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A Comprehensive Review of the Environmental Impacts of Gully Erosion in the Semi-Arid Zone of Northeastern Nigeria: Implications for Sustainable Land Management

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Abstract

Gully erosion remains one of the most serious environmental challenges affecting semi-arid regions by causing widespread damage to land, ecosystems, and livelihoods. These areas marked by low and irregular rainfall, fragile soils, and intense human pressure are particularly vulnerable to rapid land degradation. This review paper explores the environmental impacts of gully erosion, with a special focus on its implications for Nigeria. Drawing from a wide range of studies, it discusses the underlying causes and dynamics of gully formation and emphasizing on how human activities such as deforestation, overgrazing, and unsustainable farming practices have worsened natural vulnerabilities. The paper highlights the far-reaching consequences of gully erosion, including the loss of fertile agricultural land, decline in soil health, destruction of critical infrastructure, sedimentation of water bodies, and disruption of local ecosystems. In Nigeria, particularly in northern states like Adamawa, Yobe, and Borno, the problem has intensified due to increasing population pressures and shifting climatic conditions. Although various control measures from vegetation restoration to engineering solutions have been introduced, efforts are often hampered by limited resources, lack of awareness, and weak policy enforcement.This review calls for a more integrated and proactive approach to managing gully erosion by combining scientific knowledge, community participation, and effective governance. It also underscores the importance of promoting climate-resilient land management practices to protect vulnerable landscapes. By synthesizing existing research, the paper offers insights that can guide future studies, inform policy interventions, and support practical solutions aimed at mitigating the growing threat of gully erosion in Nigeria's semi-arid regions and beyond.

Keywords: Gully Erosion, Semi-Arid Regions, Environmental Degradation, Land Management, Nigeria

Introduction

Gully erosion is widely recognised as one of the most severe forms of land degradation, particularly in semi-arid and sub-humid environments where soils are fragile and vegetation cover is sparse. It represents an advanced stage of water-induced erosion, characterised by deep channels that rapidly expand and permanently remove productive land. Globally, gully erosion has been linked to declining soil fertility, disruption of hydrological systems, and increased vulnerability of rural livelihoods, especially in developing countries where dependence on land resources is high (Poesen et al., 2003; FAO, 2019).

In Nigeria, gully erosion has emerged as a critical environmental and developmental challenge, threatening agricultural productivity, infrastructure, and human settlements across several ecological zones. The problem is particularly pronounced in semi-arid and transitional regions where intense rainfall events, poor land management practices, and weak soil structures interact to accelerate land degradation. Empirical evidence from northern Adamawa State shows that over 94% of surveyed farmers reported the presence of gully erosion in their communities, with about one-third experiencing direct loss of farmland and over 20% reporting serious soil quality degradation (Usman, 2023). These findings highlight the widespread nature of the problem and its direct implications for food security and rural livelihoods.

The causes of gully erosion in Nigeria are complex and multifactorial, involving both natural and human-induced drivers. From a biophysical perspective, factors such as soil texture, slope gradient, rainfall intensity, and geological formations play a significant role in gully initiation and expansion. Geological and geotechnical studies in the Anambra Basin reveal that areas with loose, poorly consolidated soils, steep slopes, and inadequate vegetation cover are highly susceptible to gully development (Okeke et al., 2023). Similarly, erosion susceptibility modelling in southeastern Nigeria has identified porous, sandy uplands with high moisture retention as critical hotspots for gully propagation (Nwankwo et al., 2023). These natural vulnerabilities are often exacerbated by anthropogenic activities, including deforestation, unregulated road construction, overgrazing, and inappropriate agricultural practices.

The impacts of gully erosion in Nigeria extend beyond environmental degradation to include profound socio-economic consequences. Large expanses of arable land have been rendered unusable, transportation networks disrupted, and residential areas displaced. In Anambra State, gully erosion is reported to have affected more than 70% of the land area in some communities, posing severe threats to lives, properties, and public infrastructure (Okafor, 2024). Likewise, in

Ikeduru Local Government Area of Imo State, rapid gully expansion between 2017 and 2022 resulted in loss of farmlands, destruction of access roads, and increased vulnerability of local populations to poverty and displacement (Chukwuma, 2024). These cases underscore the urgency of addressing gully erosion as both an environmental and developmental concern.

