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REMOTE SENSING AND GIS APPLICATIONS IN DETERMINING SHORELINE AND SURFACE WATER QUALITY CHANGES IN BAYELSA STATE, NIGERIA

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Abstract

The study of shoreline changes is essential for updating the changes in shoreline maps and management of natural resources as the shoreline is one of the most important features on the earth's surface. Shorelines are the key element in coastal GIS that provide information on coastal landform dynamics. The purpose of this paper is to investigate shoreline changes in the study area and how it affects surface water quality using Landsat imagery from 1987 to 2016. The image processing techniques adopted involves supervised classification, object-based image analysis, shoreline extraction and image enhancement. The data obtained was analyzed and maps were generated and then integrated in a GIS environment. The results indicate that LULC changes in wetland areas increases rapidly during the years (1987-2016) from 34.83 to 38.96%, vegetation cover reduces drastically through the year which range from 30% to 20%. Polluted surface water was observed to have decreased from 30% to 20% during 1984-2010 and reduced by about 3% in 2016. In addition, the result revealed the highest level of erosion from 1987 to 2016 which is -49.60% against the highest level of accretion of 13.39% EPR and NSM -1400 erosion against 350 accretions. It was also observed that variations in shoreline changes affect the quality of surface water possibly due to shoreline movement hinterland. This study has demonstrated that through satellite remote sensing and GIS techniques, the Nigerian coastline can adequately be monitored for various changes that have taken place over the years.

Key Words: *Shoreline, Remote Sensing, Erosion, Accretion, GIS*

Introduction

Shoreline is the interface between land and water and it is considered one of the most dynamic processes in the coastal area. Shoreline position is continuously changing through the time, because of the dynamic nature of the water level at coastal boundaries such as waves, tides, groundwater, storm surges, geomorphic processes of erosion, accretion and human activities (Boak and Turner, 2005; Bird, 2000). Remote-sensing data could be used effectively to observe the changes along the coastal zone,

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including shoreline with reasonable accuracy. Remote sensing helps to replace the conservative survey data by its rhythmic and cost effectiveness.The world's coastlines are dynamic and shorelines that are in equilibrium undergo advancement towards the sea or recession towards the land which is very often due to man's construction of structures as a part of different activities in coastal zone.

The erosion trend is expected to increase under the scenario of rising sea level as a result of climate change. However, the coastal zone is increasingly under pressure from human activities such as fishing, coral and sand mining, mangrove harvesting, and seaweed farming, sewage disposal, urban expansion and tourism. Coastal zone supports many different types of livelihood that are sometimes at odds with each other. Man's endeavors such as Fishing, tourism, manufacturing, farming, and other industries are all very important to the coastal areas, but without proper planning, damaging conflicts can emerge and that can destroy the very resources that support these economic activities. Coastlines are dynamic areas (Boak and Turner, 2005). As a result; the accurate mapping of the instantaneous coastline position has always been associated with significant uncertainty. It is also controlled by the actions of rip and long shore currents, which results in cross-shore and alongshore sediment movement respectively in the littoral zone. Consequently, this affects the accuracy of computed historic rates of change and therefore the reliability of any identified erosion 'hotspots'. However, the science of coastline mapping has changed in the past 70 years due to advances in technology hence, the need to reduce uncertainty. The changes in the coastline largely depend on its geology and geomorphology; the nature of tidal waves impacting the coastline; changes in sea-level; and sediment transport by longshore currents (Carter and Woodroffe, 1994; Cowell and Thorn, 1994; Pidwirny, 2006). Coastline changes often result in erosion of coastal areas or accretion off - sediments, depending on the dominant processes acting on the coastline (Pidwirny, 2006). Likewise, the human activities that impact coastlines include; dredging, construction of breakwater infrastructure and physical development, mineral exploration, ports construction, removal of backshore vegetation, construction of barrages and coastal control works (Fanos *et al.*, 1995; Berger and Lams, 1996; Pandian *et al.*, 2004). The coastline is the bridge between aquatic life and terrestrial life, and it is usually a fragile eco-zone. As a result, the study of coastline changes can be of immense benefit to the understanding of complex coastal ecosystems. In addition, coastlines are widely used as ports for navigation and maritime commerce. They are therefore of economic value and critical to the socio-economic development of non-land locked nations. Several methods have been employed to study and monitor coastlines, including traditional methods that incorporate local observations and basic surveying techniques. Analysis of coastline changes have also been carried out using survey maps (Kadib, 1969), historical coastline mapping (e.g. XYZ), and comparison of beach profiles over a period of time (Inman and Jenkins, 1984). Other more recent methods include simulation of coastline changes using numerical models (El-Serafy, 1984); combination of coastline survey using Global Positioning System (GPS) receivers; long-shore sediment transport using numerical modeling packages such as MIKE21 and LITPACK (Pandian *et al.*, 2004); and airborne Light Detection and Ranging (LIDAR) survey methods (Robertson *et al.*, 2004). All these methods had been used with varying accuracy to determine the position of the coastline at specific time periods and to detect coastline changes over time. However, the use of satellite remote sensing techniques and geographic information systems (GIS) for the identification, mapping and analyses of coastline changes have gained prominence in recent years. As a result, high resolution satellite data have become more readily available. Previous works in this direction include Moore (2000), El-Raey *et al*. (1997) and El-Amsar (2002).

These studies showed that remote sensing techniques when combined with geomorphologic and sedimentary data can be effectively used to assess coastline changes over time. In Nigeria, there is dearth of information on accelerated marine processes along the national coastline with the notable exception of the works of Usoroh (1971), Ibe (1985), Ibe and Anita (1983), and Ebisemiju (1986). Most of these studies on the Nigerian Coastline have concentrated mainly on the mapping and origin of coastal landforms (Pugh, 1954; NEDECO, 1954; Webb, 1958, 1960; Allen, 1965; Areola, 1977; Oyegun,, 1991; Oyegoke, 1982). The portion of the study covering the Niger Delta coastline focused primarily on four major locations, namely; Escravos, Forcados, Brass coast and Ibeno Eket. However, the aim of this study is to examine the shoreline changes and to assess its effect on the water quality in the Bayelsa coastline.

