**Original Research Article**

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

**ABSTRACT**

Driven piles are widely used in foundation engineering across Lagos, Nigeria, due to their ability to support substantial structural loads in diverse soil conditions. However, the accurate prediction of their ultimate load-carrying capacity remains a challenge, particularly in areas with complex subsurface profiles. This study aims to develop an empirical model for predicting the ultimate bearing capacity of driven piles using multiple linear regression (MLR) techniques based on field data from 20 pile load test sites across Lagos. Key parameters considered include pile length, diameter, embedded depth, soil unit weight, angle of internal friction, and cohesion. The dataset was divided into two subsets, with 70% used for model development and 30% for validation. The final model demonstrated a high level of statistical reliability with a coefficient of determination (R²) of 0.912, indicating a strong correlation between predicted and actual pile capacities. Validation results showed a root mean square error (RMSE) of 198.72 kN, a mean absolute error (MAE) of 161.43 kN, and a mean absolute percentage error (MAPE) of 7.38%. Additionally, the model achieved an average prediction accuracy of 92.62%. These results confirm the model’s robustness and practical applicability in estimating pile capacities without the need for extensive and expensive field testing. The derived equation allows engineers to make quick yet reliable predictions of pile load capacity using basic soil and pile parameters, thereby streamlining the foundation design process and reducing overall project costs. In conclusion, the study provides a statistically validated, easy-to-use empirical tool that enhances the reliability and efficiency of pile foundation design in Lagos, contributing to safer and more economical construction practices in the region.

**Keywords:** driven piles, empirical model, pile load capacity, Lagos soils, regression analysis, geotechnical engineering, foundation design.

# **INTRODUCTION**

The Niger Delta is located in Atlantic Coast of southern Nigeria where River Niger divides into numerous tributaries. It is the second largest delta in the world with a coastline spanning about 450 kilometers terminating at the Imo River entrance (Awosika, 2015). The region spans over 20,000 square kilometres and it has been described as the largest wetland in Africa and among the three largest in the world (CLO, 2018). About 2,370 square kilometers of the Niger Delta area consist of rivers, creeks and estuaries, while stagnant swamp covers about 8600 square kilometers. The delta, with mangrove swamps spanning about 1900 square kilometers has the largest mangrove swamps in Africa, (Awosika, 2015). The delta falls within the tropical rain forest zone. The ecosystem of the area is highly diverse and supportive of numerous species of terrestrial and aquatic flora and fauna and human life.

The Niger Delta is highly susceptible to adverse environmental changes caused by climate change because it is located in the coastal region of the world. Coastal zone is a region of interactions between marine and terrestrial processes which can be classified according to geology, vegetation and drainage system of the coastline. It can be loosely referred to as a zone of varying breadth including the shore and extending to the landward limit of marine influence and the seaward limit of terrestrial influence (Ajao, 2014). It is an important zone which produces mineral and biological resources that sustains economies of many countries in the world including Nigeria. Eventually, due to its economic and ecological values, human population pressure is on the increase in Nigerian coastal zone on daily basis. In fact, Nigerian coastal zone especially the Niger Delta region is quintessential as it is the richest in petroleum and fishery resources in the Sub-Saharan Africa (Akande et al., 2017). However, the integrity and sustainability of coastal zone are threatened by climate change coupled with anthropogenic pressure. A projected possible impact of climate change on the coastal cities of Lagos and Port Harcourt using the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC-SCENGEN) and geographical information system (GIS) interpolation techniques confirms that sea level rise may occur with a consequence of submerging all coastal cities of the Niger Delta area and a larger part of Lagos in 2050 (Allen, 2016).

