International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 20, Issue 4 (April. 2024), PP. 36-40

Modelling and Mapping Of Erosion Vulnerability Zones in the Coastal Areas of Rivers State, Nigeria Using GIS and Remote Sensing Techniques

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Abstract- *This study presents a comprehensive assessment of coastal erosion vulnerability zones in Rivers State Nigeria, utilizing geographic information systems (GIS) and remote sensing techniques. Three distinct vulnerability zones—high, moderate, and low—are identified across the study area, covering various extents of land. Notably, Bonny emerges as the most vulnerable zone, with significant implications due to its role as a crucial oil and gas hub. Other areas, such as Degema, Okrika, Andoni, and Asari-Toru, also exhibit notable vulnerability, highlighting the importance of implementing effective erosion control and mitigation strategies. The study underscores the economic and environmental repercussions of coastal erosion, emphasizing the need for targeted conservation efforts to safeguard both natural ecosystems and culturally significant sites. Understanding these vulnerability zones is vital for informing decision-making processes aimed at preserving coastal regions and mitigating the adverse impacts of erosion on local communities and infrastructure.*
Keywords:

Date of Submission: 02-04-2024 | Date of Acceptance: 12-04-2024

I. Introduction

Coastal erosion poses a significant threat to the environmental, economic, and social well-being of coastal communities worldwide. With rising sea levels, changing climate patterns, and human activities exacerbating coastal vulnerability, understanding and effectively managing erosion-prone areas have become paramount (Nicholls & Cazenave, 2010; Ferrario *et al*., 2014). This paper focuses on the application of Geographic Information Systems (GIS) and remote sensing techniques to model and map erosion vulnerability zones in the coastal areas of Rivers State, Nigeria.

Rivers State, located in the Niger Delta region of Nigeria, boasts a diverse coastal landscape characterized by extensive river networks, mangrove forests, and dynamic shoreline ecosystems (Nwilo & Badejo, 2014; Odemerho *et al*., 2017). However, this region is also subject to the forces of coastal erosion, driven by natural processes such as wave action, tidal currents, and sediment dynamics, compounded by anthropogenic factors including urbanization, deforestation, and unsustainable land use practices (Syvitski *et al*., 2009; Turner, *et al*., 2014; Adeniyi *et al*., 2019).

In recent years, the integration of GIS and remote sensing technologies has revolutionized the study of coastal erosion, offering powerful tools for spatial analysis, data visualization, and predictive modeling (Duodu *et al*., 2018; Bao *et al*., 2020). These techniques enable researchers to assess coastal vulnerability by integrating multi-source data, including satellite imagery, topographic maps, bathymetric surveys, and field observations, to identify areas at risk and prioritize mitigation efforts (Chipofya & Mwendera, 2015).

The significance of this study lies in its focus on Rivers State, a region of strategic importance both nationally and globally (Goodwin *et al*., 2018). As one of Nigeria's major economic hubs, Rivers State hosts vital industries such as oil and gas production, shipping, and fisheries, all of which rely heavily on the integrity of coastal ecosystems and infrastructure (Nwilo & Badejo, 2014). Thus, understanding and effectively managing erosion vulnerability in this area are crucial for sustaining economic development, safeguarding livelihoods, and preserving natural resources.

Moreover, this research contributes to the broader scientific discourse on coastal erosion management, offering insights into the applicability of GIS and remote sensing techniques in tropical coastal environments (Mukhopadhyay & Khan, 2012; Turner & Fitzpatrick, 2016; Jayanthi & Chandramohan, 2016). By elucidating the spatial patterns and drivers of erosion vulnerability in Rivers State, this study provides valuable information for policymakers, urban planners, and resource managers seeking to implement evidence-based strategies for coastal resilience and adaptation (Adger *et al*., 2005).

II. Materials and Methods

2.1 Study Area

Situated in the southwestern region of Nigeria,the study area Rivers State spans approximately 11,077 square kilometers of land and water, positioned between latitudes 4° 40 and 5° 20´ N and longitudes 6° 20 and 7° 40` E.

The landscape of Rivers State is a low-lying coastal plain characterized by intricate topography shaped by a blend of natural phenomena and human activities. Geomorphological and hydrological processes, such as sediment deposition from rivers, tidal and storm-driven erosion, and subsidence caused by oil and gas extraction, collectively mold the region's terrain.