Study Area

The study area is Bayelsa State and it lies between Latitudes 4.20° N and 5.00° N of Equator and Longitudes 5.20° E and 6.40° E of Greenwich Meridian. The area is located in the core Niger Delta region at the Southern part of Nigeria (Figure1). Economically, Bayelsa State has one of the largest crude oil and natural gas deposits in Nigeria. As a result, petroleum production is extensive in the state. It has a riverine and estuarine setting. A lot of her communities are almost (and in some cases) completely surrounded by water, hence making these communities inaccessible by road. The other important cities besides Yenagoa include Akassa, [Lobia] and Amassoma. The state is within the Coastal alluvium, mangrove and fresh-water swamps hydrogeologic province. Coastal Plain Sands which constitute the regional aquifer is highly lenticular and contains irregular lenses of aquitard (Ekine and Osobonye, 1996). The topography is invariably gentle. Average elevation stands at about 50 m above sea level. The average rainfall in the area is about 1700 mm/annum (Ako, 1982), most of which occurs in the rainy season which ensures adequate recharge. There are a number of perennial streams and rivers in the area of survey. They all form a network which empties to the Atlantic Ocean. As a result, most of the terrain is marshy and in some cases form beaches.

The development of a delta is governed by the interactions of the processes of subsidence, deposition and erosion (Sullivan and Squire, 1980).

These interactions create complex sequences of interbeded sands, silts, clays and organic rich sediments termed lithofacies. The sediments which form the delta also vary with distance from sediment source. The more proximal deposition zones, such as the shoreline, are dominated by tidal channel and coastal barrier sands overlaying earlier (Holocene) marine clays (NDES, 1999). The delta slope deposition zone, in water depths of approximately 15m, is characterized by marine sands. The local geology around the Akanfa is composed of sediments which are characteristic of several depositional environments. The area essentially reflects the influence of movements of rivers, in the Niger delta and their search for lines of flow to the sea with consequent deposition of transported sediments. The surface deposits in this area comprise silt and sandy-clays. The sandy layers underlying the silt and sandy clay are predominantly medium to coarse grain sizes and found to exist in mostly medium state of compaction.

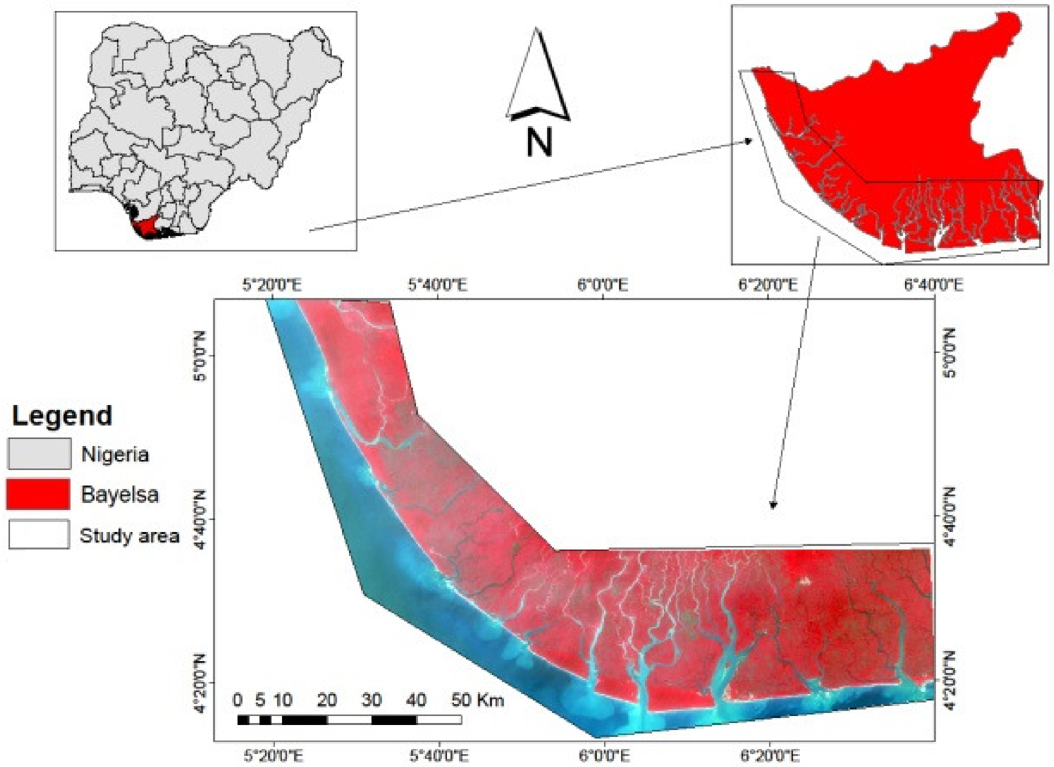

Fig. 1: Map showing the study area.

Materials and Methods

This study made use of satellite imageries of the study area. Landsat TM of 30m by 30m of 1987, 1992, 2010 and 2016 were acquired from www.usgs.gov. The satellite imageries underwent series of geo-processing in order to make them suitable for further analysis. The bands (red, blue and green) of each image were combined using ArcGIS 10.2 and geo - referenced to geographic coordinates of Universal Traverse Mercator (UTM) of Minna Datum (Zone 31N), using the same control points. Geo-referencing is important to prepare two or more satellite images for an accurate change detection comparison, it is imperative to geometrically rectify the imagery (Eludoyin *et al.,* 2011). This made it possible for all the imageries to align and overlay perfectly. The images were later subjected to image enhancement, an image processing technique. This made it possible to obtain a sharp boundary between the land and ocean which served as the shoreline. Thereafter, the digitization of the shorelines in the images of each year was done in ArcGIS 10.2 as POLYLINES (Vector Data). The digitized shorelines of each year were subjected to spatial analyses.

