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The Dynamic Nature of Niger Delta Shoreline

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Abstract: *The Niger Delta coastal exposure makes for the dynamic nature of the shoreline. Land sat Tm of 30 x 30 m of 1986 and 2010 were employed to examine the change in the shoreline of the Niger Delta. The Physical exposure of the shoreline to erosion and inundation was examined using several variables of geomorphology, Shoreline change , Relief, slope, mean wave height, relative sea level changes and tidal range. Findings revealed shoreline accretion of 274.42km3 against loss of 171.15km3. vulnerability classification recveals that the middle and eastern part of the study area falls within the cvi of very highly vulnerable, and high vulnerability. No significant relationship exist between the erosion rate of vegetated and non vegetated shoreling of the Niger Delta.*
Keywords: *Vulnerability, Inundation, Coastal, Shoreline, Exposure*

I. Introduction

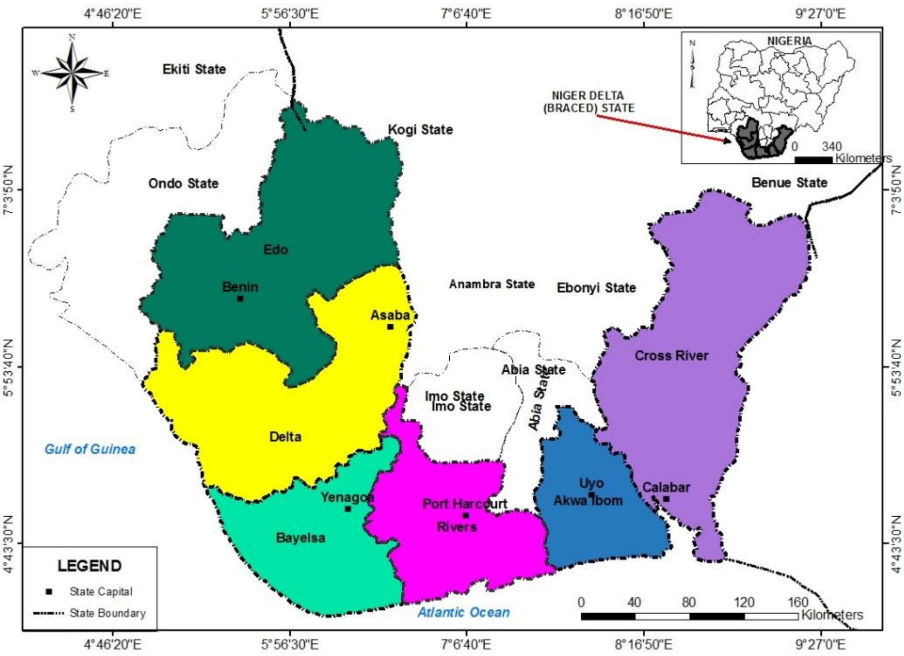
The coastal region of the Niger Delta is blessed with abundant natural resources supporting the life of man, numerous plants and animals. The coastal system is dynamic and it undergoes varying adjustment in form and process at spatial and temporal scales in response to shore-line dynamics. The shore zone is highly dynamic environment which responds in a complex pattern to extreme climatic and anthropogenic events. Millions of people visit and live in the area. However, the dynamic nature of coastal locations makes them hazardous to visitors, indigenes and Oil and Gas facilities since they could be subjected to land subsidence, eroding beaches and flood. Due to increase in coastal erosion as a result of high population growth and other factors such as storm events, seasonal fluctuation in wave energy, and changes in sea level, coastal areas are thus experiencing continued changing environmental conditions. The alarming impact of anthropogenic activities on the Niger Delta shoreline and coastal processes have prompted individuals, environmental scientists and research institutes to proffer and implement solutions to issues that make the shoreline of the region vulnerable to coastal erosion and shoreline retreat. Olarunlana (2013[1]) was of the opinion that massive land loss along the shore of the Niger Delta could be attributed to the activities of tide and wave which topple over the coastal plain initiating sheet wash processes and an imperceptible but large scale removal of surface sediments of the coastal slope which has the net effect of lowering the plain. Though some sections of the Niger Delta coastline have been pro-grading seaward, at the same time, erosion has been very aggressive in other sections of the Niger Delta. Ebisemiju (1987[2]) in Olorunlana (2013[1]) postulated that erosion and subsidence have been accelerated by the withdrawal of oil and gas from the Agbada formation in the subsurface of the region. This position is affirmed by the local people who link the incidence of accelerated coastal erosion in the region with the commencement of oil and gas exploration and exploitation. This trend is affirmed to have begun in the 1970s and has resulted in coastline recession of 3.3km between 1974 and 1996 along Awoye axis incorporating 487 hectares of the coastal plain into the Atlantic Ocean. The coast constitutes one of the most dynamic parts of the earth surface. It has continuously undergone both gradual and sudden changes with many physical processes, such as tidal flooding, sea level rise, land subsidence, volcanic activities, erosion and sedimentation. According to Maiti & Bhatta, (2009[3]), the major causes of coastal erosion and shoreline changes are sea level rise. Sea level rise is one of the often-cited effects of global warming which has a direct role on coastal erosion. Hence, sea level rise is a particular threat to human settlements because a number of large cities making 10% of the world's population live in the coastal area within an elevation below 10 meters of mean sea level (McKnight, 1992[4]).

