

An Assessment of Recent Changes in the Niger Delta Coastline Using Satellite Imagery

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Abstract

In Nigeria, there is dearth of studies on recent changes on accelerated marine processes along the national coastlines despite their importance as ports for navigation and marine commerce as well as a bridge for aquatic and terrestrial life.

This study, which deals with a time series analysis of recent changes in the Niger Delta Coastline using Satellite Imagery is an attempt at filling this gap. Landsat TM images of 1986 and Landsat ETM+ of 2003 both covering the Niger Delta area of Nigeria were used for this study and the images were processed using Erdas Imagine Version 8.7 and Arc Info 9.1 for the GIS operations. The results of the analyses show among other things that coastline erosion was dominant over accretion of sediment deposition. Also that the total area of observed changes along the coastlines was 46.535sq.km. Of this, 27.65sq.km (59.43%) constitutes eroded area, and 40.57% representing 18.88sq.km of the area showed coastal sediment accretion.

Keywords: Coastal processes, Marine erosion, Niger Delta, Satellite imagery, Accretion

1. Introduction

The coastline is generally considered to be the edge or margin of land next to the sea or ocean. Various technical definitions of coastline are used by different coastal management and regulatory agencies but most coastal zone researchers describe the coastline as the interface between land and water (Bird, 1967; Dolan et al., 1980). Coastlines are dynamic and are therefore areas of constant change (Boak & Turner, 2005). 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, 2006a). Coastline changes often result in erosion of coastal areas or accretion of sediments, depending on the dominant processes acting on the coastline (Pidwirny, 2006b).

Also 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; Ibe, 1998; Pandian et al., 2004).

The coastline is the bridge between aquatic life and terrestrial life, and it is usually a fragile ecozone. As a result, the study of coastline changes can be of immense benefit to the understanding of complex coastal ecosystems. 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 can also be carried out using survey maps (e.g., Kadib, 1969), historical coastline mapping (e.g. XYZ), and comparison of beach profiles over a period of time (e.g. Inman and Jenkins, 1984; Ibe, 1998). Other more recent methods include simulation of coastline changes using numerical models (e.g., 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 (e.g., Robertson et al, 2004). All these methods can be used with varying accuracy to determine the position of the coastline at specific time periods and to detect coastline changes over time.

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 high resolution satellite data have become more readily available. Previous works in this direction include Moore (2000), El-Raey et al (1997), El-Amsar (2002) and Liu et al (2003). 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 studies on accelerated marine processes along the national coastline with the notable exception of the works of Usoroh (1971), Ibe (1985, 1986, 1998), Ibe and Anita (1983), and Ebisemiju (1986). Previous studies of the Nigerian Coast have concentrated mainly on the mapping and origin of coastal landforms (Pugh, 1954; NEDECO, 1954; Webb, 1958, 1960; Allen, 1965; Areola, 1977; Oyegun, 1982, 1988, 1989, 1991; Oyegoke, 1982).

The Nigerian Institute of Oceanography and Marine Research (NIOMR) did a lot of work in the 1980s on coastal changes in Nigeria (Ibe 1988). The portion of the study covering the Niger Delta coastline focused primarily on four major locations: Escravos, Forcados, Brass coast and Ibena Eket (Figure 1). The coastal changes at these locations were monitored using a combination of historical data (aerial photographs) from the 1960s to 1970s and beach profiling. Their study over the 20-year period between 1960's and 1980's documented numerous cases of both erosion and accretion, but erosion was predominant (Ibe, 1988). The aim of the present study is to update the coastline change assessment conducted by NIOMR in the 1980's. The study intends to map, analyze and identify the recent changes along the coastline of the Niger Delta using satellite imagery in a GIS environment.

2. Study Area

The Niger Delta region is located in the central part of Southern Nigeria and bounded to the south by the Atlantic Ocean. This region has a coastline extending from the Benin River to the Imo River and spans about 500km (Fig. 2). Our study area extends along the Niger Delta coastline from (5°2'47.10" E 5°46'57.06" N) west of the Benin River in Edo State to (7°41'26.00"E 4°29'56.37"N) close to the Imo River in Akwa-Ibom State. The area bounds the Atlantic Ocean and four states in the South-south zone of Nigeria: Delta, Bayelsa, Rivers and Akwa-Ibom States (Figure 2).

The Niger Delta is endowed with immense natural resources, especially hydrocarbon deposits. Crude oil production and export from the region, in the range of two million barrels a day, dominates the Nigerian economy, accounting for over 90% of the Nation's total export earnings. The region is also home to the largest contiguous Mangrove forest in Africa and third largest in the world, following Indonesia and Brazil (Nwilo, 2003). Ibe (1998) identifies the swamps of the Niger delta as covering an area of about 9,000 sq. km, with the mangrove mainly vegetated, tidal flat and are flood plains, lying between mean low and high tides. The Niger River bifurcates to form deltas through which the river drains into the Atlantic Ocean. The area encompasses several ecological zones including coastal barrier islands, mangroves, freshwater swamp forest and lowland rainforests. The beaches of the region receive sand from the coastal rivers and these are re-distributed by longshore currents (Ibe, 1998).

The region is endowed with hydrocarbon resources, which are the mainstay of Nigeria's economy. Since the discovery of crude oil in commercial quantities in the area in the late 1950s, the region has witnessed major infrastructural development resulting from oil and gas exploration, upstream damming of the Niger River, and construction of ports for crude oil and gas export.

3. Data sources and preprocessing

Two sets of spatial data were used for the study. The first datasets (Table PP) consists of Landsat TM images of 1986 and Landsat ETM+ of 2003, both covering the Niger-Delta area of Nigeria. The resolution of the Landsat TM and ETM+ images was 28.5m. Based on the available image scenes, the entire Niger Delta area was divided into three main sections, namely: West Coast, South West, and South East. The images covering the West Coast and South West regions of the study area were in UTM Zone 31N, WGS 84 Datum; while the images covering the South East region of the study area were in UTM Zone 32N, WGS 84 Datum. These coordinate systems were maintained throughout the project. We acquired the images from the University of Maryland Global Land Cover Facility (URL: <http://glcf.umd.edu/index.shtml>) and processed the images for haze and geometric rectification.

The West Coast section of the study area extends from River Benin in Edo State through to the mouths of Rivers Forcados and Escravos in Delta State of Nigeria. The South Western region of the study area covers from the mouth of Ramos River eastwards in Delta State to the mouth of Santa Barbara River in Bayelsa State. The South-East covers from the eastern part of the mouth of the Santa Barbara River to about 3.2 km east of the Imo River mouth in Rivers State.

The second dataset consists mainly GIS vector layers of the Niger Delta including, administrative boundary, settlement distribution, and towns. The GIS data was acquired from the Nigeria National Space Research and Development Agency (NASRDA).

