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ARTICLE

Analysis of Shoreline Changes in Ikoli River in Niger Delta Region Yenagoa, Bayelsa State Using Digital Shoreline Analysis System (DSAS)

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ABSTRACT

The use of Digital Shoreline Analysis System was used to determine shoreline changes in Ikoli River, Yenagoa, Bayelsa State. Shoreline data were extracted from satellite imagery over thirty years (1991-2021). The basis of this study is to use Digital Shoreline Analysis System to determine erosion and accretion areas. The result reveals that the average erosion rate in the study area is 1.16 m/year and the accretion rate is 1.62 m/year along the Ikoli River in Ogbogoro Community in Yenagoa, Bayelsa State. The mean shoreline length is 5.24 km with a baseline length of 5.2 km and the area is classified into four zones to delineate properly area of erosion and accretion based on the five class of Linear regression rate, endpoint rate and weighted linear rate of which zone I contain very high erosion and high erosion with an area of landmass 255449.93 m^2 of 38%, zone II contain moderate accretion, very high accretion and high accretion with a land area of 1666816.46 m^2 with 24%, zone III has very high erosion and high erosion with an area of landmass 241610.85 m^2 of 34 % and zone IV contain moderate accretion and high accretion with land area 30888.08 m^2 with 4%. Out of the four zones, zone I and II were found to be eroding with 72% and zone II and IV contain accretion with 28%. The result shows that 44% of the area have been eroded. Therefore, coastal engineers, planners, and shoreline zone management authorities can use DSAS to create more appropriate management plans and regulations for coastal zones and other coastal parts of the state with similar geographic features.

1. Introduction

The shoreline changes have been a major issue in Yenagoa and other parts of the world, resulting in the loss of life and property, including farmlands. The fundamental aspect in the detection of shoreline changes is erosion, accretion and morphodynamics, which is a

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necessity for shoreline computation [1]. Shorelines are the land-sea interface that shifts unpredictably in reaction to one or more causes in nature, such as morphological, climatic, or geological factors [2]. Because of their dynamic environmental setting, shorelines as a borderline between land and sea are subject to constant change [3]. The dynamic interactions between and among waves, tides, rivers, and physical processes determine the shoreline features [4]. Erosion makes the shoreline more vulnerable, which can be dangerous for human activity near the shore. Furthermore, the frequent occurrence of shore disasters makes the shore extremely prone to changes such as floods, illegal sand mining, and boat movement, among other things. It is one of the most dynamic landform types on earth, undergoing fast change as a result of geology, geomorphology, and wave action along the shoreline, as well as recurrent storms, sea-level rise, sediment transport by longshore currents, and anthropogenic activity [5]. Because of its remotely sensed and repeated coverage, high resolution, multispectral capabilities, and cost-effectiveness compared to conventional techniques, remote sensing data have been widely used in shoreline change studies in recent years [6]. Several studies on shoreline change have been undertaken in India using remote sensing and Geographic Information System (GIS) techniques at various periods in the recent past [7,8]. The End Point Rate (EPR) technique, when integrated with satellite images, provides a precise and dependable approach for calculating and analyzing shoreline development [9]. Shoreline change studies can be done in a variety of ways, but the Linear Regression Rate (LRR) provides the ability to employ more than two shorelines [10]. A time series of different shoreline positions are utilized to calculate the rate of shoreline change statistics using the Digital Shoreline Analysis System (DSAS) extension tool. A proper assessment, as well as adequate care, must be taken to assure the accuracy of digitisation. For predicting patterns of shoreline behaviour, the DSAS derivation of the historical rate of change trends as an indicator of future trends has been utilized, assuming continuity in the physical, natural, or anthropogenic forcing that has induced the historical change observed at the location [11]. In this study, the DSAS tool is used to accomplish the following objectives: extracting shorelines from satellite images, analyzing the rate of change in the shoreline over thirty years, and determining the estimated erosion and accretion area.

2. Materials and Method

2.1 Location of Study

The research region is located in the central Niger Delta sedimentary basin of Southern Nigeria (Figure 1), in the Yenagoa Local Government area, which is also the capital of Bayelsa State. The location is located between 4^{0}55’0” N and 4^{0}57’0” N, and 6^{0}14’30” E and 6^{0}16’0” 25’E longitudes. The area features an excellent road network that connects the study area.