Studies by Okoronkwo and Ekuma (2015) reveal a topography marked by deltaic lobes formed through sediment deposition from numerous river channels. These lobes, interspersed with creeks and channels, regulate water and sediment flow, serving as vital habitats for diverse flora and fauna, including mangroves and coastal wetlands that furnish essential ecosystem services.

The climate of Rivers State falls under the classification of tropical wet and dry, with a distinct rainy season from April to October and a dry season from November to March. High temperatures and humidity prevail, with average temperatures ranging from 25°C to 30°C and annual rainfall averaging between 1,500 to 2,000 millimeters (Nnaji, 2016). The African Monsoon exerts significant influence, contributing to the region's substantial rainfall (Okpokwasili & Nnaji, 2014).

A prominent meteorological feature is the harmattan, a dry, dusty trade wind blowing from the northeast during the dry season, which can reduce visibility and cause respiratory issues due to airborne dust and pollutants (Nnaji, 2016). Additionally, a strong sea breeze originating from the ocean plays a crucial role in cooling the coast and supporting the local fishing industry by bringing in marine life (Okpokwasili & Nnaji, 2014).

The climate not only affects local communities and industries but also exerts a significant impact on the environment. High rainfall and humidity contribute to erosion, flooding, and other environmental challenges, particularly in coastal areas. Understanding the climate dynamics of Rivers State and its implications on the environment is paramount for devising effective management strategies to mitigate adverse impacts (Nnaji, 2016).

2.2 Methodology

The methodology employed in this research focuses on the assessment of relative priorities in modeling and mapping erosion vulnerability in coastal areas of Rivers State. The process was initiated by compiling a comprehensive set of criteria crucial for evaluating vulnerability, including slope, elevation, geology, soil type, erosivity, flow accumulation, and aspect.

To ascertain the relative importance of these criteria, the Analytical Hierarchical Process (AHP) was adopted. AHP facilitated the comparison and establishment of the hierarchy among the criteria through pairwise matrix comparisons, enabling the determination of their relative weights. This step ensured that the subsequent integration of these criteria into the vulnerability assessment would be reflective of their respective significance in contributing to erosion vulnerability.

Following the determination of relative weights, the Weighted Overlay technique was implemented. This technique enabled the synthesis of the various suitability criteria maps into a comprehensive vulnerability map. By assigning appropriate weights to each criterion, Weighted Overlay facilitated the identification of areas with higher susceptibility to coastal erosion based on the combined influence of multiple factors.

To further refine the vulnerability assessment, an iterative post-aggregation constraint was applied. This constraint aimed to delineate high vulnerability zones by considering the aggregated influence of all criteria, thus providing a detailed understanding of the spatial distribution of erosion vulnerability along the coast of Rivers State.

III. Results

The findings revealing three distinct zones of coastal erosion vulnerability: high, moderate, and low vulnerability. The high vulnerability zone spans 545.29 square kilometers, constituting 6.38% of the study area. In contrast, the moderate and low vulnerability zones cover 1941.33 and 6052.51 square kilometers, respectively, making up 22.73% and 70.89% of the total area.

Among these zones, Bonny emerges as the most vulnerable, covering approximately 139.28 square kilometers. Addressing erosion in this area is crucial due to its significance as an oil and gas hub, where severe erosion could have far-reaching environmental and economic consequences. Degema, covering about 111.28 square kilometers, ranks as the second highest in coastal erosion vulnerability. Effective planning and intervention strategies are imperative here given its substantial size and economic importance.

Okrika and Andoni, with coverage areas of 71.73 and 62.20 square kilometers respectively, occupy the third and fourth positions in vulnerability. Protecting these regions is vital not only for their rich biodiversity and cultural heritage but also for the well-being of local ecosystems and communities. Implementing coastal protection measures is essential to safeguard these culturally significant areas supporting local livelihoods.

Akuku-toru features a substantial high vulnerability zone spanning about 32.97 square kilometers. Comprehensive erosion control measures are crucial, particularly considering the region's renowned cultural and natural heritage. Emuoha's vulnerability zone, covering approximately 24.78 square kilometers, ranks seventh in vulnerability. Protective measures are necessary here, especially considering its potential impact on agriculture and infrastructure.

