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Shoreline Change Assessment in the Orashi River, Rivers State, Nigeria, using the Digital Shoreline Analysis System (DSAS)

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Abstract

Shoreline change profoundly impacts coastal geology and coastal communities. This study, spanning three decades from 1992 to 2022, employed the Digital Shoreline Analysis System (DSAS) to assess the Orashi River shoreline dynamics in Nigeria. Using Landsat imagery data from the United States Geological Survey (USGS) and ArcGIS 10.6, DSAS 5.0 software was utilized for analysis. Various statistical methods, including Linear Regression Rate (LRR), Weighted Linear Regression (WLR), End Point Rate (EPR), Net Shoreline Movement (NSM), and Shoreline Change Envelope (SCE), quantified shoreline changes. The findings consistently reveal significant shoreline regression. LRR, -1.78 to -1.07, highlights continuous landward movement, signifying erosion's persistent impact. WLR rates reaffirm this trend, closely mirroring the range of -1.78 to -1.07. EPR, -2.79 to -1.29, further underline the erosional trend, emphasizing substantial inland shifts. NSM, ranging from -48.66 to -20.30, signifies substantial shoreline retreat, showcasing erosion's profound effect. The NSM, varying from 0.69 to -11.50, illustrates dynamic shoreline movement with varying degrees of erosion. The outcomes identify prevalent erosion, particularly in Very High Erosion (VHE) areas, while High Accretion (HA) and Very High Accretion (VHA) zones experience shoreline gain. These classifications inform coastal management strategies, urging protective measures for VHE areas and development opportunities in HA and VHA zones. The variability in shoreline change underscores coastal dynamics' complexity. This study contributes to understanding the Orashi River's shoreline processes, guiding sustainable coastal management and environmental conservation efforts. Continued monitoring and research are crucial for adapting to the evolving coastal landscape's impact on the environment and local communities.

Keywords: Landsat imagery; Accretion; Erosion; Shoreline; Digital shoreline analysis system (DSAS).

1. Introduction

Shoreline change, a widely studied coastal phenomenon and one of the most prevalent natural hazards globally, Obiene, *et al.* [1] and Toure, *et al.* [2], poses a significant threat to coastal environments, human lives, and property. It plays a crucial role in various economic, ecological, and societal aspects by serving as trade hubs, diverse ecosystem habitats, and protective barriers against natural disasters like storms and floods. The complexity and dynamic nature of environmental and social processes in coastal areas make shoreline change particularly impactful on both the environment and human communities. In the context of Nigeria, the Orashi River region stands out as a prime example of the intricate interplay between human activities and natural processes, making it a focal point for the study of shoreline change [3] Situated in the Niger Delta region of Nigeria, the Orashi River area is not only teeming with biodiversity but also holds immense economic importance due to its oil and gas resources, fisheries, and agricultural potential. Nevertheless, this region faces formidable challenges stemming from a growing population and anthropogenic activities such as urbanization, industrialization, and deforestation [3]**.** As a result, shoreline change analysis assumes a pivotal role in coastal protection planning, disaster management, sea-level rise assessments, hazard zone development, numerical method calibration, and the policy-making processes related to coastal development. Various methods exist for detecting and analyzing shoreline changes, including Historical Land-Based Photographs; Coastal Maps and Charts; Aerial Photography; Beach Surveys; GPS shoreline surveys; Remote Sensing; Multispectral/Hyperspectral satellite Image analysis; Airborne Light Detection and Ranging Technology; Microwave Sensors; and Video Imaging [4]. Remote sensing, compared to traditional survey techniques, stands out as a highly effective and cost-efficient approach due to its accuracy and efficiency [5]. Additionally, Geographic Information Systems (GIS) technology enables the creation of high-quality maps and the visualization of complex data, making it a valuable tool across various disciplines in coastal studies. The Digital Shoreline Analysis System (DSAS), an extension tool, plays a pivotal role in coastal geomorphology and management. Developed by the United States Geological Survey (USGS), DSAS leverages GIS and remote sensing technologies to extract precise shoreline positions from historical aerial and satellite imagery [6]. DSAS facilitates the calculation of shoreline change rates and trends by comparing these shoreline positions over time, offering crucial insights into the causes and consequences of coastal erosion and accretion [7]. This study's primary objective is to employ DSAS comprehensively in assessing shoreline change in the Orashi River region of Nigeria. By harnessing DSAS's capabilities, we will delve into the underlying drivers of shoreline change, assess its impacts on local communities and ecosystems, and propose well-informed strategies for sustainable coastal management. Through this research, we aim to make a meaningful contribution to the body of knowledge concerning coastal dynamics in Nigeria, highlighting the significance of advanced tools like DSAS in fostering coastal resilience and long-term environmental sustainability.

