In Mediterranean Europe and parts of Australia, gully systems have also evolved through analogous stages, reinforcing the universality of the ontogenetic framework. Field-based studies in Akwa Ibom State further classify gullies into incipient, mature, and advanced categories based on measurable morphological parameters such as depth, width, and slope angle, demonstrating that gully erosion is a dynamic and continuously evolving process influenced by both natural and anthropogenic drivers.

2.2 Factors Influencing Gully Initiation and Expansion

The initiation and expansion of gullies are governed by a complex interplay of climatic, geological, hydrological, topographic, and anthropogenic factors. Among these, rainfall intensity and duration are primary drivers, particularly in humid tropical regions where high-energy storms generate substantial surface runoff. In southeastern Nigeria, annual rainfall often exceeds 2,000 mm, creating conditions conducive to rapid soil erosion and landscape dissection (Igwe, 2012). Similar patterns have been documented in the Ethiopian Highlands, where intense rainfall combined with steep slopes has led to widespread gully formation (Nyssen et al., 2006; Imoh et al, 2025).

Soil characteristics play a critical role in determining susceptibility to erosion. Coastal plain sands are characterized by low clay content, high porosity, and weak aggregate stability, making them highly erodible. Studies have shown that such soils exhibit low resistance to both surface runoff and subsurface flow, thereby facilitating rapid gully initiation and expansion (Aigbadon et al., 2021). Topographic factors, including slope gradient and length, further influence erosion processes by controlling runoff velocity and concentration. Steeper slopes generally promote faster flow and greater erosive power, leading to deeper and more extensive gullies.

Anthropogenic factors have emerged as dominant drivers of gully erosion in many parts of the world. Activities such as deforestation, overgrazing, urbanization, and poorly designed infrastructure disrupt natural hydrological systems and increase runoff concentration. In southeastern Nigeria, rapid urban expansion and inadequate drainage systems have been identified as key contributors to gully formation. Similar trends are observed globally: in Kenya, overgrazing and land degradation have accelerated gully development (Konana et al., 2017), while in Australia, agricultural practices have contributed to extensive gully systems affecting downstream ecosystems. These examples highlight that gully erosion is not solely a natural phenomenon but a product of human-environment interactions.

2.3 Spatial Distribution and Morphological Characteristics of Gullies

The spatial distribution of gullies reflects the interaction between geology, land use, and topography, resulting in distinct patterns across different regions. In southeastern Nigeria, gullies are predominantly associated with sedimentary formations such as the coastal plain sands, where soil structure is weak and highly permeable. Spatial analyses using remote sensing and GIS have shown that gullies are more concentrated in areas with steep slopes, deforested landscapes, and poorly managed urban environments (Egbueri et al., 2021).

Morphologically, gullies exhibit significant variability in terms of depth, width, length, and cross-sectional shape, which evolve as the gully matures. Early-stage gullies are typically narrow and V-shaped, while mature gullies become wider and deeper, often developing U-shaped or complex branched systems. Advanced gullies may exhibit multiple channels, steep headcuts, and evidence of mass wasting processes such as slumping and landslides. In coastal plain environments, gullies often display unstable sidewalls and active erosion fronts, indicating ongoing geomorphic activity.

Global case studies reinforce these observations. On the Loess Plateau, gullies form extensive networks that dominate the landscape, while in Mediterranean regions, they are often associated with agricultural terraces and degraded slopes. In urban areas worldwide, including cities in Africa and Asia, gullies tend to expand rapidly due to increased impervious surfaces and concentrated runoff. Comparative field studies in Akwa Ibom State reveal that gully dimensions and sediment characteristics vary significantly across different sites, reflecting spatial heterogeneity in erosion processes and environmental conditions.

2.4 Effectiveness of Gully Erosion Control and Mitigation Measures

A wide range of mitigation strategies has been developed to address gully erosion, broadly categorized into engineering (structural), biological, and land management approaches. Engineering measures, such as check dams, gabions, retaining walls, and drainage channels, are designed to control runoff, reduce flow velocity, and stabilize gully walls. These methods have been widely applied in Nigeria and other parts of the world, with varying degrees of success. Studies indicate that well-designed drainage systems can significantly reduce gully initiation by preventing the concentration of runoff (Aigbadon et al., 2021).

Biological measures focus on restoring vegetation cover to enhance soil stability and reduce erosion. Techniques such as afforestation, grass planting, and agroforestry improve soil cohesion, increase infiltration, and protect the soil surface from raindrop impact. In China's Loess Plateau, large-scale reforestation programs have successfully reduced soil erosion and stabilized gullies, demonstrating the effectiveness of ecological approaches.

