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RESEARCH ARTICLE OPEN ACCESS

Accelerated Erosion in the Niger Delta, Nigeria: A Review of Causes, Impacts, and Sustainable Management Strategies

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Abstract:

The Niger Delta, a region with diverse ecosystems, rich biodiversity, and cultural heritage, is facing significant challenges such as accelerated erosion and environmental degradation. This threatens ecosystems, communities, and sustainable development, leading to land loss, habitat degradation, infrastructure damage, and socio-economic impacts. This study aims to assess the impacts of accelerated erosion, identify drivers and factors contributing to erosion, and explore sustainable management strategies for erosion control and adaptation. The Niger Delta's geomorphology and hydrology are shaped by complex interactions between rivers, tides, sediment dynamics, and human activities. Natural processes, such as riverine erosion and coastal dynamics, and human-induced factors like oil and gas exploration, deforestation, urbanization, poor agricultural practices, uncontrolled dredging and coarse sand excavation contribute to the region's vulnerability to erosion. Addressing accelerated erosion require integrated watershed management (IWM) techniques to prevent erosion and adapt to natural resources. These require involving locals, governmental organizations, and research institutions in governance. Ecosystem-based approaches restore habitats, improve services, and encourage biodiversity conservation. IWM aids sustainable land use planning, water resource management, and community engagement. Erosion control structures and engineering solutions are essential for long-term sustainability and efficacy. Techniques like gabion baskets, retaining walls, revetments, terracing, slope stabilization, and breakwaters support coastal resilience and tourism by preserving beach profiles and stabilizing coasts.

Keywords — **Accelerated erosion, Impacts, Sustainable management, Mangrove restoration, Niger Delta**

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I. INTRODUCTION

A. Overview of the Niger Delta Region

The Niger Delta, which spans an area of around 70,000 square kilometers in southern Nigeria, is a large and environmentally varied region (Apere, 2022). The Niger River's deltaic region, which drains into the Atlantic Ocean's Gulf of Guinea, is what forms it. This region is well-known for its complex network of rivers, streams, mangrove swamps, and estuaries (Fig 1).

Okonkwo et al, (2015) reported that the Niger Delta is a low-lying coastal plain with numerous river channels and distributaries, characterized by flat terrain and a complex mosaic of ecosystems and landforms. Over millions of years, the Niger River has moved sedimentary deposits, creating a diverse ecosystem. The delta is home to a diverse range of plants and animals, relying on its vast mangrove forests for vital ecosystems (Aju and Aju, 2021; Ogbeibu and Oribhabor, 2023). Additionally, the area has significant fisheries, providing a nursery and breeding habitat for various fish species essential to local residents' livelihoods.

Nigeria's oil and gas industry is heavily dependent on the Niger Delta due to its huge onshore and offshore petroleum reserves (Ukhurebor et al. 2021; Onyena and Sam, 2020).

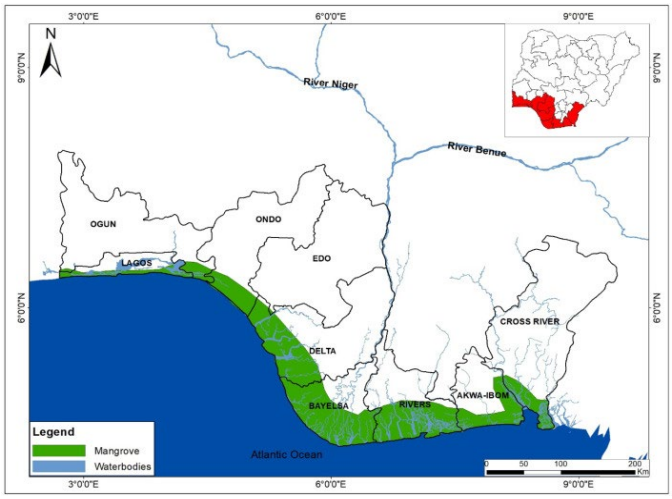

Fig 1. The Niger Delta Region, Nigeria (Source: Oweikeye, 2017)

The region's socioeconomic landscape has been profoundly impacted by oil exploration and production activities, which have not only drawn investment and infrastructure development but also exacerbated social tensions and degraded the environment (Nwozor, 2020)

The Niger Delta has a rich cultural diversity, with many different ethnic groups living there. Each group has its own language, traditions, and customs. Although oil-related activities have had an increasing impact on the socio-cultural dynamics of local populations, agriculture, fishing, and artisanal activities still constitute the region's traditional sources of income. The Niger Delta confronts numerous environmental difficulties, such as deforestation, soil erosion, pollution, and habitat destruction, despite its importance to the environment and the economy (Ukhurebor et al., 2021). The stability of the deltaic landscape is particularly threatened by accelerated erosion, which exacerbates sedimentation, coastal erosion, and land loss (Passalaequa et al., 2021)

Various development projects targeting environmental degradation, sustainable livelihoods, and inclusive growth have focused on the Niger Delta in recent decades. But making any progress in the area will need a comprehensive strategy that strikes a balance between social justice, environmental preservation, and economic growth.