4. Methodology

4.1 Image Processing

The image processing for the project was carried out using Erdas Imagine version 8.7. This was carried out at the Geographic Information Systems and Remote Sensing Laboratory of the Department of Geosciences, University of Missouri, Kansas City, USA. The acquired Landsat TM and ETM images scenes for this research work 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 Landsat ETM+ coastline was compared with the coastline boundaries of the Administrative Map of Nigeria digitized at the National Space Research and Development Agency (NASRDA) GIS/Remote Sensing Laboratory in Abuja, Nigeria. The source of the map was Federal Surveys, Nigeria. This boundary has been previously modified using NigeriaSat-1 imagery acquired in 2003 for the Coastal area of Nigeria.

Histogram equalization enhancements were carried out on all the images so as to produce sharper images. 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). Difference 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% over the period of consideration should be duly highlighted. Visual analysis and comparison of the difference 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.

4.2 GIS operations

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 km²). All GIS operations were carried out using ArcInfo 9.1.

5. Results and discussion

Along the entire coastline, coastline erosion was observed to be dominant over accretion or sediment deposition. This, when viewed from the background of previous work done by Ibe (1998), it shows that erosional tendencies are still prevalent along the Niger Delta coast. The total area of observed changes along the coastline was 46.535 sq. km. Of this, 27.657 sq. km. or 59.43% constitutes eroded area, while 40.57% representing 18.878 sq. km. of the area showed coastal sediment accretion.

5.1 West coast region of the study area

The West coast of the study area records more accretion than erosion. A total area of 9.381 sq. km. of changes was observed. Accretion accounts for 8.859 sq. km (94.44%), while erosion accounts for 0.522 sq. km (5.56%). Annual rate of accretion and erosion are 0.521 sq. km and 0.031 sq. km respectively. The four major flash points of change observed along the coastline in this area are: within the Benin river mouth, Escravos river mouth, Escravos-Forcados rivers mouth axis, and Forcados river mouth. From the mouth of the Benin River moving eastwards the trend is predominantly accretion. Of the total change of 5.561 sq. km, accretion covers 5.194 sq. km (93.40%) and erosion covers 0.367 sq. km (6.60%). Around the mouth of the Escravos River to the southeastern part of the coastline, near Ogidigben, there was no observed erosion. Accretion to the tune of 2.003 sq. km was however observed. The Escravos-Forcados axis records seaward growth of land of about 1.255 sq. km. This was spread along a coastline stretch of about 8 km. Around the Forcados river mouth area, we observed a total change of 0.562 sq. km, of which 0.407 sq. km (72.42%) and 0.155 (27.58%) where accretional and erosional, respectively.

5.2 South west region of the study area

Along this portion of the coastline of the Niger Delta was recorded massive erosion. The total area of change along the coastline stretch in this region amounts to 20.475 sq. km, consisting of several small patch hotspots along the coast. Accretion of 4.979 sq. km (24.32%) area was observed, while 15.496 sq. km (75.68%) of erosion was observed. The annual rates of erosion and accretion in this region are 0.912 sq. km and 0.293 sq. km respectively. Approximately 12% (or 2.431 sq. km.) of the entire coastline change in this section occurred around the mouth of Ramos river consisting of 1.527 sq. km. of erosion and 0.904 sq. km of accretion. Similarly, 16% of the coastline change in this section occurred around Dodo river mouth, accounting for 3.344 sq. km. of changed area comprising of 2.097 sq. km. (62.71%) and 1.247 sq. km. (37.29%) erosion and accretion, respectively. Moving eastwards along the coastline, between Dodo river and Santa Barbara river mouths, a total area of 15.604 sq. km. change in the coastline occurred. The change was made up of 11.627 sq. km. of erosion and 3.977 sq. km. of accretion.

5.3 South east region of the study area

The South-East area also records massive erosion and some accretional trends. The total change observed was 17.654 sq. km, consisting of 11.897 eroded area and 5.757 sq. km. (Table JJC). On aggregate, the annual rates of coastal dynamics in the south east section are 0.679 sq. km and 0.302 sq. km for erosion and accretion respectively

The table below shows a highlight of the changes observed in this region

S/No	LOCATION	EROSION (KM ²)	ACCRETION (KM ²)	TOTAL (KM ²)	COMMENTS
1.	Santa Barbara River to San Bartholomeo River mouth	2.858	1.272	4.130	Off coast changes of 0.19 km ² and 0.124 km ² of accretion and erosion respectively observed
2.	Between San Bartholomeo and Sombreiro Rivers	1.265	0.107	1.372	The accretion was observed mainly around Sombreiro River mouth. Erosion observed along 10.9km of coastline from San Bartholomeo River eastwards.
3	Between Sombreiro and New Calabar Rivers	3.197		3.197	This is a massively eroded area of the Niger Delta coastline. Also observed was about 0.435 km ² of accretion off the coast.
4.	Between New Calabar and Bonny Rivers	1.577		1.577	This erosion was observed along a 10.88 km coastline. This portion is the inner portion of the coastline between these rivers.
5.	From Bonny River to Andoni River	0.995	2.21	3.205	The erosion was observed from the mouth of Bonny river and extending for 6.5km of the coastline. Accretion was observed along the coastline from the point where the erosion ceased. It extends over 17km of coastline up to the mouth of Andoni River.
6	Between Andoni River and Imo River	1.18	1.11	2.29	Erosion is prevalent around the coastline nearest the mouth of Andoni river mouth, while accretional trend is towards the mouth of the Imo river.
7.	Imo River Mouth up to about 3.2 km eastwards	0.567	0.341	0.908	

Comparing the results from this study with the previous effort by Ibe (1988) to document the dynamics of coastline change in the Niger Delta, three major deductions can be drawn. First, at the Escravos area, Ibe recorded an annual erosion rate of about 20m. Comparing this with the current trends, it can be seen that over the 17 year period of this study, erosion in Escravos area has greatly reduced to a minimum. Deliberate efforts could have been geared towards erosion control, which are yielding positive results

Second, at the Forcados River mouth and adjoining coastline, Ibe's observations indicated a process of beach replenishment in November 1981. He also noted that in 1986, the Shell Petroleum Development Company (SPDC) paid particular attention to the erosion problem in the area, which was at a rate of 22m per annum by putting up erosion mitigation measures. According to Ibe's observations between 1985 and 1986, the dominant trend was erosion, but it occurred at much slower rates than recorded in the early 1980s. This study records a total change of 0.562 sq. km, of which 0.407 sq. km (72.42%) is accretional and 0.155 (27.58%) was erosional in the Forcados area. This may be an indication of the efforts of SPDC.

Third, Ibe attributed the erosion trend along the Brass coast to the highly dynamic and destructive nature of the environment. Within the period of Ibe's studies in the area, the Brass area was under serious threat of erosion in spite of efforts geared at controlling it. Between 1960 and 1980, Ibe observed about 250m of beach eroded. From his profile stations established in 1981, he monitored an annual rate of erosion to the tune of 18m per annum. This study revealed that erosion is still prevalent around the Brass coastline. From Nun River mouth through the Brass River mouth and extending towards St. Nicholas River, a total of 1.463 sq. km of erosion was observed, although some areas of accretion were observed as well.