Rise in sea level is associated with flooding of low lying coastal zones and the height of water above a reference level constitutes. One of the commonest geological hazards affecting individuals and properties more than any other hazard such that any significant rise in sea level causes erosion of the coastal zone (Bell, 2014). The soft, unconsolidated sediments are the most susceptible to coastal erosion and the nature of the coastline and coastal zone depends on the tectonic setting, materials present at the shore and the energy of the waves. Whether it is a progradation or erosion dominated environment is a factor of sediment supply, lithospheric upliftment and or subsidence, wave and current forces; and the equilibration of the beach profile. Erosion and human activity at the coastal zone are in conflict and construction of infrastructures has led to increased vulnerability that requires better planning and management of the coastal zone (Bell, 2014). The effects of hydrodynamic forcings on coastal systems places them under high water waves and currents; and swash-backwash interactions upon wave breaking with an overall tendency of erosion hence epitomizing high risk areas in terms of climate change and sea level rise. Idier et al., (2019) noted that coastal systems and low-lying areas will increasingly experience adverse impacts such as submergence, coastal flooding, and coastal erosion due to relative sea level rise which is distinct from eustatic rise in sea level caused by increased sea surface temperature, expansion of sea water and melting of polar ice due to anthropogenic global warming (Wong et al., 2014). The mean sea elevation increases at a rate equal to the rise in sea level and the beach profile shifts landwards and upwards the volume of sediments eroded equating that deposited in the nearshore zone (Woodworth et al., 2019). The contributory forcings to sea level rise include tides, atmospheric surge, vertical ground movements, swash, and wave setup which are critical for coastal flooding and erosion vulnerability. These are in addition to the factors promoting global rise in sea level. Sea level is also the vertical height of the sea surface relative to a reference level is a combination of tidal level, non-tidal residual and mean sea level (Anderson, 2017). Tides are the dominant contributor to sea level variability which can be caused by signals transmitted over 1000kms but shorter spatial changes which can cause coastal modification are due to shallow coastal water relative to the deep ocean; and the complicated shapes and features of coastlines. Tides, surges and mean sea level make up the still water level which is superimposed by ocean wind waves that span typically from 1-25 s (Anderson, 2017). The coastline also forms the boundary resulting in dynamic changes in ocean circulation with river runoff as a land variability factor (Hanson et al., 2013). Coastal ocean circulation is controlled by bathymetry, shape of coastal boundary and vertical ground movements acting to introduce changes alongshore and between the coast and the ocean. The wave field impinging at the coast is composed of waves of different origins, ages and periods.

Wave energy flux drives coastal erosion hence a major contributor to shoreline evolution such as beach profile modification. Wind waves contribute to flooding through overflowing, overtopping and breaking of natural barriers while river runoff contributes to signals of the order of centimeter scale (Abija, 2019). Relative sea level rise is caused by ground subsidence, increase in volume or mass of water, changes in shape of the oceanic basin and the terrestrial hydrologic regimes. The seasonal cycle of mean sea level contains small long periods and astronomical tidal contributions (Pugh & Woodworth, 2014). Recent submergence of many fluvial marine deltaic margins around the world has been attributed to eustatic rise in sea level resulting from global warming, melting of polar ice and sea water expansion (Abija, 2019). Global sea level is rising at a rate of 1.6 mm/year and 0.6 mm/year respectively since the mid-nineteenth century and the previous two millennia while predicted a eustatic sea level rise of 20 cm/year anthropogenic climate change, global ice melting and ocean warming are the major culprits implicated as causative factors (Woodworth et al., 2019). Projected that global sea level will rise by 0.5-1 m in 2100 and coastline changes have been linked to relative rise in sea level, sediment discharge and complex, inter-related factors. The consequences are that shorelines will retreat, coastal erosion will increase, and massive wetlands shall be lost (Berry et al. 2017).

Mishra (2017) reported a subsidence induced coastline recession of 16-31 m representing 48% of Sri Lankan coast. Estimates that sea-level rise places 21,000-55,000 km2 of valuable Australian coastal land at risk from intrusion of saline groundwater and the estimates that a sea level-rise of just one metre places some 30,000 km of roads and $ 226 billion of infrastructure at direct risk from inundation. The Intergovernmental Panel on Climate Change has reported that anthropogenic climate induced changes will cause extreme temperatures and weather conditions, rapid and extensive alterations to global ecosystems with unknown consequences on human populations (Okunola 2019). Coastal settlements, groundwater-supported ecosystems and groundwater users (farmers, factories and mines) are assets under direct attack of the sea level rise prompting the need for adaptation strategies. Some of the direct impacts of climate change in coastal zones are expected to include eustatic sea-level rise, hazardous storm surges, flood inundation, increased erosion, increased seasonality in groundwater recharge, rising groundwater levels, saline intrusion and enhanced mobilization of contamination. Coastal beaches are naturally under diurnal and seasonal inundation cycles due to changing tides and waves with associated sediment aggradation and degradation. The beach profile equilibrium may be overwhelmed by episodic high wave energy causing net sand losses. The net volumetric change depends on the intensity and duration of total wave energy, beach slope angle and hydrodynamic forcings (Stojanov et al., 2016). Observed that coastlines adjust to rate of change of longshore transport (divergence of the drift) thus a lowering of the ground surface elevation induces a fall in slope, relative rise in sea level (which is different from eustatic sea level rise) and encroachment of the shoreline.