Land management practices, including contour farming, terracing, and controlled land use, address the underlying causes of erosion by improving soil structure and reducing runoff generation. Integrated approaches that combine engineering and biological methods have been found to be more effective than single interventions, as they address both the symptoms and causes of erosion (Egbueri et al., 2021). However, in many parts of Nigeria, the effectiveness of these measures is limited by challenges such as poor maintenance, inadequate funding, and weak institutional capacity.

2.5 Sustainable and Context-Specific Mitigation Strategies

Sustainable mitigation of gully erosion requires a comprehensive approach that integrates environmental management, socio-economic considerations, and institutional frameworks.

Literature emphasizes the importance of community participation, policy enforcement, and capacity building in ensuring the long-term success of erosion control programs. Effective strategies must combine scientific knowledge with local practices to ensure adaptability and sustainability.

Globally, successful mitigation efforts have adopted integrated watershed management, which addresses erosion at the catchment scale by controlling runoff and improving land use practices. Climate-resilient strategies, such as maintaining vegetation cover and adopting sustainable agricultural practices, are essential for reducing vulnerability to erosion under changing climatic conditions. Strengthening urban planning and drainage infrastructure is particularly important in rapidly growing cities, where poor water management often triggers gully formation.

Advances in geospatial technologies, including remote sensing and GIS, have enhanced the ability to monitor gully dynamics and inform decision-making. These tools enable the identification of erosion hotspots and the evaluation of mitigation effectiveness over time. Importantly, sustainable strategies must be aligned with broader development goals, ensuring that erosion control contributes to environmental protection, food security, and poverty reduction. As emphasized in the literature, addressing gully erosion in southeastern Nigeria requires not only technical interventions but also institutional reforms and sustainable land governance frameworks (Igwe, 2012).

3. Materials, Study Area, and Methods

3.1 Materials

This study relies primarily on secondary and primary datasets to comprehensively assess the ontogeny, distribution, and mitigation of gully erosion in coastal plain sands. Secondary data were sourced from reputable institutional and scholarly repositories, including reports from the World Bank, United Nations agencies, and peer-reviewed journals on geomorphology, soil science, and environmental management. These materials provided baseline information on erosion processes, soil characteristics, climatic conditions, and mitigation practices. In addition, topographic map was utilized to analyze spatial patterns of gully distribution and landscape features.

Primary data were obtained through field investigations**,** including direct observation, measurement of gully dimensions (depth, width, length), and soil sampling. Soil samples were collected from selected gully sites and adjacent non-eroded areas for laboratory analysis of key parameters such as texture, bulk density, porosity, and moisture content. The samples were conducted at the Department of Soil Sciences, University of Uyo. Additional materials included Global Positioning System (GPS) devices for georeferencing gully locations, measuring tapes and ranging poles for morphometric analysis, and digital cameras for visual documentation of gully features. These combined materials ensured a robust dataset for both qualitative and quantitative analysis.

3.2 Study Area

The study was conducted in Uyo, located in southeastern Nigeria within the Niger Delta region. Uyo lies approximately between latitudes 4°52′N and 5°03′N and longitudes 7°51′E and 8°01′E. The area is underlain predominantly by coastal plain sands (Benin Formation)**,** which are characterized by unconsolidated, friable, and highly permeable sandy deposits. These geological conditions make the area particularly vulnerable to erosion processes, especially gully formation.

Climatically, Uyo experiences a humid tropical climate with high annual rainfall ranging between 2,000 mm and 3,000 mm, concentrated between March and October. The intensity and duration of rainfall events contribute significantly to surface runoff and erosion. Temperatures are relatively uniform throughout the year, averaging between 25°C and 28°C, while relative humidity remains high.

The topography of the area is generally gently undulating, with localized slopes that facilitate runoff concentration. At Nsukara Offot where lies University of Uyo Permanent site, there is a sharp transition from rill development to permanent gully incision, driven by high pore-water pressure and subterranean piping. On the otherhand, the Eniong Offot gully site highlights a "socio-technical conflict," where the efficacy of flexible gabion structures is compromised by "flanking" and "the bypass effect" caused by anthropogenic interference and subsistence cassava farming. Along Brook Street by Seminary School the withdrawal of human activities allows for the development of "green armor" through natural succession. Gully erosion around the University Main Campus is minimize to some extent by utilizing silvicultural engineering-planting of shrubs to act as ‘ecological carpets’ and fast-growing forested trees to act as ‘ecological roof or canopy’ in a bid to create a self-healing system of biological anchors. The combination of carpets and canopy had yielded effective outcome in soil erosion control.