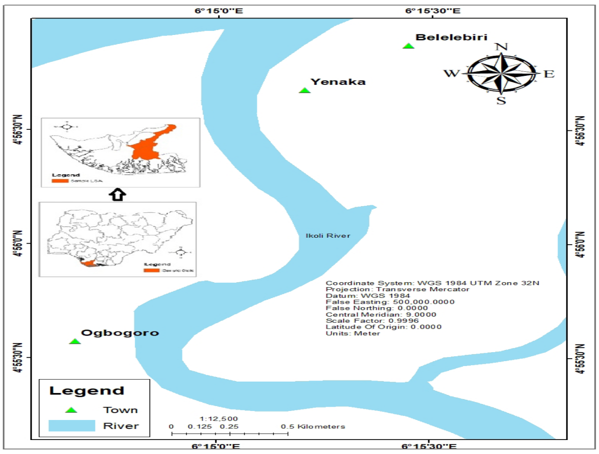

Figure 1. Map of the study area

2.2 Material

Measurement Table, GPS, Geotag Camera, Field noted book and Pen.

2.2.1 Source of Data

The Ikoli River’s long-term shoreline change assessment was evaluated for 30 years, from 1991 to 2021. Evaluations of three shorelines extracted from different time-period satellite imageries are used to assess shoreline change. In Table 1, multi-temporal Landsat satellite data for 1991, 2016, and 2021 was acquired from the USGS website [12]. It is better to use satellite data in December or January to prevent mist and haze, as well as other types of atmospheric problems. As a result, satellite data for December and January of each study year was retrieved.

Table 1. List of Data Satellite collected

Satellite Data	Date	Spatial Resolution (m)	Source
Landsat 5	28/02/1991 Path: 189, Row: 57	30	[12]
Landsat 8	26/12/2016 Path: 189, Row: 56	30	[12]
Landsat 8	6/1/2021 Path: 189, Row: 56	30	[12]
Google Earth Imagery	06/02/2021	3m	[12]

2.2.2 Data Processing

Shorelines from multi-temporal satellites are retrieved in vector data form using online visual digitizing in ArcGIS10.6. For shoreline extraction, each multi-temporal satellite image was manually scanned and individually digitized. After that, the shoreline data from various periods were entered into the Digital Shoreline Analysis System (DSAS) for further computation of shoreline change over 30 years from 1991 to 2021 (Figure 2). The ObjectID (a unique number provided to each item), shape (polygon), date (original year), and shape length, ID, and uncertainty values are all used in the DSAS program to generate shoreline positions. In the attribute table, shorelines extracted at different dates were merged as a single feature, resulting in a single shapefile including numerous shorelines. The cross-shore transacts for calculating the shoreline change are collected and generated by meticulously digitizing the direction and shape of the outer shoreline baseline. The rates of shoreline change were calculated using the United States Geological Survey's ArcGIS tool and the DSAS version 5 software (USGS).

2.3 Methods

2.3.1 Statistical Technique

Statistical techniques like Linear Regression Rate (LRR), End Point Rate (EPR) and Net Shoreline Movement (NSM) in DSAS were used in the study.

DSAS version 5.0 tool developed by the USGS is an extension for ArcGIS version 10.6 software. It uses several statistical techniques to compare shoreline positions through time and evaluate shoreline changes the methods used in DSAS are described below and other statistical parameters are described by Himmelstoss et al. [13].

2.3.2 Long-term Changes

Long-term shoreline changes are calculated using multi-temporal Landsat satellite data. We employed a linear regression rate of change statistics after digitizing multi-temporal satellite data, which is determined by fitting a least square regression line to all shoreline points for certain transacts. Then, in the Weighted Linear Regression (WLR) approach, a weight value was added, which represents the uncertainty associated with each shoreline. According to Genz et al. [14], the weight (w) is defined as a function of the variance in the uncertainty of the measurement (e).

$$W=1(e)^2 \tag{1}$$

2.3.3 Uncertainties and Errors

Total Positional Uncertainty (Et) is the result of all errors that were previously estimated. It is defined as the square root of the sum of the squares of the sources of previous errors [15]. It was calculated by using (2):

$$\text{Et}=\pm\sqrt{E^2s+E^2td+E^2d+E^2p+E^2r} \tag{2}$$

where Es is the seasonal error, Et is the tidal error, Ed is the digitizing error, Ep is the pixel error, and Er is the rectification error. The total positional uncertainties were used as weights (weighted linear regression or weighted least squares) in the shoreline change analysis in the DSAS.