The Niger Delta coast is vulnerable to climate change induced flooding and erosion; and the region lack data for evaluation of vulnerabilities. The coastal zone is inundated by diurnal tides, surf zone induced waves and longshore current subjecting the environment to erosion which is visible in several coastal communities as retreating coastlines. Beach hazards have been identified in terms of the vulnerability of coastal areas to damage with regard to loss of property or infrastructure and coastal infrastructures such as jetties which were accessible without walkways as at the time of design and construction have to be improvised with walkways or totally inaccessible from the shoreline (Kreibich et al. 2011). Assessed coastal erosion in the region between 1963 and 1990 and reported that 75% of the coastline is eroding implicating anthropogenic activities such as dredging canalization, harbor protection works and upstream dams and reservoirs as causes of accelerated erosion. The region is also reported to be facing relatively strong environmental changes resulting from complex interaction of natural and human induced processes with periods of erosion and accretion (Ekegren et al. 2020). Reported a massive 9.1 km2 land loss with average annual erosion rate of 4.55 km2 ± 1.21 km2/year between 2010 and 2012 (Silvast et al. 2020). A delta wide attempt at studying the rate of progradation was made by who compared paleo and present coastline positions on a regional scale as observed by (Kreibich et al. 2011). In their assessment of recent changes in the Niger Delta coastline using satellite imagery indicated that coastline erosion was dominant over accretion with a total area of 46.535 sq.km observed changes along the coastlines. Of this, 27.65 sq.km (59.43%) constitutes eroded area, and 40.57% representing 18.88 sq.km of the area showed coastal sediment accretion.

Many cities across the world are facing enormous problems posed by climate change to their communities, populations and critical infrastructure (Pelling and Blackburn 2014; Sarker et al. 2020). Climate-related extreme events such as flooding, heat waves, storm surges and droughts are imposing heavy burden on societies (Mishra 2017; Cian et al. 2020). As a result of high population growth rate and proliferation of slums in Asia and Africa, cities in these continents have been identified as the two most vulnerable areas to the impacts of climate change (UN-HABITAT 2016; Lutz and Muttarak 2017). The major challenge of these regions and global communities in general centres on the capacity to implement appropriate actions that will mitigate and enhance the capacities of vulnerable communities to adapt to the threats and risks of climate change (Garschagen and Kraas 2010; Okunola 2019). This is further compounded by a number of epistemological and methodological shortcomings which have significantly affected future risk trends and adaptation needs (Silvast et al. 2020).

Despite the uncertainty surrounding the future risk of climate change, the complete picture of future risk trends and adaptation pathways is still unclear to the decision- makers (Clay and King 2019). This is attributed to the fact that the scientific method and tools to assess future risk have skewed towards assessing future climate hazards, resulting in an incomplete picture with limited validity and usability for adaptation planning (Birkmann et al. 2021; Garschagen et al. 2021). Therefore, a sound understanding of future risk trends is required for successful adaptation planning. The realization of this has led to the development and adoption of new adaptation pathways for assessing future risk.

Several scholars such as Li et al. (2018), Okunola (2019) and Huq et al. (2020) have posited that the occurrence frequency and magnitude of future environmental and sea level rise” may vary, owning to differences in the socioecological nature of hazards in different parts of the world. Most models (IPCC 2001; Hertel et al. 2010; Tejedor et al. 2021) however indicated that environmental and sea level rises will be severe near the equator, hence, in Sub-Saharan Africa than in most other major regions on earth. By implication, Nigeria is highly vulnerable to the impacts of climate change like other countries in Sub- Saharan Africa (Haider 2019; Onwutuebe 2019). As noted by the World Bank (2021), rural and urban communities in Nigeria are at risk of climate change because of increased temperatures, flooding, increased aridity, and soil erosion, particularly for poor and vulnerable groups. This necessitates the need for stakeholders to take into consideration emerging risks along with existing risks. In order to approach the problem appropriately, it is important to take into consideration local communities’ understanding of climate change, adaptation strategies as well as factors influencing their level of adaptation to climate change risks since they perceive climate as having a strong emotional, spiritual and physical dimension (Wang et al. 2018).