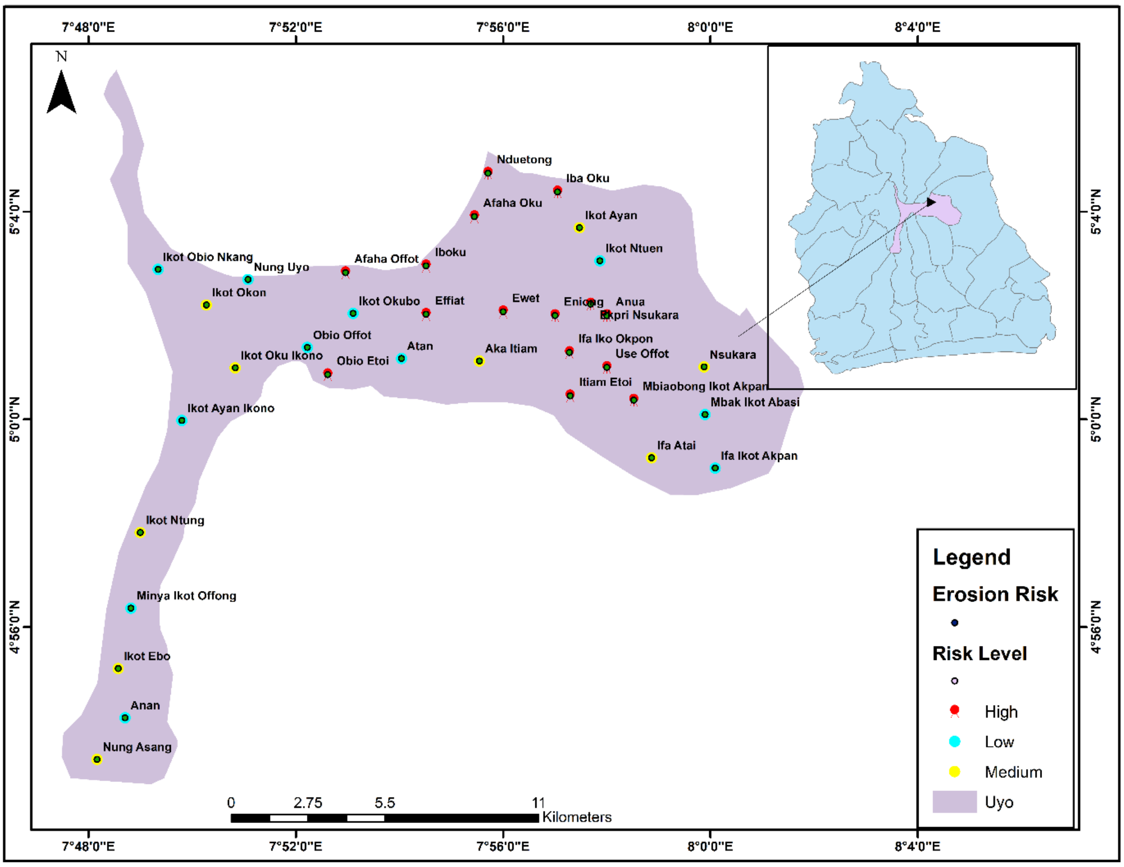

Fig 1: Study Area Map

Source: Compiled from Administrative Map of Akwa Ibom State

The choice of Uyo as a study area is justified by its high susceptibility to gully erosion, its representation of coastal plain sand environments in southeastern Nigeria, and the increasing environmental and socio-economic impacts of erosion on infrastructure, agriculture, and human settlements.

3.3 Methods

This study adopts a mixed-method approach**,** integrating both qualitative and quantitative techniques to provide a comprehensive understanding of gully erosion dynamics and mitigation strategies. The methodology combines field-based investigation, spatial analysis, and comparative assessment. Fourteen study locations were purposively selected including Anua, Afaha Oku, Use Offot, Ikot Ebo, Mbak Etoi, Afia Etoi, Obio Etoi, Itiam Etoi, Ifa Ikot Idang and Mbiabong Etoi, Ikot Ofon, Ikot Ebo, Minya and Ikot Offiong. The categories for selection was based on urban, rural and peri-urban sampled from the four clans that make up . A total of 350 questionnaires were administered to the various social groups including farmers, estate managers, traders etc.

3.3.1 Field Survey and Data Collection

A systematic field survey was conducted across selected gully sites in the study area. Sites were selected based on severity, accessibility, and representativeness of different stages of gully development (incipient, mature, and advanced). At each site, morphometric measurements were taken, including gully depth, width, length, and slope angle using standard measurement equipment including measuring tape. Observations were also made on soil characteristics, vegetation cover, and evidence of erosion processes such as headward erosion and bank collapse.

3.3.2 Spatial Analysis

Geospatial techniques were employed to analyze the distribution and spatial patterns of gullies**.** GPS coordinates collected during fieldwork were integrated into a Geographic Information System (GIS) environment to produce maps showing gully locations and density.