2. Study area

The chosen study location is situated in the southern part of Nigeria, specifically in Ahoada West, Rivers State. This region falls within the geographical coordinates of 5° 5' 11" North latitude and 6° 28' 31" East longitude, as illustrated in Figure 1. A significant portion of the population in Ahoada West LGA sustains their livelihoods through fishing and farming. The area is known for the cultivation of various crops, including oil palm, yam, cassava, and a diverse range of vegetables. Additionally, the local economy benefits substantially from mineral resources such as crude oil and natural gas deposits in Ahoada West.

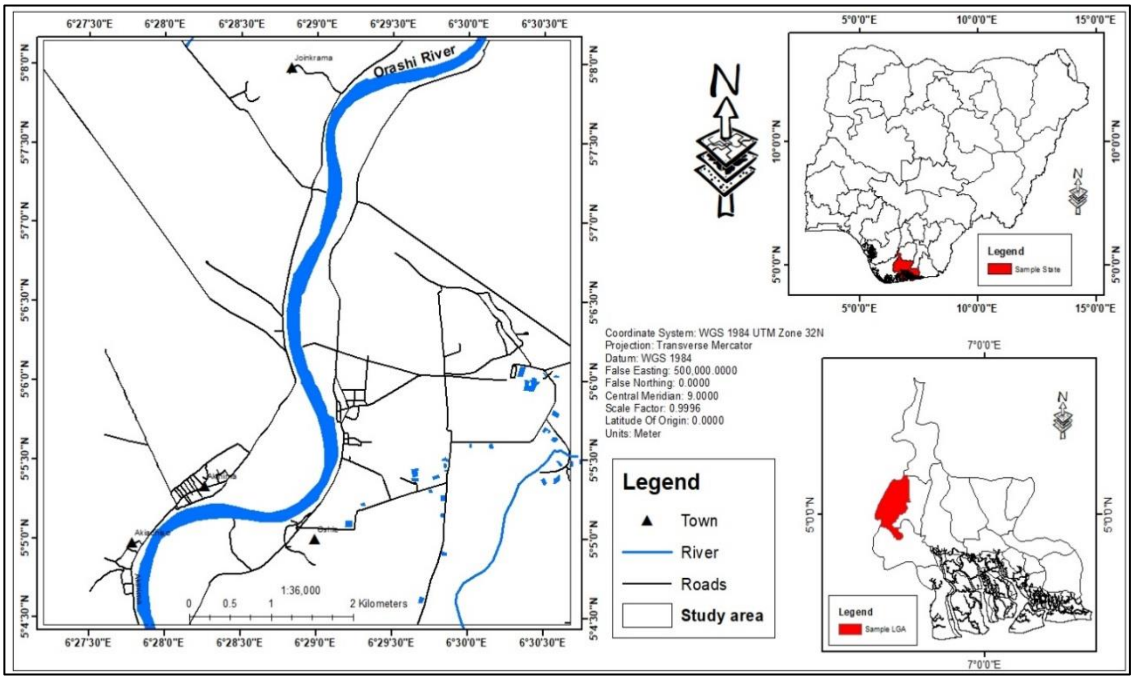

Figure-1. Map of the study area

3. Geology of the Study area

The study area is situated in the southwestern region of the Niger Delta, which is a sedimentary basin formed as a result of a failed rift junction between the South American and African plates during the late Jurassic to mid-Cretaceous period [8]. Encompassing a vast land expanse exceeding 105,000 square kilometers [9], the Niger Delta Basin is characterized by various geological formations. Within the study area, notable geological formations include the Akata Formation, Agbada Formation, and Benin Formation. The Akata Formation, the oldest and deepest among them, spans from the Paleocene to the Holocene age [10]. Comprising substantial layers of shales, turbidite sands, and smaller quantities of silt and clay, this formation represents deposits from deep marine environments, with plant remnants found near its boundary with the overlying Agbada Formation [10]. It hosts a diverse microfauna, including planktonic foraminifera, indicative of a shallow marine shelf depositional setting [9]. The Akata Formation exhibits varying thicknesses, ranging from 0 to 6,000 meters, and is primarily subsea, not visible from the shoreline [11].

4. Material and Methods

4.1. Material

4.1.1. Data Collection

Over 30 years (1990-2020), we tracked Orashi River shoreline changes using three different satellite images. We acquired multi-temporal Landsat data (TM, ETM+, and OLI) from the US Geological Survey website for 1992, 2002, 2012, and 2022. To ensure data quality, we chose images from December or January, reducing issues like cloud cover and atmospheric distortions.

Table-1. List of Data Satellite collected

Satellite Data	Date	Spatial Resolution (m)	Source
Landsat 5	12/24/1992 Path: 189, Row: 56	30	https://earthexplorer.usgs.gov/
Landsat 7	12/08/2002 Path: 189, Row: 56	30	https://earthexplorer.usgs.gov/