Some notable studies have investigated individuals and households adaptation strategies to climatic events in the Global South and North (Kreibich et al. 2005, 2011; Botzen et al. 2013; Stojanov et al. 2016). For instance, Stojanov et al. (2016) stated that the most common household adaptation to climate change in the North-Eastern part of the Czech Republic is the repair of damaged properties instead of implementing costly adaptation measures. The studies of Kreibich et al. (2005) and Kreibich et al. (2011) likewise divided household adaptation strategies into low-cost, medium and high cost adaptation strategies. The low-cost measures include assistance of neighbours affected by climate change events, gathering of information relating to precautionary measures and relocation of properties at risk from ground floor to safer locations (Dey et al. 2016; Okunola and Bako, 2021). Furthermore, Kreibich et al. (2011) stated that securing of flood embankments and barriers, adaptation of the interior (e.g. floor replacement) and flood insurance constitutes medium adaptation strategies to climate change effects. On the other hand, the high cost flood adaptation strategies entailed sealing important parts of the house, constructing small anti-flood walls on the surrounding lands or fortifying the cellar and foundations of the building and using solid and water-resistant materials (Daramola et al. 2016). This study also examined residents’ adaptation strategies to climate change effects and factors influencing their choice of strategies.

Studies by authors such as Jabeen et al. (2010) and Weru et al. (2017) examined household resilience strategies to climate change effects in informal settlements of sub- Saharan African cities. These studies established that the provision of funds to low-income households to build better housing, barriers to prevent the entrance of floodwater into homes, house designs that keep down high temperatures food stores on top of high furniture or shelves and electrical wiring constitute major household resilience to climate change impacts in the informal settlement of Dhaka and Nairobi. However, these studies did not consider formal settlements of these cities.

1. **MATERIALS AND METHOD**

The study was carried out in Opobo Kingdom. The population of the study will be 5,000 persons dwelling in Opobo Local Government Area. The study population consisted of residents, environmental officers, and local experts in the selected community. A **purposive sampling technique** was employed to select key informants and households most affected by coastal changes. A sample of **200** respondents was selected based on proximity to the shoreline and observable impacts of sea level rise.

#### **2.1 Primary Data**

1. **Structured Questionnaire**: A structured questionnaire with both closed and open-ended questions was administered to gather data on local experiences, observed sea level changes, and environmental impacts.
2. **GPS and Elevation Survey**: Geographic coordinates and elevation measurements were taken using handheld GPS devices to determine local topography and land subsidence.
3. **Tide Gauge Data**: Where available, local tide gauge readings were obtained from coastal monitoring stations.