Zhang, Bruce, and Stephen, (2004[5]), argued that despite the dense population density of coastal regions globally, and the degree of human interface in the region, these activities are neither uniform nor extensive enough to produce the amount of beach erosion taking place worldwide. The third assessment report of the Intergovernmental Panel on Climate Change (IPCC) concluded that the increasing green house gas concentration is having a detectable effect on earth's climatic system, including an increase in global sea level (IPCC, 2001[6]). They posit that, these effects are likely to intensify in the wake of this century hence, an increase of global surface temperature. The effect of this would raise sea level by expanding ocean water, melting glaciers, and increasing potential for the melting of the Greenland and West Antarctic Ice Sheet. Sea level rise would therefore increase the susceptibility of coastline to oceanic surges therefore threatening the populations and ecosystem that are in the shore zone through the permanent inundation of low – lying shoreline, amplification of episodic flooding events, and increased beach erosion (Mathew, Michael and Michael, 2005[7]). Moreover evidence suggest that coastal beaches recover their long term trend position regardless of storm severity which demonstrates that storms are not responsible for pervasive beach erosion (Zhang, Bruce and Stephen, 2004[5]). Therefore, sea level rise has been isolated as the most probable cause of widespread beach erosion occurring worldwide (Leatherman 1991[8]; Zhang, Bruce, and Stephen, 2004[5]). Shoreline inundation and beach erosion though related, are distinct in processes which hasten shoreline retreat (Zhang, Bruce, and Stephen ibid, 2004[5]). Unlike inundation, which drowns the shoreline, erosion redistributes sediments from the onshore to offshore areas. Sea level rise does not directly erode beaches and coastline rather rising sea level acts as a swelling tide that allows waves to act further up the beach profile.

Bruun, (1962[8]) shows that as sea level rises the upper part of the beach is eroded and deposited just offshore in a fashion that restores the shape of the beach profile with respect to sea level. The 'Bruun Rule' implies that a one meter rise in sea level would generally cause shore to erode 50 to 200 meters along sandy beaches, even if the visible portion of the shore is fairly steep. Bruun, therefore, constructed a simple geometric model which predicted that coastlines will retreat at a rate of 50 to 100 times greater than the rate of sea level rise. Zhang, Bruce and Stephen (2004[5]), found that U. S east coast beaches have retreated by an estimated 23.8 meter on average for each 0.3 meter of sea level rise over the last century which is in agreement with Bruun's principle. The New Jersey shoreline change rate on the other hand was estimated by the same authors to occur at 36.6 meter per 0.3 meter of sea level rise assuming a sandy beach environment. Given sea level rise projections of 0.61 meter and 1.22 meter, future shoreline change rate may increase to between 73 meter and 146 meter over the next century (Mathew, Michael, Machael, 2005[7]). Assessing the susceptibility of the New Jersey coast to erosion their findings revealed that 81 percent of the coastline are critically eroding, 9.7 percent non - critically eroding and 8.8 percent non - eroding or stable. This is in line with the findings of the New Jersey Department of Environmental Protection (NJDEP, 1981 [9]), sited in Mathew, Michael and Machael, (2005[7]), categorizing 32.9 percent of the shoreline as critically eroding, 18 percent as significantly eroding, 38.5 percent as moderately eroding and 10.6 percent as non – eroding. Arising from the foregoing, there is need to understand global environmental change and how it affects and threatens the Niger Delta coastline, Nigeria. The aim of this study is to evaluate the spatio-temporal changes along the Niger Delta Shoreline.

II. The Study Area

The study area falls within the Niger Delta located in southern Nigeria. The area is endowed with abundant water and mineral resources. It stretches between latitude 4^0 12' 30.892'' through 4^0 50' 10.7'' North of the equator and longitude 4^0 56' 15'' through 9^0 40' 2.654'' East of the Greenwich Meridian. The region is made up of six states of Akwa Ibom, Bayelsa, Cross River, Delta, Edo and Rivers with a total area of 84,643km2 bounded by the Atlantic Ocean to the south as shown in Fig. 1 below.