B. Significance of Accelerated Erosion Study in the Region

Accelerated erosion in the Niger Delta region is causing significant ecological, economic, and human-related impacts (Ugwu et al., 2021; Ominikari and Nimiye, 2023). It leads to land degradation, reducing biodiversity, habitat destruction, and loss of ecosystem services. Mangrove forests, particularly susceptible to erosion, pose a threat to the stability of the deltaic landscape and are essential for fisheries, coastal protection, and carbon sequestration (Akram et al., 2023; Bhowmik et al., 2022).

Coastal erosion also results in the loss of infrastructure, populated areas, and valuable property along the delta's shoreline. Inland locations are exposed to storm surges, flooding, saltwater intrusion, and community displacement, weakening the delta's ability to withstand rising sea levels and climate change (Bhattachan et al., 2018)

Soil fertility and agricultural productivity are also being negatively affected by erosion. The Niger Delta's rich topsoil will be lost, reducing the area's ability to support agriculture and provide a living. As erosion worsens, smallholder farmers may see a decline in yields and revenue, threatening food security and poverty.

Water quality in the Niger Delta is also being negatively affected by accelerated erosion, affecting fish populations, aquatic plants, and wildlife (Numbere et al., 2023; Aa et al., 2022). This decline in water quality jeopardizes the health and productivity of fisheries, which are essential for the region's food security and way of life.

C. Objectives of the Study

The objectives of the study on accelerated erosion in the Niger Delta, Nigeria, are:

- Investigate the Causes and Mechanisms of Accelerated Erosion.
- Assess the Impacts of Accelerated Erosion on the Environment and Communities.
- Evaluate Existing Erosion Management Strategies and Policies.
- Propose Sustainable Mitigation and Adaptation Strategies.

II. Causes of Accelerated Erosion in the Niger Delta

A. Natural Factors

The Niger Delta's susceptibility to erosion is significantly shaped by natural processes like subsidence, sea level rise, and river dynamics (Dada et al., 2018; Fubara, 2022). It is crucial to understand how these natural elements interact in order to evaluate erosion risk and create practical mitigation plans.

Subsidence: The slow sinking or lowering of the ground surface in relation to sea level is referred to as subsidence. Subsidence is a naturally occurring geological phenomenon in the Niger Delta, fueled by tectonic activity, sediment compaction, and human-caused processes like petroleum exploitation (Daley and Daley, 2018)

Sediment compaction: Subsidence occurs in the deltaic zone as a result of the weight of deposited sediments and the consolidation of underlying layers (Changxing et al., 2007). Land sinking occurs gradually as a result of diagenesis and compaction of the accumulated sediment (Wang et al., 2021).

Tectonic activity: The region in which the Niger Delta is situated is tectonically active, with faulting, uplift, and subsidence linked to local geological processes (Okiwelu et al.,2012). In the deltaic environment, land deformation and localized subsidence can be caused by tectonic movements, such as faulting and subsurface faulting.

Sea Level Rise: Global climate change is causing sea levels to increase due to the melting of glaciers and polar ice caps, as well as the thermal expansion of seawater (Allison et al., 2021; Parker, 2014). Coastal regions that are low lying, like the Niger Delta, are more vulnerable to erosion and flooding due to rising sea levels. Residents of communities near the Atlantic Ocean and coastlines in the Niger Delta have called on the Nigerian Government and authorities to protect them from ocean surge and coastal erosion. Some of the affected areas include Forcados and Ogulagha in Delta State, Odioma, Twon-Brass and Sangana in Bayelsa State, Kula and Bonny in Rivers State. (https://punchng.com /bayelsa-coastal-communities-lament-ocean-encroachment-erosion/).