2.3.4 Net Shoreline Movement (NSM)

NSM is associated with the dates of two shorelines. It reports a distance in meters. It calculates the distance between the oldest and the youngest shorelines at each transect [11].

2.3.5 Shoreline Change Envelope (SCE)

SCE calculates a distance in meters between "the shoreline farthest from and closest to the baseline at each transect" [13]. It is not associated with the dates of these shorelines [13].

2.3.6 End Point Rate (EPR)

EPR is determined by dividing NSM by the period elapsed, as in (3) [16,13,11].

$$R=D/T_e \tag{3}$$

where R is in meters per year (m/yr), D is in meters and T_e is the period elapsed between the oldest and the most recent shoreline (years). EPR still works well when we have only two shorelines to analyze the evolution [17].

2.3.7 Linear Regression Rate (LRR)

LRR corresponds to the value of the slope of a least-squares regression line, as in (4), that fits all points of intersection between all shorelines and a specific transect [11,18].

$$y= m.x+b \tag{4}$$

where y is the distance from baseline, m is the slope (LRR method), and b is the y-intersect (where the line crosses the y-axis) [13].

2.3.8 Weighted Linear Regression rate (WLR)

The WLR approach determines the best-fit regression line by using linear regression with a weight (for each coastline position) based on the shoreline uncertainty. The weight is the squared total positional uncertainty reversed [15].

This method increases the influence of shoreline points with smaller total positional uncertainty on the best-fit regression line. The slope of this regression line is the shoreline change rate in m/yr, as in (5).

$$y=m_w.x+b_w \tag{5}$$

where m_w is the slope (WLR method) and b_w is y-intersect [13]. WLR method requires at least three historical shoreline positions [15].

3. Results and Discussion

3.1 Extraction of the Shorelines from the Satellite Imageries

The shoreline changes along with various towns and their environs, as seen in Figure 2 is extracted from Landsat imagery using ArcGIS software. In 1991 the extracted shoreline length is 4.87 km, 2016 is 5.66 km and 2021 is 5.20 km and the shoreline changes from 1991 to 2016 is 25years and 1991 to 2021 is 30 years which make it to be long term changes which as a result led to destroy of building and farmland due to erosion activities in the area in Figure 3 and it means shoreline length is 5.24 km while the baseline length is 5.2 km.

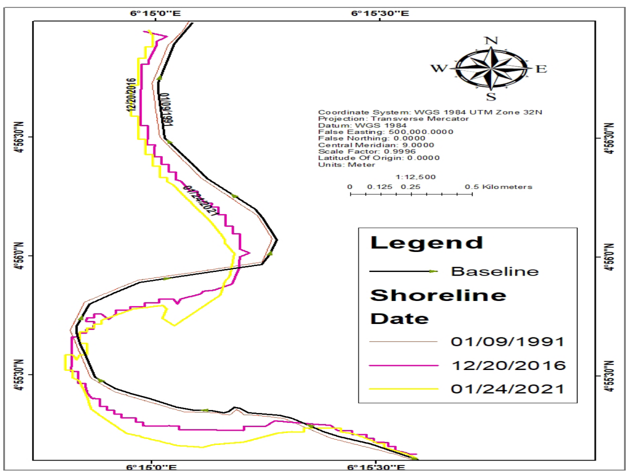

Figure 2. Map showing shoreline changes in Ikoli River

Table 2. Shoreline length and date from satellite

S/N	Date	Shoreline length (km)	Baseline Length (km)
1	01/09/1991	4.87	
2	12/20/2016	5.66	5.2
3	01/24/2021	5.20	
Mean		5.24	

Figure 3. Image of erosion activities along Ikoli River in Ogbogoro Town, Yenagoa Bayelsa State in 2021.