6. Conclusion

Limitations for this project may include the spatial resolution of the satellite imagery used. To further enhance the project, high-resolution images of selected sites may 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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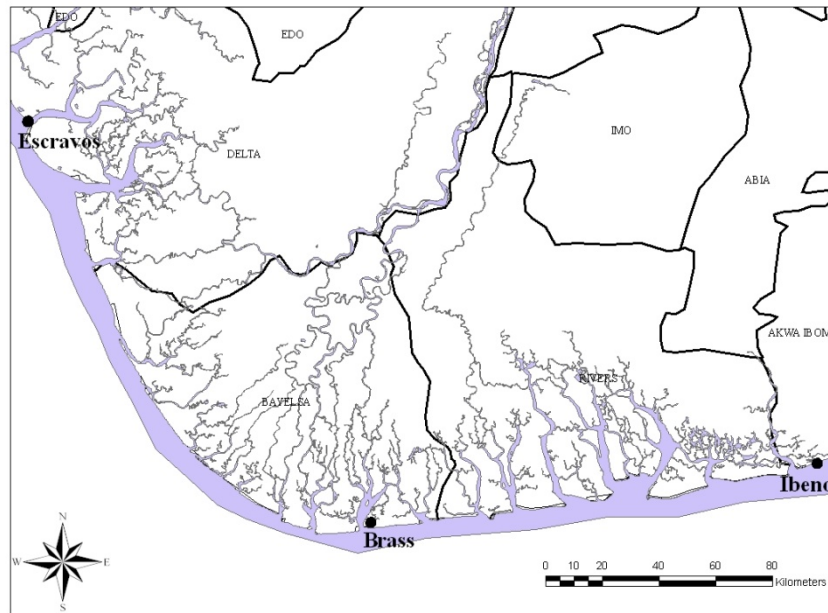