Coastal erosion: The erosive impact of waves and storm surges is amplified by rising sea levels, which speeds up coastal erosion and land loss along the delta's shoreline (Griggs and Reguero, 2021; Rezaie et al., 2019). As sea levels rise, vulnerable places like barrier islands, tidal flats, and mangrove forests are more vulnerable to erosion and flooding (Asari et al., 2021). Abija et al., (2020) reported that between 1991 and 2018, net shoreline retreat and erosion in Bayelsa, Rivers, and Akwa Ibom States were observed, with rates of 11.1 m/yr., 7.2 m/yr., and 5.5 m/yr., respectively, in the end point rate of shoreline migration and erosion.

Saltwater intrusion: The infiltration of salty water into freshwater aquifers and surface water bodies due to sea level rise can also have an impact on the ecosystem's well-being, agricultural productivity, and water quality in the deltaic region (Nwankwoala and Ngah, 2014).

River Dynamics: River dynamics in the Niger Delta have a major impact on erosion susceptibility (Abija et al., 2020). These factors include sediment transport, channel shape, and flow regimes.

Sediment transport: The Niger River and its tributaries transport vast quantities of sediment downstream, which contributes to the progradation and sedimentation of the deltaic landscape (Drake et al., 2022). Changes in sediment load, river discharge,

and channel morphology influence erosion and deposition rates in the deltaic environment.

Eli and Agusomu (2018) reported that unconsolidated sand soil as river bank material, excessive meandering nature of the river, high stream velocity, steep river bank were some the causes of streambank erosion.

B. Anthropogenic Factors

Natural processes in the Niger Delta are exacerbated by anthropogenic causes, which further heighten the region's susceptibility to environmental deterioration. These factors include:

Oil and Gas Exploration: Oil and gas exploration in the Niger Delta has led to landscape erosion, habitat degradation, and disruption of natural drainage patterns. As seen in Fig 1, oil spills contaminate soil, water bodies, and ecosystem health (Onyena and Sam, 2020; Aa et al., 2022; Numbere, 2021; Akinrinwoye, 2022)

Fig 1. An aerial view of the Niger Delta near Port Harcourt, Nigeria in 2018, with evidence of oil spills which has increase soil erodibility.(Credit: Ron Bousso/Reuters)

Deforestation: Deforestation, primarily due to logging, agricultural expansion, and urbanization, has significantly reduced forest cover in the Niger Delta, increasing soil instability and erosion susceptibility (Numbere, 2019). It also disrupts hydrological processes, altering rainfall infiltration, runoff patterns, and sediment transport dynamics, exacerbating erosion and sedimentation in downstream areas.

Urbanization: Urbanization in the Niger Delta has led to the conversion of natural habitats into built-up areas, causing soil sealing, surface runoff, and erosion (Bilgiç and Baba, 2023). The expansion of informal settlements, industrial zones, and infrastructure projects encroaches on wetlands, floodplains, and coastal areas, displacing vegetation and exacerbating erosion hazards (Taiwo, 2014).

Agricultural Practices: Agricultural activities, including mechanized farming, monoculture plantations, and shifting cultivation, contribute to soil erosion and land degradation in the Niger Delta (Lal and Okigbo, 1990). Weeding for agriculture exposes soils to erosion by wind and water, particularly on slopes and river banks.

Intensive cultivation practices, such as tillage and cultivation of tuber crops like cassava, yam potato etc on the banks of the rivers and flood prone plains (Fig 2). This will disturb the soil structure, reduce organic matter content, and increase soil vulnerability to erosion during heavy rainfall events.

Fig 2. Cultivation of yam and potato on streambank. Okolobiri, Bayelsa State

Uncontrolled dredging and coarse sand excavation:

Uncontrolled dredging, which is common in many shallow streams for the construction of roads and buildings, has severely disrupted and devastated the habitat of aquatic plants and animals in the Niger Delta. Some regions excavate coarse sands on the streambanks because they are used in place of coarse aggregates as seen in Okwagbe, Delta State and Mbiama, Rivers State. This stirs up sediments and suspended particles, which makes the water murky downstream and causes streambank erosion (Fig 3). There could be effects on aquatic life and a disturbance of the natural equilibrium of the ecosystems.

Fig 3. Uncontrolled dredging on shallow streams causing severe erosion along Igbogene-Gbrain road, Bayelsa State.

III. IMPACTS OF ACCELERATED EROSION IN THE NIGER DELTA

The Niger Delta has experienced significant land and coastal loss due to accelerated erosion, causing serious consequences for communities, ecosystems, and socioeconomic growth. The erosion of the delta's shoreline leads to the steady retreat of land and the loss of significant coastal habitats like beaches, dunes, and mangrove forests. This increases vulnerability to flooding, storm surges, and seawater intrusion, endangering human populations, livelihoods, and infrastructure along the shoreline.