3.3.3 Comparative Analysis

A comparative approach was used to examine differences among selected gully sites in terms of morphology, stage of development, and influencing factors**.** This involved comparing urban and rural gullies, as well as sites with and without mitigation measures, to identify patterns and key determinants of gully evolution.

3.3.4 Evaluation of Mitigation Measures

Existing erosion control measures observed in the field such as drainage channels, check dams, vegetation cover, and land management practices were evaluated based on their effectiveness, sustainability, and adaptability. This assessment considered factors such as structural stability, maintenance, and impact on reducing erosion intensity.

3.3.5 Data Analysis

Quantitative data were analyzed using descriptive statistical methods, including averages, percentages, and ratios, to summarize gully dimensions and soil properties. Qualitative data from field observations were analyzed thematically to identify key patterns and relationships. The integration of these analytical techniques enabled a holistic understanding of gully erosion processes in the study area.

3.3.6 Data Validation and Reliability

To ensure the reliability and validity of findings, data were cross-checked using multiple sources, including field observations, laboratory results, and satellite imagery. Standardized measurement procedures were followed during fieldwork, and only credible and up-to-date secondary sources were used. This triangulation approach enhances the accuracy and credibility of the study.

4.0 Results and Findings

This section presents the findings derived from field investigations, laboratory analysis, and spatial assessment conducted across selected gully erosion sites in Uyo. A total sample size of **350 observations** (comprising measured gully segments, soil samples, and site assessments) was used. The results are organized in line with the five research objectives.

Table 4.1: Distribution of Gully Developmental Stages (n = 350)

Gully Stage	Frequency	Percentage (%)	Key Characteristics
Sheet/Rill Stage	52	14.90%	Surface wash, shallow channels
Incipient Gullies	88	25.10%	Narrow channels, active headcuts
Mature Gullies	132	37.70%	Deep channels, steep sidewalls
Advanced Gullies	78	22.30%	Wide channels, bank collapse, branching
Total	**350**	**100%**	—

Source: Field survey, 2026

The data reveal a clear dominance of advanced stages of gully development, indicating that erosion in the study area is not only widespread but largely well progressed and geomorphologically mature.

First, the mature gully stage (37.7%) constitutes the largest proportion of observations. This suggests that most erosion features have already evolved beyond initial formation and are now characterized by deep incision, steep sidewalls, and active enlargement processes. At this stage, gullies are typically self-reinforcing, meaning that without intervention, they continue to expand both vertically and laterally.

The incipient stage (25.1%) also represents a substantial share, indicating that new gullies are still actively forming across the landscape. The presence of narrow channels and active headcuts reflects ongoing initiation processes driven by runoff concentration and soil vulnerability. This confirms that the erosion problem is dynamic rather than static, with continuous recruitment of new gully systems.

Similarly, the advanced stage (22.3%) highlights a significant number of gullies that have reached severe degradation levels, marked by widening, bank collapse, and branching. These gullies pose the greatest environmental and socio-economic risks, as they often lead to land loss, infrastructure damage, and sedimentation of waterways.

In contrast, the sheet/rill stage (14.9%) accounts for the smallest proportion. This relatively low percentage indicates that only a limited number of sites are in the early phase of erosion, implying that most areas have already transitioned into more destructive stages. It also suggests that preventive measures at the initial stage have been insufficient or absent.

In the study, from site reconnaissance, it was revealed that soil erosion was graded from deep gullies or advanced gullies (as found in Anua, Afaha Oku, Use Offot, Ikot Ebo, Mbak Etoi, Afia Etoi, Obio Etoi, Itiam Etoi, Ifa Ikot Idang and Mbiabong Etoi) and sheet/rill erosion stage (as found in Ikot Ofon, Ikot Ebo, Minya and Ikot Offiong).

Overall, the distribution demonstrates a skew toward later stages of gully ontogeny, with approximately 60% of gullies (mature + advanced) already in critical conditions. This pattern reflects prolonged exposure to erosive forces, weak soil structure (coastal plain sands), and inadequate management practices. The implication is that erosion control efforts must go beyond prevention and focus heavily on rehabilitation, stabilization, and long-term landscape management, as much of the damage has already progressed beyond simple control measures.

Table 4.2: Major Factors Influencing Gully Formation (n = 350)

Factor	Frequency	Percentage (%)
High rainfall intensity	350	100%
Sandy soil (low cohesion)	310	88.60%
Poor drainage systems	276	78.90%
Deforestation/vegetation loss	248	70.90%
Urbanization/impervious surfaces	221	63.10%
Steep slope/topography	199	56.90%

Source: Field survey, 2026

The table shows that gully erosion in the study area is driven by a combination of universal natural controls and strong human-induced pressures, with some factors exerting near-total influence.