3.2 Rate of Shoreline Change in Different Zones

DSAS computed total transacts 196 for the whole Ikoli River and the rate of shoreline changes for four zones in the study area in Table 3 and Figure 4 shows that zone I, has 2.02 km in 1991, 2.26 km in 2016 and in 2021 the shoreline length is 1.81 km in Figure 5 with erosion present and 81 transects numbers identify with transect order ranging from 113 to 193, short count contain 2 as 2 and 3 as 78 with an azimuth of 230.23 minimum and 344.626 maximum, but a majority of the transect shows erosion. The average rate over 153 transects, was −3.91 m/year along those transects with erosion trend, the overall shoreline change rate shows a negative trend throughout the zone indicating erosion is reported along the shoreline in Ogbogoro community and also from Figure 5 the highest shoreline length zone is found in zone I from 1991 to 2016 and 2021 while the lowest shoreline length is identified in zone IV from 1991 to 2016 and 2021.

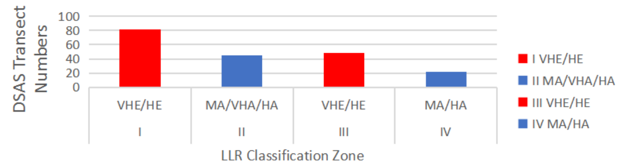

Figure 4. DSAS Transect Numbers Erosion and Accretion zone

Table 3. DSAS Transect Numbers and Shoreline Length zone

S/N	Zone	DSAS Transect Numbers	shoreline Length (km)		
			1991	2016	2021
1	I	81	2.02	2.26	1.81
2	II	45	1.12	1.16	1.28
3	III	48	1.24	1.54	1.55
4	IV	22	0.49	0.60	0.56

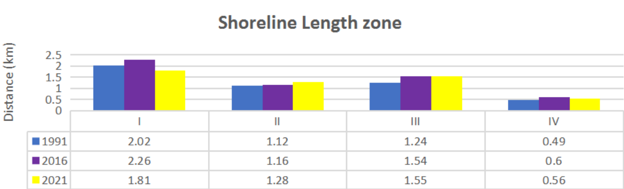

Figure 5. Shoreline Length zone from 1991 to 2021

In zone II, the overall shoreline change rate shows a positive trend throughout the zone, indicating accretion is present along the shoreline. The shoreline change rate contains a shoreline length of 1.12 km in 1991, 1.16 km in 2016, 1.28 km in 2021, and is observed to contain accretion in Table 10 and Figure 9. The average rate over 45 transects was 4.56 m/year along those transects, with transect order ranging from 69 to 113, and short counts contained 2 as 4 and 3 as 43 with an azimuth of 255.57 minimum and 344.46 maximum in Table 10 and the majority of the area increase in land from the flow of water against a shore or bank in Figure 8.

For zone III, the shoreline change analysis shows an erosion trend in Table 11 and Figure 9, but erosion is significant. In this zone, the shoreline change rate contains a shoreline length of 1.24 km in 1991, 1.54 km in 2016, 1.55 km in 2021, and the average erosion is 5.20 m/year. Erosion is observed along the shoreline of the Ikoli river with transect numbers of 48 and a minimum value of azimuth of 129.80 and a maximum value of 257.4.

In zone IV in Table 3 and 12, the average rate over 22 transects was 1.50 m/year along those transects, with a transect order ranging from 1 to 43, with an azimuth of 203.4 min. and 217 max. in Table 12, and the area showing an increase in land from the flow of water against a shore in Figure 8 with a shoreline change rate of 0.49 km in 1991, 0.60 km in 2016, and 0.54 km in 2021.

3.3 Estimation Erosion and Accretion Area

The study area has been classified into four zones in Table 4 and Figure 6, indicating zone I has a 265449.93 m^2 area with very high erosion and high erosion in the study area, with 38% in Figure 5. Zone II contains 166816.46 m^2 with moderate accretion, high accretion, and very high accretion, with 24% in Table 5. Zone III has a 241610.85 m^2 area of landmass with very high erosion and high erosion present, indicating 34% of the mass land is eroded in Table 5, Figures 6 and 8. Zone IV contains 30888.08 m^2 in Tables 4 and 7 with moderate accretion and high accretion present at 4% in the zone.

From Table 6, the result indicates that the percentage of erosion is greater than the percentage of accretion, i.e. the total percentage of erosion is 72% and accretion is 28%, but the percentage difference is 44%. This implies that 309356.20 m^2 of the mass of land in the Ogbogoro community is eroded and the government and relevant agencies like NDDC need to come to their aid to embark on land reclamation and shoreline protection to avoid continued loss of land and properties.