A. Land Degradation

Wetland degradation is another major effect of erosion, as it can lead to habitat degradation and the loss of ecosystem services. This lowers carbon sequestration, decreases biodiversity, and weakens coastal ecosystems' ability to withstand climate change and sea level rise (He and Silliman, 2019). Agricultural land degradation in the deltaic region is also affected by erosion, resulting in soil deterioration, loss of arable land, and decreased agricultural output (Ukhurebor et al., 2021). This affects food security and rural livelihoods, particularly smallholder farmers who depend on agriculture for a living.

Soil fertility degradation is another major issue, presenting problems for food security, agricultural productivity, and sustainable land use. Factors contributing to this degradation include the loss of topsoil, nutrient depletion, soil compaction, erosion-induced soil compaction, salinization and acidification, decreased soil productivity, and agro-biodiversity (Karlen and Rice 2018).

Soil erosion and degradation reduce the diversity of plant species, crop types, and genetic resources that are suited to the specific environmental circumstances in a given area. This puts the security of food and nutrition in the area at risk, as it reduces resistance to diseases, insect pests, and climate change.

B. Contamination of Water Bodies and Groundwater

The Niger Delta's accelerated erosion poses significant threats to the environment and human health, leading to groundwater and water body contamination. Sediment transport, agricultural runoff, urban runoff, industrial pollution, oil spills, saltwater intrusion, and habitat degradation are all contributing factors to water pollution (Ogidi and Akpan, 2022). Sediment-laden runoff from eroding land surfaces into water bodies, such as rivers, streams, estuaries, and coastal zones, carries contaminants like pesticides, heavy metals, and organic compounds. Agricultural runoff introduces

nutrient-laden pollutants, such as phosphorus and nitrogen, which can lower water quality and damage aquatic ecosystems. Urban runoff, fueled by impervious surfaces like roads and buildings, carries pollutants like heavy metals, petroleum products, and litter into water bodies, contaminating surface water and degrading aquatic habitats. Industrial pollution, including oil and gas exploration, refining, and petrochemical production, releases pollutants into the environment through oil spills (Ogolo et al., 2022). Oil-contaminated silt from spill sites can be mobilized by erosion, dispersing pollutants over wide areas and harming aquatic ecosystems and drinking water supplies. Saltwater intrusion into surface water bodies and freshwater aquifers worsens the situation, making groundwater resources unfit for agricultural, irrigation, and drinking purposes, especially in coastal areas (Basack et al., 2022). Habitat degradation, caused by sediment deposition from erosion, decreases light penetration and suffocates benthic creatures, putting hazardous aquatic species at risk.

C. Increased Vulnerability to Flooding

The Niger Delta's accelerated erosion poses a significant threat to infrastructure, livelihoods, and human settlements due to various factors. Soil erosion, which occurs during severe rainfall, increases surface runoff, causing sand deposits in river channels, floodplains, and coastal regions. Sedimentation, which is transported by erosion, builds up in river channels, altering hydraulic conditions and increasing flood risk in riverine areas. Riverbank erosion increases flood susceptibility, causing instability in neighboring land and causing property damage, loss of land, and community relocation (Das et al., 2014). Coastal erosion, caused by wave action, storm surges, and sea level rise, increases the risk of flooding in coastal settlements, making inland areas more susceptible to flooding during storm events (Musa et al., 2014).

D. Displacement of Communities and Loss of Livelihoods

The Niger Delta is experiencing significant erosion, leading to the displacement of communities and loss of livelihoods. This is primarily due to the loss of usable land and infrastructure, particularly around the coastline and riverbanks. The gradual encroachment of water bodies into inhabited areas increases the likelihood of displacement. Infrastructure damage, such as houses, schools, hospitals, and other community facilities, renders affected areas hazardous or unsuitable for locals, exacerbates the loss of community assets and relocation. Islam, (2023) reported that coastal communities are forced to shift inland or migrate to urban centres due to erosion-induced land loss, increasing social tensions, disrupting customary livelihoods, and diminishing the resilience of communities, especially for vulnerable groups.

Eroding also affects agricultural land, reducing crop yields and food security, threatening rural lives. Displaced communities struggle to access arable land, water resources, and productive assets, as they rely heavily on agriculture for subsistence and income production.

Fishing communities are also affected by coastal erosion and habitat deterioration, reducing fish populations and causing food insecurity and financial hardship (Akankali and Jamabo, 2012).