Image Processing

The image processing for the project was carried out using ArcGIS 10.2. The acquired Landsat TM and ETM images scenes for this study were pre-processed, that is the radiometric and geometric corrections, and geo-referencing have been done. However, the coastlines boundaries were verified using existing vector maps for consistency and accuracy.

The band combination used for the images was: Red – band 6, Green – band 4, and Blue – band 2. The reason for using the thermal band was for clear distinction of the coastline boundary (El-Asmar, 2002). The different images (change detection analysis) were generated between the before images (Landsat TM) and the after images (Landsat ETM+). The software was programmed to detect the minimum level of change of 1%. This means that an area identified to have changed for as low as 1% during the period of consideration should be duly highlighted. Visual analysis and comparison of the different images with the original images was used to identify areas of positive changes seawards (coastline accretion) represented in white (or green on the highlight image), and areas of negative changes coastline erosion) shown in black (or red on the highlight images). The areas of observed changes were extracted into a GIS database using ArcInfo 9.1.

GIS Analysis

The basic GIS operations carried out on the processed images are digital extraction of identified areas of changes along the coastline, digitization of the coastlines for the years of study and area calculation in order to know the size of changes (in km^2). All GIS operations were carried out using ArcInfo 9.1.

Results and Discussion

The images generated during the period of study are presented as figures 2 to 5. The variations in the shoreline also affect the quality of surface water over time. As the shoreline moves hinterland, more surface water are polluted (Figures 2 to 5).