Table 4. Estimate area of Linear regression rate zone

S/N	Zone	Area (m^2)	LRR
1	I	265449.93	VHE/HE
2	II	166816.46	MA/VHA/HA
3	III	241610.85	VHE/HE
4	IV	30888.08	MA/HA

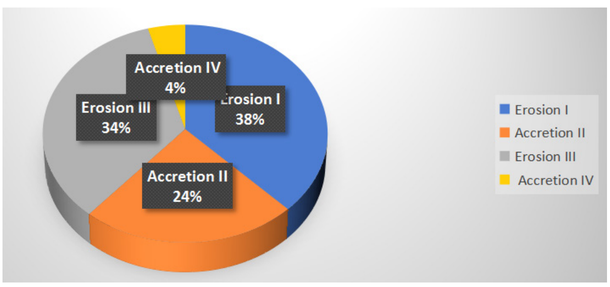

Figure 6. Zone Area in Percentage of Erosion and Accretion

Table 5. Percentage of Erosion and Accretion zone

S/N	Zone	LRR	%
1	I	Erosion	38
2	II	Accretion	24
3	III	Erosion	34
4	IV	Accretion	4

Table 6. Total Percentage of Erosion and Accretion zone

S/N	Zone	LLR	Area (m^2)	Total %
1	I and III	Erosion	507060.8	72
2	II and IV	Accretion	197704.5	28
Difference			309356.3	44

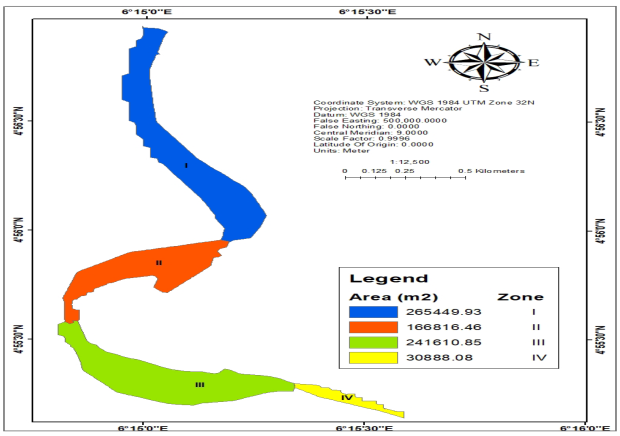

Figure 7. Map showing shoreline Area in Ikoli River

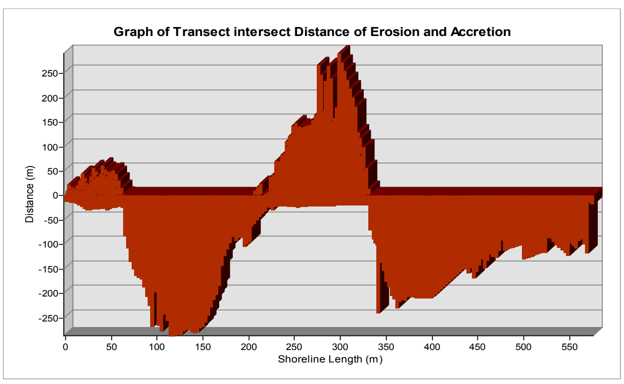

Figure 8. Transect interest Distance of erosion and Accretion

3.4 Mean Shoreline Change Trend in the Selected Zones of Ikoli River

There is a variation in the mean rate of accretion and erosion in the four selected Ikoli River Linear Regression Rate (LRR) which are classified into five, namely very high erosion, high erosion, moderate accretion, high accretion, and very high accretion in Figure 10 and Table 7. Figure 9 shows that the mean erosion rate of 3.91 m/year is found in zone I, which contains both very high erosion and high erosion. This is the highest compared to zone III, which has a mean of 5.56 m/year and is the lowest in Figure 9, which also contains very high erosion and high erosion in Table 8. The mean annual accretion for zone 2 is 4.56 m/year and is the highest rate that is found along the zone, while zone IV is 1.51 m/year as shown in Figure 9, Table 10, and 12.