Cultural heritage is also at risk, as displacement undermines cultural identity and community resilience, leading to the loss of ancestral lands, traditional knowledge, and cultural legacy. Indigenous groups struggle to protect their ancestral areas and cultural legacy due to their strong ties to land and natural. The loss of cultural heritage assets also poses a threat to the spiritual, aesthetic, and historical significance of the delta, affecting community cohesion and sense of place.

IV. SUSTAINABLE MANAGEMENT STRATEGIES FOR EROSION CONTROL AND ADAPTATION

A. Restoration of Mangroves and Wetlands

Restoring mangroves and wetlands in the Niger Delta is a sustainable management approach that offers numerous benefits for community well-being, coastal protection, and ecological resilience (Sam et al., 2023). These ecosystems are crucial for reducing erosion, protecting coastal people from dangers, and preserving biodiversity (Sutton-Greir and Sandifer, 2019). They help in erosion mitigation by stabilizing shorelines, absorbing wave energy, and retaining sediment. They also improve soil stability by binding soil particles, enhancing soil structure, and reducing surface runoff.

Mangroves and wetlands act as natural flood barriers, slowing down floodwaters and protecting settlements from storm surges and tidal inundation. Their lush vegetation absorbs rainfall, lowers surface runoff, and controls hydrological flows, reducing flood risks.

Restoration of mangroves and wetlands improves habitat quality, biodiversity, and ecosystem resilience (Zhang et al., 2022). They support fisheries, wildlife, and ecosystem services by restoring freshwater swamps, tidal marshes, and mangroves, which generate homes for various flora and fauna.

Restoring wetlands and mangroves is an efficient carbon sink, reducing the effects of climate change and fostering climate resilience in coastal ecosystems (Chow, 2018). Participatory approaches to mangrove and wetland restoration foster traditional knowledge, cultural values, and adaptive tactics, promoting sustainability and ownership.

B. Soil Conservation Practices

Effective soil conservation strategies for reducing Niger Delta erosion and adapting to it include contour bunding and agroforestry. These techniques increase soil fertility, lessen erosion, and strengthen tolerance to environmental stresses. By including crops, bushes, and trees, agroforestry reduces erosion and surface runoff, thereby stabilizing the soil. By introducing organic matter, cycling nutrients, and enabling nitrogen fixation by leguminous trees, it also improves soil fertility. In addition to reducing temperature extremes and increasing soil moisture retention, agroforestry also modifies microclimate conditions, enhancing the resilience of agricultural systems against climate change.

By reducing soil erosion, preserving soil structure, and promoting soil moisture retention, it also aids in soil conservation. By creating a terracing effect, contour bunds protect crop roots from soil erosion and waterlogging while also minimizing soil disturbance and maintaining soil fertility. All things considered, these methods will help the Niger Delta's long-term adaptation and management of erosion.

C. Integrated Watershed Management Approaches

In the Niger Delta, integrated watershed management (IWM) techniques provide a comprehensive approach to erosion prevention and adaptation (Adeshina et al., 2021). These techniques acknowledge the interdependence of land, water, and other natural resources in a watershed and aim to encourage coordinated actions that improve the resilience, health, and well-being of ecosystems and people.

Watershed planning and governance involve incorporating local people, governmental organizations, non-governmental organizations, and research institutions in governance structures and decision-making (Erdogan, 2013). Ecosystem-based approaches are used to restore natural habitats, improve ecosystem services, and encourage biodiversity conservation. This helps watersheds to stabilize soil, lower sedimentation, and protect watercourses from erosion.

Integrated watershed management also incorporates soil conservation practices, such as agroforestry, contour bunding, cover crops, and conservation tillage, to control and adapt to erosion. Sustainable land use planning, such as spatial planning, land use zoning, and land tenure reform, is aided by IWM (Tang and Adeshina, 2022).

Water resource management is the focus of IWM, preserving aquatic ecosystems, reducing pollution, and conserving water. Approaches like water harvesting, floodplain restoration, and wetland conservation improve water availability, replenish groundwater, and reduce erosion likelihood. Community engagement and capacity-building are also essential aspects of IWM (Obando et al., 2018). Participatory approaches foster social participation, gender parity, and indigenous knowledge, strengthening community resilience and fostering a sense of ownership over natural resource management projects.