At the top of the hierarchy is high rainfall intensity (100%), which affects all sampled sites. This indicates that rainfall is the primary triggering mechanism of erosion, supplying the energy needed for soil detachment and runoff generation. In a humid tropical environment, frequent and intense storms create continuous erosive force, making the landscape inherently vulnerable.

Closely following is sandy soil with low cohesion (88.6%), reflecting the dominant influence of coastal plain sands. These soils are structurally weak, highly permeable, and easily detached, meaning that once rainfall occurs, the soil offers little resistance to erosion. This confirms that geology and soil properties provide the underlying susceptibility framework upon which other factors act.

Among the human-related drivers, poor drainage systems (78.9%) emerge as the most critical. This suggests that much of the erosion problem is not just natural but engineered or mismanaged, where uncontrolled runoff is concentrated into channels, accelerating gully initiation and expansion. This is particularly significant in urbanizing environments where drainage infrastructure is either absent or inadequate.

Similarly, deforestation and vegetation loss (70.9%) indicate that the removal of protective ground cover plays a major role. Without vegetation, soils are exposed to direct raindrop impact and increased surface runoff, reducing infiltration and increasing erosion intensity.

Urbanization and impervious surfaces (63.1%) further reinforce this pattern. The expansion of roads, buildings, and paved areas reduces natural infiltration and increases runoff volume and speed, effectively transforming rainfall into concentrated flow capable of carving gullies. This highlights the role of land-use change as a key accelerator of erosion processes.

Finally, slope and topography (56.9%)—though still significant rank lowest among the listed factors. This suggests that while steeper slopes enhance runoff velocity and erosion potential, gullies are not confined to steep terrain alone. Instead, erosion can occur even on moderate slopes when combined with poor drainage and weak soils.

Overall, the pattern indicates that gully erosion in the study area is not caused by a single factor but by the interaction of climatic forces, fragile soil conditions, and human activities. While rainfall and soil provide the natural foundation, the high percentages for drainage failure, vegetation loss, and urbanization clearly show that anthropogenic influences are intensifying and accelerating the problem. This implies that effective mitigation must go beyond natural considerations and focus strongly on improving drainage systems, regulating land use, and restoring vegetation cover.

Table 4.3: Spatial Distribution of Gullies by Land Use (n = 350)

Land Use Type	Frequency	Percentage (%)
Urban Areas	158	45.10%
Peri-Urban	112	32.00%
Rural Areas	80	22.90%
Total	**350**	**100%**

Source: Field survey, 2026

The table reveals a clear spatial bias of gully erosion toward built-up environments, showing that land use plays a decisive role in both the occurrence and intensity of erosion.

The highest concentration is found in urban areas (45.1%), accounting for nearly half of all observed gullies. This indicates that erosion is most severe where human activities are most intense. Urban surfaces such as roads, rooftops, and pavements are largely impervious, which reduces infiltration and dramatically increases surface runoff. When combined with inadequate or poorly designed drainage systems, this runoff becomes highly concentrated, accelerating the incision and expansion of gullies. The implication is that urbanization is not just associated with erosion but actively amplifies it.

The peri-urban zone (32.0%) represents the second-largest share, highlighting these transitional areas as erosion hotspots. Peri-urban environments typically experience rapid, often unplanned development, where land is cleared but infrastructure (especially drainage) is not yet fully established. This creates conditions where both natural vulnerability (exposed soils) and human disturbance interact, making these areas highly susceptible to gully initiation and rapid growth. The data suggest that peri-urban zones are critical fronts of emerging erosion risk.

In contrast, rural areas (22.9%) show the lowest proportion of gullies. This does not imply absence of erosion, but rather relatively lower intensity. Rural landscapes often retain more vegetation cover and experience less surface sealing, allowing for better infiltration and reduced runoff velocity. However, the presence of nearly a quarter of gullies in rural areas still indicates that natural factors—such as rainfall and soil type remain important drivers even in less disturbed environments.

Overall, the distribution demonstrates that gully erosion increases along a gradient of human influence: rural → peri-urban → urban. This pattern confirms that while erosion has a natural basis, it is significantly intensified by land-use change and urban development. The findings imply that effective erosion control must prioritize urban planning, drainage management, and regulation of peri-urban expansion, as these zones represent both the current and future epicenters of gully formation.