Given the scale and complexity of gully erosion in Nigeria, effective mitigation requires a comprehensive understanding of its underlying drivers, impacts, and management options. While several studies have examined gully erosion at local and regional scales, there remains a need for an integrated synthesis that connects environmental processes with socio-economic implications, particularly within semi-arid contexts. This review therefore aims to consolidate recent research on gully erosion in Nigeria, with emphasis on its causes, environmental and socio-economic effects, and existing mitigation strategies, in order to support evidence-based policy formulation and sustainable land management practices.

Aim

The aim of this paper is to review the environmental impacts of gully erosion in semi-arid regions, with particular focus on its causes, effects, and mitigation strategies in Nigeria.

Objectives

The specific objectives of the study are to:

- Identify the major natural and anthropogenic drivers of gully erosion in semi-arid environments.
- Examine the environmental and socio-economic impacts of gully erosion in Nigeria.
- Review and highlight effective mitigation and management strategies for controlling gully erosion.

RELATED REVIEW

Gully erosion in Nigeria has attracted increasing scholarly attention over the years, with studies progressively incorporating advanced methodologies to examine its causes, consequences, and mitigation strategies. The earliest contribution in this review is by Nwankwoala (2019), who employed mathematical and predictive tools—including the Universal Soil Loss Equation (USLE) and the Normalized Difference Vegetation Index (NDVI)—to estimate soil loss and assess vegetation's impact on erosion. Additionally, logistic regression models were used to evaluate the likelihood of gully occurrence based on various factors. His study underscored the devastating effects of gully erosion in southeastern Nigeria, including land degradation, water contamination, and displacement of communities. While proposing control measures such as vegetation planting and regulatory enforcement, the paper lacks a critical assessment of the feasibility of these interventions.

In 2020, Iro conducted a 30-year remote sensing analysis on land cover change and its relationship with gully erosion in southeastern Nigeria. He reported a strong negative correlation ($r = -0.9$) between vegetation cover and gully expansion, thus validating the importance of remote sensing as a monitoring tool. Similarly, Ojeaga et al. (2020) carried out

geotechnical evaluations in Isuikwuato and Umuahia, Abia State. Their findings identified the soils as sandy and non-cohesive, and thus highly susceptible to erosion. The authors also pointed to rainfall, drainage patterns, and geological conditions as significant contributors, emphasizing the need for improved soil management strategies. Continuing this line of investigation, Nwachukwu and Nwosu (2021) focused on vegetation loss due to human activities such as farming and construction, and its implications for gully formation. They concluded that vegetation degradation accelerates erosion processes and recommended localized afforestation as a cost-effective and sustainable control strategy. In a related 2021 study, Aigbadon, Ocheli, and Akudo conducted a geotechnical survey of gully-prone areas in Iguosa, southern Nigeria. Their work identified Ajali sands as having low cohesion and plasticity, making them particularly vulnerable to erosion. Additionally, steep slopes and dense vegetation complicated both erosion control and research logistics.

These findings were later reinforced by repeated references to the same studies by Ojeaga et al. (2020), Aigbadon et al. (2021), and Nwachukwu and Nwosu (2021), who collectively emphasized the combined influence of poor soil characteristics, rainfall, topography, and anthropogenic pressures. Moving into 2022, several studies adopted geospatial and modeling techniques to further refine erosion assessments. For instance, Osumgborogwu et al. (2022) employed high-resolution satellite imagery to analyze gully evolution between 2009 and 2018. Their results demonstrated a notable increase in both the number and length of gullies, alongside a decline in fallow land and a rise in non-vegetated surfaces—directly linking land-use changes to surface runoff and erosion intensification. Similarly, Ayadiuno et al. (2022) used geospatial and laboratory methods to quantify soil loss at the Ibeziako site in Nsukka, reporting an alarming 83.3 tonnes/ha/yr. Their analysis tied the erosion levels to rainfall intensity and land use, advocating slope stabilization and reforestation as mitigation strategies. Additionally, Eloudi et al. (2022) utilized ensemble models—combining Random Forest with Multi-Criteria Decision-Making (MCDM) techniques such as AHP and Weight of Evidence—to assess erosion sensitivity in semi-arid regions. Their model achieved high predictive accuracy (AUC ≈ 0.89), and simulations forecasted a significant expansion of erosion-prone areas by 2040, driven by reduced vegetation, declining rainfall, and rising temperatures. This study demonstrated the robust potential of machine learning in erosion prediction. In 2022 as well, Maina assessed the persistence of gully erosion in Damagum Town, Yobe State, despite existing biological and engineering controls. The study revealed that substandard materials and issues like insect infestations undermined the effectiveness of mitigation efforts, leading to continued loss of farmland and property.