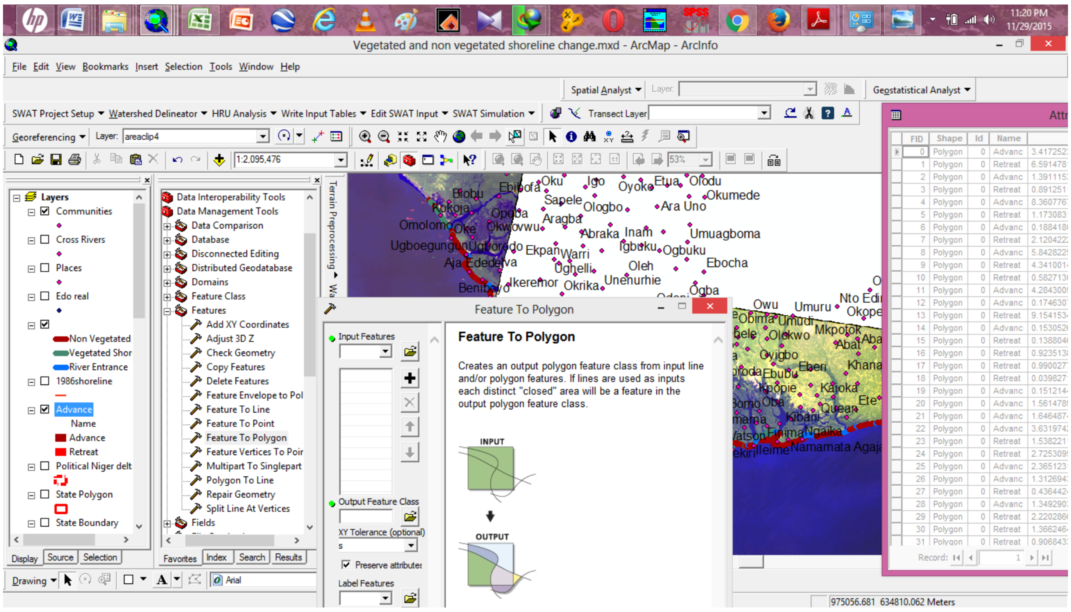
Note: Highlighted States Constitutes the Niger Delta BRACED States
Source: Adapted from NASRDA, 2010 and Digitized by Researcher

Figure1. Niger Delta (BRACED) States, Nigeria.

Five geomorphic units of Strand Coast, Delta Flank, Arcute Delta, Transgressive Mud Coast, and Barrier Lagoon Coast are pronounced in the region based on morphological characteristic, nature of the beach material/sediment, beach slope and vegetation (Oyegun, 1993[10]). The Arcute Niger delta which consists of medium to coarse sand with a shore length of 256km and a beach width of 50m is the most dominant morphological feature of the shoreline. The shoreline protrudes in an arc like form into the Atlantic Ocean with distributaries opening into the Atlantic Ocean through 19 estuaries or tidal river inlets. The barrier – lagoon coastline of the Lagos-Lekki area of the Nigeria coastline evolved from the coalescence of fossil barrier sand ridges which sandwich the lagoons that run parallel to the coastline. The Transgressive mud coast lies between the Benin river entrance and the Lekki Lagoon and stretches for 50 to 70km in length with pronounced presence of berm cliff of over 1m high, cut in mud and fronted by an extending 1-2km off shore terrace into the Atlantic Ocean (Oyegun, 1993[10]). The Niger Delta flanks are the adjourning area east and west of the arcuate Niger delta. The relative unbroken coastline of the eastern margin to include the mouth of Qua Ibo and Cross River estuaries is the strand coastline and it witnesses relatively stepper inter – tidal slopes than the other stretch of the Niger delta. The region is underlain by Basement Complex and Sedimentary Rocks most notable in the Oban and Obudu Areas while the Sedimentary rocks are found in the coastal areas of the study area. The major soil types in the region are hydromophic and organic soil which are mostly noticeable along the coastal flank developed on alluvial, marine and fluvial marine deposits of variable texture. On the barrier ridges, soil types found are regosols with poorly – developed profiles lying below a thin humic horizon.

III. Methodology

This study utilised Landsat Tm for the year 1986 and 2010 over the study area to model the changes in shoreline over time. The landsat imagery was processed and analyzed to derive a sharp format for shoreline delineation and extraction. The shoreline was digitized and converted from polyline to polygon feature to enable the measurement of the area of the shoreline that had undergone erosion or accretion between 1986 and 2010 with an assumed depth or height of 1m for erosion and accretion respectively. This was calculated by importing the geo – processed landsat image of the study area into a geo-information environment. The shoreline of the region at each of the years between 1986 and 2010 was extracted and analyzed for changes over time as shown in Fig. 2 and Appendix 1. The elevation of settlements was derived from the digital elevation model - see Fig. 2. Their location from the geo-referenced base map of study area was used to determine the distances of settlements from the shoreline to ascertain their sensitivity to shoreline dynamics- see Fig. 3.



Source: Authors'

Figure 2 Calculation of Shoreline Attributes

The shoreline as delineated is the interface or the intersecting zone between the land and water. Its rate of change (km/yr) was calculated as the rate of change for each transect within a 1 – minute grid cell and was averaged to determine the shoreline change rate where positive numbers indicate accretion and negative numbers indicate erosion. This was possible as the Image of the study area for the year 1986 and 2010 was classified to enable the extraction of the shoreline within the study time. Fig. 2 shows the digitized shoreline of the study area, its conversion to polygon using polyline to polygon conversion tools in the Arc GIS environment and the calculation of the area eroded or gained in km^2.

