**Original Research Article**

**Rate of Sea Level Rise in Selected Coastal Community in The Niger Delta Region of Nigeria**

**ABSTRACT**

This study assessed the rate of shoreline change and sea level rise along the coast of the Opobo Kingdom in Nigeria's Niger Delta, one of the most vulnerable coastal regions in West Africa. Due to its low-lying terrain and vulnerability to tidal forces, the area was increasingly threatened by erosion and land loss brought on by climate change.

The Digital Shoreline Analysis System (DSAS) was used in the study to measure shoreline dynamics using multi-temporal Landsat satellite imagery from 1984, 2000, 2012, and 2020. It evaluated both short- and long-term coastal changes by computing change statistics like End Point Rate (EPR) and Linear Regression Rate (LRR). For a more thorough spatial analysis, the study area was separated into three zones (A, B, and C). The findings demonstrated a dominant trend of erosion along the shore. At an average LRR of -5.89 ± 3.00 m/year, Zone B was found to be the most dynamic section, whereas Zone A displayed the lowest erosion at -2.23 ± 0.75 m/year. Over the course of the 36-year study period, the average LRR for the entire area was -3.94 ± 1.28 m/year, which suggests a steady rate of coastal retreat. These patterns were influenced by a number of factors, including underlying geology, tidal and wave energy, embankment conditions, and human activities like boat wave impacts and sand mining. Conversely, places with natural backstops and vegetation demonstrated greater resistance to shoreline retreat.

The study emphasized the necessity of combining local knowledge with geospatial tools in adaptation planning and supplied crucial data for Niger Delta coastal zone management. Its results provided a transferable methodology for monitoring and mitigating shoreline change in other vulnerable deltaic environments around the world, and they also supported the design of site-specific interventions.

**Keywords:** Sea level rise, shoreline change, coastal erosion, Niger Delta, Digital Shoreline Analysis System (DSAS), Landsat imagery, coastal vulnerability, adaptation strategies.

# **INTRODUCTION**

One of the world's most ecologically and economically significant deltas is the Niger Delta, which is located along southern Nigeria's Atlantic coast. It was created at the point where the River Niger empties into the Gulf of Guinea, and it covers an area of more than 20,000 square kilometers. With over 2,370 km² of rivers, creeks, and estuaries and roughly 8,600 km² of stagnant swamps, this area is home to a dense network of rivers, estuaries, mangrove forests, and swamplands (Awosika, 2015; CLO, 2018). It is the largest mangrove ecosystem in Africa, with the mangrove forests alone covering about 1,900 km². Millions of people depend on these coastal ecosystems for their farming, fishing, and oil-related livelihoods in addition to their rich biodiversity. The Niger Delta, which is a region of humid tropical rainforest, is extremely susceptible to environmental stresses, particularly those brought on by climate change. The area is one of the most vulnerable in Sub-Saharan Africa to the effects of sea level rise (SLR) and coastal erosion because of its low elevation and long coastline. Tidal, wave, and sediment transport processes affect coastal zones, such as the Niger Delta, which are generally characterized as transitional areas between marine and terrestrial environments. Global climate change and unsustainable development practices have made these dynamic landscapes more susceptible to human and natural influences. According to recent studies, sea levels along Nigeria's coast are rising at an alarming rate. Local estimates range from 3.1 to 4.5 mm/year, which is higher than the global average of 1.7 to 3.2 mm/year over the past century (Anderson, 2017; World Bank, 2021). Annual shoreline retreats of up to 5.8 meters have been documented in some Niger Delta regions by satellite-based observations and tide gauge data; this has resulted in sediment loss and harm to livelihoods and infrastructure (Abija, 2019; Clay & King, 2019). The region's socio-ecological fabric is directly at risk due to the increased frequency and severity of coastal flooding, saltwater intrusion, and beach and wetland erosion brought on by the rising sea level (Akande et al., 2017).

The Niger Delta's coastal erosion is caused by both natural and man-made factors. The area is naturally unstable due to its soft, unconsolidated sedimentary deposits, tidal flows, and wave energy (Bell, 2014). Numerous factors, such as sediment supply, subsidence, tectonic activity, and storm surge dynamics, affect coastlines that are prone to erosion (Anderson, 2017; Kreibich et al., 2011). Sand mining, dredging, canalization, and embankment construction are examples of anthropogenic activities that have exacerbated erosion rates, resulting in substantial land loss and community displacement. Understanding the equilibrium between sediment supply and wave-induced erosion requires an understanding of progradation, which is the outward construction of a shoreline caused by sediment deposition. But in the Niger Delta, upstream damming and deforestation have seriously hampered natural progradation, decreasing sediment inflow and raising the coastline's net erosional footprint. Recent studies have used multi-temporal Landsat imagery and the Digital Shoreline Analysis System (DSAS) to document retreat rates in a number of deltaic islands. These rates range from 1.8 m/year to as high as 6.2 m/year between 1984 and 2020 (Pugh & Woodworth, 2014).

