

Factors Responsible For Shoreline Changes Along Bonny and Kaa Shoreline, Rivers State

Emeazor Christian¹, T.C Nwofor², C F Ikebude³

¹Student, Centre for Geotechnical and coastal research, University of Port Harcourt,

²Director, Centre for Geotechnical and coastal research, University of Port Harcourt,

³Assistant Director, Centre for Geotechnical and coastal research, University of Port Harcourt

Date of Submission: 05-07-2025

Date of Acceptance: 15-07-2025

ABSTRACT

This study investigates the factors responsible for shoreline changes along the Bonny and Kaa coastal regions in Rivers State, Nigeria. Shoreline instability in these communities has led to erosion, habitat degradation, and increased risk to infrastructure and livelihoods. A structured questionnaire using a 4-point Likert scale was administered to 300 respondents, including residents, environmental workers, and local stakeholders. The analysis revealed that wave erosion (80%), sand mining (80%), and oil exploration (78%) were the most agreed-upon factors influencing shoreline change. Additionally, lack of shoreline protection (77%) and construction along the coast (74%) were identified as significant contributors. While natural factors such as tidal action (70%) and rainfall (70%) also played a role, human activities were more prominently cited. The study recommends the construction of shoreline protection structures, strict regulation of sand mining, and mangrove restoration as strategic interventions to reduce erosion and promote coastal sustainability. These findings underscore the urgent need for integrated coastal zone management to safeguard the Bonny and Kaa shorelines from further degradation.

I. INTRODUCTION

The Bonny and Kaa shorelines in Rivers State, Nigeria, face significant environmental challenges that result in ongoing shoreline changes. These changes are influenced by a myriad of factors encompassing both natural and anthropogenic processes. A comprehensive understanding of these dynamics is crucial for effective coastal management and adaptation

strategies. One of the critical natural factors impacting shoreline changes is climate variability, particularly through alterations in wave climate and storm events. Research indicates that increased meteorological events, such as those driven by climate change, contribute to intensified coastal flooding and erosion. Bevacqua et al. confirm that failure to address these meteorological influences in coastal planning might leave communities vulnerable to flooding and other related hazards [1]. Furthermore, significant climate events like El Niño and La Niña impact shoreline stability, with evidence showing that erosion can be more intense during El Niño years due to increased storm frequency [2].

Wave dynamics are another pivotal factor affecting shoreline morphology. Changes in wave height, variability, and the direction of wave action significantly influence sediment transport processes, which are foundational to shoreline changes. Castelle et al. highlight that wave height variability can explain a substantial proportion (70–80%) of shoreline variability, emphasizing the importance of understanding wave behavior in coastal planning [3]. The dynamics of the shoreline, particularly near river mouths like those of Bonny and Kaa, can be severely affected by these waves, leading to erosion and altering sediment distribution patterns as a result of varying wave influences [4].

Human activities also play a considerable role in exacerbating shoreline changes. Urban development, sand extraction, and inadequate coastal management are human-induced factors that influence shoreline stability. Zhang and Hou indicate that anthropogenic influences can dramatically alter coastal environments, sometimes

overshadowing natural processes. Their findings suggest that localized human actions significantly modify both the pace and nature of shoreline changes [5]. Furthermore, shoreline constructions such as jetties and artificial reefs intended for protection can sometimes lead to unintended consequences, resulting in localized erosion or altered coastal dynamics [6].

Moreover, geographical considerations such as topography and sediment type must be accounted for when examining shoreline changes. Ghanavatiet al. discuss how varying coastal geometries can alter responses to climatic forces, indicating that understanding localized geological features is essential for predicting shoreline changes in specific areas like Bonny and Kaa [4]. This is why this study seeks to ascertain the factors responsible for shoreline changes along Bonny and Kaa shoreline, Rivers State.

II. MATERIALS AND METHODS

Bonny and Kaa Shore is situated at the southern edge of Rivers State in the Southern Niger Delta region of Nigeria. It was formally known as Ibani or Ubani town. It lies along the Bonny River (eastern distributaries and 6 miles upstream from the Bight of Biafra. It is located at latitude $40^{\circ} 26' 57''$ N and $40^{\circ} 31' 42''$ longitude $70^{\circ} 3' 8.1''$ and $70^{\circ} 9' 38''$. The Kaa River flows in a southeasterly direction into a large body of water which also flows almost vertically and slight southeasterly into the Bight of Bonny. It runs in between the two neighboring estuaries of the New Calabar River to the west and the Andoni River to the east. The Cawthome channel links the New Calabar channel and Bonny River estuary. Bonny covers a total land area of about 651.20km^2 .