Figure 1. The Niger Delta coastline

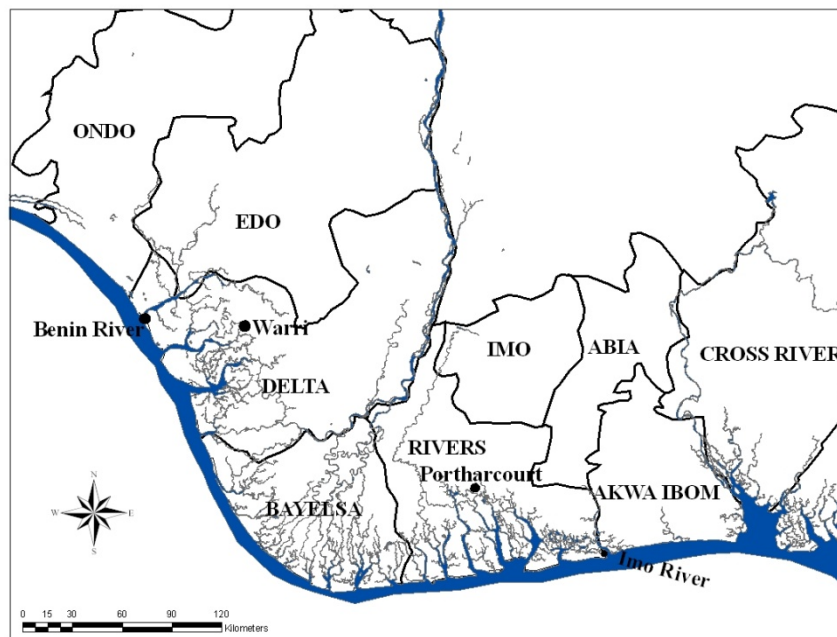


Figure 2. The Niger Delta and its states

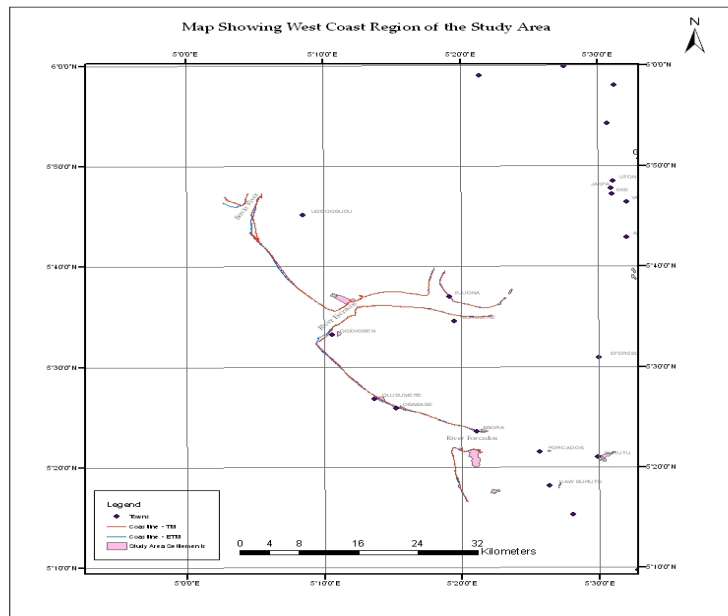


Figure 3. Map of the West Coast Region of the Niger Delta Coastline

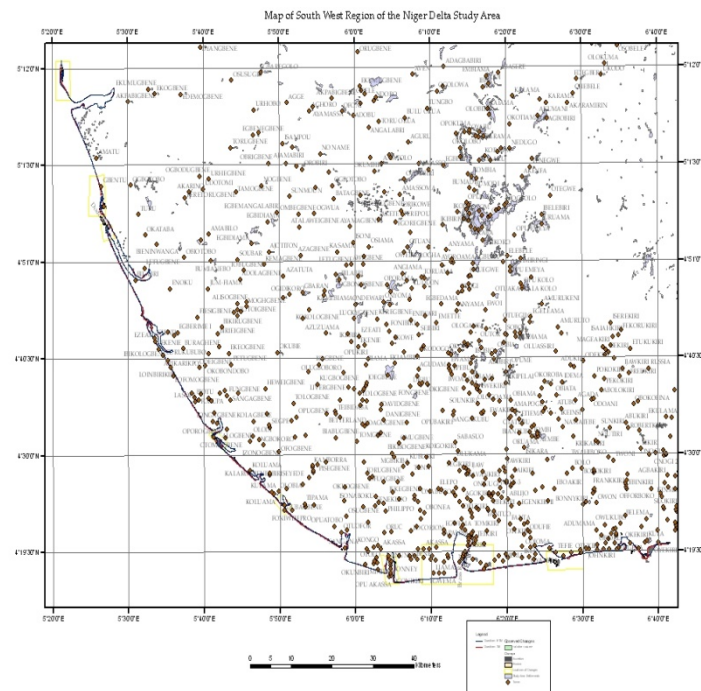


Figure 4. Map of the South West Region of the Niger Delta Coastline