In this study, DSAS metrics, including End Point Rate (EPR) and Linear Regression Rate (LRR), were applied over several time periods (1984, 2000, 2012, and 2020) to evaluate the rate and spatial extent of shoreline changes. More dynamic zones, like Zone B, had higher rates up to -5.89 ± 3.0 m/year, while the overall average LRR along the Opobo Kingdom coast showed an erosional trend of -3.94 ± 1.28 m/year. This emphasizes how highly variable and complex coastal dynamics are, impacted by both external hydrodynamic forces and local geomorphology (Wang et al., 2018). The study area's high level of exposure to wave and tidal energy is one noteworthy aspect. Because they transfer energy over great distances and alter shoreline processes in shallow coastal waters, tides play a major role in sea level variability (Anderson, 2017). Longshore currents and sediment transport are influenced by bathymetry, shoreline orientation, and vertical ground movements, which govern coastal circulation patterns. The beach profile is shaped and the rates of erosion or accretion are determined by wave energy flux, which is primarily driven by wind-wave interactions and ocean swell (Berry et al., 2017; Hanson et al., 2013). This study used beach profile measurements using Real Time Kinematic (RTK) GPS surveying equipment in addition to satellite-based shoreline monitoring. By using RTK to gather high-resolution elevation data along several beach transects, it was possible to precisely quantify changes in sediment volume, beach slope, and crest elevation. These measurements were made along roughly 6 kilometers of Opobo Kingdom's active coastline, focusing on both developed and natural areas. Elevation profiles were examined to verify shoreline retreat rates obtained from remote sensing and to evaluate seasonal and interannual variability.

In order to comprehend how tidal forcing, wave setup, and storm surge dynamics affect local SLR scenarios, hydrodynamic modeling was incorporated into the study. Projected storm surge frequencies under RCP 4.5 and 8.5 scenarios, historical tide gauge records, and bathymetric inputs were all included in the model. The model's primary outputs were flood frequency, depth, and extent, which were superimposed on land use maps to calculate the exposure and vulnerability of residential areas and vital infrastructure. A framework for scenario-based adaptation planning at the local and municipal levels was made available by this modeling technique. It is still difficult to find enough long-term tidal gauge stations along Nigeria's coastline. Two accessible ocean monitoring stations in Bonny and Forcados provided the tide gauge data used in this investigation. To guarantee consistency, data were standardized and calibrated against satellite altimetry records. These datasets allowed for reconstruction of tidal anomalies, seasonal patterns, and non-tidal residuals, which are important for distinguishing between short-term fluctuations and long-term sea level trends (Anderson, 2017).

Unchecked coastal degradation and sea level rise have serious repercussions. The lack of protective infrastructure and adaptive capacity puts low-income households, who frequently live in informal settlements close to the water's edge, at disproportionate risk (Clay & King, 2019; Daramola et al., 2016). In addition to saline intrusion into freshwater sources, the destruction of homes, schools, and marketplaces puts local economies, food security, and public health at risk. Additionally, displacement brought on by SLR is becoming a new source of internal migration, which puts pressure on the population in safer inland regions (Li et al., 2018; Abija, 2019). This study aims to improve the scientific understanding of coastal vulnerability in the Niger Delta by combining field-based assessments, hydrodynamic modeling, and geospatial analysis in light of these difficulties. The results are meant to influence national coastal zone management frameworks as well as community-based adaptation planning, among other areas of policy and practice. The research advances the larger objective of enhancing coastal resilience in Nigeria's most vulnerable deltaic environments by pinpointing erosion hotspots, projecting future risk trajectories, and assessing the effectiveness of existing mitigation techniques (UN-HABITAT, 2016; World Bank, 2021). Even though earlier research has shed light on adaptation tactics and community resilience, there is still a lack of high-resolution, localized data to quantify the extent and causes of coastal change over extended periods of time (Mishra, 2017). In order to fill that gap, this study offers scenario-based flood modeling, empirical analysis of adaptation responses, and spatially disaggregated erosion estimates. The research also recognizes the value of participatory mapping and indigenous knowledge systems as instruments for putting scientific findings into context and improving community involvement in climate risk governance (Wang et al., 2018; Kreibich et al., 2011).

1. **MATERIALS AND METHOD**

In order to evaluate sea level rise (SLR) and coastal erosion in the Opobo/Nkoro Local Government Area (LGA), Niger Delta, Nigeria, this study used a mixed-methods approach that combined geospatial analysis, field observation, and socioeconomic surveys. While the qualitative components involved comprehending community-level adaptation strategies through focus groups and household questionnaires, the quantitative components concentrated on shoreline change detection using geospatial techniques. A thorough evaluation of the region's biophysical and human vulnerabilities was made possible by the combination of physical measurements and socioeconomic data.