The study area enjoys tropical hot monsoon climate due to its latitudinal position. The tropical monsoon climate is characterized by heavy rainfall from April to October ranging from 2000mm to 2500 mm with high temperature all the year round and a relatively constant high humidity. The relief is generally lowland which has an average of elevation between 0m and 20m above sea level. The vegetation found in this area includes

raffia palms, thick mangrove forest and light rain forest. The soil is usually sandy or sandy loam underlain by a layer of impervious pan and is always leached due to the heavy rainfall experienced in this area. The study area is well drained with both fresh and salt water. Due to continuous heavy rainfall and river flow, the study area experiences severe flooding almost every year.

Geologically, the region comprises an alluvial sedimentary basin and basement complex, with mean grain sizes ranging from 2.5 mm to 3.0 mm [1]. Notable concentrations of dark-colored heavy minerals are found along the upper reaches of the active beach. The vegetation is dominated primarily by mangrove swamps, light rainforests, and thick mangrove forests. The most common coastal plant identified in the area is the creeping vine *Ipomoea aquatica*.

The tides occur with a period of approximately 12 hours and 25 minutes, and with amplitude that is influenced by the alignment of the sun and moon and the shape of the earth. The wind direction is dominant in a southwesterly direction. The study area experiences two high and two low tides per day, with a tidal range that varies across the Niger Delta and has an average value of 1.8 m [1]. The difference in tidal amplitude is accentuated due to the low volumes and frequency of freshwater discharge at the sub-deltas on the eastern side of the Arcuate Delta, thereby allowing marine processes to play a more active role in shaping the sub-delta morphology.

It is generally erosional as compared to the more depositional active Western Delta shoreline. This can be attributed, primarily, to the configuration of the active river systems on the delta's surface. Oil and gas facilities such as the AGIP's major exporting terminal and other associated facilities are located along the vulnerable shoreline. The estimated population is in the region of 100, 000 and is likely to increase on the commencement of the LNG project. Retreat of the shoreline threatens coastal settlement, loss of recreational grounds and oil export handling facilities.