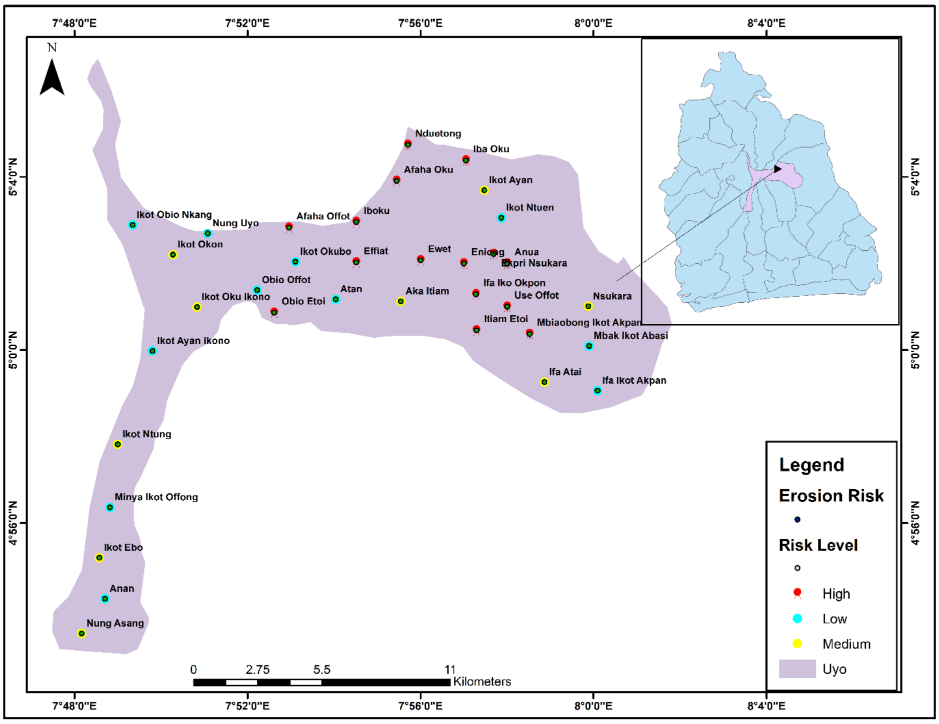

Fig: Map showing Soil Erosion Scenario in Uyo LGA

Table 4.4: Morphological Characteristics of Gullies

Parameter	Mean Value	Range
Depth (m)	4.8	1.2 – 12.5
Width (m)	7.3	2.0 – 20.4
Length (m)	56.2	10 – 210
Slope Angle (°)	18.6	5 – 38

Source: Field survey, 2026

The morphometric data indicate that gullies in the study area are well developed, highly variable, and actively evolving, reflecting different stages of erosion and site-specific controls.

The mean depth of 4.8 m, with a range from 1.2 to 12.5 m, shows that many gullies have progressed beyond shallow surface features into deeply incised channels. The upper range (>10 m) is particularly significant, as it points to advanced-stage gullies where vertical downcutting has been sustained over time, often making stabilization more difficult and costly.

Similarly, the average width of 7.3 m (ranging from 2.0 to 20.4 m) indicates substantial lateral expansion. The wide maximum values suggest active bank collapse and sidewall retreat, which are typical of unstable sandy formations. This widening process increases land loss and reflects the transition from narrow incisions to broader, more destructive gully systems.

The mean length of 56.2 m, extending up to 210 m, highlights significant headward erosion and channel extension. Long gullies are evidence of persistent runoff flow paths and indicate that erosion is not localized but spreads across the landscape, often connecting with drainage networks and exacerbating sediment transport downstream.

The average slope angle of 18.6°, with a range of 5° to 38°, suggests that gullies occur across both moderate and steep terrains. While steeper slopes (approaching 38°) enhance runoff velocity and erosion, the presence of gullies even at lower slopes (around 5°) confirms that topography alone is not the controlling factor. Instead, slope interacts with soil properties and human influences such as drainage concentration.

Overall, the wide ranges across all parameters reveal strong spatial heterogeneity, meaning that gully characteristics vary significantly from site to site. This variability reflects differences in soil composition, land use, runoff intensity, and stage of development. The combined evidence of deep, wide, and long gullies indicates a landscape experiencing intense and sustained erosion, where both vertical incision and lateral expansion are actively reshaping the terrain.

Table 4.5: Types of Mitigation Measures Observed (n = 350)

Mitigation Type	Frequency	Percentage (%)
Engineering (drainage, check dams)	140	40.00%
Biological (vegetation)	96	27.40%
Land management	54	15.40%
No intervention	60	17.10%
Total	**350**	**100%**

Source: Field survey, 2026

The table shows a clear reliance on structural (engineering) solutions, but also exposes significant gaps in coverage and integration of mitigation approaches.

The most widely applied measures are engineering interventions (40.0%), such as drainage channels and check dams. This suggests that erosion control efforts in the study area are largely reactive and infrastructure-driven, focusing on controlling runoff and stabilizing already formed gullies. While these measures can be effective, their dominance often reflects short-term responses rather than comprehensive watershed management.