**2.1 Study Area and Coordinates**

Within Opobo/Nkoro LGA in Rivers State, Opobo Kingdom is situated between latitudes 4°28'00" and 4°34'30" N and longitudes 7°29'00" and 7°37'30" E. Estuaries, riverine networks, and a concentration of mangrove and swamp forest vegetation define this coastal area that is bounded by the Atlantic Ocean. The region is susceptible to changes in sea level and shoreline retreat because of its humid tropical climate, which also features high annual rainfall and tidal inundations. Sand mining, fishing, human settlements, and growing infrastructure development have all increased the risk of erosion and submersion.**2.2 Data Sources and Collection**

***2.2.1 Remote Sensing and GIS Data***

The United States Geological Survey (USGS) Earth Explorer platform provided the satellite imagery for the four time periods of 1984, 2000, 2012, and 2020. In order to examine past changes in the coastline, the datasets included cloud-free Landsat TM, ETM+, and OLI imagery. To guarantee accuracy in shoreline delineation, image preprocessing included geometric correction, atmospheric correction, and image enhancement.

In order to facilitate hydrodynamic assessment and vulnerability mapping, topographic maps, digital elevation models (DEMs), and bathymetric data were also gathered from national mapping agencies and incorporated into the spatial database. QGIS 3.26 and ArcGIS 10.8 were used for all spatial analysis.***2.2.2 Shoreline Extraction and Change Analysis***

The wet/dry sand interface, as described in the shoreline mapping literature, served as a consistent proxy for the manual digitization of shoreline vectors for the four time points. The Digital Shoreline Analysis System (DSAS) version 5.1, a USGS ArcGIS extension, was used to process these digital shorelines.

1. Two main rates were determined by the analysis:**End Point Rate (EPR)**: Measuring the distance between the oldest and most recent shorelines divided by the elapsed time.
2. **Linear Regression Rate (LRR)**: Estimating long-term shoreline change trends using a best-fit line through multiple shoreline positions.

In order to generate rate-of-change statistics across more than 1,200 points, transects were cast at 50-meter intervals perpendicular to the general shoreline orientation.

**2.3 Coastal Vulnerability Assessment**

To assess coastal susceptibility, the shoreline change data were reclassified into four susceptibility zones:

1. Class 1 (Low): Accretion > 2 m/year
2. Class 2 (Moderate): Accretion < 2 m/year
3. Class 3 (High): Erosion < 2 m/year
4. Class 4 (Very High): Erosion > 2 m/year

The modified framework of Tejedor et al. (2018) served as the basis for this classification, which made it possible to visualize vulnerability patterns spatially along the coast. Coastal Vulnerability Index (CVI) layers were derived using elevation and slope data from DEMs.

**2.3 Field Measurements and Instrumentation**

Detailed elevation profiles were recorded along a few chosen transects using Real-Time Kinematic (RTK) GPS surveys. The area where important infrastructure and community settlements are concentrated, or about 3.8 kilometers of coastline, was covered by these surveys.

RTK data allowed for centimeter-level accuracy in the vertical and horizontal positioning of beach profile points. Elevation data under different SLR scenarios were used to analyze beach slope, sediment transport potential, and inundation risk.Two ocean monitoring stations in the Niger Delta provided the tidal data used to improve hydrodynamic understanding. Sea surface height, wave height, and wind conditions were measured hourly by the tide gauges between 2010 and 2020. With the aid of these data, tidal forcing was modeled and the local Mean Sea Level (MSL), which served as a benchmark for shoreline retreat analysis, was established.

**2.4 Socio-Economic and Perception Data**

In Opobo/Nkoro LGA, 150 households in high-, medium-, and low-density settlements were given structured household surveys. The sample was selected through stratified random sampling to ensure representative coverage. The questionnaire focused on:

1. Perceptions of coastal changes and climate variability
2. Household adaptation practices
3. Demographics (age, gender, income, education)
4. Access to infrastructure and environmental information

Traditional leaders, government representatives, and environmental non-governmental organizations were also interviewed through Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs). The historical shoreline changes and adaptation barriers that satellite data could not capture were contextualized by these qualitative inputs.

**2.5 Hydrodynamic and Modeling Framework**

Despite not using sophisticated numerical models, the study used DEM overlays to model basic inundation scenarios with projected SLR scenarios of +0.5 m and +1.0 m by 2100 based on regional climate model outputs and IPCC RCP 8.5. Critical exposure zones under future sea level scenarios could be identified thanks to these models.