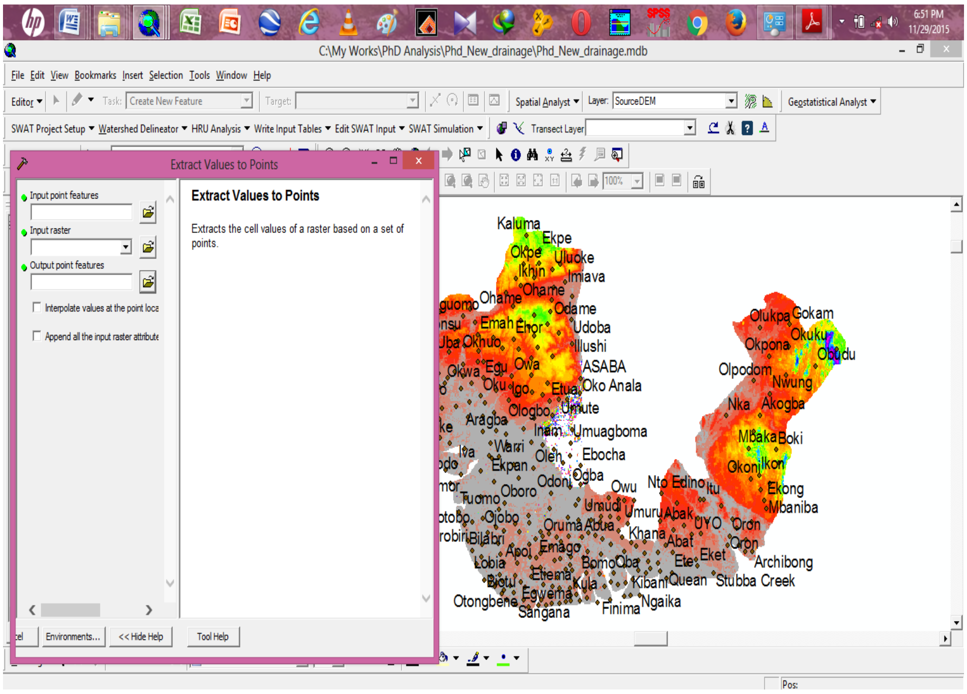


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Figure 3 Extraction of Communities Elevation in the Arc GIS using 30meter DEM

Fig. 3 shows print screen of procedure in the extraction of the elevation of settlements using the raster digital terrain model. Community actual location (x and y coordinates) was imported into the ArcGIS environment where they were labelled and overlain on the terrain model of the region. Using the ArcGIS software, the elevation of each community was then extracted from the raster overlay.

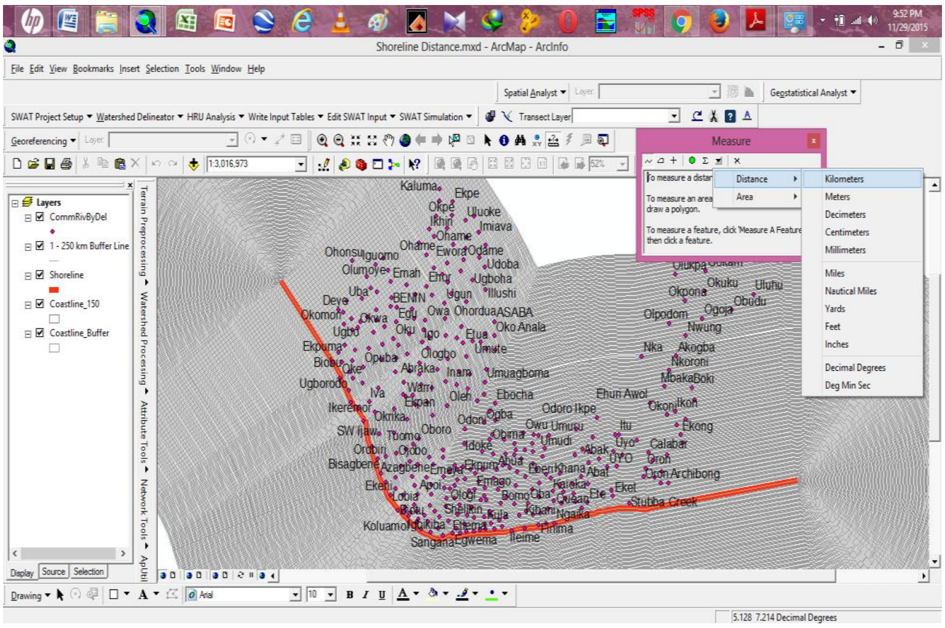

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Figure4. Buffering of Shoreline to ascertain Community Distance from Shoreline

The print screen shown in Fig. 4 shows the buffering of shoreline (red line) of the study area in kilometres alongside the community overlay which aided the determination of the distances of each community from the shoreline and their subsequent classification into groups in relation to their distances.