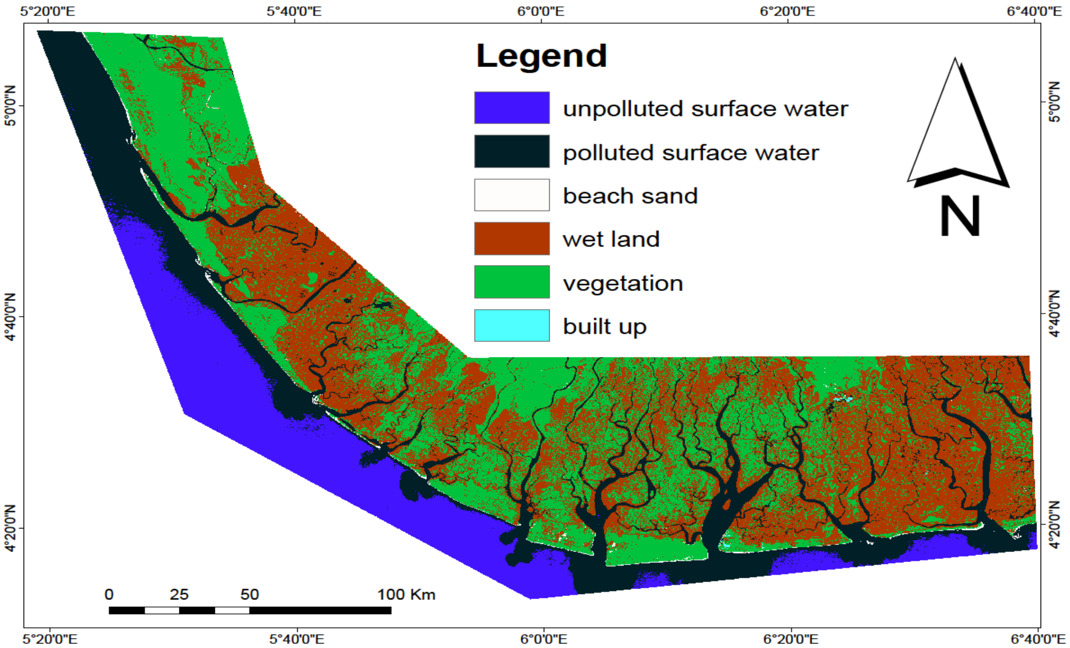

Fig. 2: Map showing the LULC for 1987 of the study area

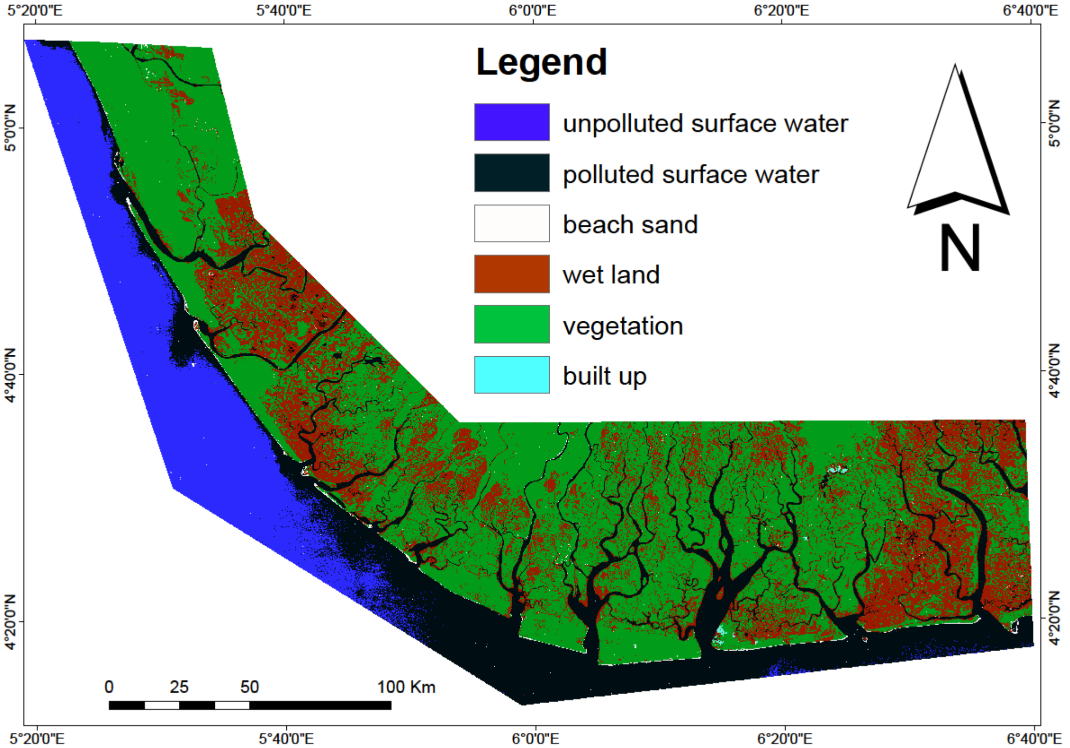

Fig. 3: Map showing the LULC for 1992 of the study area.