By comparing shoreline retreat data with seasonal wave height and wind direction data gathered from NOAA archives and local observations, the impact of wave energy was evaluated. This made it possible to infer the dynamics of beach morphology and the intensity of longshore transport. It is advised that future research employ additional modeling techniques, such as hydrodynamic modeling using Delft3D or SWAN, which can more accurately model sediment transport, storm surge propagation, and inundation dynamics.

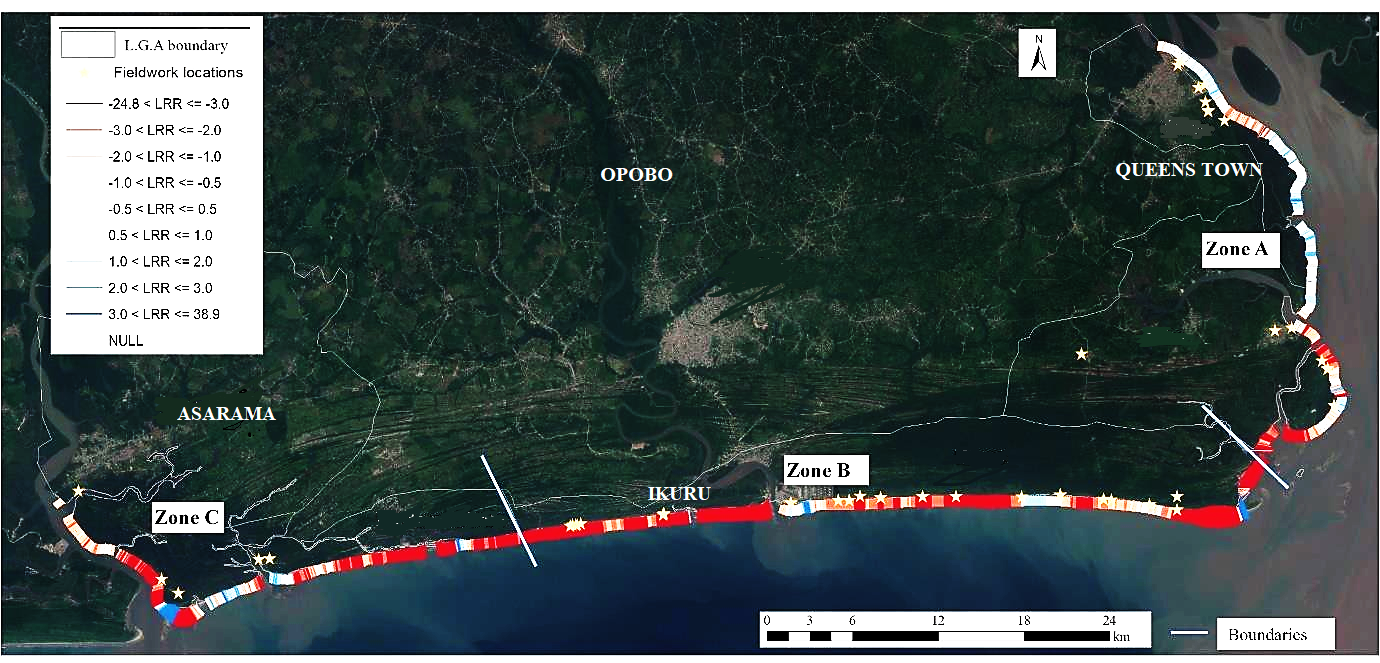
* 1. **Data Analysis**

To determine trends and variability, quantitative data from the shoreline analysis were statistically examined. To find significant variations in adaptive capacity among settlements, socioeconomic variables were subjected to descriptive statistics and inferential tests like ANOVA. For ease of query and visualization, all data were kept in relational databases. To bolster the conclusions and arguments made in the results section, graphs, maps, and tables were created

1. **RESULT AND DISCUSSION**

**3.1 Rate of change along the Opobo axis of the Strand Coast from 1984 - 2020**

Even though the long-term shoreline change analysis's findings show that much of the coast has experienced significant erosion, the conversation would be lacking if it did not also identify areas that are exposed and those that have obvious mitigation or adaptation measures in place. The Zone B stretch, which is the most dynamic of the three zones (A, B, and C) and has the highest average erosion rates, is also the most exposed because it lacks engineered protective features like seawalls, groynes, or embankments. This area is mostly made up of mangrove zones and low-lying settlements, where wave energy accelerates shoreline retreat by acting directly on loose soil.



**Figure 1. Long-term (1984-2020) coastal change analysis (LRR) along the studied coast overlain on a Sentinel 2A image of the study area.**

Zone A, on the other hand, has small areas with community-driven adaptation measures like wooden revetments, sandbag barriers, and planted mangrove buffer strips, even though it is undergoing moderate erosion. Even though they are unofficial, these nature-based solutions show how indigenous knowledge can help protect shorelines and could account for some transects in that area having comparatively lower rates of erosion.