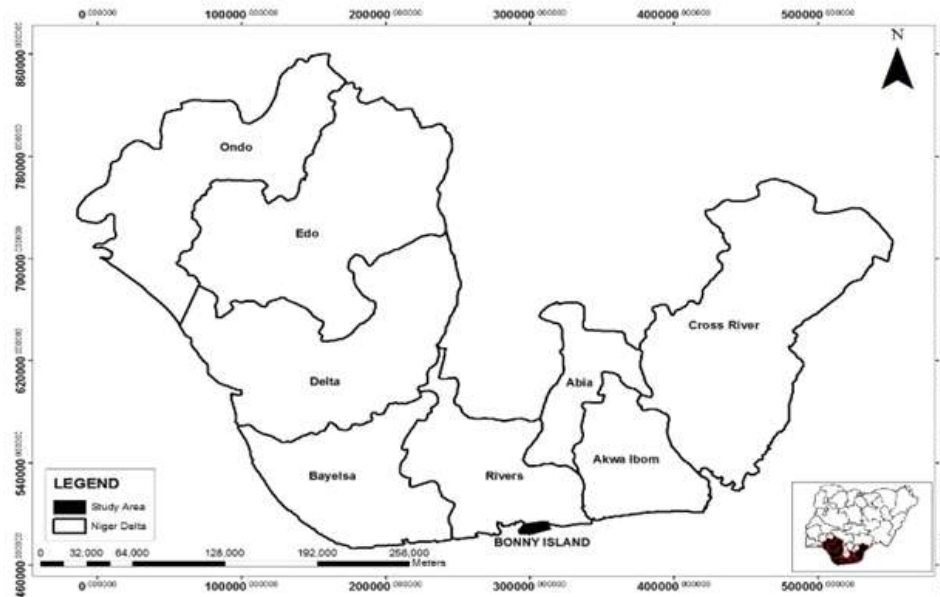


Figure 1Map of Study Area

A mixed-scale approach involving the integration of primary and secondary data was employed using government sources and databases from other organizations. The raw spatial data and satellite images used in the research were obtained from the United States Geological Survey (USGS) and the GIS Laboratory of the Department of Geography and Environmental Studies, University of Port Harcourt. A hard copy map from the Federal Surveys of Nigeria (1974), labeled 1.500/620/9-74 with a scale of 1:50,000, along with its digital (soft) version, was procured from the Office of the Surveyor-General of Nigeria. The datasets used include three Landsat images covering the study area for a 20-year period, specifically for the years 2000 and 2020. Landsat Thematic Mapper (LTM) images from 2000 and 2020, with a spatial resolution of 30 x 30 meters, were acquired from the USGS and used for various analyses.

The method adopted is primarily GIS-based and comprises several procedural steps. A historical shoreline database of Bonny was created using ESRI ArcGIS. This database contains three historical shoreline positions spanning from 2000 to 2020. Temporal resolution plays a key role in shoreline monitoring—not only to ensure the data accurately represents the selected period of analysis (whether short-term for event-based changes or long-term for secular trends), but also to address cost-effectiveness considerations [1].

The long-term shoreline variation was defined as the period (twenty years) necessary to relatively minimise the short-term changes and delineate the true long-term trend while the short-term shoreline variations was defined as the period (ten to fifteen years) necessary to capture shoreline changes due to possible storm events, seasonality of the wave climate, longshore migration of sand bodies or impacts of engineering activities like beach nourishment. Each shoreline will be digitized from Landsat images in a polyline shapefile using ArcGIS to confirm the shoreline position. The shoreline proxy will be boundary between the dry and wet sand seen in the Landsat images. The other digitized shorelines will be appended on the recent Landsat image hence creating historical shoreline positions. A baseline polyline shapefile will be created and the outer offshore baseline constructed by hand through digitizing a line onscreen in ArcGIS and estimating a preferred location by eye in order to obtain desired transect orientations across the historical shorelines and parallel the general orientation of the historical shorelines in the GIS. Following the creation of the baseline, transect lines will be casted perpendicular to the baseline at a 50m spacing and transect length of 1000m spacing along the baseline. Transect lines will be intersected with the historical shorelines to produce a database of points, which will record the locations of historical shoreline positions along

each transect through time. The estimate for shoreline position error will be set at 1m.

Statistics will be calculated for transects in the AMBUR (Analyzing Moving Boundaries Using R) software and stored in a data table with the confidence level calculated for linear regression set at 95%. Analysis will be done for the entire stretch of the Bonny shoreline as well as the study area. Subsequently, a projection of future shoreline positions based on calculated shoreline rate-of-change statistics. The area of accretion or erosion will also be measured using a polygon shapefile. Ground truthing on the entire study area will be conducted for one week. The aim is to gather information from the field and interview the people

from the study area. The persons to be interviewed will be asked about the status of the shoreline in relation to previous years. Their responses will be corrected with the with the GIS analytical findings. A number of photographs will also taken of the study site using a digital camera in order to capture the area's current appearance.

III. RESULT AND DISCUSSION

Along the coast of Kuruma, 4417 transects have negative distances and 1520 positive. The largest landward movement was 515.90 m, and the greatest seaward movement was 1324.71 m (Figure 1a and Table 1).