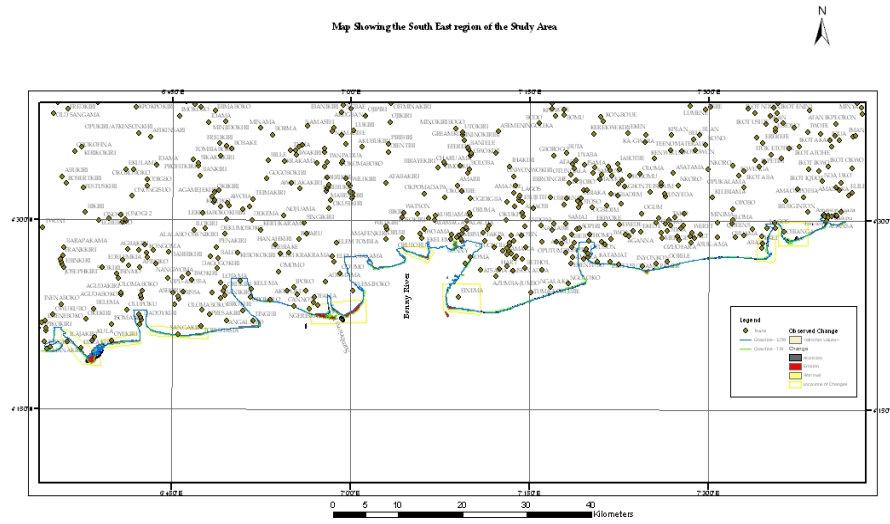


Figure 5. Map of the South East Region of the Niger Delta Coastline

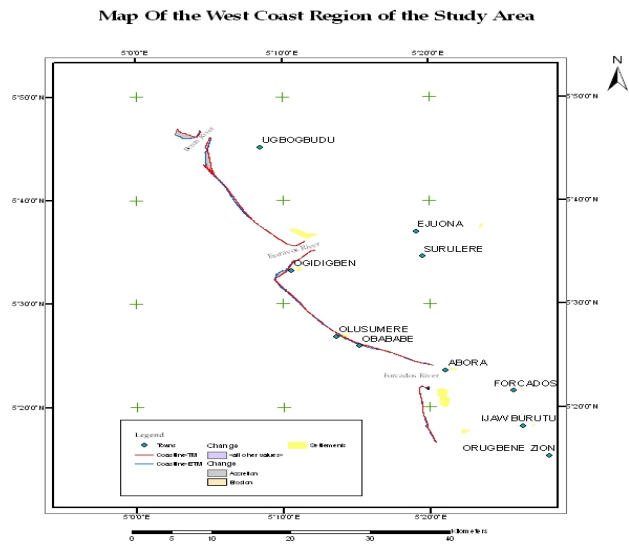


Figure 6. Map showing the entire West Coast region of the Study Area

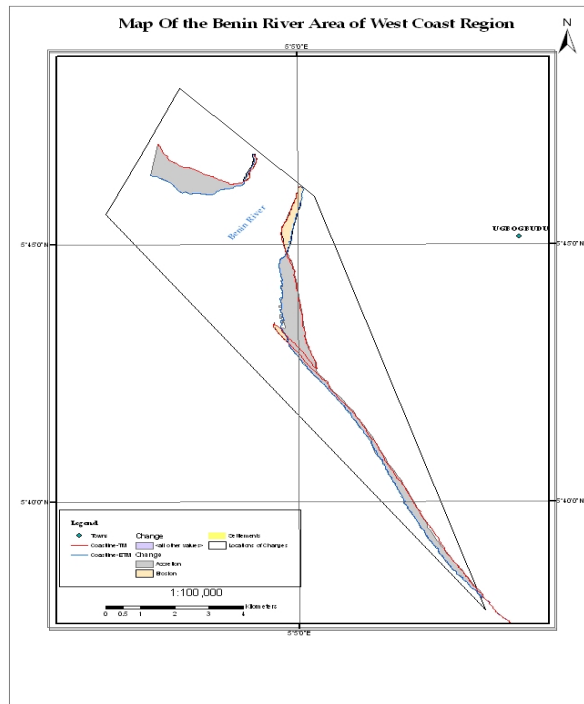


Figure 7. Map showing Benin River Mouth and coastline

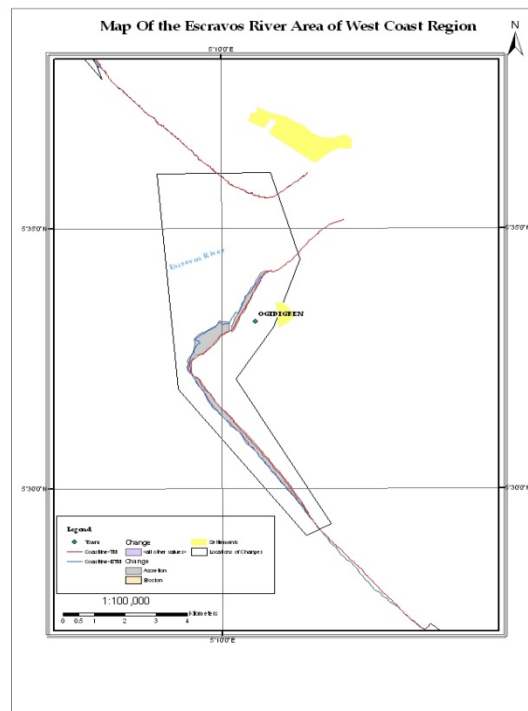