Zone C includes portions of the coast with government-initiated interventions, like concrete embankments and elevated walkways along the waterfront settlements, even though it is also undergoing erosion. Some transects show a discernible slowdown in shoreline retreat between 2015 and 2020, which is consistent with the implementation of these structural measures between 2012 and 2015. This suggests that the interventions have temporarily buffered against wave-induced erosion. However, a number of areas close to these protected areas are still at risk because of poor maintenance and sparse coverage.

## Over 75% of the coastline is still exposed overall, especially in areas lacking natural buffers or adaptive infrastructure. This necessitates a focused approach to shoreline management, giving high-erosion transects in Zones B and portions of C priority, where immediate action is required to save ecosystems, infrastructure, and livelihoods.

## 3.2 Comparative analysis of the long-term shoreline changes along the different zones in the study area due to sea level rise

Long-term shoreline changes between three zones of the study area were compared using the LRR results obtained from the manually derived shoreline. This made it possible to evaluate the trend analysis relationship as well as the spatial variation in patterns and rates of change between zones. The findings of the comparative analysis are compiled in Table 1.

**Table 1. Summary of the LLR results across the study area**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Section of zone | Maximum Erosion  (m/yr) | Maximum Accretion  (m/yr) | Average LRR  (m/yr) | Uncertainty of average rate  (m/yr) |
| Entire shoreline | -24.8 | 38.82 | -2.7 | +0. I8 |
| Zone A | -24.8 | 3.09 | -0.54 | +0.13 |
| Zone B | -24.7 | 38.82 | -4.46 | +0.34 |
| Zone C | -14.86 | 14.85 | -2.44 | +0.99 |

In zone A, shoreline changes were analyzed using 88 transects, of which 48.48% (42 transects) showed accretion and 51.52% (46 transects) showed erosion. While 14.97% of the erosional transects displayed significant accretion, only 33.12% displayed significant erosion. Any transects with a magnitude larger than the uncertainty (plus/minus the confidence interval value) are considered to have significant erosion or accretion in the DSAS. From 1984 to 2020, the maximum landward movement (erosion) observed in the zone was -24.8m/yr with an average of - 1.91+0.13m/yr, while the maximum seaward movement (accretion) was 3.09m/yr with an average of 0.91+0.13m/yr. The region is eroding, albeit slowly, according to the overall average LRR of -0.54+0.13m/yr. In zone B, shoreline changes were analyzed using 79 transects in total; 91.1% (63 transects) showed erosion, and 8.9% (16 transects) showed accretion. 4.91% of the erosional transects showed significant accretion, and 77.02% showed significant erosion. The zone's maximum seaward movement (accretion) was 38.82 m/yr with an average of 3.44 + 0.34 m/yr, while the maximum landward movement (erosion) was -24.7 m/yr with an average of -4.46 + 0.34 m/yr between 1984 and 2020. The land is eroding, as indicated by the overall average LRR of -4.46+0.34m/yr. A total of 724 transects were drawn for zone C, spaced 50 meters apart, from the offshore to the land. The results showed that 61.45% of the transects with significant erosion were among the 80.66% (584 transects) of the transect area that is erosional. The shoreline is moving landward at a rate of at least 3 meters per year, as indicated by the zone's maximum erosion rate of -14.86 meters per year and average erosion rate of -3.82+0.99 meters per year. With only 140 transects (19.34%) showing rates of accretion, the maximum accretion rate in the region is 14.85 m/yr, whereas the average rate is 3.28+0.99 m/yr. The land is primarily erosive, as indicated by the overall average LRR of -2.44+0.99m/yr. In general, zone B has the highest average erosion and accretion rates, while zone A has the lowest, according to the bar plots in Figure 2 and the average erosion and accretion rates calculated from the extracted shorelines of the entire coast (table 2) from 1984 to 2020.

**Table 2. Results showing long-term changes (1984-2020) along the Opobo coast**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Strand Coast of Opobo State** | **LONG-TERM CHANGES (1984-2020)** | | | | | | | | | | | |
| **Linear regression rate (LRR) Results** | | | | | | | | | | | |
| **Max. Erosion rate (m/yr)** | **Average erosion (m/yr)** | **No. of erosional transects** | **% Of erosional transects** | **% Of statistically significant erosion** | **Max. Accretion rate (m/yr)** | **Average Accretion (m/yr)** | **No. of accretional transects** | **% Of accretional transects** | **% Of statistically significant accretion** | **Overall average LRR (m/yr)** | **Uncertainty of average rate (m/yr)** |
| Entire coast | -24.8 | -4.13 | 1973 | 76.15 | 59.32 | 38.82 | 1.84 | 618 | 23.85 | 8.49 | -2.7 | +/- 0.18 |
| Zone A | -24.8 | -1.91 | 406 | 51.52 | 33.12 | 3.09 | 0.91 | 382 | 48.48 | 14.97 | -0.54 | `+/- 0.13 |
| Zone B | -24.7 | -5.23 | 983 | 91.1 | 77.02 | 38.82 | 3.44 | 96 | 8.9 | 4.91 | -4.46 | +/- 0.34 |
| Zone C | - 14.86 | -3.82 | 584 | 80.66 | 61.45 | 14.85 | 3.28 | 140 | 19.34 | 6.77 | -2.44 | +/- 0.99 |