Landsat 8	12/12/2012 Path: 189, Row: 56	30	https://earthexplorer.usgs.gov/
Landsat 8	01/10/2022 Path: 189, Row: 56	30	https://earthexplorer.usgs.gov/

4.1.2. Data Processing

The DSAS (Digital Shoreline Analysis System) tool is a critical resource for coastal management and decision-making [12]. It automates essential coastal analysis tasks, such as area measurement, rate calculation, statistical data generation, and shoreline prediction, through a beta model. DSAS also provides 30-year shoreline projections with ambiguity bands, aiding coastal planning [12]. To analyze shorelines, multi-temporal satellite imagery was manually digitized in vector format using ArcGIS 10.4. Each image was individually digitized. The data from different time periods was then input into DSAS 5.0 for calculating 30-year shoreline changes from 1992 to 2022. The resulting dataset had various attributes, including object ID, shape, date, shape length, ID, and uncertainty values. These shorelines were merged into a single feature in an attribute table. To calculate shoreline changes accurately, the outer shoreline baseline was digitized, capturing its direction and shape. Cross-shore transects were generated for change calculations using DSAS version 5, with the assistance of a United States Geological Survey (USGS) ArcGIS tool.

5. Methods

5.1. Statistical Approaches

In this study, we employed various statistical techniques, such as Linear Regression Rate (LRR), End Point Rate (EPR), and Net Shoreline Movement (NSM), using the Digital Shoreline Analysis System (DSAS) to analyze shoreline changes [12]. DSAS 5.0, developed by the United States Geological Survey (USGS) for ArcGIS 10.6, employs statistical methods to assess shoreline changes over time.

For long-term shoreline changes, we utilized multi-temporal Landsat satellite data and employed Weighted Linear Regression (WLR) [13]. The weight (w) used in WLR is determined as $W=1/(e^2)$, where e represents measurement uncertainty (1).

Total Positional Uncertainty (Et) was computed as the square root of the sum of squared errors from various sources, including seasonal error (Es), tidal error (Et), digitizing error (Ed), pixel error (Ep), and rectification error (Er) [14].

$$Et = \pm\sqrt{(Es^2 + Et^2 + Ed^2 + Ep^2 + Er^2)} \qquad (2)$$

This Et value was used as a weight in the shoreline change analysis within DSAS, employing weighted linear regression or weighted least squares.

Net Shoreline Movement (NSM) measures the distance between the oldest and most recent shorelines at each transect [15].