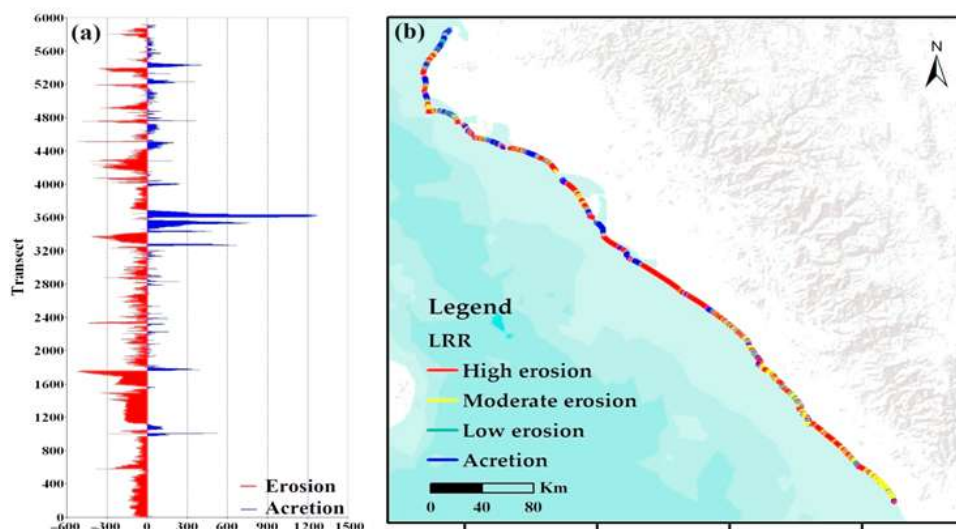


Figure 1. Shoreline dynamics and evaluation, (a) NSM (m), (b) LRR (m/year), along Kuruma.

The result of the LRR statistic (Figure 1a) shows that Kuruma presented with constant erosion with an overall rate of change of -1.58 m/year along its coast. Seventy-eight percent of the shoreline is eroding at an average rate of -3.33 m/year.

The rest of the shoreline is accreting at an average rate of 4.89 m/year. A maximum erosion and accretion rate of -20.87 and 55.21 m/year, respectively, were observed. Though WLR presented with an overall rate of change of -1.12 m/year lower than that of LRR, it followed a similar trend to the LRR (Figure 1b).

A large portion of Kuruma is shoreline that has experienced significant erosion, largely attributed to the construction of tank farms along many of its rivers. These developments have

resulted in the retention of sediments that would have otherwise reached the ocean, leading to sediment starvation and erosion, particularly at the mouths of these rivers [1]. Another reason for the high erosion rate along the Kuruma coast is its exposure to constant meteorological activity. Positioned in a natural tropical cyclone corridor, the region experiences increased shoreline variability and short-term erosional events, some of which become permanent and adversely impact both the coastal system and nearby infrastructure.

Kuruma is also affected by various anthropogenic activities along the shoreline, such as the construction of breakwaters, jetties, and other coastal protection structures. These directly and indirectly interfere with natural sediment transport. Given that approximately 80% of the

community resides near these coastal zones, human activities have further heightened the vulnerability of the coastal environment to erosion. This situation aligns with findings by Thinh and Hens [2], who noted that anthropogenic coastal modifications significantly influence sediment dynamics.

Several coastal investigations have been conducted in Kuruma and surrounding areas. For instance, Strauss et al. [3] documented that the region is already highly eroded. Similarly, Stronkhorst et al. [4] analyzed historical shoreline changes and identified a long-term erosion rate of -5.4 m/year. Jimenez-Illescas et al. [5] found that the Kuruma shoreline has retreated by up to 300 meters along its 4.5 km stretch, recommending the use of geo-tubes as a mitigation measure. Other beaches in the area, such as Coconut Estate Beach, have also experienced erosion rates of -1.9 ± 0.9 m/year over the past decade, which is comparable to the rates observed in this study [6]. Coastal variability has similarly affected nearby lagoon systems, such as the Topolobampo lagoon, where tidal hydrodynamics continue to influence sediment export and shoreline fluctuation.

In Oloma, shoreline monitoring revealed 9558 transects with negative distances and a maximum landward movement of -2880.39 m. In contrast, 1348 transects recorded positive distances with a maximum seaward movement of 747.76 m. The Sonora coast exhibited a general linear

regression rate (LRR) of -4.57 m/year, making it the most variable region in terms of shoreline dynamics. Overall, 88% of the Sonora shoreline is undergoing erosion at an average rate of -5.42 m/year, while the remaining 12% is accreting at an average rate of 1.75 m/year. The maximum recorded erosion and accretion rates were -118.08 m/year and 43.12 m/year, respectively. The weighted linear regression (WLR) method showed a rate of -3.69 m/year, consistent with the LRR trend with only a 0.88 m/year difference.

Unlike Kuruma, the northern coast of Oloma faces extreme erosion primarily due to oil and gas operations. These activities have substantially disrupted river discharge and sediment delivery, causing sediment starvation in the delta and contributing to significant shoreline retreat. This observation aligns with Laksono et al. [7], who argued that reduced sediment supply due to water abstraction for agriculture and domestic use is a major factor in beach loss. Additionally, the marine environment in this region experiences both semi-diurnal and diurnal tidal cycles, with tidal ranges from 6.95 m in Kuruma to approximately 10 m in the Oloma delta. Today, sediment dispersal, transport, and deposition in these regions are predominantly controlled by oceanic forces rather than fluvial processes, further exacerbated by the anthropogenic pressures from tourism and residential development in coastal zones.