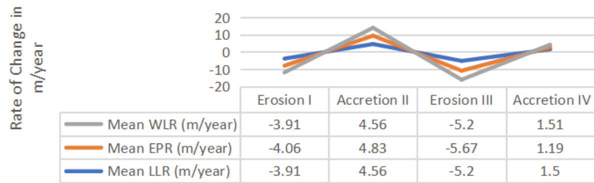

Figure 9. Erosion and Accretion Trend

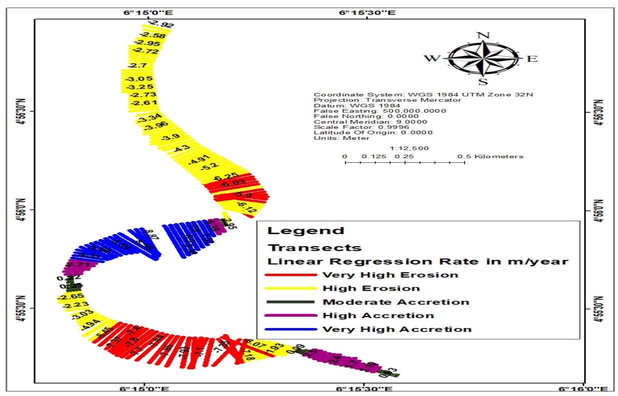

Figure 10. Shoreline accretions and erosion in Ikoli River with LRR

Table 7. Linear regression rate of five classes

S/N	LLR	LRR
1	−8.07- −5.84	Very High Erosion (VHE)
2	−5.84 - −0.52	High Erosion (HE)
3	−0.52 - 1.02	Moderate Accretion (MA)
4	1.02 - 3.82	High Accretion (HA)
5	3.82 - 9.39	Very High Accretion (HA)

Table 8. Linear regression rate zone

S/N	Zone	LRR
1	I	VHE/HE
2	II	MA/VHA/HA
3	III	VHE/HE
4	IV	MA/HA

There is a deviation in the mean rate of accretion and erosion in the four selected Ikoli River in terms of End Point Rate (EPR) in Figure 11. Mean accretion rate of 4.83 m/year is found in zone II which is highest amongst all in Figure 9 and Table 10, whereas zone IV has an accretion rate of 1.19 m/year in Table 12 and Figure 9 while Mean erosion for zone I and III is −4.06 and −5.67 m/year respectively in Figure 9.

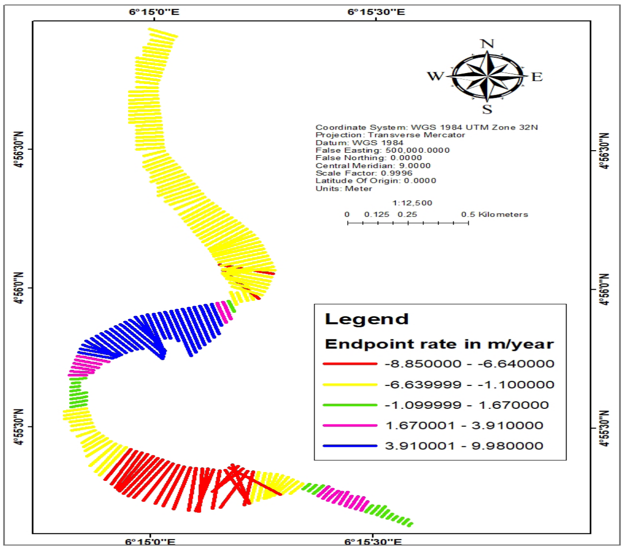

Figure 11. Shoreline accretions and erosion in Ikoli River with EPR

The Weighted Linear regression (WLR) in Figure 12, mean accretion rate of 4.56 m/year is found in zone II which is highest amongst all in Figure 9 and Table 10, whereas zone IV accretion rate 1.52 m/year which is lowest amongst all in Table 12 and Figure 9. Mean erosion for zone I is −0.91 and −5.2 m/year respectively Figure 9.