Port Harcourt, encompassing approximately 23.56 square kilometers, ranks sixth in vulnerability. Erosion in this area could have severe economic and infrastructural consequences, given its status as a major commercial and industrial center. Asari-Toru, with an area coverage of approximately 22.41 square kilometers, stands as the ninth highest in vulnerability. Focused erosion management strategies are essential to safeguard its coastal assets, including riverine communities and areas of cultural significance.

Opobo/Nkoro features a high vulnerability zone spanning approximately 20.59 square kilometers, ranking eighth in vulnerability. Effective erosion control and mitigation strategies are required to protect this area and its associated ecosystems.

Understanding these vulnerability zones is crucial for environmental conservation, enabling the precise targeting of initiatives aimed at safeguarding ecologically delicate regions with abundant biodiversity. The delineation of high vulnerability zones, particularly within economically pivotal areas like Bonny and Degema, highlights the potential economic repercussions of coastal erosion.

The heightened vulnerability of Bonny is significant due to its role as an oil and gas hub, posing a tangible threat to infrastructure and potentially culminating in environmental calamities. Coastal erosion also threatens essential infrastructure elements such as roads, bridges, and ports, underscoring the importance of tackling erosion in areas like Port Harcourt for regional development.

Preserving culturally significant locales, exemplified by Okrika, Andoni, and Asari-Toru, is of utmost importance in safeguarding the cultural heritage cherished by local communities. Coastal erosion poses a menace capable of erasing historical sites and invaluable artifacts of cultural significance, (see figure 1).