IV. Results And Discussion

IV.I SPATIO - TEMPORAL PATTERN OF SHORELINE CHANGES

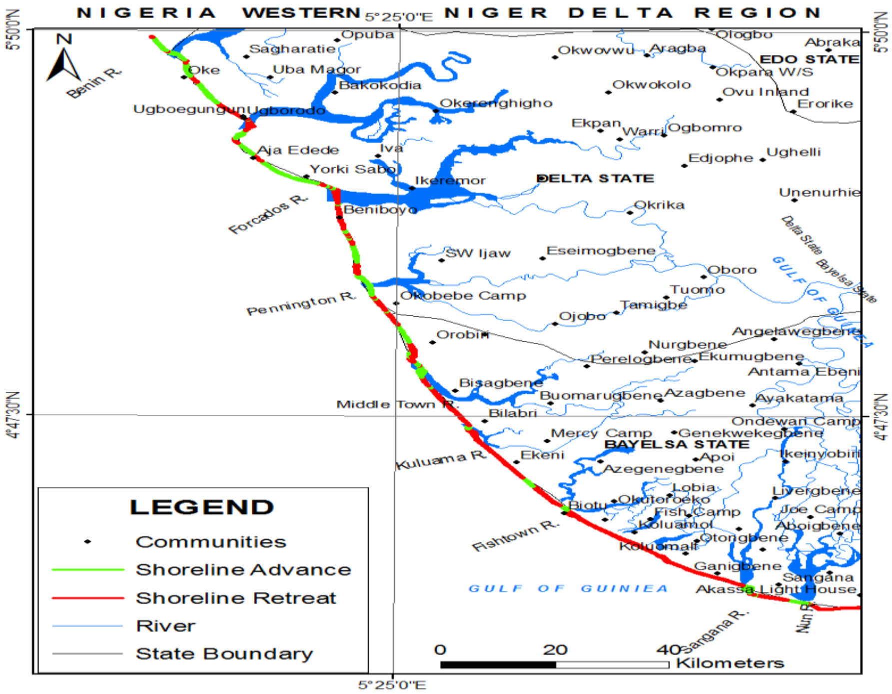
In order to establish if the global trend in sea level has any impact on the shoreline of the study area, spatio - temporal changes along the shoreline were determined between 1986 and 2010. The shoreline was subjected to geographic analysis using satellite images of 1986 and 2010 as shown in Appendix 1 and 2 which show the area of shoreline that experienced retreat or advance in 1986 and 2010. The analysis shows a volumetric gain in shoreline accretion of 103.27km^3 over the period of study.

Table 2 Summary Statistics of Coastal Erosion and Accretion

Issue	No. of Cases	Mean (km^3)	Standard Deviation
Erosion/Shoreline Retreat	61	2.760	1.6480
Accretion/Shoreline Advance	64	4.287	2.05

Source: Authors'

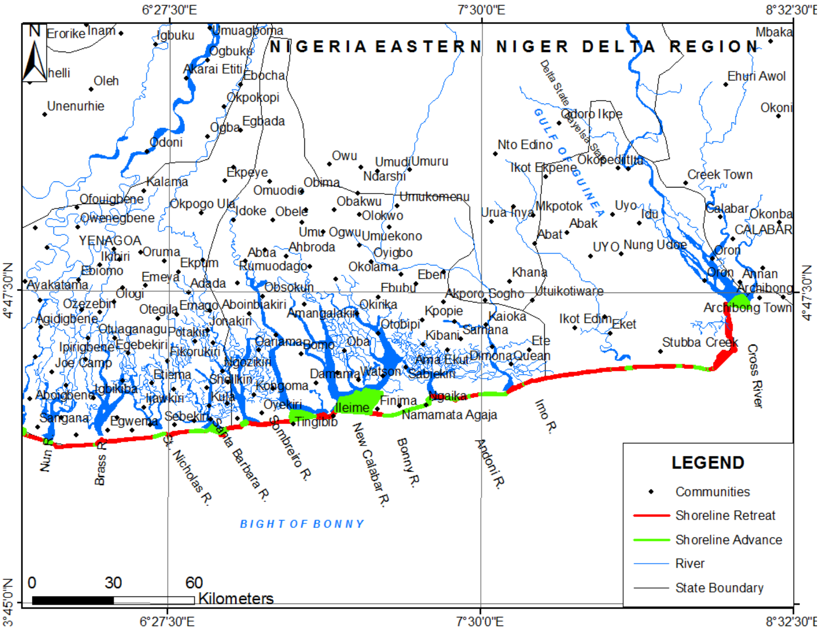
The average volume of shoreline advance over the study period is 4.3km^3 with a standard deviation of 2.05, while the average volume of shoreline retreat over the study period is 2.8km^3. Table 2 shows a higher mean and standard deviation for accretion than the mean and standard deviation of the area eroded. The data were further subjected to parametric analysis to see if difference in the volume of beach erosion or accretion over the study period using the Student t test. The test for the equality of variance gives a value of 9.82 at 123 degree of freedom which shows that there is no significant difference in the volume of erosion and accretion. Hence, erosion and accretion in the study area are very similar in trend.