D. Erosion Control Structures and Engineering Solutions

The Niger Delta requires sustainable erosion control and adaptation techniques, which include erosion control structures and engineering solutions. These measures should be combined with community involvement and natural-based strategies to ensure long-term sustainability and efficacy. Gabion baskets and retaining walls are commonly used erosion control structures to stabilize shorelines, riverbanks, and hillsides, preserving property and infrastructure from soil erosion. Riprap and revetments are large boulders placed along riverbanks, coastal regions, and embankments to reduce wave energy, stop erosion, and stabilize slopes. Terracing involves building steps or benches on sloping land to lower the gradient, prevent erosion, and preserve soil moisture. Slope stabilization techniques like vegetative cover, erosion control blankets, and geotextiles are used to stabilize slopes and encourage revegetation. Breakwaters and shoreline protection are offshore constructions erected parallel to the coast to lessen erosion, break up waves, and shield coastal infrastructure from storm surges and wave activity. These techniques support coastal resilience and tourism by preserving beach profiles, stopping erosion, and stabilizing coasts.

V. CONCLUSION

In conclusion, the wide-ranging environmental, socioeconomic, and cultural effects of accelerated erosion in the Niger Delta make it imperative to address it since they represent serious hazards to the region's ecosystems, communities, and sustainable development. Principles of environmental sustainability, social equality, and cultural heritage preservation must lead integrated approaches that emphasize ecosystem restoration, community resilience, and adaptive governance in order to effectively manage erosion.

REFERENCES

Aa, I., Op, A., Ujj, I., & Mt, B. (2022). A critical review of oil spills in the Niger Delta aquatic environment: causes, impacts, and bioremediation assessment. *Environmental Monitoring and Assessment*, *194*(11), 816.

Abija, F. A., Abam, T. K. S., Teme, S. C., & Eze, C. L. (2020). Relative sea level rise, coastline variability and coastal erosion in the Niger Delta, Nigeria: implications for climate change adaptation and coastal zone management. *Earth Science Climatic Change*, *11*, 9.

Adesina, J. A., Jiang, J., & Xiaolan, T. (2021). Integrated Watershed Management Framework and Groundwater Resources in Africa-A Review of West Africa Sub-region.

Aju, P. C., & Aju, J. A. (2021). Mangrove Forests in Nigeria: why their restoration, rehabilitation and conservation matters. *African Journal of Environmental and Natural Science Research*, *4*(1), 84-93.

Akankali, J. A., & Jamabo, N. A. (2012). Effects of flooding and erosion on fisheries resources in Niger Delta, Nigeria. *European Journal of Scientific Research*, *90*(1), 14-25.

Akinrinwoye, C. O. (2022). *Assessment of land cover, atmospheric data and human population changes: the case of River Niger Delta in Nigeria* (Doctoral dissertation, Southern University and Agricultural and Mechanical College).

Allison, I., Paul, F., Colgan, W., & King, M. (2021). Ice sheets, glaciers, and sea level. In *Snow and ice-related hazards, risks, and disasters* (pp. 707-740). Elsevier.

Apere, T. O. (2022) Emerging Opportunities in the Niger Delta Area. PHJHDS Vol 10No 4. pp25-43

Asari, N., Suratman, M. N., Mohd Ayob, N. A., & Abdul Hamid, N. H. (2021). Mangrove as a natural barrier to environmental risks and coastal protection. *Mangroves: Ecology, Biodiversity and Management*, 305-322.

Basack, S., Loganathan, M. K., Goswami, G., & Khabbaz, H. (2022). Saltwater intrusion into coastal aquifers and associated risk management: Critical review and research directives. *Journal of Coastal Research*, *38*(3), 654-672.

Bhattachan, A., Jurjonas, M. D., Moody, A. C., Morris, P. R., Sanchez, G. M., Smart, L. S. & Seekamp, E. L. (2018). Sea level rise impacts on rural coastal social-ecological systems and the implications for decision making. *Environmental science & policy*, *90*, 122-134.

Bhowmik, A. K., Padmanaban, R., Cabral, P., & Romeiras, M. M. (2022). Global mangrove deforestation and its interacting social-ecological drivers: A systematic review and synthesis. *Sustainability*, *14*(8), 4433.

Bilgiç, E., & Baba, A. (2023). Effect of Urbanization on Water Resources: Challenges and Prospects. *Groundwater in Arid and Semi-Arid Areas: Monitoring, Assessment, Modelling, and Management*, 81-108.

Changxing, S., Dian, Z., Lianyuan, Y., Bingyuan, L., Zulu, Z., & Ouyang, Z. (2007). Land subsidence as a result of sediment consolidation in the Yellow River Delta. *Journal of Coastal Research*, *23*(1), 173-181.

Chow, J. (2018). Mangrove management for climate change adaptation and sustainable development in coastal zones. *Journal of Sustainable Forestry*, *37*(2), 139-156.