Figure 8. Map showing Escravos River mouth and coastline

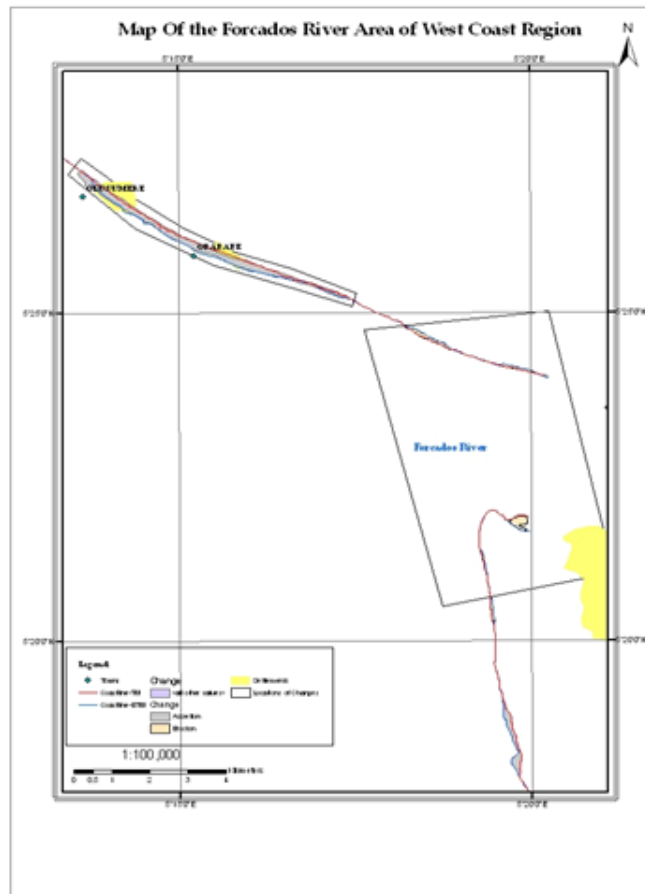


Figure 9. Map showing River Forcados mouth and coastline

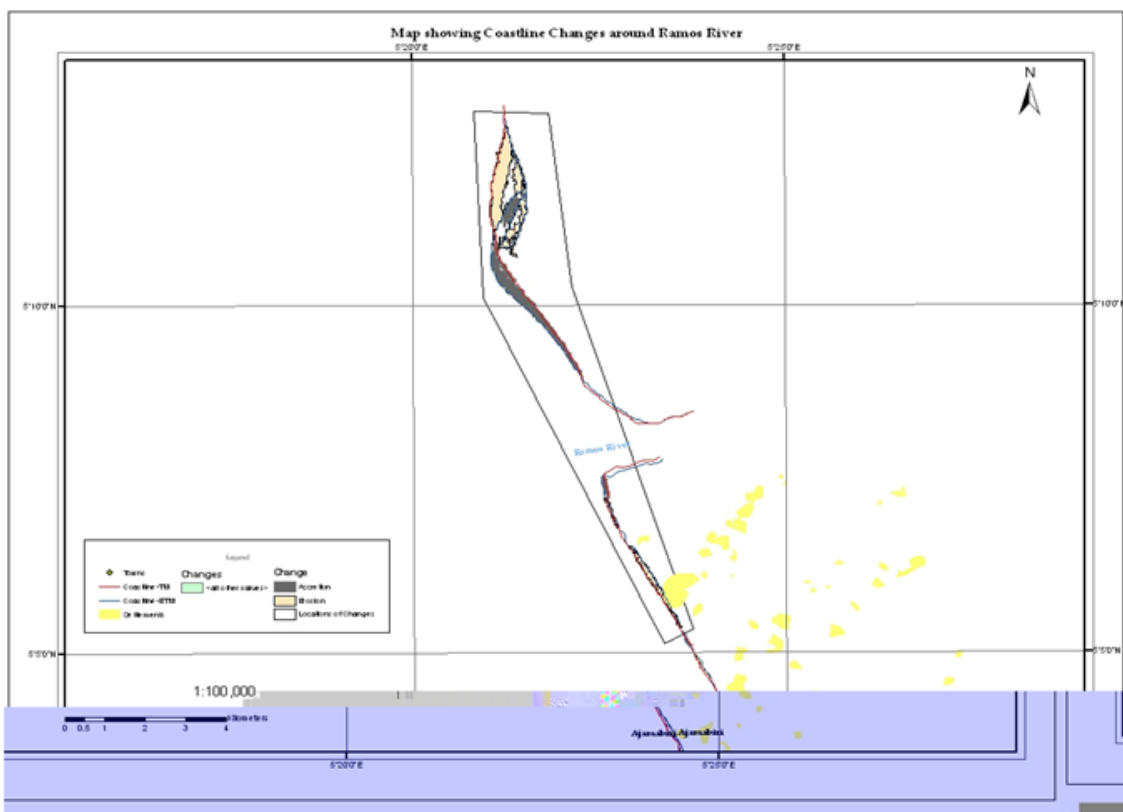


Figure 10. Map showing Ramos River and Coastline

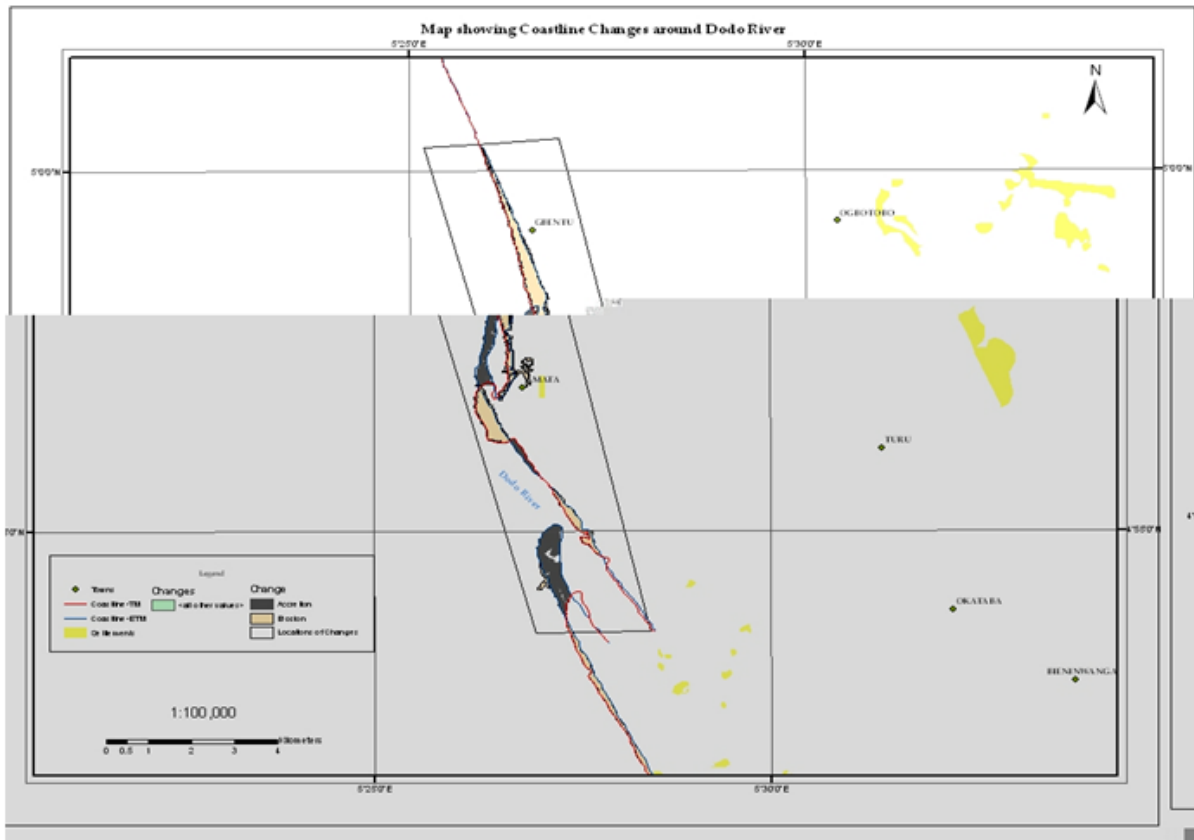


Figure 11. Map of Dodo River and coastline