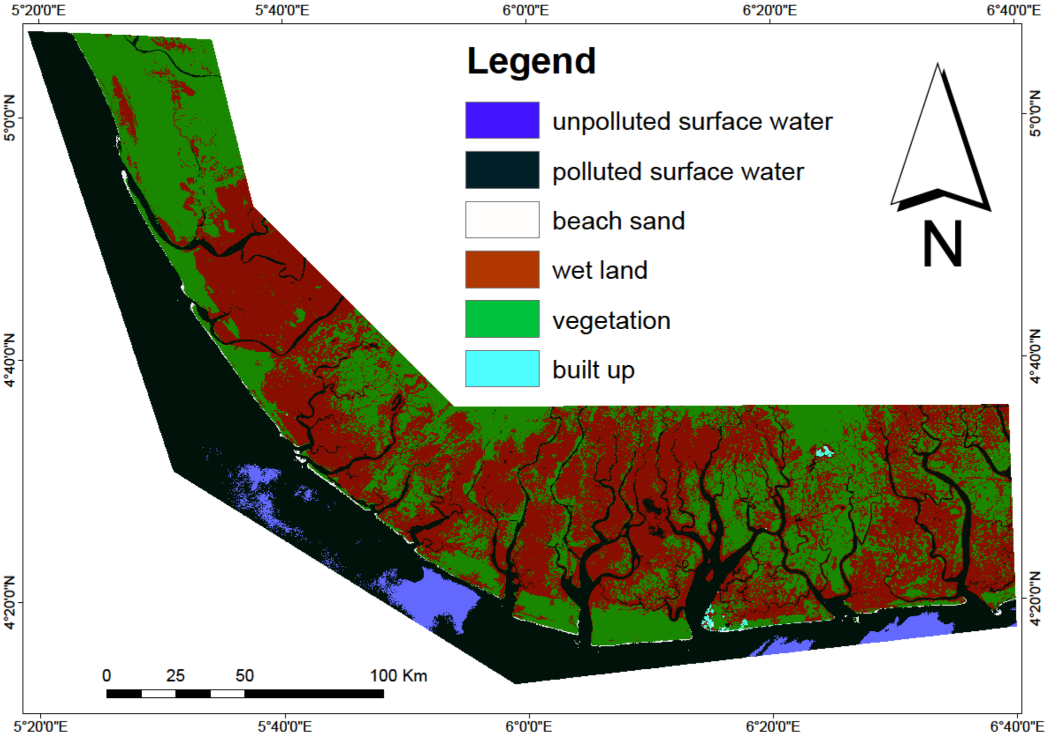

Fig. 4: Map showing the LULC for 2010 of the study area

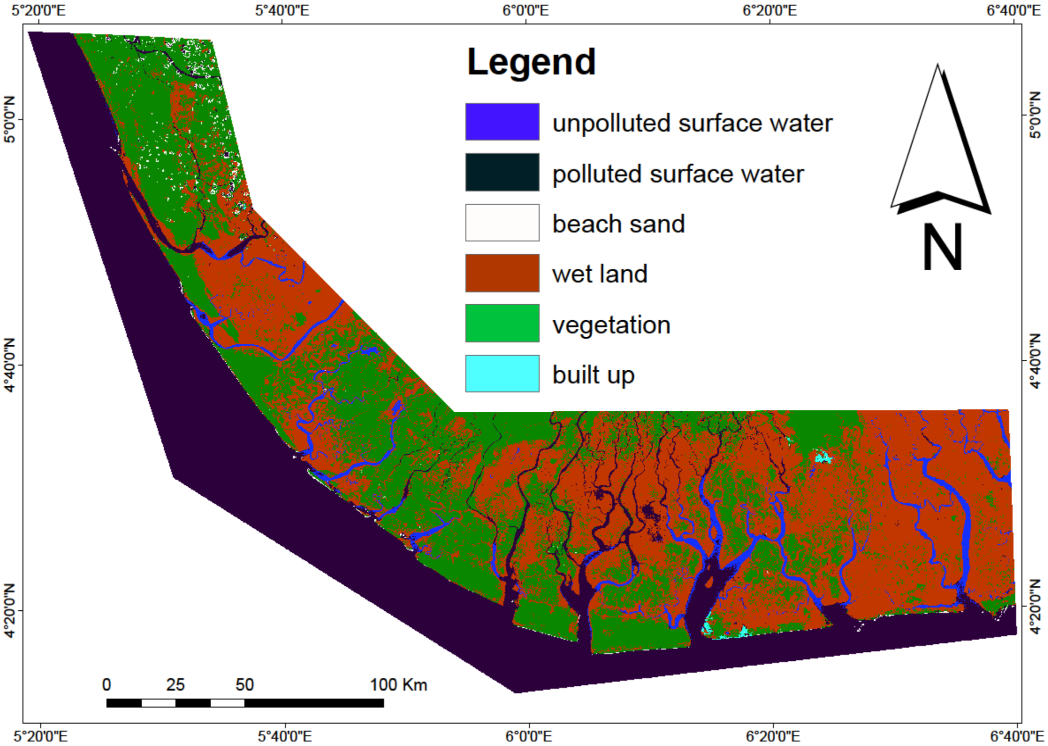

Fig. 5: Map showing the LULC for 2016 of the study area

From the classified images, (Table 1) the built up area increased from 0.03% in 1987 to 0.05% in 1992 to 0.11% in 2010 and 2016 with the vegetated area decreasing throughout the time series from 30.47% to 30.40% and 30.36% to 28.01% respectively. The wetland area reduced within the time series from 34.83% to 34.69% and increased from 35.47% to 36.98% in 2016. The beach sand reduced from 0.44% to 0.37% which indicates that this period underwent erosion and the increase of beach sand to 0.48% was due to accretion in 2016, as indicated in Table 1. The total area covered by water body increased between 1987 and 1992 from 31.23% to 34.44% reducing to 33.69% in 2010 and increasing further to 34.41% in 2016. The increase and decrease in surface water body can be an indication of erosion and accretion in the study area.

Table 1: Time series analysis of landuse/landcover change

	1987		1992		2010		2016	
NAME	Area (m^2)	Percent (%)	Area (m^2)	Percent (%)	Area (m^2)	Percent (%)	Area (m^2)	Percent (%)
Unpolluted Surface water	910817100	15.13	848996100	14.10	162537564	2.70	1878976800	31.20
Polluted Surface water	114997140	19.10	1224891000	20.34	1865891632	30.99	193141800	3.21
Beach sand	26232300	0.44	24601500	0.41	22163812	0.37	28742400	0.48
Wet land	209681460	34.83	121398400	34.69	2135825692	35.47	2226947400	36.98
Vegetation	1834504200	30.47	2705897700	30.40	1827807608	30.36	1686725100	28.01
Built up	2099700	0.03	3291300	0.05	6716952	0.11	688600	0.11

The total length of the extracted shoreline of 1987 Landsat image is 179773.78m, for year 1992 is 179367.44m, for year 2010 is 179137.19m, and for year 2016 is 183771.93m. The shorelines are represented with different colours in figure 6. A closer look at the digitized shorelines showed that there is a remarkable change in the shape of the shoreline over time as indicated in figure 7. The result of the analysis revealed changes in the Bayelsa shoreline, the net change measured as the distance between the most recent and earliest shorelines (1987, 1992, 2010 and 2016). The sum total of the magnitude of net erosion that occurred during the different periods under investigation is shown in the Table 2.