Source: Authors'

Figure 5 Pattern of Shoreline Changes in the Western Niger Delta

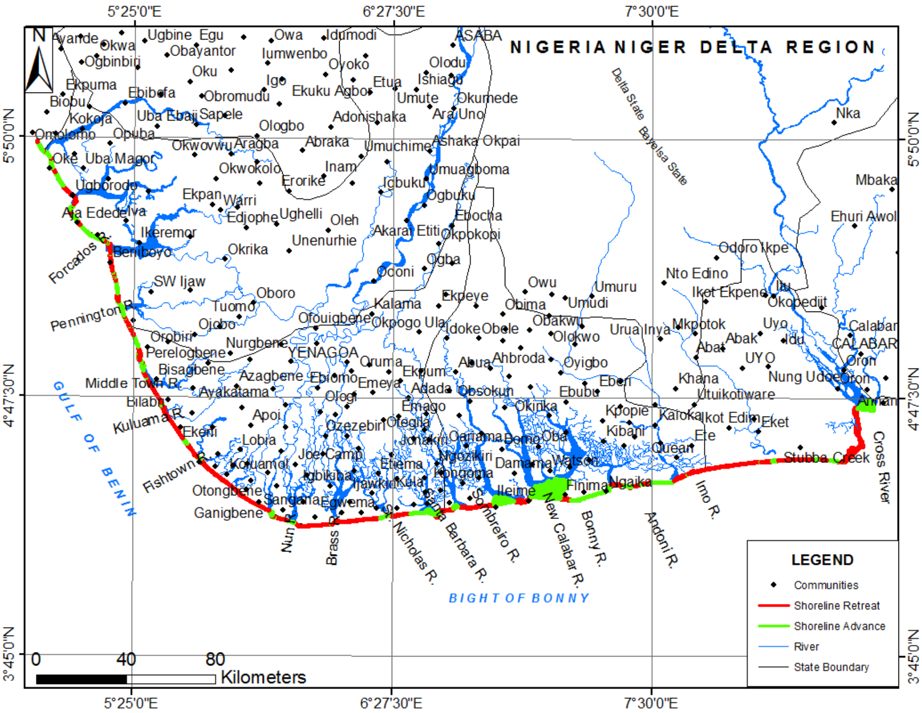
Fig. 5 shows the western shoreline of the study area that either accreted or retreated between the time steps of 1986 and 2010. The red colour polyline in the legend represents areas of shoreline retreat (loss) while the medium apple coloured polyline in the legend represent areas of shoreline advance (gain) to water body.



Source: Author's

Figure 6 Pattern of Shoreline Change in the Eastern Niger Delta Flank

Fig. 6 shows the Eastern Delta Flank that either accreted or retreated between the time steps of 1986 and 2010. The red polyline in the legend still represent areas of shoreline loss while the medium apple coloured polyline in the legend represent shoreline gain. Pronounced loss in shoreline is noticeable in the region.



Source: Authors'

Figure7. Pattern of Shoreline Change in the Niger Delta

Fig. 7 shows the pattern of change in shore line retreat or advance over the time steps of 1986 and 2010. The red polyline and the medium apple polyline signify changes (Retreat or Advance respectively) in the study area. The blue polygon signifies water bodies in the study area.

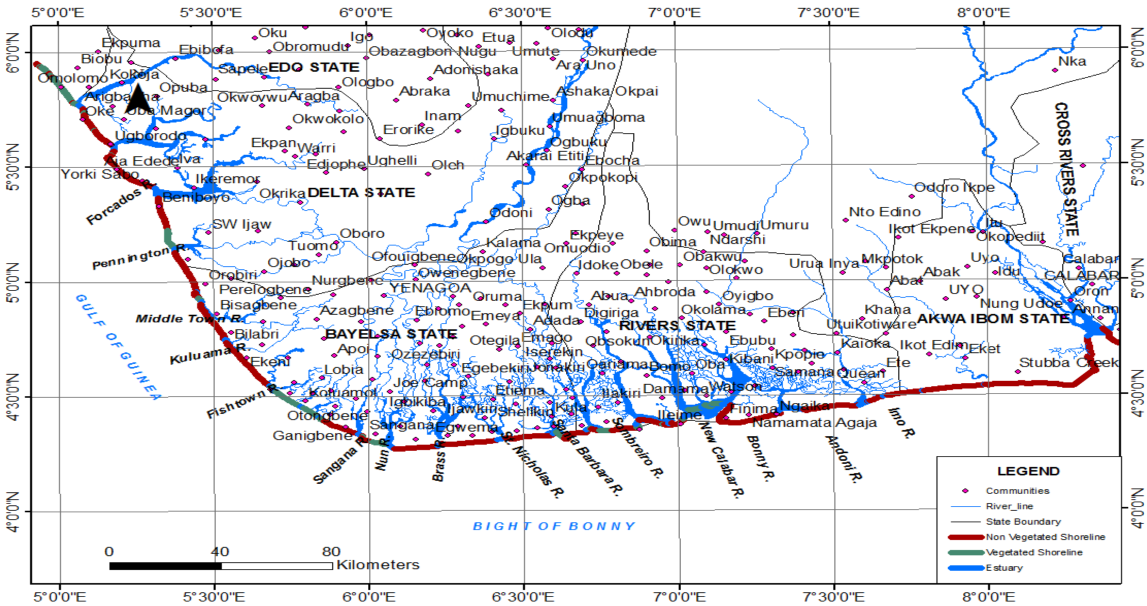
Table 3 Summary Statistics of Coastal Erosion and Accretion Volume in Eastern and Western Niger Delta.