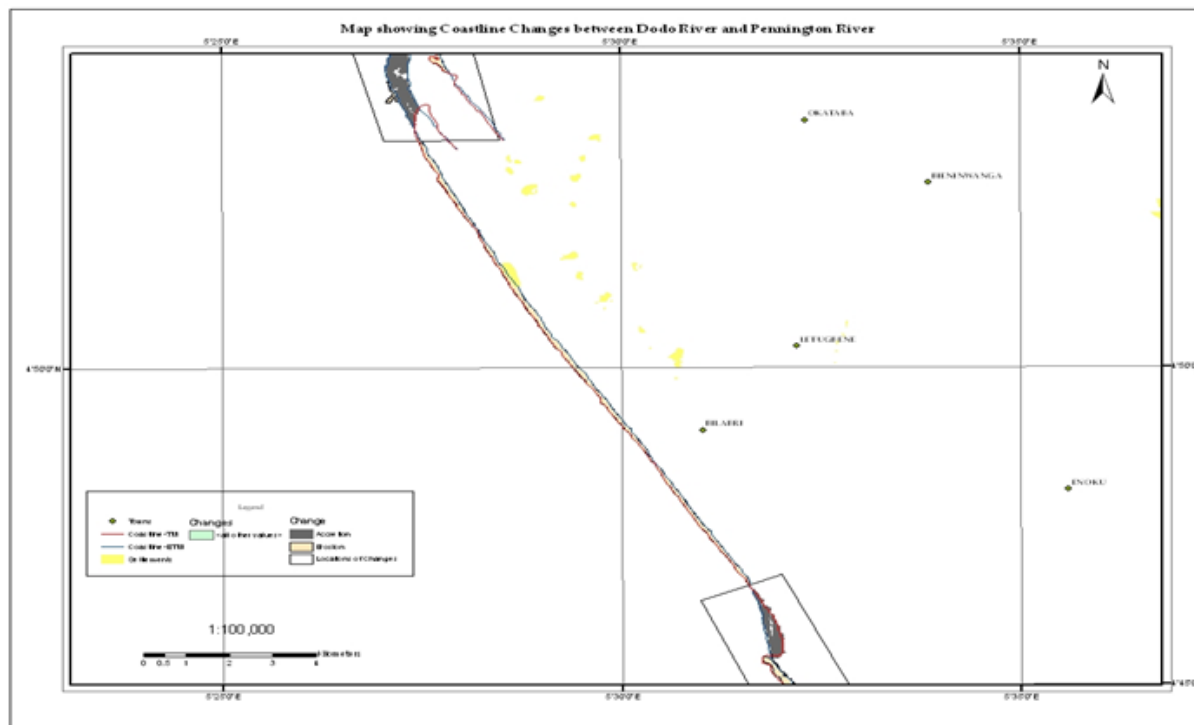


Figure 12. Map of coastline between Dodo and Pennington Rivers

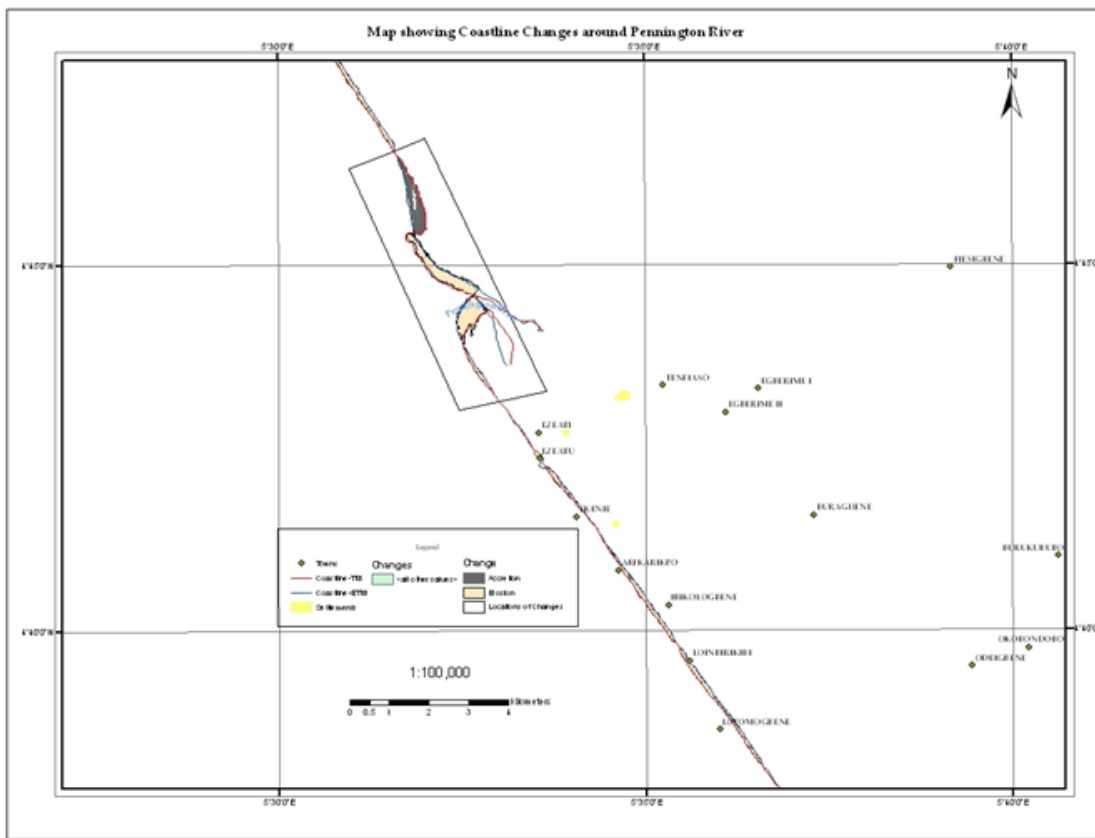


Figure 13. Map of Pennington River and coastline

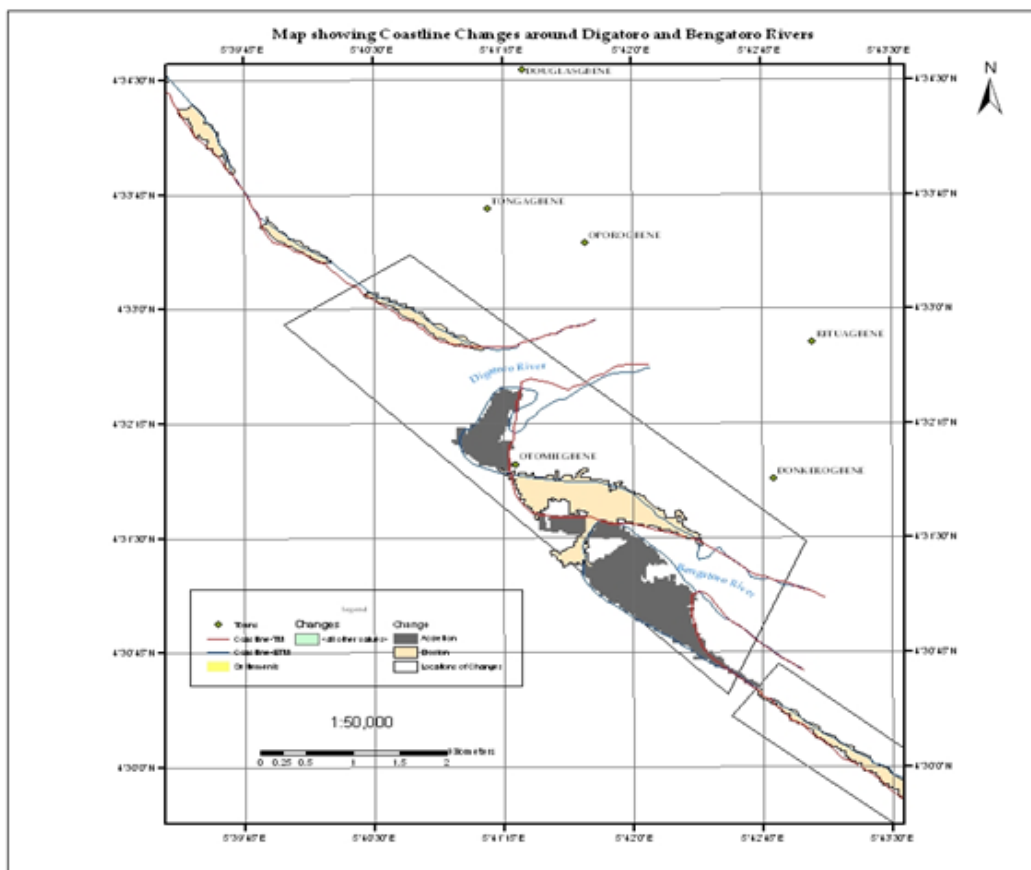


Figure 14. Map of Digatoro and Bengatoro Rivers and coastline

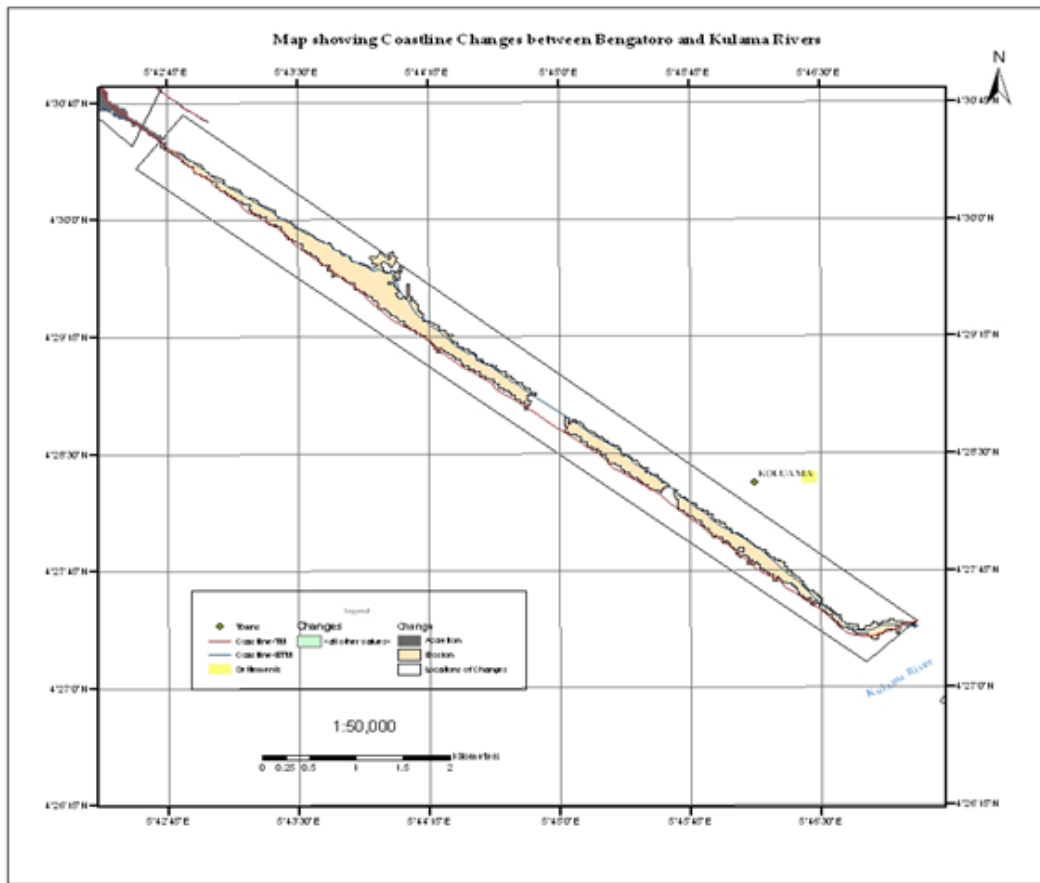