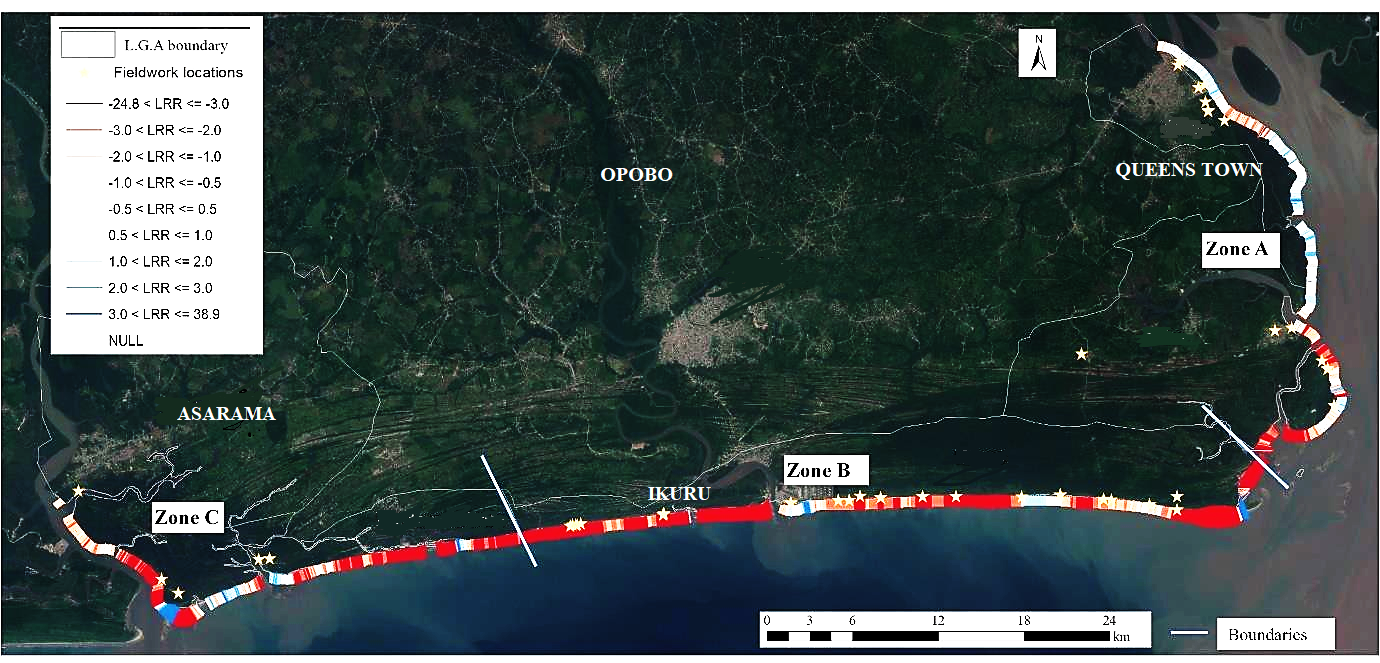
#### **2.2 Secondary Data**

1. **Satellite Imagery and Remote Sensing Data**: Landsat imagery and Digital Elevation Models (DEMs) for the past 30 years were analysed to assess shoreline movement and inundation patterns.
2. **Sea Level Rise Datasets**: Sea level trends from global databases such as the **Permanent Service for Mean Sea Level (PSMSL), NOAA, and IPCC reports** were incorporated.
3. **Climatic Records**: Rainfall, temperature, and tidal patterns from the Nigerian Meteorological Agency (NiMet) and Nigerian Hydrological Services Agency (NIHSA) were also analysed. Percentage, mean and standard deviation will be used to analyze the data gotten form the questionnaires while R, GIS, DSAS, ArcGIS was used to analyse data gotten from the field survey.

**3. RESULT AND DISCUSSION**

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

An overall historical trend assessment along the entire coast is performed, as well as a change assessment in the different zones delineated for this study. The results derived using both the manual and semi-automated derived shorelines show noticeable and significant changes in the movement of the shoreline (Figure 1).



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

The similarities and differences in sea level rise trends between the three different zones are studied here. The Linear regression rates (LRR) enable the quantification of erosion and accretion per year from 1984 to 2020. The results obtained in this section demonstrate the variability of coastal erosion and accretion in the different zones over 36 years assessed over a four-step time interval of 1984, 2015, 2018 and 2020. The total number of transects used for the entire coast is 591, with erosion accounting for 76.15 % (351 transects) and accretion accounting for 23.85 % (table 1). The overall average LRR of -2.7+0.18m/yr derived from the result, indicates that the area is predominantly eroding.

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

Using the LRR results derived from the manually derived shoreline, a comparative analysis of long-term shoreline changes between three zones of the study area was completed. This enabled an assessment of the spatial variation in patterns and rates of change between zones, as well as an assessment of the trend analysis relationship. Table 1 summarizes the results of the comparative analysis.

**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 |

For zone A, a total of 88 transects were used to analyse shoreline changes, with 51.52% (46 transects) showing erosion and 48.48% (42 transects) showing accretion. Only 33.12% of the erosional transects showed significant erosion, while 14.97% showed significant accretion. In the DSAS, significant erosion or accretion refers to all transects with a magnitude greater than the uncertainty (plus/minus the confidence interval value). 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 overall average LRR of -0.54+0.13m/yr indicates that the area is eroding, albeit at a low rate. For zone B, a total of 79 transects were employed to analyse shoreline changes, with 91.1% (63 transects) showing erosion and 8.9% (16 transects) showing accretion. 77.02% of the erosional transects exhibited significant erosion, while 4.91% exhibited significant accretion. From 1984 to 2020, the maximum landward movement (erosion) measured in the zone was -24.7m/yr with an average of -4.46+0.34m/yr, whereas the maximum seaward movement (accretion) was 38.82m/yr with an average of 3.44+0.34m/yr. The total average LRR of -4.46+0.34m/yr indicates that the land is eroding. For zone C, a total of 724 transects were cast from the offshore to the land at an interval of 50m. According to the findings, 80.66% (584 transects) of the transect area is erosional, and 61.45% of the erosional transects had significant erosion. The maximum erosion rate in this zone is -14.86m/yr, while the average erosion rate is -3.82+0.99m/yr, which implies that the shoreline is moving landward at a rate of at least 3m/yr. The maximum accretion rate in the area is 14.85m/yr, with only 140 transects (19.34%) demonstrating rates of accretion, while the average rate of accretion is 3.28+0.99m/yr. The overall average LRR is -2.44+0.99m/yr, which indicates that the land is predominantly erosional.