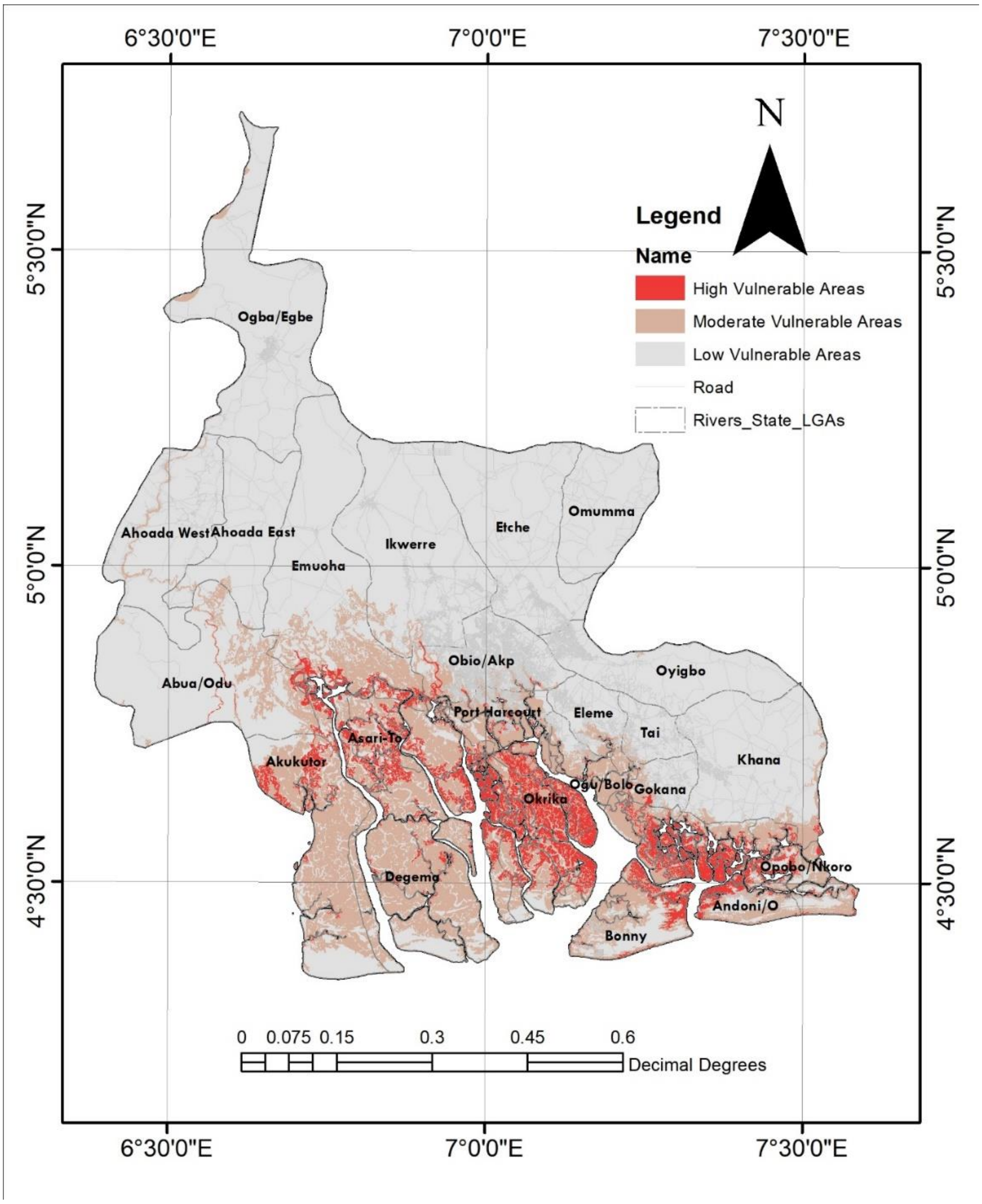

Figure 1: Coastal Erosion Vulnerability in Rivers State, Nigeria

3.1 Discussion of Results

The findings outlined in the study regarding coastal erosion vulnerability zones have significant implications for achieving sustainable development goals (SDGs), particularly those related to environmental conservation, economic prosperity, infrastructure development, and cultural preservation.

1. **Environmental Conservation (SDG 14 - Life Below Water, SDG 15 - Life on Land):** Identifying and understanding coastal erosion vulnerability zones are crucial steps in conserving marine and terrestrial ecosystems. High vulnerability zones often coincide with areas of rich biodiversity and unique ecosystems. Preserving these areas is essential for maintaining ecosystem services, biodiversity, and the overall health of marine and terrestrial environments.

2. **Economic Prosperity (SDG 8 - Decent Work and Economic Growth, SDG 9 - Industry, Innovation, and Infrastructure):** Coastal erosion poses significant economic risks, especially in economically pivotal areas like Bonny and Degema. The potential loss of infrastructure, industrial assets, and disruption of economic activities could hinder economic growth and development. Addressing erosion through effective planning and intervention strategies is essential for sustaining economic activities, protecting livelihoods, and promoting resilient infrastructure development.

3. **Infrastructure Development (SDG 9 - Industry, Innovation, and Infrastructure):** Coastal erosion threatens essential infrastructure elements such as roads, bridges, ports, and energy infrastructure. Tackling

erosion in vulnerable areas like Port Harcourt is critical for preserving transportation networks, ensuring access to markets, and supporting regional development. Integrating erosion control measures into infrastructure planning and development strategies is necessary for building resilient infrastructure that can withstand the impacts of coastal erosion.

4. **Cultural Preservation (SDG 11 - Sustainable Cities and Communities, SDG 12 - Responsible Consumption and Production):** Coastal erosion poses a threat to culturally significant locales, erasing historical sites and artifacts of cultural significance. Protecting these areas is crucial for preserving cultural heritage, maintaining community identities, and promoting sustainable tourism. Implementing erosion management strategies that consider cultural values and community participation is essential for safeguarding cultural assets and promoting sustainable development.

IV. Conclusion

The findings of this study underscore the critical importance of identifying and understanding coastal erosion vulnerability zones for sustainable development efforts. Through meticulous analysis, we have delineated three distinct zones of vulnerability – high, moderate, and low – revealing the extent of risk posed to coastal areas within the study region.

These findings carry significant implications across various dimensions of sustainable development. From environmental conservation and economic prosperity to infrastructure development and cultural preservation, addressing coastal erosion emerges as a multifaceted challenge requiring integrated and proactive solutions.

Furthermore, the study highlights the need for tailored intervention strategies that account for the unique characteristics and vulnerabilities of each zone. By prioritizing areas of high vulnerability, such as Bonny and Degema, and implementing targeted erosion control measures, we can mitigate the potential economic, environmental, and social impacts associated with coastal erosion.

Ultimately, our findings emphasize the imperative of proactive management and collaborative action to safeguard coastal communities, preserve natural habitats, and promote sustainable development in the face of coastal erosion challenges. Moving forward, continued research, stakeholder engagement, and policy support will be essential for translating these findings into effective strategies that contribute to the achievement of sustainable development goals and the resilience of coastal regions worldwide.

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