Dada, O. A., Li, G., Qiao, L., Asiwaju-Bello, Y. A., & Anifowose, A. Y. B. (2018). Recent Niger Delta shoreline response to Niger River hydrology: Conflict between forces of Nature and Humans. *Journal of African Earth Sciences*, *139*, 222-231.

Daley, T., & Daley, T. (2018). The Price of Oil. *A Play for Oil: The Stories Behind the Discovery and Development of Oil and Gas*, 193-220.

Das, T. K., Haldar, S. K., Gupta, I. D., & Sen, S. (2014). River bank erosion induced human displacement and its consequences. *Living Reviews in Landscape Research*, *8*(3), 1-35.

Drake, N. A., Candy, I., Breeze, P., Armitage, S. J., Gasmi, N., Schwenninger, J. L., ... & Manning, K. (2022). Sedimentary and geomorphic evidence of Saharan megalakes: A synthesis. *Quaternary Science Reviews*, *276*, 107318.

Eli, H. D and Agusomu, T. D (2018) Causes of Nun River bank erosion at Okoloba in Kolokuma Local Government Area, Bayelsa State, Nigeria, Journal of Environment and Earth Science. Vol 8. No 5. 17-22

Erdogan, R. (2013). Stakeholder involvement in sustainable watershed management. In *Advances in landscape architecture*. IntechOpen.

Fubara, D. M. J. (2022). Analysis of Hydrological Characteristics: A Case Review of the Niger Delta. *Journal of Water Resource and Protection*, *14*(9), 611-631.

Griggs, G., & Reguero, B. G. (2021). Coastal adaptation to climate change and sea-level rise. *Water*, *13*(16), 2151.

He, Q., & Silliman, B. R. (2019). Climate change, human impacts, and coastal ecosystems in the Anthropocene. *Current Biology*, *29*(19), R1021-R1035.

https://punchng.com/bayelsa-coastal-communities-lament-ocean-encroachment-erosion/Assessed 2/4/2024

Islam, M. R. (2023). *Climate Change, Migration and Conflict in Bangladesh*. Taylor & Francis.

Isyaku, U. (2021). What motivates communities to participate in forest conservation? A study of REDD+ pilot sites in Cross River, Nigeria. *Forest Policy and Economics*, *133*, 102598.

Karlen, D. L., & Rice, C. W. (Eds.). (2018). *Enhancing soil health to mitigate soil degradation*. MDPI.

Lal, R., & Okigbo, B. (1990). *Assessment of soil degradation in the Southern states of Nigeria*. Washington DC: World Bank.

Lane, P. N., & Sheridan, G. J. (2002). Impact of an unsealed forest road stream crossing: water quality and sediment sources. *Hydrological processes*, *16*(13), 2599-2612.

Musa, Z. N., Popescu, I., & Mynett, A. (2014). The Niger Delta's vulnerability to river floods due to sea level rise. *Natural Hazards and Earth System Sciences*, *14*(12), 3317-3329.

Numbere, A. O. (2019). Mangrove habitat loss and the need for the establishment of conservation and protected areas in the Niger Delta, Nigeria. *Habitats of the World-Biodiversity and Threats*, *13*.

Numbere, A. O. (2021). Managing Natural Resources Through Ecological Intensification in Oil-Rich Niger Delta. *Sustainable Intensification for Agroecosystem Services and Management*, 615-655.

Numbere, A. O., Gbarakoro, T. N., & Babatunde, B. B. (2023). Environmental degradation in the Niger Delta ecosystem: the role of anthropogenic pollution. In *Sustainable utilization and conservation of Africa's biological resources and environment* (pp. 411-439). Singapore: Springer Nature Singapore.

Nwankwoala, H. O., & Ngah, S. A. (2014). Groundwater resources of the Niger Delta: Quality implications and management considerations. *International Journal of water resources and environmental engineering*, *6*(5), 155-163.

Nwozor, A. (2020). Depoliticizing environmental degradation: revisiting the UNEP environmental assessment of Ogoniland in Nigeria's Niger Delta region. *GeoJournal*, *85*(3), 883-900.

Obando, J. A., Luwesi, C. N., Förch, N., Opiyo, A. O., Shisanya, C., & Förch, G. (2018). Kenya success story in water resources management: participatory capacity building in integrated watershed management. In *Hydrology and Best Practices for Managing Water Resources in Arid and Semi-Arid Lands* (pp. 185-208). IGI global.