Overall, the average erosion and accretion rates computed from the extracted shorelines of the entire coast (table 2) from 1984-2020, as well as the bar plots in figure 2, reveal that zone B has the highest average erosion and accretion rates, whereas zone A has the lowest erosion and accretion rates.

**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 |

Long-term coastal changes have revealed places that are vulnerable to erosion and accretion. Using DSAS calculations, this research evaluated accretional and erosional trends in three study zones. Supporting the conclusions are the field survey data and observations presented in Chapter 4, which also includes a comprehensive analysis and discussion of the field work. The study coast's three zones (A, B, and C) provide for a more focused interpretation of the rates of erosion and accretion as well as a better understanding of the spatial variety of shoreline dynamics. These findings demonstrate that during a 36-year span, various parts of the coastline experience variable rates of erosion and accretion.

Zone A: The data indicate 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, even though erosion is the dominant trend in zone A. These low average values may be related to several factors that are discussed in more detail later on. Regional variations exist in the rates of erosion and accretion, however, with some locations experiencing greater rates than others. The generally low average LRR values are the cause of this. It is feasible to explain these differences and low rates by pointing out that, although certain areas of the coast remain susceptible and unprotected, two of the three locations in this zone (Opobo) have portions of their coastlines embanked to reduce the impacts of erosion. These strong erosion control measures (embankments) are located in Opobo, which also has the oldest wood carving in Africa, a plethora of ancestor sculptures (masquerades), and a 1958-founded history museum. The area's reduced rates of erosion and low susceptibility to erosion are probably due to the embankment of certain locations that have seen a lot of human activity. Although Rangel-Buitrago et al. (2018) point out that there are certain drawbacks, adopting hard erosion controls has garnered a lot of attention as one of the best ways to reduce coastal erosion. According to Pranzini et al. (2015), there is one such prohibition on the Russian Baltic shoreline that goes back to the 1800s. Years later, the difficult hard structures there proved to be problematic, requiring their replacement with more successful soft erosion control techniques. The zone A embankment barely covers 15–20% of the shore, putting other areas at risk from flanking or downdrift erosion. Downdrift erosion has affected a number of fish terminals and villages in this zone, including the Brama community, which lies just behind the Ibaka settlement and is home to the sea port with embankment. Comparable to the findings of Frihy et al. (2013), which illustrate the impacts of coastal erosion in various regions of Egypt's Mediterranean coast, Zone A's embankment has a similar effect on coastal erosion. The study's conclusions indicate that beach erosion has a substantial impact on the Nile delta because, in contrast to other coastal regions that are not shielded from erosion, like Alexandria's northwest coast, which is protected by about 67% consolidated carbonate ridge and 20% engineered structures, dunes make up about 60% of the coast there. Except for the low-lying regions, the Sinai shoreline is equally safe. Darwish et al. (2016) conducted a similar study in Egypt and assessed a morphological 70-year change in the coast between 1945 and 2015. They found that while the engineered structure along the Alexandria coast has kept the area stable, erosion is occurring more quickly in the Damietta section of the coast due to the fact that erosion is occurring there. Their data showed a steadily increasing trend in erosion in the region prior to the sea wall's construction, suggesting that the area's management system had decreased erosion and subsequently enhanced accretion.