The Shoreline Change Envelope (SCE) calculates the distance between the shoreline farthest from and closest to the baseline at each transect [12].

End Point Rate (EPR) is determined as $R = D / Te$, (3)

where R is the rate in meters per year, D is the distance in meters, and Te is the time elapsed between the oldest and most recent shorelines in years [12, 15, 16];.

Linear Regression Rate (LRR) is represented by the slope value (m) of a least-squares regression line, given by the equation $y = mx + b$ (4)

Oyedotun [15]; Prukpitikul, *et al.* [17], where y signifies the distance from the baseline, m is the slope (LRR method), and b is the y-intercept [12].

Weighted Linear Regression Rate (WLR) incorporates weights based on shoreline uncertainty to determine the best-fit regression line, affecting both the slope (mw) and y-intercept (bw) in the equation $y = mw*x + bw$ [12]. WLR requires a minimum of three historical shoreline positions [14].

6. Result and Discussion

6.1. Shoreline Extraction

Shoreline alterations along the Orashi River, which traverses Ahoada East LGA and its vicinity, can be observed in Figure 2. These changes were derived from Landsat imagery using the ArcGIS software. The analysis revealed shoreline lengths of 61.21 km in 1992, 73.85 km in 2002, 65.27 km in 2012, and 62.84 km in 2021 as seen in Table 2 and Figure 2. The examination of shoreline changes spans three intervals: from 1992 to 2002 (a 10-year duration), from 1992 to 2012 (a 20-year period), and from 1992 to 2022 (approximately 30 years). Over this extended timeframe, significant long-term changes, notably erosion, became evident, resulting in the deterioration of buildings and agricultural areas.

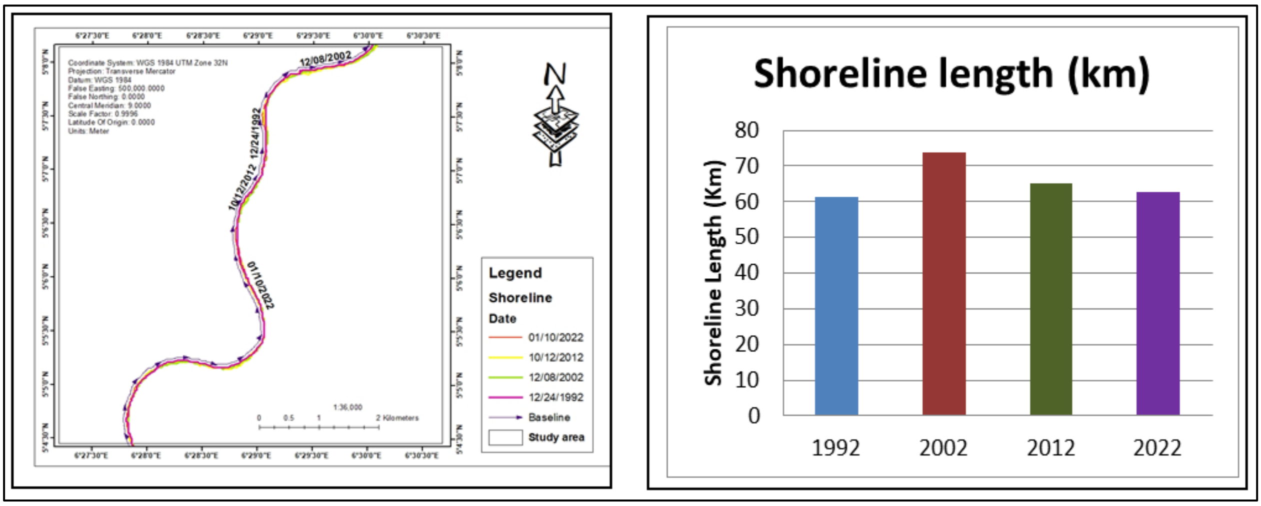

Figure-2. Map showing shoreline changes in Orashi River and Chart of Shoreline Length against year

Table-2. Shoreline Length and Date from Satellite

S/N	Date	Shoreline length (km)	Baseline Length (km)
1	12/24/1992	61.21	1
2	12/08/2002	73.85	
3	10/12/2012	65.27	
4	01/10/2022	62.84	

6.2. Mean Shoreline Change Trend in the Selected Zones of Orashi River

6.2.1. Linear Regression Rate

The Linear Regression Rate quantifies the long-term shoreline change by fitting a linear regression model to the shoreline positions over the study period. Table 3 presents the results of Linear Regression Rate, showing a range of values from -1.78 to -1.07, indicating an overall retreat of the shoreline as seen in Figure 3.