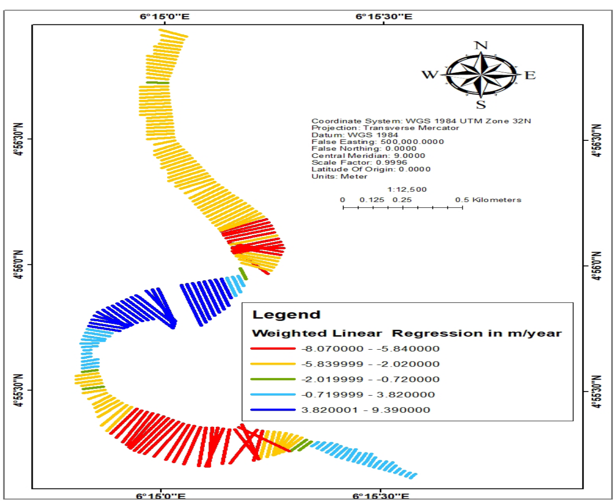

Figure 12. Shoreline accretions and erosion in Ikioli River with WLR

The results from zone I in Table 9 and Figure 13 indicated that the Net Shoreline Movement (NSM) ranged from −219.47 to −43.18 m with a mean shape length of 0.14 km, indicating erosion. Zone II contains a minimum value of 51.88 m and a maximum value of 309.64 m with an average value of 0.15 km, indicating accretion in Table 10. Zone III ranges from −274,83 to −11.33 m and has a mean value of −173.91 with a mean shape length of 0.19 km, indicating erosion in Table 11, and Zone IV has a range value of 17.055 m to 77.35 m with a mean value of 0.05 km, indicating accretion in Table 12.

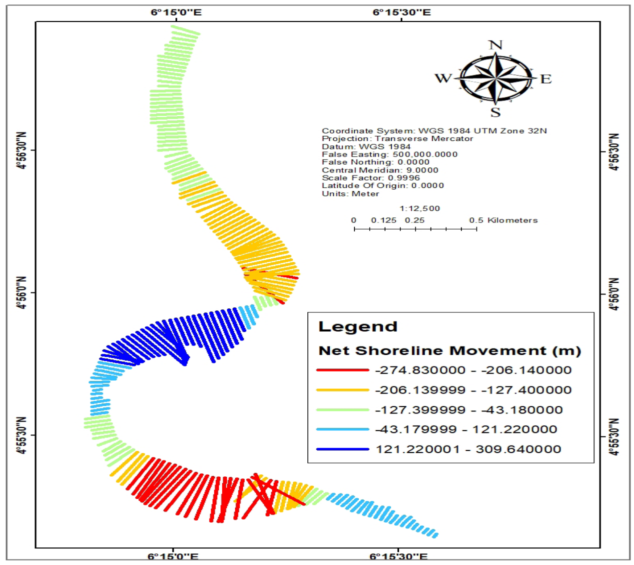

Figure 13. Shoreline accretions and erosion in Ikioli River with NSM

The study was carried out to examine the Ikoli River's shoreline modification. The findings suggest that the majority of the shoreline is at risk of erosion (Table 4 and Figure 14). When erosion and deposit are assessed in the four zones of the research region, erosion dominates while accretion is less active along the shore. The geology, as well as other physical and cultural elements, of the Ikoli River shore region, are diverse. Physical inspection in Figure 8 reveals sand, clay, sand dunes, deltas, and other features. Understanding the mechanisms of erosion, sediment deposition, flooding, and sea-level changes that alter the shoreline is critical for planning shore protection work because erosional processes can affect the stability and productivity of the aquatic environment, which can have serious consequences for the community along the shore. Because of the tidal water pressure, loose bank materials, and shoreline pattern, freshly exposed and steep slope sites are more active in the erosion process. Under the influence of river power, coastline erosion results in the migration of the shoreline onto land and bottom bed erosion. Disasters in shared areas are caused by both natural and manmade reasons. Wind, waves, tides, sediment supply, changes in relative sea level, and human interventions all affect the shoreline, and these activities constantly generate shoreline changes across a range of time intervals. The above study has consequences for the design and development of the Ogbogoro community's shore tract, as well as other shore locations, in terms of infrastructure development, tourism, and recreational places, among other things. It can also help identify coastal vulnerability in terms of shoreline dynamics and the hazards that come with them.