Geomorphic Process	Region	No. of Cases	Mean (km^3)	Standard Deviation
Erosion/Shoreline Retreat	Eastern Niger Delta	27	2.29	1.48
	Western Niger Delta	34	3.39	1.81
Accretion/Shoreline Advance	Eastern Niger Delta	54	4.77	2.16
	Western Niger Delta	10	.13	.41

Source: Authors'

The average volume of shoreline advance over the study period was 4.3km^3. From the division of the Niger Delta into the Western and Eastern Niger Delta using the Nun River Estuary as the point of departure, the mean shoreline retreat or advance in cubic kilometre for the Western Niger Delta was 3.39 km^3 and .13km^3 respectively. The mean shoreline retreat or advance for the Eastern Niger Delta was 2.29 and 4.77km^3 respectively. Table 3 shows that there is more accretion in the Eastern than the Western area while there is more Erosion in the Western than the Eastern zone of the Delta.

The rate of change between vegetated and non vegetated sections of the shoreline was examined and analysed to determine the pattern of variation. The analysis revealed that 19.7% of shoreline retreat occurred along the vegetated segment of the shoreline while 80.3% of shoreline retreat occurred in the non-vegetated segment of the shoreline. This resulted in the loss of 1,171km^3 along exposed sections of the shoreline in contrast to the loss of 127.35km^3 along vegetated reaches of the shoreline. The data were further subjected to parametric analysis to see if a significant difference exists in the volume of erosion and accretion along vegetated and non vegetated sections of the shoreline using the student t test. The test for equality of variance for vegetated and non vegetated shoreline gave a t value of .863 at 56 degree of freedom. With a p value greater than 0.05 it signifies insignificant difference between the tested variables. This shows that the shoreline has similar erodability of its materials with the vegetated sections being more resistant to erosion than the exposed ones.



Source: Author's

Figure 8 Community Location in Relation to Shoreline Vulnerability

As observed in fig. 8 shoreline retreat is more dominant along non - vegetated section of the shoreline than along vegetated ones. Arising from this, a community protected by a stretch of Mangrove vegetation from the Atlantic Ocean is less vulnerable to shoreline recession than communities protected by coastal sand beach.

Table 4 Summary Statistics of Coastal Erosion along Vegetated and non Vegetated shoreline of the Niger Delta.

Section	No. of Cases	Mean (km^3)	Standard Deviation
Vegetated Shoreline	8	3.91	1.85
Non Vegetated Shoreline	50	2.54	1.57

Source: Authors'

The average volume of shoreline advance over the study period is 4.3km^3 while that of shoreline retreat over the study period is 2.8km^3. The Table 4 shows the mean volume of erosion along the vegetated sections of the shoreline is 3.91 km^3 with a standard deviation of 1.85 km^3 while the mean of erosion along the non vegetated sections of the shoreline is 2.54 km^3 with a standard deviation of 1.57 km^3.

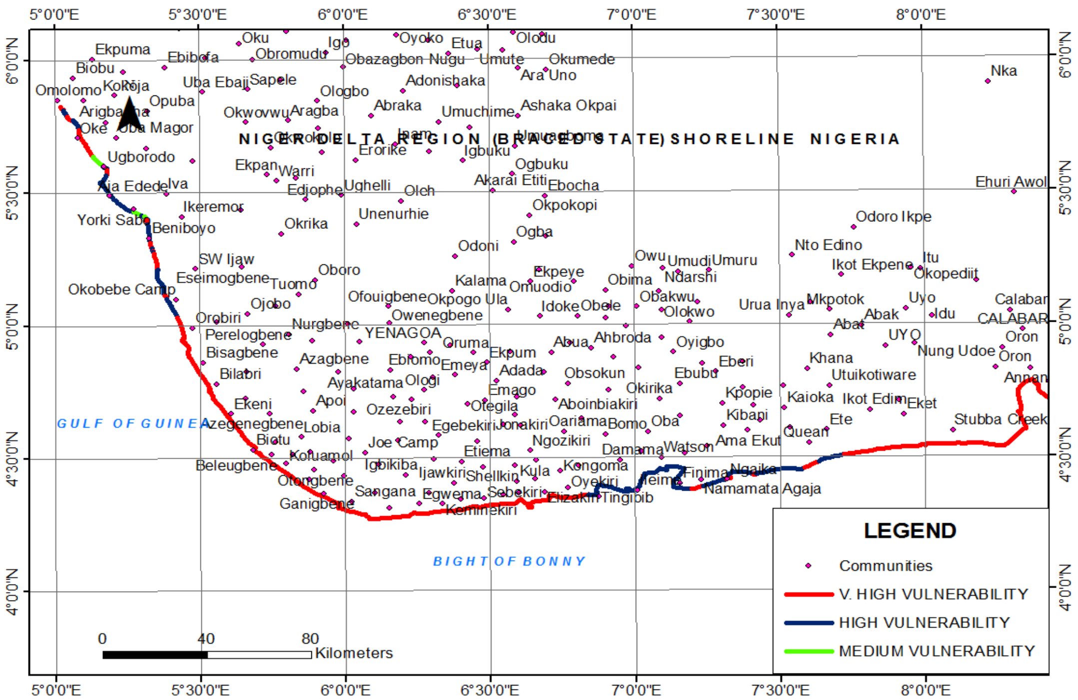
Table 5 Community Mean Distance and Exposure Level to Shoreline Dynamics