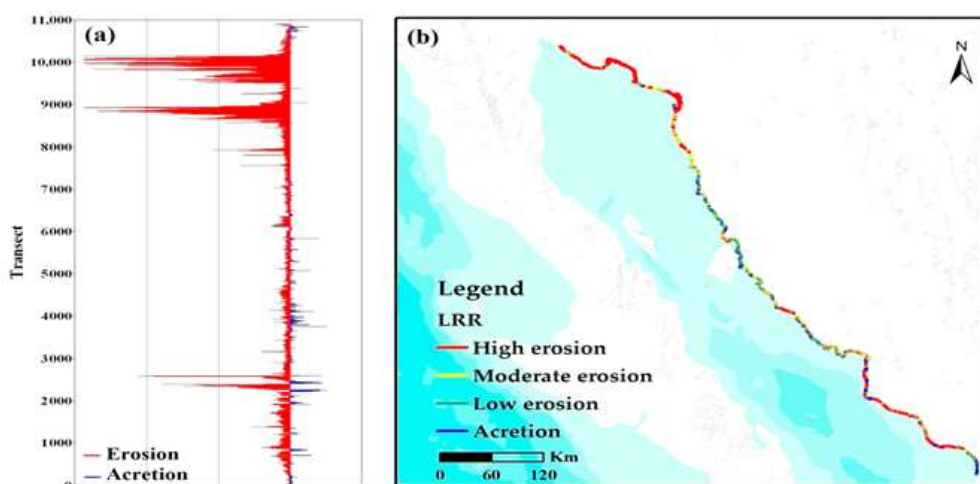


Figure 2. Shoreline dynamics and evaluation, (a) NSM (m), (b) LRR (m/year), and (c) WLR (m/year) along Oloma.

In the case offon the coast of Kalaibiamma, 749 transects had negative distances and 544 positives. The most landward movement

was -1650.21 m, and the maximum seaward movement was 278.6 m (Figure 3). The LRR presented an overall rate of change of -2.35

m/year, 47.8% of the coast presented erosion with an average rate of 5.88m/year, and 51.2% of the coast presented accretion with an average rate of 0.89m/year. The maximum observed rate of erosion and accretion was -46.27 and

6.54m/year, respectively (Figure 4.5 and Table 3). The overall rate of change WLR was -1.89 m/year with a similar trend to LRR along the coast (Figure 3b)

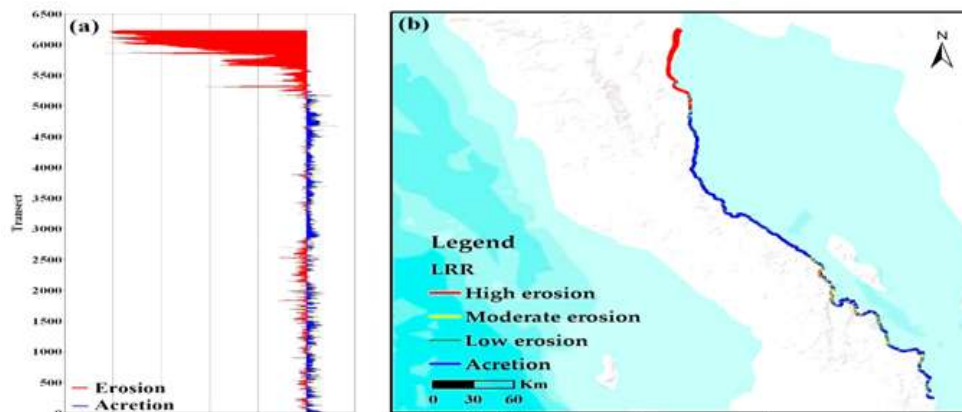


Figure 3 Shoreline dynamics and evaluation, (a) NSM (m), (b) LRR (m/year), and (c) WLR (m/year) for Abalamabie.

For Abalamabie, the results revealed that the upper coast is dominated by significant erosion, primarily attributed to human activities. At present, the volume of sediments reaching the coastline is minimal, rendering the area increasingly sensitive to variations in physical conditions [1]. Consequently, the variability of the shoreline is now influenced less by sediment supply and more by the mechanisms of sediment transport governed by oceanic forcing in the region [1]. Additionally, shoreline analysis for Abalamabie indicated that 5,571 transects exhibited negative distances, with a maximum landward retreat of -176.94 m, while 4,518

transects displayed positive distances, with a maximum seaward advance of 318.92 m.