6.2.2. End Point Rate

End Point Rate estimates shoreline change by comparing the positions of the initial and final endpoints over the study period. The results in Table 3 reveal End Point Rate values ranging from -2.79 to -1.29, indicating a significant shoreline retreat (Figure 3).

6.2.3. Weighted Linear Regression

Weighted Linear Regression assigns different weights to shoreline positions based on their proximity to the end points. It provides a more accurate representation of shoreline change trends. Table 3 indicates Weighted Linear Regression values ranging from -1.78 to -1.07, consistent with the Linear Regression (Figure 4).

6.2.4. Net Shoreline Movement (NSM)

Net Shoreline Movement measures the overall change in shoreline position between the starting and ending points. The NSM values presented in Table 3 range from -48.66 to -20.30, signifying substantial shoreline retreat as seen in Figure 4.

6.2.5. Shoreline Change Envelope

The Shoreline Change Envelope represents the range of shoreline changes observed during the study period. Table 3 displays the Shoreline Change Envelope with values spanning from 0.69 to -11.50, indicating variability in shoreline changes across the study area in Figure 5.

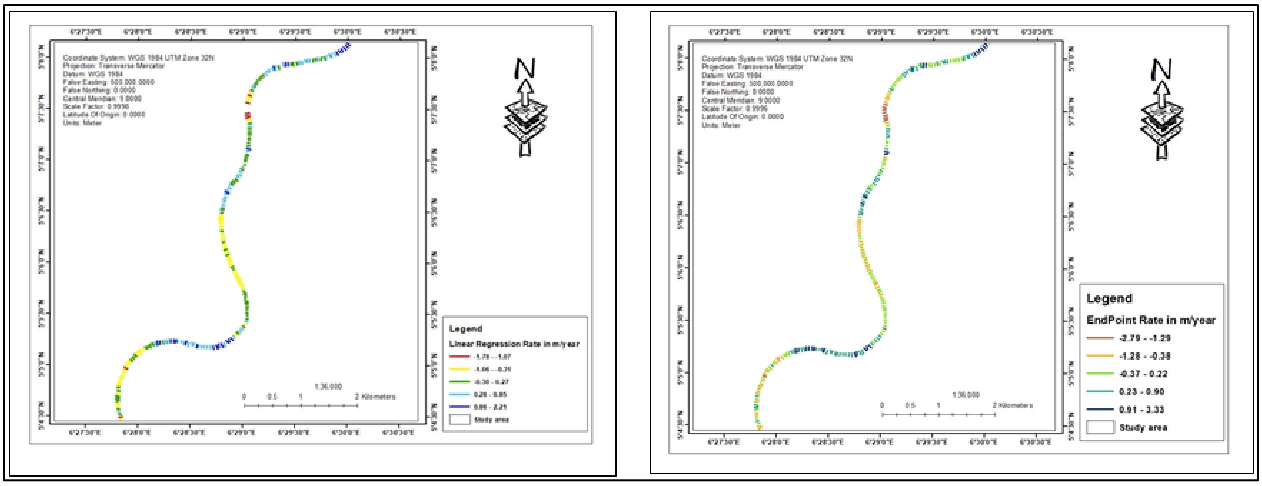

Figure-3. Shoreline Accretion/Erosion and Linear Regression Rate (LRR) in Orashi River