States	No of Communities	Mean Distance to Shoreline ?(m^2)	Percentage Exposed	
			Very High Exposure	High Exposure
Bayelsa	95	16.10	49.4	50.6
Rivers	58	14.86	46.5	53.5
Akwa Ibom	24	34.87	12.5	87.5
Cross River	31	146.83	6.5	93.5
Edo	73	105.95	1.4	98.6
Delta	68	16.79	45.5	54.5

Source: Author's

Table 5 Shows Summary Statistics of Community Exposure to Shoreline Dynamics in the Niger Delta. From the table, Cross Rivers and Edo states enjoys a very high distance from the shoreline which resulted in their lower value in terms of exposure to shoreline dynamics in relation to other states in the study area. Other states like Bayelsa, Rivers and Delta are almost 50 percent exposed to shoreline dynamics and other coastal perturbations which are attributed to their distance from the shoreline recorded at very low with a mean of 16.10, 14.86 and 16.79 respectively.

The vulnerability of the Niger Delta coastal region to sea level rise and the relative vulnerability of the study area were interpreted following Coastal Vulnerability Index (CVI) formulation as applied by the US Geologic Survey (USGS) 1999 to evaluate the potential vulnerability of the US coastline at a National Scale (Thieler and Hammar-klose, 1999) and on a more detailed scale for the US National Park Service (Thieler *et al*, 2002). Absolute values for vulnerability are standardized in the following classes Low – 1 (2.2 < CVI < 6.3), Medium – 2 (6.4 < CVI < 10.00), High – 3 (10.1 < CVI < 14.1), Very High – 4 (CVI > 14.2) see Appendix 7.



Source: Author's

Figure 9 Vulnerability Index map of the Niger Delta Shoreline

From Fig 9, vulnerability rating was done for the shoreline of the Niger Delta to examine areas of the shoreline that are sensitive to erosion and inundation. The vulnerability of the shoreline is at the peak in the eastern end of the Niger Delta (River Calabar, Nun and Brass estuary) with pocket of high vulnerability rating along the Bonny, Forcados and Excravos river estuary. This implies that the shoreline of the area associated with high and very high vulnerability need to be given adequate attention for flood mitigation and control measures.

V. Conclusion

Findings reveal that Shoreline of the study area has undergone retreat and advance over the period of 1986 and 2010 with a volumetric gain in shoreline advance of 103.27km^3. While 127.35km^3 of shoreline retreat occurred along vegetated segments of the shoreline, 1043.65km^3 of shoreline retreat occurred along non-vegetated segments of the shoreline. 19.7% of these retreat in shoreline occurred along vegetated segments while 80.3% occurred along the non vegetated segments of the shoreline. The study revealed that accretion volume over the time steps of the study was more than that of erosion with a net gain of 103.27km^3 in favour of accretion. This finding corresponds with that of kuenzer, Sybrand, Ursular and Stefan, (2014), that the annual accretion rate was higher than that of erosion for the Niger Delta. Findings from the physical exposure index of the area adapted from the classification for the US National Park (Thieler and Hammar-klose, 1999[11]), Orissa State Coast, East Coast of Indian Ocean (Kumar *et al*, 2010), Andalusia Coastline (Emiliano *et al*, 2011) reveals that the regions' values for shoreline vulnerability range from Low – 1 (2.2 < CVI < 6.3), Medium – 2 (6.4 < CVI < 10.00), High – 3 (10.1 < CVI < 14.1), to Very High – 4 (CVI > 14.2). Fig. 9 shows that the middle and eastern part of the study area fall within the class of very high vulnerability. Industrial areas of the environs of Bonny, Forcados and Excravos fall within the classes of High Vulnerability though, erosion rate along vegetated and non vegetated segments of the shoreline in the study region have similar trends. The communities along the shoreline without protective mangrove vegetation are more exposed and as such more vulnerable to shoreline dynamics along the coastline of the Niger Delta. It is thus recommended that institutional framework be put in place to mitigate the impact of global warming and rising sea level on erosion and flooding of the vulnerable communities along the shoreline of the region. The installation of tidal gauges along with other observatory equipment to develop a database of early warning systems for the region is very paramount in this regard.

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