The results reveal that the coast of Abalamabie is the most stable, in contrast to the other states (Figure 4.7a). Its overall rate of change was -0.31 m/year. The results show that 66.14% of the shoreline is undergoing erosion with an average rate of -0.83m/year, while the rest is undergoing accretion with an average rate of 0.7m/year, and a maximum erosion and accretion rate of -22 and 14.32m/year, respectively (Figure 8b). The WLR presented an overall rate of change of -0.45m/year with a trend very similar to the LRR with a difference of 0.14 (Figure 8c).

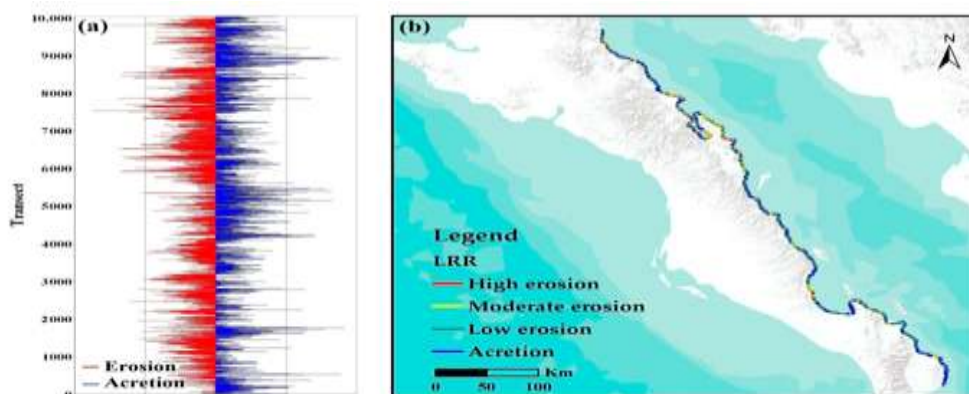


Figure 4. Shoreline dynamics and evaluation, (a) NSM (m), (b) LRR (m/year), and (c) WLR (m/year) for Abalamabie.

Abalamabie.

The primary factors responsible for beach variability in Abalamabie are attributed to climate change, which increases wave energy and the frequency of tropical cyclones. These climatic events lead to alternating periods of erosion and accretion, aligning with findings from studies on the Pacific coast [1]. Although anthropogenic impacts are locally significant, such as in Loreto and La Paz, where alterations to the natural sedimentary system have resulted in either erosion or accretion, the influence of natural sediment transport remains substantial [2]. Research by Panama [1] estimated the accretion and erosion rates of the Bonny coastline using Landsat satellite imagery for the period 1984–2016. That study also

investigated barrier rock deposits formed by lateral transport from neighboring rocky shores, which are frequently subjected to storm-induced erosion.

Furthermore, a scatterplot and regression analysis were conducted using data derived from the Linear Regression Rate (LRR) of actual and model-predicted shorelines for each location. The results indicated a strong relationship, with R^2 values exceeding 0.78 across all four areas analyzed. For the entire shoreline, the regression yielded an R^2 of 0.95, confirming a strong correlation between the actual shoreline position and the predicted shoreline position based on the model.

Table 1: Factors responsible for shoreline changes along Bonny and Kaa shoreline

Statement	Strongly Disagree		Disagree		Agree		Strongly Agree	
	(Freq)	(%)	(Freq)	(%)	(Freq)	(%)	(Freq)	(%)
Tidal action	30	10.0%	60	20.0%	120	40.0%	90	30.0%
Wave erosion	15	5.0%	45	15.0%	105	35.0%	135	45.0%
Sea level rise	45	15.0%	75	25.0%	90	30.0%	90	30.0%
Rainfall	30	10.0%	60	20.0%	120	40.0%	90	30.0%
Sand mining	18	6.0%	42	14.0%	114	38.0%	126	42.0%
Construction	27	9.0%	51	17.0%	108	36.0%	114	38.0%
Oil exploration	24	8.0%	42	14.0%	102	34.0%	132	44.0%
Mangrove loss	36	12.0%	54	18.0%	96	32.0%	114	38.0%
Weak regulations	33	11.0%	57	19.0%	105	35.0%	105	35.0%
No protection	21	7.0%	48	16.0%	111	37.0%	120	40.0%
Low awareness	42	14.0%	66	22.0%	96	32.0%	96	32.0%
Government inaction	36	12.0%	72	24.0%	111	37.0%	81	27.0%