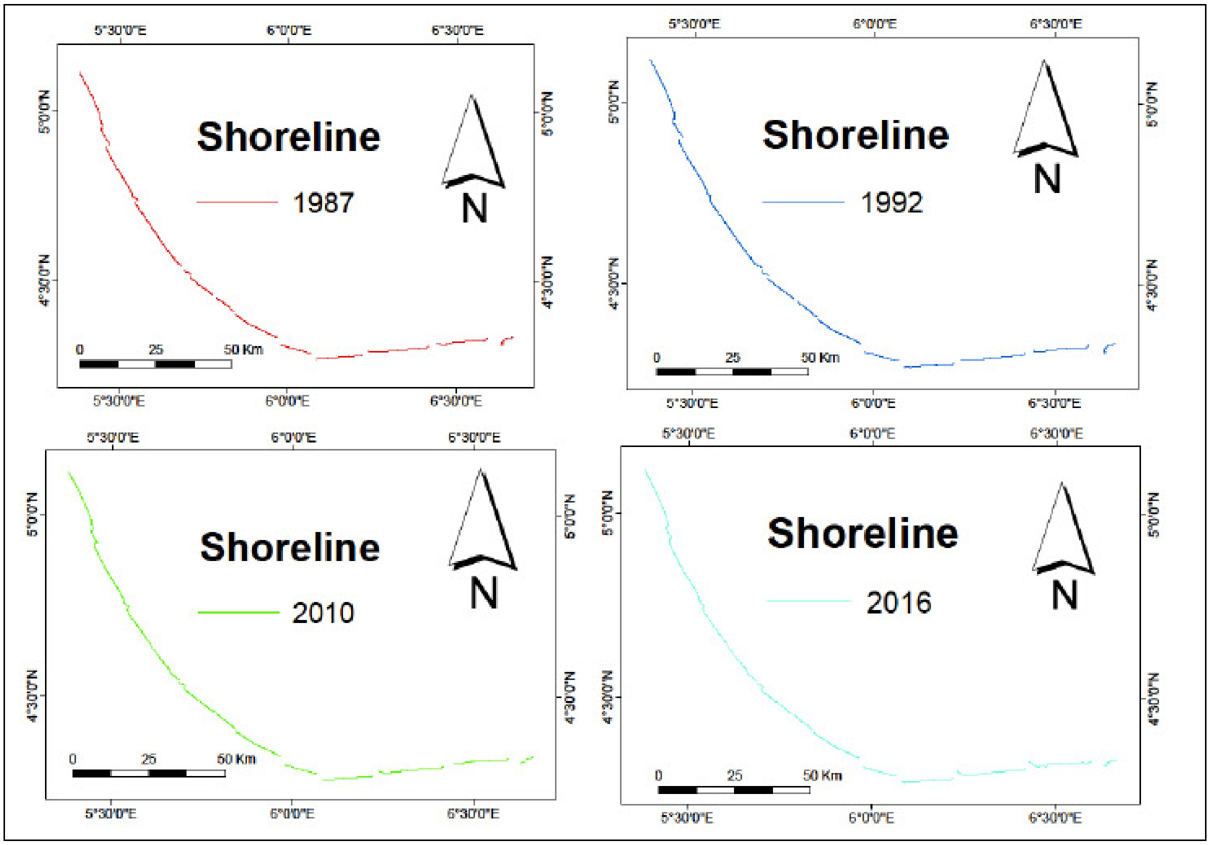

Fig. 6: Map showing the shorelines of each year of the study area

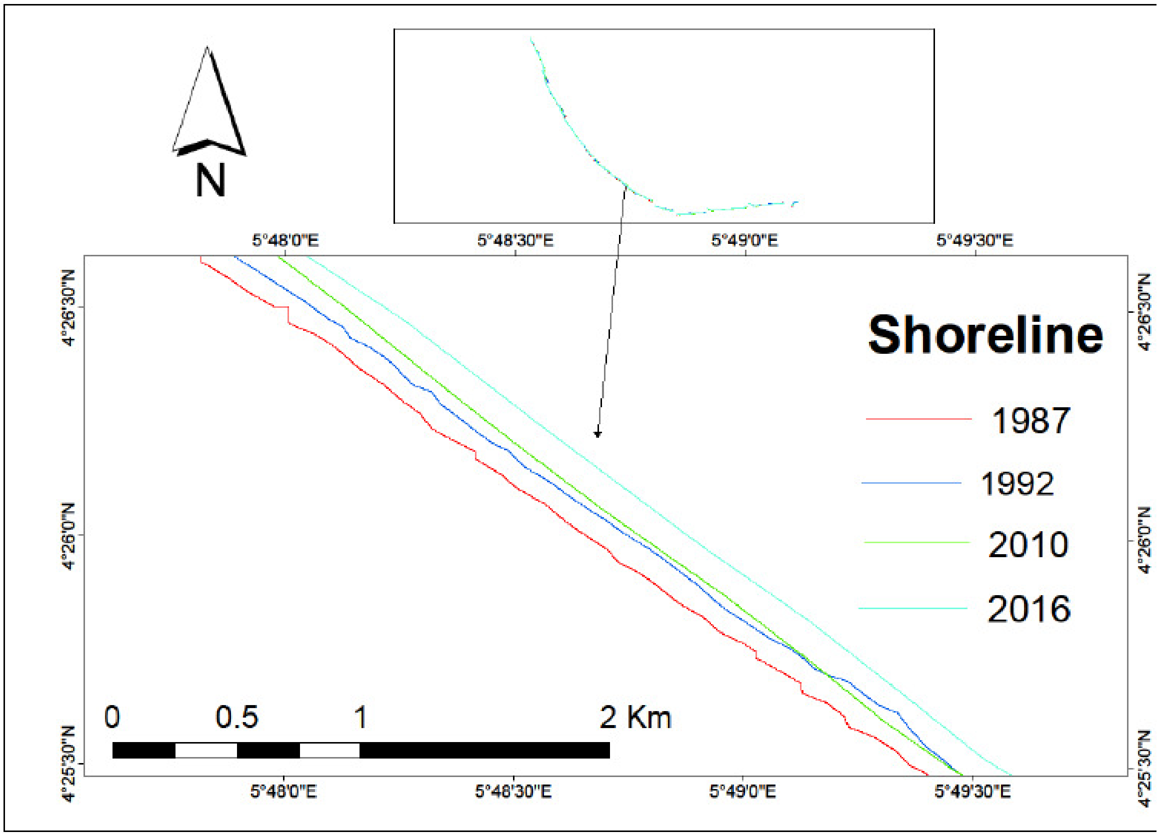

Fig. 7: Map showing the shoreline changes of the study area.

Table 2: Erosion and Accretion Rate

Periods	Erosion	Accretion	Net Change	Annual Rate of Erosion
1987-1992	-1940.98m	9334.1m	-7393.12m	-465.52m
1992-2010	-17559.74m	3583.98m	13975.76m	-676.5m
2010-2016	-3233.69m	7574.45m	-4340.76m	-650.65m
1987-2016	-12465.89m	10191.41m	2274.48m	-365.12m

To compute the shoreline rate of change, that is, the rate at which the coastline is eroding/ accreting; the End Point Rate (EPR) method was used. From the result generated by DSAS in the rate of change analysis result, the rate of erosion in the year 1987-1992 is -465.52m/ yr, 1992-2010 is -676.5m/ yr, 2010-2016 is -650.65m/ yr while 1987-2016 is -365.12m/yr, Table 2.