Comparable breakwater structures constructed in the Nigerian Barrier Lagoon in the Lekki area could not make this claim. Using remote sensing technology, Danladi et al. (2017) investigated sediment loss in the Lekki section of the Barrier-Lagoon coast during a 43-year period as a result of SLR. The research was done both before and after the construction of a breakwater to halt coastal erosion. This research also looked at the differences in erosional patterns that occurred before and after the construction of a breakwater structure. The findings demonstrated that between 2010 and 2012, there was a pattern of alternating coastal erosion and accretion, with more erosion taking place in the area in 2011 and more accretion in 2012. The study argues that even though a breakwater was built in 2013 to prevent erosion, it actually made matters worse by upsetting the erosion-accretion pattern and causing a cumulative erosion pattern. Following the discovery of a continuous erosion trend from 2013 to 2016, the Goshen Beach Estate axis had a significant loss of about 66.1 meters to the ocean. As of 2013, there is around 77 meters of land lateral to the beach at this location. However, the sea level decreased by almost 6.1 meters when the barrier was built. Rangel-Buitrago et al. (2018) argue that while hard-coastal defences appear to preserve the shoreline, they have disadvantages and generally lend support to the notion that countries using hard defence strategies ought to transition to more practical and affordable soft strategies, such as ecosystem-based coastal erosion management. While using ecosystem-based erosion control has benefits (such re-establishing the natural wetland near the shore), Gracia et al. (2018) and Rangel-Buitrago et al. (2018) note that sufficient acreage must separate the community from the beach for this technique to be successful. Gracia et al. (2018) provide a thorough discussion on how to effectively deploy soft erosion treatments, such the ecosystem-based management program. Second, geomorphology and geology have a major impact on coastline change rates there. Geology influences a rock's resistance to erosion, with harder rocks having a greater resistance than softer rocks, according to Boateng (2012). In Keta, Ghana, where the study coast is similar to this one, the softer rock geology is one of the factors regulating erosion, the research found that this was the case. The region's abnormally high topography is supported by substantial layers of worn laterites that are visible at the base, according to fieldwork for this research.

Compared to the other low-lying, easily eroded loose coastal plain sand zones throughout the study coast, these weathered laterites, which incorporate clay, are stronger and more erosion-resistant. The erodibility factor was evaluated in the field using a textural feel analysis of the cohesiveness and stickiness of the soil to ascertain the soil's resistance to deformation (FAO 2006). The zone has the greatest topography in the study area as compared to the other zones, along with a relatively high topography along most of its shoreline. These characteristics enhance its geology.

Zone B: According to long-term data, zone B, the most active section of the study coast, has an average erosion rate of -5.23 m/yr and an average accretion rate of 3.44 m/yr. Because of this, coastal erosion is the zone's main trend. The study's fieldwork also demonstrated this erosional tendency. Additionally, the findings coincide with and mirror those of Ituen et al. (2014), who examined shoreline alterations in zone B from 1986 to 2008 and found rates of erosion and accretion of -3.9 m/yr and 2 m/yr, respectively. The zone is especially sensitive to SLR due to its high rates of erosion, which are most likely brought on by its proximity to the Atlantic Ocean and feeling of community, according to the DSAS data. According to Williams et al. (2017), the community's susceptibility to coastal erosion is significantly influenced by its proximity to the ocean. Setback restrictions for coastal management are in place for a variety of various sorts of coastal regions worldwide, according to Williams et al. (2017). Buildings must have a minimum distance from the Mean High-Water Mark, according to one such law. They stressed that there are a variety of lengths along different beaches, based on the varied kinds of coastlines and the regulatory body in charge of coastal planning in the region. There is no defined minimum distance for coastal areas. Williams et al. (2017) offered a typical illustration of different setbacks on different kinds of beaches along the same coast. They showed that the minimal setback was 10 meters along the cliff's edge and 30 meters along the sandy Barbados beach. This management approach is not without its problems, despite the fact that many countries have embraced it. Given worries about residences that experience sea level rise during severe weather, it is uncertain what the proper minimum distance to use is (Williams et al. 2017). There are no minimum setbacks on the distance to the mean high-water mark, which makes the implementation of developmental setbacks in the study coast challenging. This is one of Ekong's (2017) recommendations to decrease the consequences of coastal erosion.   
  
Coastal erosion is not just determined by a community's proximity to the coast or openness to the ocean. According to Fourie et al. (2015), the geology, wave action, and substratum load are important elements determining the pace of coastal erosion. The geomorphology of Zone B and Monwabisi, Northern are the same. Due to the many estuaries that dot Cape Town, South Africa's False Bay beachfront, erosion is a common occurrence. Because to wave action, the beach is mostly sandy and highly erodable (Fourie et al. 2015). Zone B has a long-term overall average LRR of -4.46+0.34 m/yr, which indicates that erosion is the zone's primary tendency, based on DSAS data. This demonstrates how susceptible the area is to coastal erosion. The overall average LRR result shows that this zone is more susceptible to coastal erosion when compared to other coastal zones. The ground truthing operation revealed that this barrier island, zone B, was the flattest of the three zones. The sea's tides, waves, and currents greatly affect this low elevation coastal zone (LECZ), which is defined as heights of 10 meters or less. The study region is geologically underlain by late Cretaceous to Quaternary sediments, which are a part of the beach ridge complex, alluvium, and coastal plain sands (Edet et al. 2014). The sea level riseplain mud and clays in the alluvial sands contain fine to very coarse granules and are light grey in colour, according to Edet (2017).