Places that are susceptible to erosion and accretion have been identified by long-term coastal changes. This study assessed accretional and erosional trends in three study zones using DSAS computations. The three zones (A, B, and C) of the study coast allow for a more focused interpretation of the accretion and erosion rates and a better comprehension of the spatial variety of shoreline dynamics. These results show that different portions of the coastline undergo different rates of accretion and erosion over a 36-year period.

Zone A: Although erosion is the predominant trend in zone A, the data show low overall average values, with an average accretion of 0.91 m/yr, an average erosion rate of -1.91 m/yr, and an LRR of -0.54+0.13 m/yr. A number of factors that are covered in more detail later on may be connected to these low average values. Nonetheless, there are regional differences in the rates of accretion and erosion, with some places seeing higher rates than others. This is due to the generally low average LRR values. The fact that two of the three locations in this zone (Opobo) have parts of their coastlines embanked to lessen the effects of erosion, even though some parts of the coast are still vulnerable and unprotected, makes it possible to explain these variations and low rates. Opobo, which also boasts the oldest wood carving in Africa, numerous ancestor sculptures (masquerades), and a history museum established in 1958, is home to these robust erosion control measures (embankments). The area's low susceptibility to erosion and lower rates of erosion are most likely caused by the embankment of some heavily populated areas. Hard erosion controls have received a lot of attention as one of the most effective ways to reduce coastal erosion, despite the fact that there are some disadvantages (Rangel-Buitrago et al., 2018). One such prohibition on the Russian Baltic shoreline dates back to the 1800s (Pranzini et al., 2015). When the challenging hard structures there became problematic years later, they had to be replaced with more effective soft erosion control methods. Only 15% to 20% of the shore is covered by the zone A embankment, which puts other places at risk of downdrift or flanking erosion. Several fish terminals and villages in this area, including the Brama community, which is located directly behind the Ibaka settlement and has a sea port with an embankment, have been impacted by downdrift erosion. Zone A's embankment has a similar effect on coastal erosion to the findings of Frihy et al. (2013), which show the effects of coastal erosion in different areas of Egypt's Mediterranean coast. According to the study's findings, beach erosion significantly affects the Nile delta because dunes make up roughly 60% of the coast in Alexandria, whereas other coastal areas that are not protected from erosion, such as the northwest coast of Alexandria, which is shielded by roughly 67% consolidated carbonate ridge and 20% engineered structures. The Sinai coastline is just as safe, with the exception of the low-lying areas. A similar study was carried out in Egypt by Darwish et al. (2016), who evaluated a 70-year change in the coast's morphology between 1945 and 2015. They discovered that although the engineered structure along the Alexandria coast has maintained stability, erosion is happening more quickly in the Damietta section of the coast because of this. According to their data, the area's erosion trended steadily upward before the sea wall was built, indicating that the management system in place had reduced erosion and consequently improved accretion.