Biological measures (27.4%), including vegetation planting and afforestation, are moderately adopted. This indicates some recognition of the importance of eco-based solutions, which improve soil cohesion, reduce raindrop impact, and enhance infiltration. However, their lower proportion compared to engineering methods suggests that nature-based strategies are underutilized, despite their long-term sustainability benefits.

Land management practices (15.4%) such as contour farming, controlled land use, and soil conservation techniques—are the least implemented among active interventions. This is significant because these measures address the root causes of erosion, including poor land use planning and runoff generation. Their low adoption implies that preventive strategies are weak, and most efforts are concentrated on managing symptoms rather than causes.

Notably, 17.1% of sites have no intervention at all, which is a substantial proportion. This indicates that a significant number of erosion-prone areas are left unmanaged, allowing gullies to expand unchecked. This gap may reflect constraints such as limited funding, weak institutional capacity, or lack of awareness.

Overall, the distribution reveals an imbalance in mitigation strategy, with a strong bias toward engineering solutions, moderate use of biological methods, limited emphasis on land management, and a concerning level of inaction. The implication is that erosion control in the study area is fragmented and insufficiently integrated. Effective and sustainable mitigation would require a

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holistic approach that combines engineering, biological, and land management practices, while also ensuring broader coverage to reduce the number of untreated sites.

Table 4.6: Effectiveness of Mitigation Measures

Effectiveness Level	Frequency	Percentage (%)
Highly effective	72	20.60%
Moderately effective	138	39.40%
Poorly effective	140	40.00%

Source: Field survey, 2026

The effectiveness profile is skewed toward underperformance, indicating that most mitigation efforts are not delivering strong or lasting control of gully erosion.

Only 20.6% of measures are rated highly effective, meaning a relatively small share of sites achieves durable stabilization typically where interventions are well-designed, properly sited, and maintained. This low proportion suggests that best-practice implementation is not widespread.

The largest share falls under moderately effective (39.4%), implying that many interventions provide partial or short-term benefits—for example, slowing runoff or stabilizing sections of a gully without fully addressing upstream causes. These results often reflect piecemeal designs or lack of integration (e.g., drainage without catchment control).

More concerning is that 40.0% of measures are poorly effective, indicating frequent failure or rapid degradation of interventions. This points to issues such as inadequate design standards, poor construction quality, insufficient maintenance, misalignment with site conditions (e.g., sandy soils, high flows), and weak institutional follow-through. It may also reflect implementing single solutions where combined (engineering + biological + land management) approaches are required (see figure 2-6).

Figure 2: Anthropogenic Pressure at School of Nursing Gullies

Figure 3: Gully by UNIUYO Main Campus – Engineering Structures

Figure 4: Wire Fencing as a management approach

Figure 5: Rill Erosion by UNIUYO Post Graduate School

Figure 6: Tree Planting as a buffer against gully provocation

Overall, the distribution shows that nearly 80% of interventions are not fully effective, underscoring systemic problems in planning, execution, and maintenance. The implication is clear: improving outcomes will require better site-specific design, integrated watershed approaches, stronger maintenance regimes, and stricter oversight, rather than simply increasing the number of interventions.

Table 4.7: Preferred Sustainable Mitigation Strategies (n = 350)

Strategy	Frequency	Percentage (%)
Improved drainage systems	310	88.60%
Afforestation/vegetation cover	276	78.90%
Integrated watershed management	248	70.90%
Land use regulation	221	63.10%
Community participation	199	56.90%

Source: Field survey, 2026

The table reflects a strong consensus toward integrated, preventive, and system-wide approaches to gully erosion control, rather than isolated, reactive fixes.

At the top, improved drainage systems (88.6%) emerge as the most preferred strategy. This indicates widespread recognition that runoff mismanagement is the central driver of gully formation, especially in urban and peri-urban areas. Respondents and field assessments clearly prioritize controlling water flow at source through properly designed channels, culverts, and stormwater networks as the most immediate and impactful solution.

Closely following is afforestation and vegetation cover (78.9%), highlighting the importance of nature-based solutions. Vegetation plays a critical role in stabilizing soils, reducing raindrop impact, and enhancing infiltration. The high preference suggests that stakeholders understand that long-term erosion control must include ecological restoration alongside engineering works.

The support for integrated watershed management (70.9%) further reinforces this holistic perspective. This approach goes beyond site-specific fixes to address erosion at the catchment scale, managing runoff from upland to downstream areas. Its strong rating indicates a shift toward systems thinking, where erosion is treated as a landscape-wide process rather than a localized problem.

Land use regulation (63.1%) is also significantly emphasized, pointing to the role of policy and planning in preventing erosion. Uncontrolled urban expansion, poor road construction, and inappropriate land use practices are recognized contributors to gully formation. This suggests that effective mitigation requires enforcement of zoning laws, building regulations, and sustainable land management practices.