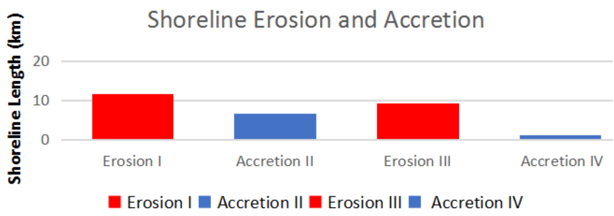

Figure 14. Shoreline Erosion and Accretion

3.6 Risk Analysis of Shoreline Changes

Risk analysis is vital in studying the shoreline for effective planning and management circumstances in the Niger Delta and other regions of the world to avoid serious erosion consequences. It is also critical to understand the terrain of the area by conducting hydrological and surface assessments to investigate the statuary of the area, particularly in terms of the drainage system, when making decisions for the construction of structures and site suitability, including settlements, farming, road and railway construction. Building structures and piling the shoreline in the study area could have reduced the loss of life because most areas of terrain have poor drainage systems resulting to loss of properties (Figure 3).

4. Conclusions

This study showed that combining remote sensing and GIS technology can be extremely valuable for long-term shoreline change studies using Landsat imagery with reasonable precision. The average erosion rate in the research region is 1.16 meters per year, whereas the accretion rate is 1.62 meters per year along the Ikoli River in Ogbogoro, Bayelsa State. The mean shoreline length is 5.24 km with a baseline length of 5.2 km and the area is classified into four zones to delineate properly area of erosion and accretion based on the five class of Linear

Table 9. Statistical technique results from Digital Shoreline Analysis System Zone 1

	Trans Order	Azimuth	Shr Count	TCD	SCE	NSM	EPR	LRR	WLR	Length (km)
Mini	113.00	230.23	2.00	2825.00	43.18	−219.47	−7.07	−6.39	−6.39	0.06
Max	193.00	344.26	3.00	4825.00	219.47	−43.18	−1.67	−0.90	−0.90	0.24
Mean	153.00	264.36	2.95	3825.00	125.58	−125.19	−4.06	−3.91	−3.91	0.14

Table 10. Statistical technique results from Digital Shoreline Analysis System Zone II

	TransOrder	Azimuth	ShrCount	TCD	SCE	NSM	EPR	LRR	WLR	Length(km)
Mini	69.00	255.57	2.00	1725.00	28.44	51.88	1.67	−0.90	0.90	0.01
Max	113.00	344.46	3.00	2825.00	309.64	309.64	9.98	9.39	9.39	0.31
Mean	91.00	310.92	2.89	2275.00	157.88	145.30	4.83	4.56	4.56	0.15

Table 11. Statistical technique results from Digital Shoreline Analysis System Zone III

	TransOrder	Azimuth	ShrCount	TCD	SCE	NSM	EPR	LRR	WLR	Length (km)
Mini	22.00	129.80	2.00	550.00	41.76	−274.83	−8.85	−8.07	−8.07	0.03
Max	69.00	257.40	3.00	1725.00	274.83	−11.33	−0.37	−0.72	−0.72	0.27
mean	45.50	209.64	2.94	1137.50	176.11	−173.91	−5.67	−5.20	−5.20	0.19

Table 12. Statistical technique results from Digital Shoreline Analysis System Zone IV

	TransOrder	Azimuth	ShrCount	TCD	SCE	NSM	EPR	LRR	WLR	Length(km)
MIN	1.00	203.40	2.00	25.00	20.17	17.05	0.57	0.37	0.37	0.003
MAX	22.00	217.66	3.00	550.00	86.92	77.35	2.49	2.58	2.58	0.09
MEAN	11.50	211.09	2.92	287.50	59.10	36.96	1.19	1.50	1.51	0.05

regression rate, endpoint rate and weighted linear rate of which zone 1 contain very high erosion and high erosion with an area of landmass 255449.93 m^2 of 38%, zone II contain moderate accretion, very high accretion and high accretion with a land area of 1666816.46 m^2 with 24%, zone III has very high erosion and high erosion with an area of landmass 241610.85 m^2 of 34 % and zone IV contain moderate accretion and high accretion with land area 30888.08 m^2 with 4%. Out of four zones, zone I and II are found to be eroding with 72% and zone II and IV contain accretion with 28%. The result shows that 44% of the area has been eroded. Therefore, Coastal engineers, planners, and shoreline zone management authorities may find the map output more useful in developing appropriate management plans and regulations for the beach or coastal zones of the Ikoli River, as well as other coastal areas of the state with similar geographic circumstances.

Recommendations

The rate of change along the shoreline must be monitored to detect eroding areas from time to time.

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