This was not true of comparable breakwater structures built in the Lekki area of the Nigerian Barrier Lagoon. Danladi et al. (2017) examined sediment loss caused by SLR over a 43-year period in the Lekki section of the Barrier-Lagoon coast using remote sensing technology. The study was conducted both prior to and following the installation of a breakwater to prevent coastal erosion. This study also examined the variations in erosional patterns that took place prior to and following the installation of a breakwater structure. The results showed that the area experienced more erosion in 2011 and more accretion in 2012, indicating a pattern of alternating coastal erosion and accretion between 2010 and 2012. The study contends that although a breakwater was constructed in 2013 to stop erosion, it actually made things worse by creating a cumulative erosion pattern and disrupting the erosion-accretion pattern. There was a notable loss of roughly 66.1 meters to the ocean along the Goshen Beach Estate axis after a continuous erosion trend was discovered between 2013 and 2016. There are about 77 meters of land lateral to the beach here as of 2013. But when the barrier was constructed, the sea level dropped by nearly 6.1 meters. Although hard-coastal defenses seem to protect the shoreline, Rangel-Buitrago et al. (2018) contend that they have drawbacks and generally support the idea that nations employing hard defense strategies should switch to more realistic and cost-effective soft strategies, like ecosystem-based coastal erosion management. Although there are advantages to employing ecosystem-based erosion control (such as restoring the natural wetland close to the shore), Gracia et al. (2018) and Rangel-Buitrago et al. (2018) point out that in order for this method to be effective, there needs to be enough land separating the community from the beach. A comprehensive analysis of the implementation of soft erosion treatments, such as the ecosystem-based management program, is given by Gracia et al. (2018). Second, the rates of coastline change there are significantly influenced by geology and geomorphology. According to Boateng (2012), geology affects a rock's resistance to erosion, with harder rocks having a higher resistance than softer rocks. According to the research, one of the elements controlling erosion in Keta, Ghana, where the study coast is comparable to this one, is the softer rock geology. According to fieldwork for this study, significant layers of worn laterites that are visible at the base support the region's unusually high topography. These weathered laterites, which contain clay, are more resilient to erosion and stronger than the other low-lying, readily eroded loose coastal plain sand zones along the study coast. Using a textural feel analysis of the soil's cohesiveness and stickiness, the erodibility factor was assessed in the field to determine the soil's resistance to deformation (FAO 2006). Compared to the other zones in the study area, the zone has the highest topography, and the majority of its shoreline is relatively high. Its geology is enhanced by these features.

Zone B: The most active area of the study coast, zone B has an average erosion rate of -5.23 m/yr and an average accretion rate of 3.44 m/yr, based on long-term data. Thus, the primary trend in the zone is coastal erosion. This erosional tendency was also shown during the fieldwork for the study. Furthermore, the results align with and reflect those of Ituen et al. (2014), who studied shoreline changes in zone B between 1986 and 2008 and discovered accretion and erosion rates of 2 m/yr and -3.9 m/yr, respectively. According to the DSAS data, the zone is particularly vulnerable to SLR because of its high rates of erosion, which are probably caused by its closeness to the Atlantic Ocean and sense of community. Williams et al. (2017) state that the community's closeness to the ocean has a major impact on its vulnerability to coastal erosion. According to Williams et al. (2017), setback restrictions for coastal management are in place for a variety of different types of coastal regions worldwide. One such law requires buildings to be at least a certain distance from the Mean High-Water Mark. Based on the different types of coastlines and the regulatory body responsible for coastal planning in the area, they emphasized that different beaches have varying lengths. For coastal areas, there is no set minimum distance. A typical example of various setbacks on various types of beaches along the same coast was provided by Williams et al. (2017). They demonstrated that the minimal setback was 30 meters along the sandy Barbados beach and 10 meters along the edge of the cliff. Although many nations have adopted this management approach, it is not without issues. It is unclear what the appropriate minimum distance to use is because of concerns about homes that experience sea level rise during severe weather (Williams et al. 2017). The implementation of developmental setbacks in the study coast is difficult because there are no minimum setbacks on the distance to the mean high-water mark. Ekong (2017) suggests this as one way to lessen the effects of coastal erosion.

A community's openness to the ocean and proximity to the coast are not the only factors that affect coastal erosion. Geology, wave action, and substratum load are significant factors influencing the rate of coastal erosion, claim Fourie et al. (2015). Zone B and Monwabisi, Northern, have the same geomorphology. Erosion occurs frequently along Cape Town's False Bay beachfront because of the numerous estuaries that dot the area. The beach is mostly sandy and extremely erodible due to wave action (Fourie et al. 2015). Based on DSAS data, Zone B's long-term overall average LRR of -4.46+0.34 m/yr suggests that erosion is the zone's main tendency. This illustrates the region's vulnerability to coastal erosion. Comparing this zone to other coastal zones, the overall average LRR result indicates that it is more vulnerable to coastal erosion. This barrier island, zone B, was the flattest of the three zones, according to the ground truthing operation. This low elevation coastal zone (LECZ), which is defined as heights of 10 meters or less, is significantly impacted by the tides, waves, and currents of the sea. The late Cretaceous to Quaternary sediments that make up the beach ridge complex, alluvium, and coastal plain sands geologically underlie the study area (Edet et al. 2014). Edet (2017) states that the alluvial sands' sea level riseplain mud and clays are light grey in color and contain fine to very coarse granules.