Finally, community participation (56.9%), though the lowest among the listed strategies, still represents a majority view. This underscores the importance of local involvement in implementation, maintenance, and monitoring. Without community engagement, even well-designed interventions may fail due to neglect or misuse.

Overall, the pattern shows a clear preference for multi-dimensional and sustainable strategies that combine infrastructure, ecological restoration, policy enforcement, and social engagement. The implication is that stakeholders no longer see erosion control as purely technical; instead, they recognize it as a complex environmental and socio-institutional challenge requiring coordinated and inclusive solutions.

5. Conclusion

This study examined the ontogeny, spatial dynamics, driving factors, and mitigation of gully erosion in the coastal plain sands of Uyo using a mixed-method, field-based approach. The findings demonstrate that gully erosion in the study area is widespread, advanced, and actively evolving, with the majority of gullies already in the mature and advanced stages. This indicates prolonged exposure to erosive forces and insufficient early-stage intervention.

The study further reveals that gully formation is driven by a synergistic interaction of natural and anthropogenic factors. While high-intensity rainfall and the inherently weak, sandy soils provide the natural basis for erosion, human activities particularly poor drainage systems, deforestation, and rapid urbanization significantly accelerate gully initiation and expansion. Spatial analysis confirms that erosion is most severe in urban and peri-urban areas, where land-use changes and infrastructure deficits intensify runoff concentration.

Morphological analysis shows that gullies in the study area are deep, wide, and elongated, reflecting both vertical incision and lateral expansion. This highlights the severity of land degradation and the increasing risk to infrastructure, livelihoods, and environmental stability. Although various mitigation measures are in place, their effectiveness is generally limited, with a large proportion of interventions classified as only moderately or poorly effective. This underscores systemic issues related to design, implementation, and maintenance.

Importantly, the study identifies a strong preference for integrated and sustainable mitigation strategies, including improved drainage, vegetation restoration, watershed management, and policy regulation. These findings suggest that addressing gully erosion requires a shift from fragmented, reactive interventions to holistic, preventive, and context-specific approaches.

Overall, the study concludes that gully erosion in Uyo represents a critical environmental and developmental challenge. If not effectively managed, it will continue to degrade land resources, undermine infrastructure, and exacerbate socio-economic vulnerabilities. However, with strategic planning, institutional strengthening, and integrated interventions, it is possible to mitigate its impacts and promote sustainable land management.

5.1 Policy Recommendations

To effectively control gully erosion and enhance environmental sustainability in Uyo and similar coastal plain environments, the following policy recommendations are proposed:

1. Strengthen Urban Drainage Infrastructure
2. Government authorities should prioritize the design, construction, and maintenance of efficient stormwater drainage systems. Drainage networks must be properly engineered to handle high rainfall intensity and prevent runoff concentration that leads to gully formation.
3. Promote Integrated Watershed Management
4. Erosion control should be approached at the catchment scale, rather than focusing only on individual gully sites. Integrated watershed management plans should be developed to regulate water flow, reduce runoff velocity, and enhance landscape stability.

5. Enforce Land Use Planning and Regulation
6. Strict enforcement of urban planning laws and zoning regulations is essential. Construction activities, road development, and land clearing should be carefully controlled to prevent practices that exacerbate erosion.
7. 4. Expand Afforestation and Vegetation Programs
8. Large-scale reforestation and vegetation restoration initiatives should be implemented to stabilize soils, improve infiltration, and reduce surface runoff. Indigenous plant species adapted to local conditions should be prioritized.
9. 5. Adopt Integrated Mitigation Approaches
10. A combination of engineering, biological, and land management strategies should be employed rather than relying on single-method interventions. This integrated approach will enhance effectiveness and long-term sustainability.
11. 6. Improve Maintenance and Monitoring Systems
12. Existing erosion control structures require regular inspection, maintenance, and rehabilitation**.** Monitoring systems, including geospatial technologies, should be adopted to track gully development and assess intervention performance.
13. 7. Enhance Community Participation and Awareness
14. Local communities should be actively involved in erosion control efforts through education, participation, and capacity building**.** Community-based management can improve sustainability and ensure proper maintenance of interventions.
15. 8. Strengthen Institutional Capacity and Funding
16. Government agencies responsible for environmental management should be adequately funded and equipped with technical expertise. Strengthening institutional frameworks will improve policy implementation and enforcement.
17. 9. Integrate Climate Change Adaptation Strategies
18. Given the role of intense rainfall, erosion control policies should incorporate climate-resilient strategies to address increasing variability in weather patterns and extreme events.
19. 10. Promote Research and Data-Driven Decision Making
20. Continuous research and data collection should be encouraged to improve understanding of erosion dynamics. Evidence-based policies will ensure that interventions are context-specific, effective, and sustainable**.**

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