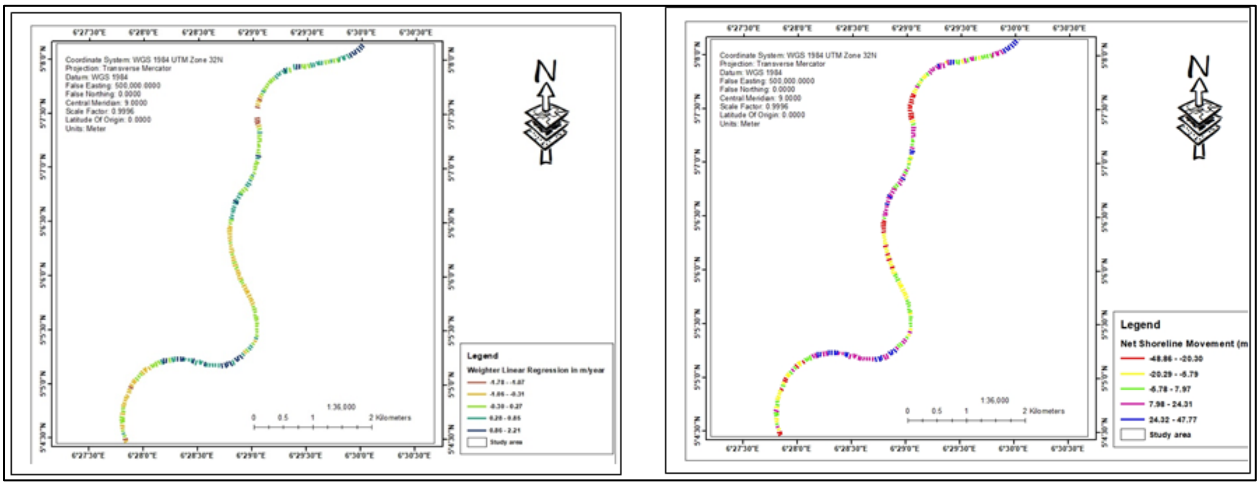

Figure-4. Weighted Linear Regression (WLR) and Net Shoreline Movement (NSM) in Orashi River

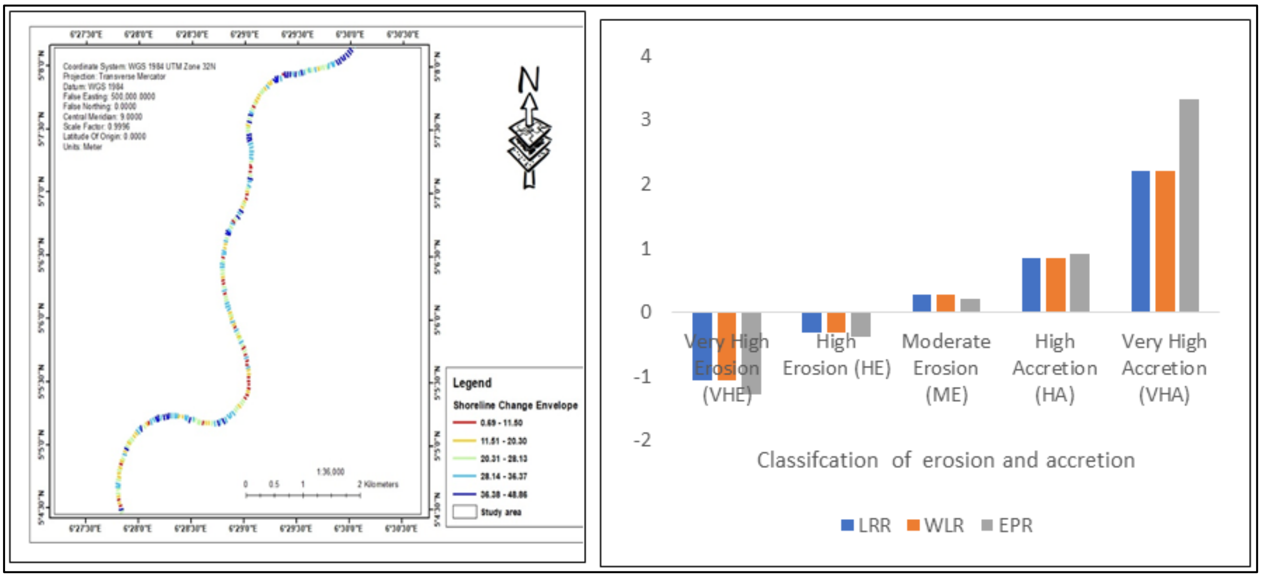

Figure-5. Shoreline Change Envelope (SCE) and classification of erosion and accretion in Orashi River