Research in 2023 further advanced the integration of modeling, fieldwork, and socio-economic analyses. Enemuoh et al. (2023) applied artificial neural networks to predict gully expansion trends in southeastern Nigeria for the decade 2020–2030. Their model, validated at 79.24% accuracy, projected widespread gully development across Abia, Anambra, Enugu, Ebonyi, and Imo States, underscoring the need for proactive environmental planning. Similarly, Umego et al. (2023) employed geospatial modeling to explore how both topography and human actions influence erosion. They recommended the use of high-resolution imagery

and digital elevation models to improve prediction and guide management interventions. This recommendation was reiterated across three distinct references in the same year, indicating the authors' consistent advocacy for technologically informed approaches. From a geological standpoint, Odoh et al. (2023) conducted drone-based geological mapping and laboratory tests in Ukpor, southeastern Nigeria. Their analysis revealed that poorly graded, coarse-grained sands are most vulnerable to erosion. Accordingly, they called for stabilization techniques and improved vegetation management. Meanwhile, Alhassaan et al. (2023) took a socio-economic perspective, surveying 400 farmers in Northern Adamawa. Results showed that over 94% of respondents were aware of gully erosion, with 76% identifying it as a threat to their livelihood. Loss of farmland (33.3%), soil degradation (20%), and higher crop transportation costs (12.5%) were some of the major impacts cited, highlighting erosion's adverse effects on rural economies. Churu et al. (2024) adopted a mixed-methods approach in a tropical semi-arid region, combining household surveys, interviews, field observations, and laboratory tests to assess gully drivers. They identified deforestation (60%), surface runoff (37%), and steep terrain (34%) as primary contributors. Over a 45-year period, the area experienced significant arable land loss and sediment displacement. Although some gullies offered temporary benefits such as water sources and mineral exposure, these were largely unsustainable under changing climate conditions.

Finally, Jackie (2024) provided a comprehensive overview of gully erosion's environmental and anthropogenic triggers. She argued for an integrated soil conservation framework that incorporates hydrological and bio-environmental dynamics. Notably, she called for further research on sub-surface erosion and the behavioral patterns of farmers in adopting conservation strategies. Despite the availability of erosion control techniques, Jackie highlighted that implementation gaps remain a substantial challenge.

RESULTS AND FINDINGS

The review of existing literature on gully erosion in Nigeria reveals consistent patterns across different ecological zones and study contexts. Rather than isolated occurrences, the findings indicate interconnected environmental, anthropogenic, technical, and socio-economic factors that collectively drive gully initiation, expansion, and persistence. For clarity, the key findings of this review are organised into four thematic areas.

1. **Soil Characteristics and Topographic Susceptibility:** One of the most consistent findings across the reviewed studies is the inherent vulnerability of soils and terrain in erosion-prone regions of Nigeria. Research repeatedly identifies sandy, loose, and poorly consolidated soils—particularly the Ajali Sand Formation—as highly susceptible to gully initiation and rapid enlargement (Ojeaga et al., 2020; Aigbadon, Ocheli & Akudo, 2021; Odoh et al., 2023). These soils exhibit low cohesion and weak structural stability, which significantly reduce resistance to concentrated surface runoff. When such soil conditions occur on steep or undulating slopes, the erosive power of rainfall is amplified, accelerating gully development. This finding underscores that gully erosion in many Nigerian landscapes is partly driven by intrinsic geotechnical weaknesses that require location-specific and technically informed interventions.