Similar to other coastal zones, Zone C exhibits an erosional tendency with an average annual LRR of -2.44+0.99m/yr. The findings indicate that the main process at work in the area being studied is erosion. This zone has an average erosion rate of -3.82 m/yr and an average accretion rate of 3.28 m/yr, making it the second most dynamic section of the examined coast according to the data. Due to the noticeable vegetation backstop (see figure 3) along a significant portion of the shore, the effect of erosion from direct field observation is currently lower than that of zone B, despite the fact that there is a noticeable amount of erosion occurring here. Additionally, mangroves' natural engineering qualities are crucial for halting coastal erosion (Gracia et al. 2018; Brunier et al. 2019). A 38-year (1976–2014) study by Brunier et al. (2019) found that the Guianas' coast was losing mangrove-dominated rice polders at a rate of up to -200 m/yr. But before these buffer wetlands and mangroves were turned into rice polders, the rates of erosion were less than -100 m/yr. Winterwerp et al. (2020) give another excellent illustration of how mangroves facilitated accretion on the Suriname portion of the Guyana coast and how the removal of mangroves has been connected to ongoing erosion in some coastal areas. There are still areas of that beach with communities that are directly exposed to the sea, despite the fact that the community in zone C has moved behind the vegetation backstop. As a result, those areas are more vulnerable to erosion than the areas along river channels. This is understandable since narrower channels might lessen the force of the wind and waves traveling through them and their effect on the coastline (Gracia et al., 2018). Furthermore, the vegetative backstop protects against wave and wind action. The settlement movement behind the vegetative backstop in this area also helped to lessen the effects of coastal erosion.

Overall, the findings also demonstrated that regions exposed to the Atlantic Ocean experience higher rates of erosion. This is probably because climate change would make these regions more vulnerable to tidal currents, winds, tsunamis, and SLR—all of which are constant in these regions. The frequency and intensity of strong boat waves—a wave pattern produced by moving boats or vessels—are a significant human activity that may explain and contribute to the erosion in these areas, in addition to the impact that climate change is having on erosion rates. According to Herbert et al. (2018), high-energy boat waves may be a factor in the erosion and eradication of salt marshes and other beachside vegetation. There is a lot of waterway traffic and boat wakes because the primary economic activities in the Opobo shoreline region are fishing and operating commercial and recreational boats. This is most likely exacerbating the erosion on the study coast. Bilkovic et al. (2017) found a connection between boat wakes, coastal erosion, and turbidity in the Chesapeake Bay.

Due to the complexity of the factors causing coastal erosion, an assessment necessitates a more flexible approach that incorporates both social and physical knowledge in order to comprehend the situation and offer practical management recommendations, particularly in low-coastal and data-poor environments. We should encourage this strategy. According to Oppenheimer et al. (2019), the IPCC has promoted adaptation as a means of reducing coastal erosion. Their desire is supported by this recommendation.

1. **CONCLUSION**

Although climate change has existed throughout Earth's geologic history, human activity—particularly that of industrialized nations—is primarily responsible for its current, severe, and swift manifestations. Coastal flooding, shoreline erosion, and relative sea level rise have become major environmental concerns in the Niger Delta. The region's low elevation, dense population, and inadequate mitigation infrastructure all contribute to its vulnerability. According to this study, only 23.85% of shoreline transects exhibit accretion, while 76.15% (351 out of 591) experience erosion. The long-term average Linear Regression Rate (LRR) from 1984 to 2020 was -2.7 ± 0.18 m/year. Zone A showed the least amount of erosional impact, while Zone B, the most dynamic and critically exposed of the designated coastal zones, recorded the highest erosion rates with LRR values as high as -5.89 ± 3.0 m/year. Zone C displayed intermediate dynamics, with large areas still at risk from insufficient coverage, but isolated pockets benefited from earlier shoreline reinforcement projects.

The Residents' Response Index (RRI), which averages 3.67 throughout the study area, indicates a moderate but increasing level of awareness and coping effort among communities in response to the effects of climate change. However, there was a severe lack of proactive or preemptive adaptation measures, such as land use controls, disaster risk reduction measures, and storm surge barriers erected by the government. This disparity implies that instead of receiving proactive structural protection or policy support, residents are compelled to use reactive coping.

Given these results, Zone B needs to receive immediate attention because it has the worst erosion and the fewest mitigation measures, putting communities at serious risk. Reforestation of mangroves, the installation of engineered coastal defenses, and the incorporation of community-based early warning systems ought to be prioritized interventions. In order to direct future coastal planning and adaptation in this deltaic area, shoreline monitoring through satellite and ground-based surveys should also be institutionalized. To ensure sustainable management of the Niger Delta's delicate coastline in the face of rising seas, strategic cooperation between local, state, and federal authorities is essential.

**RECOMMENDATIONS**

1. Given the significance of the Nigerian Coastal Zone to the country's economy, sufficient attention should be paid to it by putting in place location-specific, sustainable mitigation strategies that ensure the region's successful adaptation to climate change.
2. Given the current climate variation, the state and federal governments of Nigeria, development partners, and private sector actors should carry out their assigned roles in climate change responses, measures, and actions to implement context-specific policies to address barriers to the adoption of advanced sea level rise adaptation strategies across various residential densities in Opobo and other areas with comparable characteristics.

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1.

2.

3.

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