Table-3. Result from DSAS and classification of erosion and accretion in Orashi River

Linear Regression Rate	***Weighted Liner Regression***	***End Point Rate***	***Net Shoreline Movement (NSM)***	**Shoreline Change Envelope**	**Classification of Erosion and Accretion**
-1.78 – -1.07	-1.78 – -1.07	-2.79 – -1.29	-48.66 – -20.30	0.69 – -11.50	Very High Erosion (VHE)
-1.06 – -0.31	-1.06 – -0.31	-1.28 – -0.38	-20.29 – -5.79	11.51 – 20.30	High Erosion (HE)
-0.30 – 0.27	-0.30 – 0.27	-0.37 – 0.22	-5.78 – 7.97	20.31 – 28.13	Moderate Erosion (ME)
0.28 – 0.85	0.28 – 0.85	0.23 – 0.90	7.98 – 24.31	28.14 – 36.37	High Accretion (HA)
0.86 – 2.21	0.86 – 2.21	0.91 – 3.33	24.32 – 47.77	36.38 – 48.86	Very High Accretion (VHA)

6.2.6. Erosion and Accretion Patterns

The analysis demonstrates that the Orashi River shoreline has undergone diverse changes over the past 30 years. The classification of erosion and accretion categories provides insights into the spatial distribution of these processes (Table 3).

6.2.7. Very High Erosion (VHE)

The shoreline segments in Table 3 and Figure 5 falling within the range of -1.78 to -1.07 for Linear Regression Rate, Weighted Linear Regression, and -2.79 to -1.29 for End Point Rate exhibit very high erosion rates. The Net Shoreline Movement (NSM) values in the range of -48.66 to -20.30 further confirm significant erosion. The Shoreline Change Envelope, spanning from 0.69 to -11.50, underscores the dynamic nature of these areas. This classification indicates that certain portions of the Orashi River shoreline have experienced severe erosion over the past 30 years, warranting immediate attention for coastal protection and management.

6.2.8. High Erosion (HE)

Shoreline segments with erosion rates (Table 3 and Figure 5) falling within the range of -1.06 to -0.31 for Linear Regression Rate, Weighted Linear Regression, and -1.28 to -0.38 for End Point Rate are categorized as experiencing high erosion. The NSM values ranging from -20.29 to -5.79 indicate substantial erosion, though less severe than in the VHE category. The Shoreline Change Envelope between 11.51 and 20.30 suggests areas with notable variability in shoreline movement. These findings identify regions with ongoing erosion issues that require monitoring and potential mitigation measures.

6.2.9. Moderate Erosion (ME)

Shoreline segments with erosion rates ranging from -0.30 to 0.27 for Linear Regression Rate, Weighted Linear Regression, and -0.37 to 0.22 for End Point Rate fall into the moderate erosion category. NSM values between -5.78 and 7.97 indicate relatively stable or only mildly eroding areas as seen in Table 3 and Figure 5. The Shoreline Change Envelope spanning from 20.31 to 28.13 suggests moderate variability in shoreline movement. These segments may not be facing immediate threats but still require continuous monitoring to assess long-term trends.

6.2.10. High Accretion (HA)

Shoreline segments with accretion rates falling within the range of 0.28 to 0.85 for Linear Regression Rate, Weighted Linear Regression, and 0.23 to 0.90 for End Point Rate are classified as experiencing high accretion in Table 3 and Figure 5. NSM values ranging from 7.98 to 24.31 indicate significant accretion. The Shoreline Change Envelope between 28.14 and 36.37 suggests areas with moderate variability in shoreline movement. High accretion zones may be susceptible to changes in sediment supply and require monitoring to assess potential impacts on coastal dynamics.