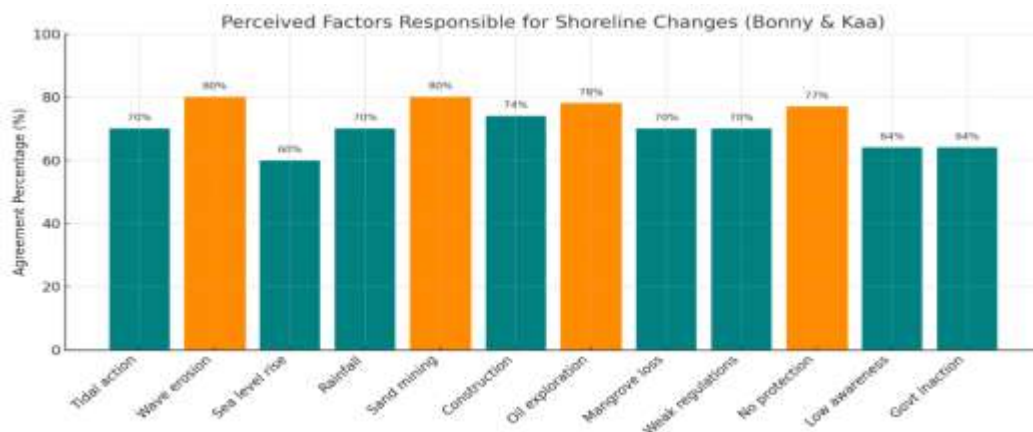


Fig. 5: Factors responsible for shoreline changes along Bonny and Kaa shoreline

The analysis of responses from 300 participants reveals that a variety of natural and human-induced factors contribute to shoreline changes along the Bonny and Kaa coastal areas in Rivers State. A significant portion of respondents acknowledged tidal action as a key factor, with 120 individuals (40%) agreeing and 90 (30%) strongly agreeing—amounting to 210 (70%) in total. This suggests that tides are widely perceived to influence the retreat of shorelines. Wave erosion received the highest level of agreement among all the factors surveyed. While only 15 respondents (5%) strongly disagreed and 45 (15%) disagreed, a remarkable 105 (35%) agreed and 135 (45%) strongly agreed, resulting in 240 participants (80%) identifying it as a major driver of coastal change. Opinions on sea level rise were more divided. Although 90 respondents (30%) agreed and another 90 (30%) strongly agreed, a notable 120 (40%) either disagreed (25%) or strongly disagreed (15%), indicating a more mixed awareness or belief in its local effects. Similarly, rainfall was perceived as influential by a majority, with 210 respondents (70%) agreeing or strongly agreeing. Specifically, 120 (40%) agreed and 90 (30%) strongly agreed, while 30 (10%) strongly disagreed and 60 (20%) disagreed. The issue of sand mining drew substantial concern. A combined 240 respondents (80%) considered it a contributor to shoreline erosion, with 114 (38%) agreeing and 126 (42%) strongly agreeing. Only a small fraction—6% strongly disagreed and 14% disagreed—opposed this view. In terms of construction activities near the shoreline, 108 respondents (36%) agreed and 114 (38%) strongly agreed, summing up to 222 (74%) who believed such development disturbs the natural balance of the coast. Oil exploration was also recognized as a major factor, with 234 respondents (78%) agreeing (34%) or strongly agreeing (44%). This reflects community awareness of the environmental impact of oil-related activities in the Niger Delta region. The loss of mangroves, which naturally stabilize coastlines, was confirmed as significant by 210 respondents (70%). Out of these, 96 (32%) agreed and 114 (38%) strongly agreed. A minority—12% strongly disagreed and 18% disagreed—downplayed its impact. Regarding regulatory enforcement, a total of 210 participants (70%) blamed weak policies and oversight for the worsening condition of the shoreline. Agreement was split evenly: 105 (35%) agreed and 105 (35%) strongly agreed. There was