Zone C, with an average annual LRR of -2.44+0.99m/yr, shows an erosional tendency similar to other coastal zones. The results show that erosion is the primary process operating in the region under study. Based on the data, this zone is the second most dynamic portion of the examined coast, with an average erosion rate of -3.82 m/yr and an average accretion rate of 3.28 m/yr. Even though there is a noticeable amount of erosion happening here, the effect of erosion from direct field observation is now lower than that of zone B due to the noticeable vegetation backstop (see figure 3.) throughout a good chunk of the shore. Moreover, the inherent engineering properties of mangroves are essential for stopping coastal erosion (Gracia et al. 2018; Brunier et al. 2019). According to a 38-year (1976–2014) research by Brunier et al. (2019), the coast in the Guianas, South America, was losing rice polders dominated by mangroves at a pace of up to -200 m/yr. However, the rates of erosion were less than -100 m/yr before these mangrove and buffer wetlands were converted into rice polders. Another great example of how mangroves promoted accretion on the Suriname section of the Guyana coast and how mangrove removal has been linked to continuous erosion in certain coastal places is provided by Winterwerp et al. (2020). Even though the community in this zone C has relocated behind the vegetation backstop, there are still parts of that beach with communities that are directly exposed to the sea (see figure 4). Because of this, those regions are more susceptible to erosion than the sections along river channels. This makes sense, as smaller channels may decrease the power of the wind and waves passing through them and their impact on the shore (Gracia et al., 2018). In addition, the vegetative backstop shields against wind and wave action. The impacts of coastal erosion were also mitigated by the settlement movement in this area behind the vegetative backstop.

All things considered, the results also showed that greater rates of erosion are seen in areas that are exposed to the Atlantic Ocean. This is likely due to the fact that climate change would increase these areas' susceptibility to SLR, winds, tsunamis, and tidal currents—all of which are constant in these areas. Apart from the effect that climate change is having on erosion rates, a key human activity that might explain and contribute to the erosion in these locations is the frequency and severity of powerful boat waves, a wave pattern created by moving boats or vessels. High-energy boat waves may contribute to erosion and the elimination of beachside vegetation, including salt marshes, according to Herbert et al. (2018). Because fishing and running commercial and leisure boats are the main economic activities in the Opobo shoreline region, there is a great amount of waterway traffic and boat wakes. This is probably making the study coast's erosion worse. In a 2017 research, Bilkovic et al. discovered a relationship between turbidity, coastal erosion, and boat wakes in the Chesapeake Bay.   
Because the factors contributing to coastal erosion are complex, an assessment, especially in low-coastal and data-poor environments, requires a more flexible approach that allows for a combination of physical and social knowledge in order to understand the situation and provide useful management advice. We ought to support this tactic. Oppenheimer et al. (2019) state that the IPCC has advocated for adaptation in the reduction of coastal erosion. This recommendation supports their desire.

1. **CONCLUSION**

Climate change is not a new phenomenon in Earth History but the alarming and phenomenal climatic variations in this Era is consequent upon anthropogenic inducements mostly by the developed countries in the world. Relative sea level rise, coastal flooding and erosion have become a stack reality in the Niger Delta region. Due to its dynamic nature under the influence of constant inundation, continuous monitoring and management is recommended. It could be concluded from the results that respondents in the three residential densities relied more on coping measures to climate change effects than anticipatory measures. On the other hand, the three adaptation measures expressed to have lowest importance were: emplacement of storm surge barriers by government and community groups, provide efficient mechanisms for disaster risk reduction, use of windbreaks/ shelter belts and restriction of land reclamation activities in newly developed areas by government. Furthermore, the average residents’ response index (RRI) for the study area was 3.67, while the RRI of the high, medium and low residential densities were 3.59, 3.69 and 3.72 respectively. These responses indicated that the intensity of responses to climate change effects was on the increase along the residential densities.

**RECOMMENDATIONS**

1. Given the importance of the Nigerian Coastal Zone in Nigerian economy, adequate attention should be made by implementing sustainable mitigation measures which are location specific and guarantee effective adaptation to climate change in the area.
2. The state and the federal government of Nigeria, development partners, and the private sector actors under the current climate variation should undertake their designated roles in climate change responses, measures and actions to implement context-specific policies to address impediments to the adoption of advanced sea level rise adaptation strategies across different residential densities in Opobo and others with similar attributes.

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