Ogbeibu, A. E., & Oribhabor, B. J. (2023). The Niger Delta Mangrove Ecosystem and Its Conservation Challenges. In *Mangrove Biology, Ecosystem, and Conservation*. IntechOpen. DOI: 10.5772/intechopen.112543

Ogidi, O. I., & Akpan, U. M. (2022). Aquatic biodiversity loss: impacts of pollution and anthropogenic activities and strategies for conservation. In *Biodiversity in Africa: potentials, threats and conservation* (pp. 421-448). Singapore: Springer Nature Singapore.

Ogolo, N. A., Anih, O. C., & Onyekonwu, M. O. (2022). Sources and effects of environmental pollution from oil and gas industrial operations. *Arabian Journal of Chemical and Environmental Research*, *9*(01), 98-121.

Okiwelu, A. A., Obianwu, V. I., Eze, O., & Ude, I. A. (2012). Magnetic anomaly patterns, fault block tectonism and hydrocarbon related structural features in the Niger Delta basin. *Journal of applied geology and geophysics*, *2*(1), 31-46.

Okonkwo, C. N. P., Kumar, L., & Taylor, S. (2015). The Niger Delta wetland ecosystem: What threatens it and why should we protect it? *African Journal of Environmental Science and Technology*, *9*(5), 451-463.

Ominikari, A. G., & Nimiye, C. M. (2023). Assessment of rural farmers'perceived effect of soil erosion on farming activities in Ikeduru Local Government Area of Imo State, Nigeria. *FUDMA JOURNAL OF SCIENCES*, *7*(2), 114-117.

Onyena, A. P., & Sam, K. (2020). A review of the threat of oil exploitation to mangrove ecosystem: Insights from Niger Delta, Nigeria. *Global ecology and conservation*, *22*, e00961.

Oweikeye, P. E. (2017). GIS-based mapping and analysis of oil-pollution in Niger-Delta coastal environment. *Unpublished master's thesis, University of Aberdeen, Scotland*.

Parker, A. (2014). Present contributions to sea level rise by thermal expansion and ice melting and implication on coastal management. *Ocean & coastal management*, *98*, 202-211.

Passalacqua, P., Giosan, L., Goodbred, S., & Overeem, I. (2021). Stable≠ sustainable: Delta dynamics versus the human need for stability. *Earth's Future*, *9*(7), e2021EF002121.

Rezaie, A. M., Ferreira, C. M., & Rahman, M. R. (2019). Storm surge and sea level rise: Threat to the coastal areas of Bangladesh. In *Extreme Hydroclimatic Events and Multivariate Hazards in a Changing Environment* (pp. 317-342). Elsevier.

Sahavacharin, A., Sompongchaiyakul, P., & Thaitakoo, D. (2022). The effects of land-based change on coastal ecosystems. *Landscape and Ecological Engineering*, *18*(3), 351-366.

Sam, K., Zabbey, N., Gbaa, N. D., Ezurike, J. C., & Okoro, C. M. (2023). Towards a framework for mangrove restoration and conservation in Nigeria. *Regional Studies in Marine Science*, 103154.

Sutton-Grier, A. E., & Sandifer, P. A. (2019). Conservation of wetlands and other coastal ecosystems: a commentary on their value to protect biodiversity, reduce disaster impacts, and promote human health and well-being. *Wetlands*, *39*(6), 1295-1302.

Taiwo, O. J. (2014). Are wetland threats synonymous with environmental problems? analysis of threats to coastal and inland wetlands environment in Nigeria.

Tang, X., & Adesina, J. A. (2022). Integrated watershed management framework and groundwater resources in Africa—a review of west Africa sub-region. *Water*, *14*(3), 288.

Ugwu, C. F., Ogba, K. T., & Ugwu, C. S. (2021). Ecological and economic costs of oil spills in Niger delta, Nigeria. In *Economic Effects of Natural Disasters* (pp. 439-455). Academic Press.

Ukhurebor, K. E., Athar, H., Adetunji, C. O., Aigbe, U. O., Onyancha, R. B., & Abifarin, O. (2021). Environmental implications of petroleum spillages in the Niger Delta region of Nigeria: a review. *Journal of Environmental Management*, *293*, 112872.

Wang, J., Fu, Y., Yan, Z., Fu, J., Xie, J., Li, K., & Zhao, Y. (2021). Influence of sedimentation and diagenesis on reservoir physical properties: a case study of the Funing Formation, Subei Basin, eastern China. *Frontiers of Earth Science*, 1-17.

Zhang, Y., Zhang, L., Kang, Y., Li, Y., Chen, Z., Li, R., ... & Wang, M. (2022). Biotic homogenization increases with human intervention: implications for mangrove wetland restoration. *Ecography*, *2022*(4).