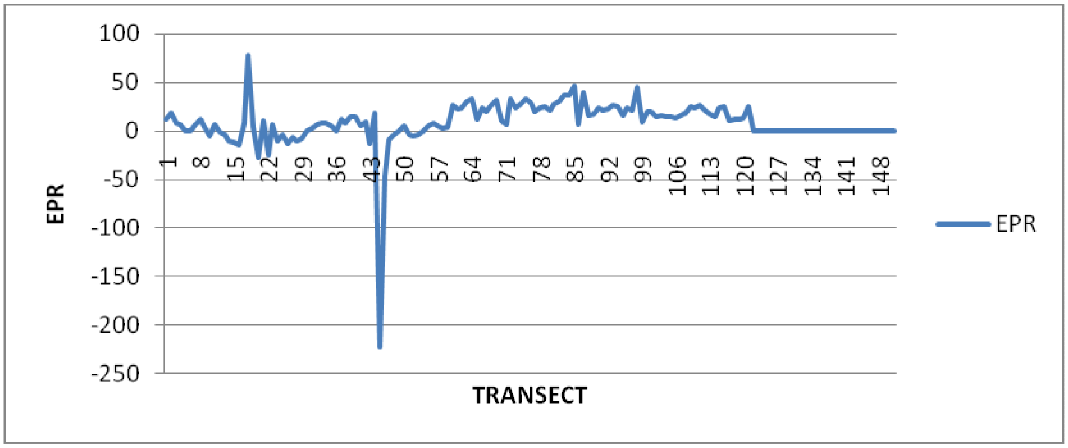

Fig. 8a: EPR of the shoreline 1987 – 1992

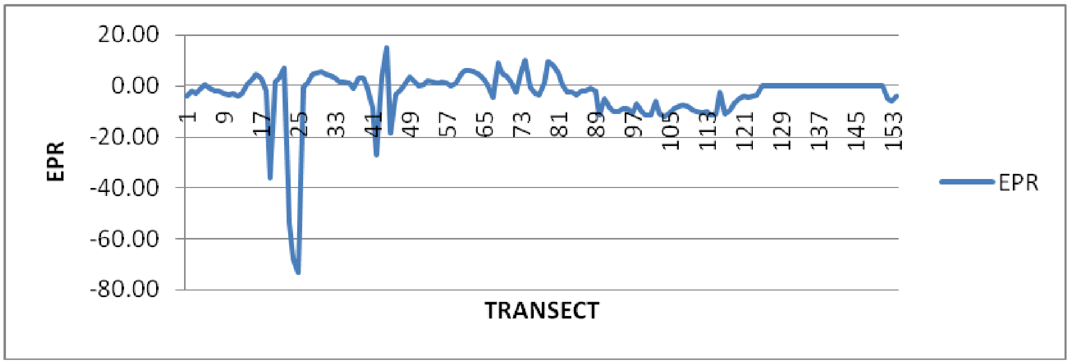

Fig. 8b: EPR of the shoreline 1992 - 2010

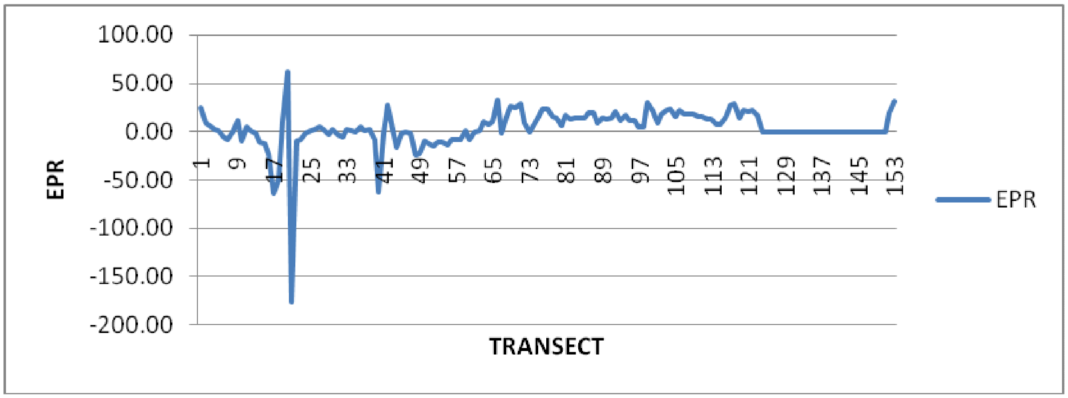

Fig. 8c: EPR of the shoreline 2010 - 2016

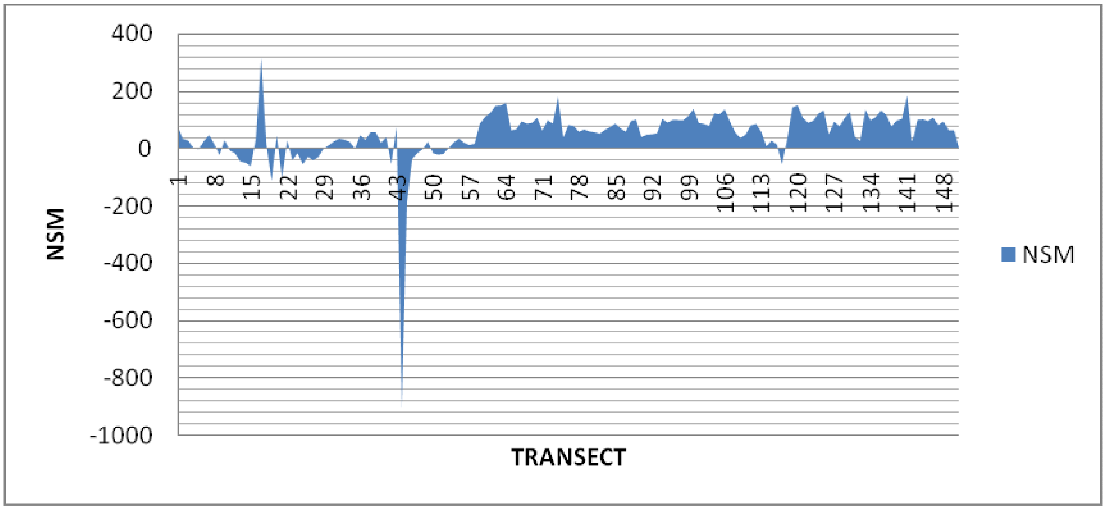

Fig. 9: Net Shoreline Movement 1987 – 1992

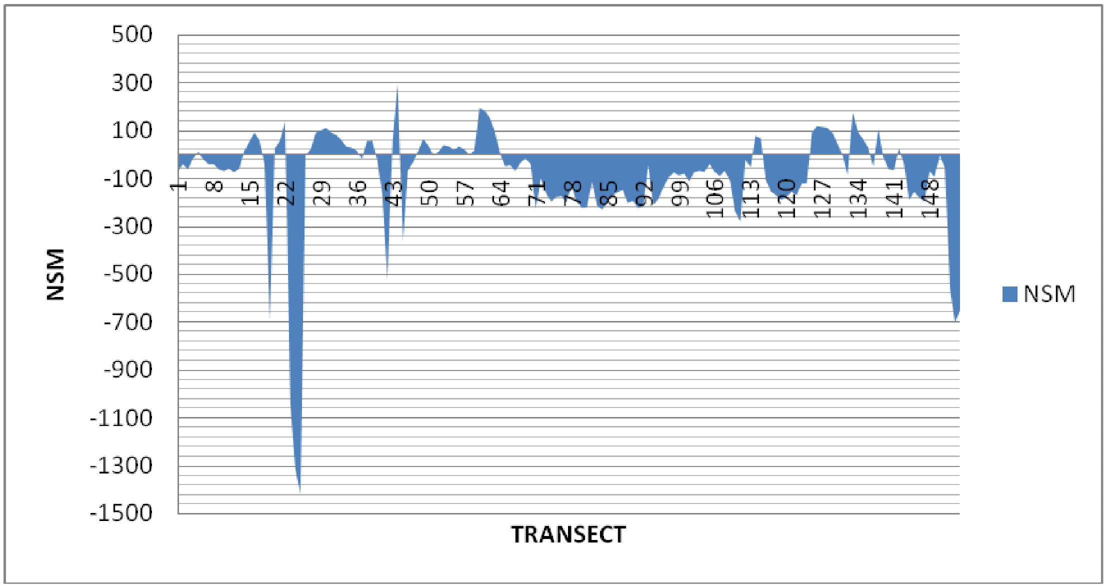

Fig. 10: Net Shoreline Movement 1992 - 2011

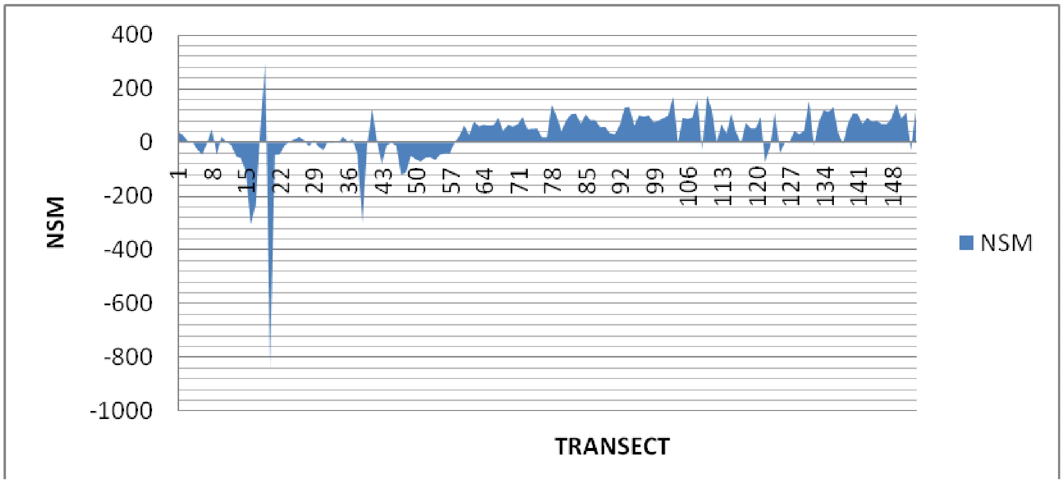

Fig. 11: Net Shoreline Movement 2011 - 2016

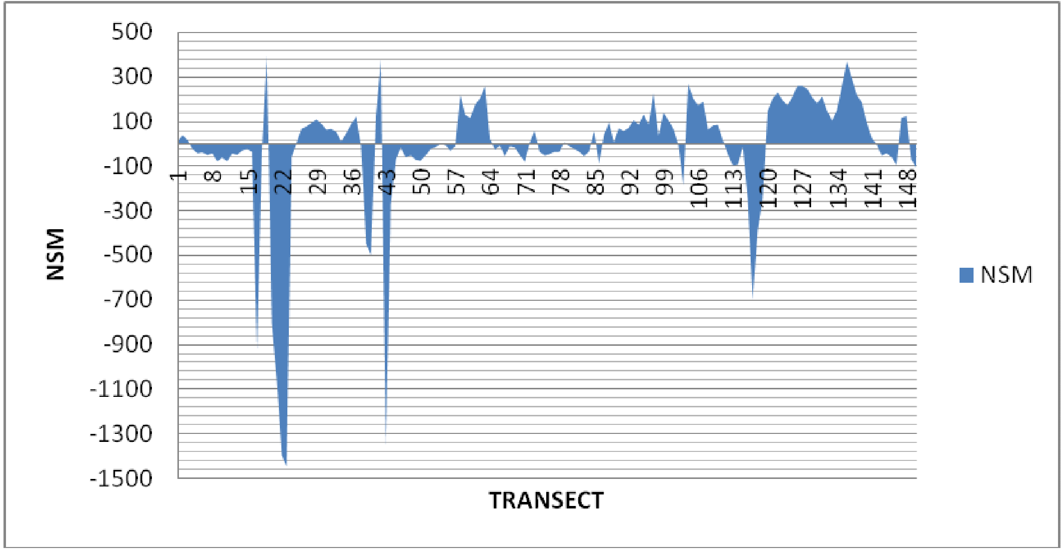

Fig. 12: Net Shoreline Movement 1987 - 2016

Conclusion

Remote sensing and GIS technique has proved useful from time in memorial for checking out the coastal environment and monitoring the changes overtime in the coastal zone. It has been observed that shoreline change in the study area results from both erosional and accretion processes. The study has revealed that erosion level in the area is more than accretion during the period studied (1987 – 2016). However, the limitation in this study is the spatial resolution of the satellite imagery used. Therefore, to further enhance the study, high-resolution images of selected sites should be used to increase the accuracy of measurements of coastline changes. Nonetheless, this study has been able to ascertain that through satellite remote sensing and GIS techniques, the Nigerian coastline can adequately be monitored for various changes that take place.

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