also a strong response to the lack of shoreline protection structures, with 111 (37%) agreeing and 120 (40%) strongly agreeing. This totals 231 participants (77%) who believed that proper engineering interventions are lacking. Public awareness was another area of concern, where 96 respondents (32%) agreed and another 96 (32%) strongly agreed that limited knowledge among the populace exacerbates shoreline degradation. However, a combined 36% of participants (14% strongly disagreed and 22% disagreed) expressed less concern about awareness levels. Finally, government inaction was cited by 192 respondents (64%) as a critical issue, with 111 (37%) agreeing and 81 (27%) strongly agreeing. Still, 108 respondents (36%) either disagreed (24%) or strongly disagreed (12%), pointing to a divide in perceptions of government responsibility.

IV. CONCLUSION

In conclusion, the Bonny and Kaa shoreline is subjected to a multitude of factors contributing to shoreline changes. Continuous monitoring and integrated management approaches are essential for building more resilient coastal ecosystems. Addressing the impacts of climate change, human-induced modifications, and local geological influences will be fundamental in shaping future shoreline management practices and ensuring the sustainability of these crucial coastal regions.

REFERENCES

- [1]. R. Correll-Brown, E. Wellman, D. Eulie, S. Scyphers, C. Smith, M. Polk, et al., "Shifting baselines may undermine shoreline management efforts in the United States," *Front. Clim.*, vol. 4, 2022. [Online]. Available: <https://doi.org/10.3389/fclim.2022.719109>
- [2]. Y. Cui, F. Yan, B. He, C. Ju, and F. Su, "Characteristics of shoreline changes around the South China Sea from 1980 to 2020," *Front. Mar. Sci.*, vol. 9, 2022. [Online]. Available: <https://doi.org/10.3389/fmars.2022.1005284>
- [3]. B. Gutierrez, N. Plant, and E. Thieler, "A Bayesian network to predict coastal vulnerability to sea level rise," *J. Geophys. Res. Atmos.*, vol. 116, no. F2,

2011. [Online]. Available: <https://doi.org/10.1029/2010JF001891>
- [4]. N. Hoa, C. McAlpine, D. Pullar, S. Leisz, and G. Gramotnev, "Drivers of coastal shoreline change: Case study of Hon Dat coast, Kien Giang, Vietnam," *Environ. Manage.*, vol. 55, no. 5, pp. 1093–1108, 2015. [Online]. Available: <https://doi.org/10.1007/s00267-015-0455-7>
- [5]. E. Lazarus and A. Murray, "Process signatures in regional patterns of shoreline change on annual to decadal time scales," *Geophys. Res. Lett.*, vol. 34, no. 19, 2007. [Online]. Available: <https://doi.org/10.1029/2007GL031047>
- [6]. E. Lazarus, A. Ashton, and A. Murray, "Large-scale patterns in hurricane-driven shoreline change," in *Coastal Sediments 2011*, pp. 127–138. [Online]. Available: <https://doi.org/10.1029/2011GM001074>
- [7]. G. Masselink, B. Castelle, T. Scott, and A. Konstantinou, "Role of atmospheric indices in describing shoreline variability along the Atlantic coast of Europe," *Geophys. Res. Lett.*, vol. 50, no. 22, 2023. [Online]. Available: <https://doi.org/10.1029/2023GL106019>
- [8]. A. Sarhan, M. Iskander, K. Nassar, and M. Elgamal, "Shoreline changes detection using digital shoreline analysis system: Case study Damietta – Port Said coastal area, Egypt," *MEJ Mansoura Eng. J.*, vol. 47, no. 1, pp. 35–48, 2022. [Online]. Available: <https://doi.org/10.21608/bfemu.2022.236869>
- [9]. H. Tian, K. Xu, J. Goés, Q. Liu, H. Gomes, and M. Yang, "Shoreline changes along the coast of mainland China—Time to pause and reflect?" *ISPRS Int. J. Geo-Inf.*, vol. 9, no. 10, p. 572, 2020. [Online]. Available: <https://doi.org/10.3390/ijgi9100572>
- [10]. X. Wang, Y. Liu, F. Ling, Y. Liu, and F. Fang, "Spatio-temporal change detection of Ningbo coastline using Landsat time-series images during 1976–2015," *ISPRS Int. J. Geo-Inf.*, vol. 6, no. 3, p. 68, 2017. [Online]. Available: <https://doi.org/10.3390/ijgi6030068>