2. **Vegetation Degradation and Unsustainable Land Use Practices:** The loss of vegetation cover and poor land use practices emerge as dominant anthropogenic drivers of gully erosion. Several studies demonstrate a strong relationship between vegetation depletion and gully expansion. For example, Iro (2020) reports a strong negative correlation ($r = -0.9$) between vegetation cover and erosion intensity, indicating that areas with sparse vegetation experience significantly higher erosion rates. Similarly, Nwachukwu and Nwosu (2021) link increased gully occurrence to deforestation associated with agricultural expansion, road construction, and urban development. The removal of vegetation reduces soil cohesion, increases surface runoff, and weakens natural erosion control mechanisms. These findings highlight the central role of land use management and afforestation in mitigating gully erosion.
3. **Effectiveness and Sustainability of Erosion Control Measures:** Although various biological and engineering control measures have been implemented across affected regions, the reviewed literature reveals limited long-term success in many cases. Poor design standards, inadequate maintenance, and failure to adapt interventions to local environmental conditions are recurring challenges. Maina (2022) documents continued gully expansion in Damagum Town despite the presence of control structures, attributing failure to the use of substandard construction materials and damage from biological agents such as termites. Similarly, Jackie (2024) notes that conservation techniques are often applied in isolation, without integrating community participation or local ecological knowledge. This finding suggests that erosion control efforts in Nigeria frequently lack sustainability due to weak institutional support, limited technical capacity, and poor stakeholder involvement.
4. **Socio-Economic Impacts and Community Vulnerability:** Beyond its physical manifestations, gully erosion exerts severe socio-economic impacts, particularly in rural and agrarian communities. Evidence from Northern Adamawa indicates that more than 76% of surveyed farmers perceive gully erosion as a direct threat to their livelihoods (Alhassaan et al., 2023). Key consequences identified in the literature include loss of cultivable land, reduced agricultural productivity, increased transportation costs, displacement of households, and declining soil fertility. These impacts collectively deepen poverty levels and exacerbate food insecurity. The findings therefore establish gully erosion as not only an environmental issue but also a significant development challenge that undermines rural resilience and economic stability.

Summary of Key Findings

Overall, the review demonstrates that gully erosion in Nigeria is driven by a complex interaction of vulnerable soil conditions, land use mismanagement, ineffective control measures, and socio-economic pressures. The persistence of the problem reflects gaps in integrated planning, policy enforcement, and community-based approaches, pointing to the need for sustainable, context-sensitive erosion management strategies.

CONCLUSION

The reviewed literature underscores the multifaceted nature of gully erosion in Nigeria, driven by both natural and anthropogenic factors. Inherent soil fragility, unsustainable land use practices, ineffective erosion control measures, and substantial socio-economic consequences are recurring themes. Despite a growing body of research, there remains a gap in translating scientific insights into sustainable, locally adapted solutions. Moreover, while advances in geospatial and modeling technologies have improved erosion assessment and prediction, practical implementation and community-based interventions remain limited. Thus, an integrated and interdisciplinary approach is essential to addressing gully erosion comprehensively.

RECOMMENDATIONS

Gully erosion poses a significant environmental threat in semi-arid regions, particularly in Nigeria where fragile soils, intense seasonal rainfall, and poor land management practices exacerbate the problem. The rapid expansion of gullies leads to the destruction of arable land, displacement of communities, and degradation of vital infrastructure such as roads and buildings. Moreover, it contributes to sedimentation in waterways, reducing water quality and availability for both agricultural and domestic use. The loss of vegetation cover and topsoil also undermines biodiversity and the natural resilience of ecosystems, compounding the long-term ecological damage.

To address these impacts, it is recommended that a multi-pronged strategy be adopted, integrating community-based land use planning, afforestation, and sustainable agricultural practices. The Nigerian government and relevant stakeholders should invest in early detection and monitoring systems using geospatial technologies to map and predict gully formation. Additionally, implementing soil conservation techniques, such as contour plowing and the construction of check dams, can significantly reduce runoff and soil loss. Educational campaigns and capacity-building programs are also essential to empower local communities to take proactive roles in preventing gully erosion and preserving their environment.

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