6.2.11. Very High Accretion (VHA)

From Table 3 and Figure 5 the shoreline segments with accretion rates in the range of 0.86 to 2.21 for Linear Regression Rate, Weighted Linear Regression, and 0.91 to 3.33 for End Point Rate fall into the very high accretion category. NSM values between 24.32 and 47.77 indicate substantial accretion. The Shoreline Change Envelope spanning from 36.38 to 48.86 suggests areas with relatively stable or gradually expanding shorelines. Very high accretion zones may indicate sediment deposition and potential impacts on adjacent ecosystems. Monitoring is necessary to understand the long-term consequences of such rapid accretion.

The results of this shoreline change analysis in the Orashi River region provide valuable insights into the coastal dynamics of this area over the past three decades. Several key points can be drawn from the findings:

6.2.12. Erosion Hotspots

The presence of both very high and high erosion zones highlights the vulnerability of certain stretches of the Orashi River shoreline in Table 3 and Figure 4. These areas may be experiencing accelerated erosion due to a combination of natural processes and human activities. Coastal erosion can lead to the loss of land, damage to infrastructure, and threats to local ecosystems. Urgent measures, such as shoreline protection and restoration, may be needed in VHE areas, while HE areas require ongoing monitoring and adaptive management strategies.

6.2.13. Accretion Patterns

The identification of high and very high accretion zones suggests that sediment deposition is occurring in certain parts of the study area in Table 3 and Figure 4. Accretion can have both positive and negative effects, such as the creation of new land and potential impacts on habitats. Understanding the drivers of accretion in these areas is essential for informed coastal management. Monitoring these zones over time will help assess whether accretion rates remain stable or exhibit variability.

6.2.14. Coastal Vulnerability

The classification of shoreline segments into different erosion and accretion categories provides a comprehensive assessment of coastal vulnerability. This information is vital for local authorities, policymakers, and community stakeholders to prioritize resource allocation and adaptation strategies. It is also crucial for planning sustainable coastal development and safeguarding critical ecosystems.

6.2.15. Data Continuity

Continued monitoring of the Orashi River shoreline is essential to track changes over time, refine the classification categories, and assess the effectiveness of any mitigation or adaptation measures implemented. Long-term data continuity will enable a better understanding of the complex interactions between natural processes and human interventions along the coast.

7. Conclusion

This study employs the Digital Shoreline Analysis System (DSAS) to assess shoreline change in the Orashi River, Nigeria, over a 30-year period from 1992 to 2022. The results reveal the prevalence of erosion along the shoreline, with varying degrees of severity. High erosion rates are observed in Very High Erosion (VHE) areas, while High Accretion (HA) and Very High Accretion (VHA) regions experience shoreline gain. The classification of erosion and accretion areas provides valuable information for coastal management and conservation efforts. Immediate action is needed to protect Very High Erosion (VHE) areas, while opportunities for development and restoration exist in High Accretion (HA) and Very High Accretion (VHA) zones. The variability in shoreline change rates underscores the complex nature of coastal dynamics and the need for comprehensive monitoring and management strategies. This study contributes to the understanding of shoreline change processes in the Orashi River region, aiding in the development of sustainable coastal management plans and environmental conservation initiatives. Continued monitoring and research are essential to adapting to the evolving coastal landscape and its impact on the environment and local communities.

The Contribution to Knowledge

This study significantly contributes to our understanding of shoreline change in the Orashi River, Nigeria, from 1992 to 2022, using the Digital Shoreline Analysis System (DSAS). It classifies areas into Very High Erosion (VHE), High Accretion (HA), and Very High Accretion (VHA), providing crucial insights for coastal management. VHE areas require immediate protection, while HA and VHA regions offer opportunities for sustainable development. The study highlights the complexity of coastal dynamics and the need for adaptable strategies. It informs the development of sustainable coastal management plans and underscores the importance of ongoing research and monitoring in addressing environmental challenges and community well-being.

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