Figure 15. Map of coastline between Bengatoro and Kulama Rivers

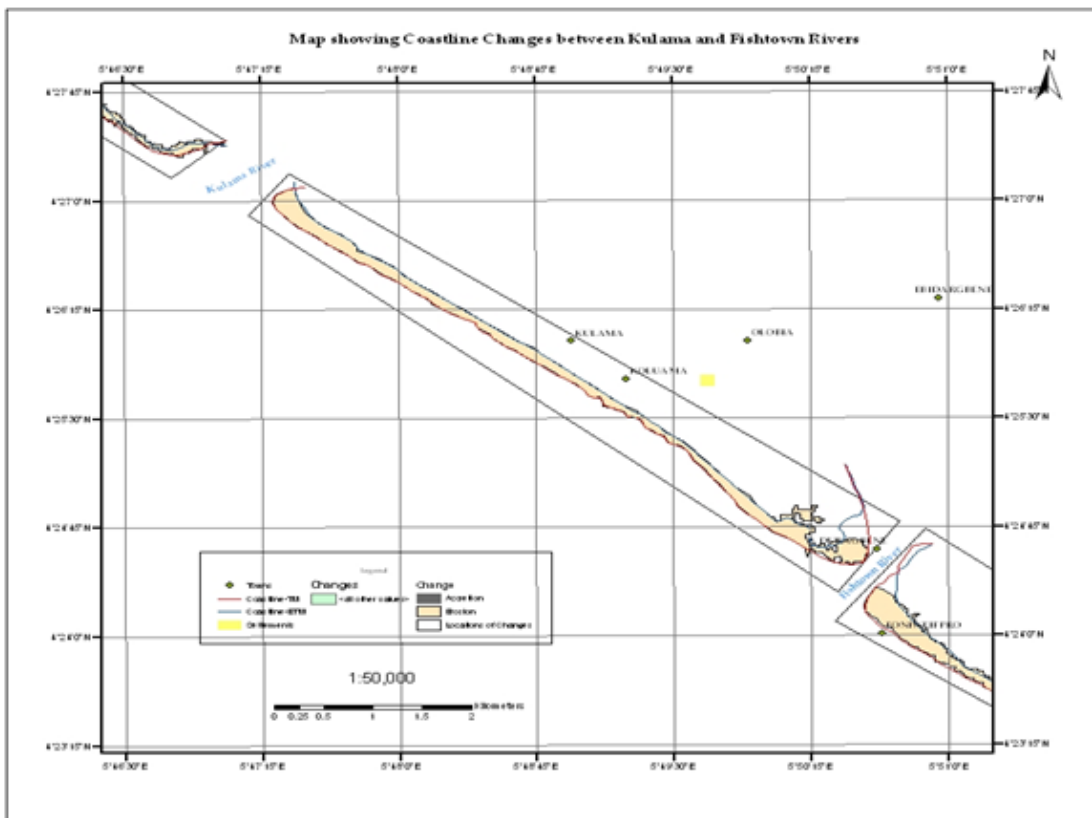


Figure 16. Map of Kulama and Fishtown Rivers and coastline

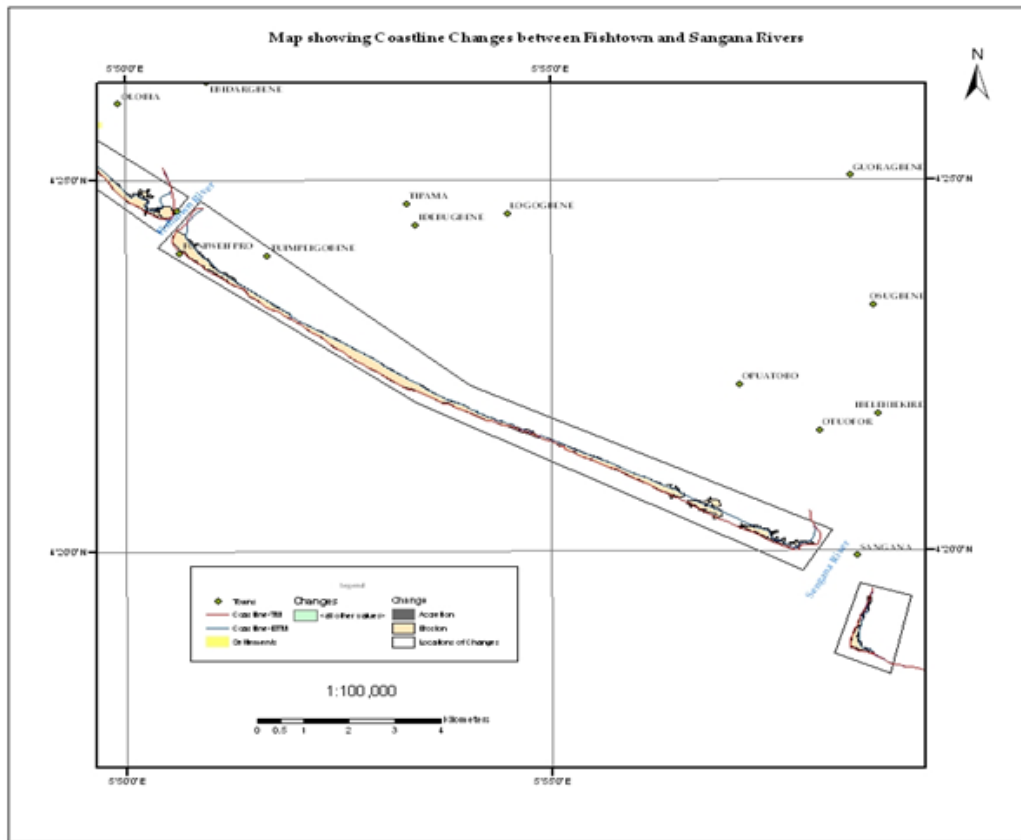


Figure 17. Map of coastline between Fishtown and Sengama Rivers

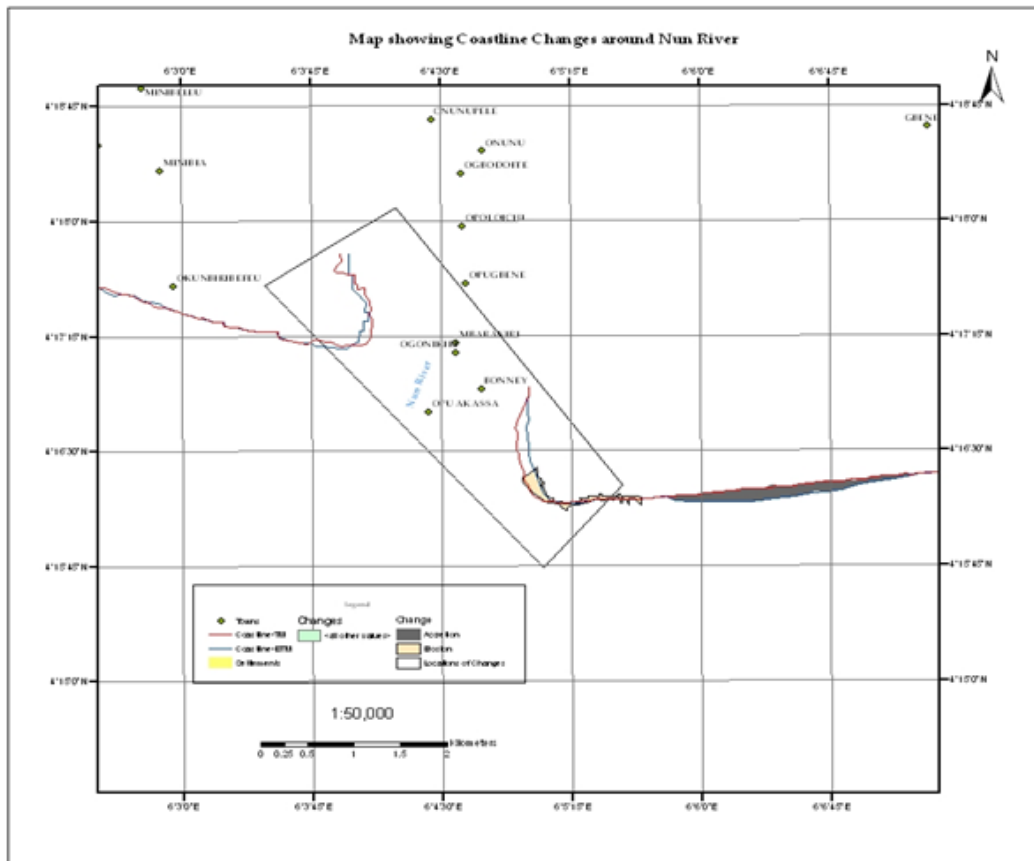


Figure 18. Map of Nun River and coastline

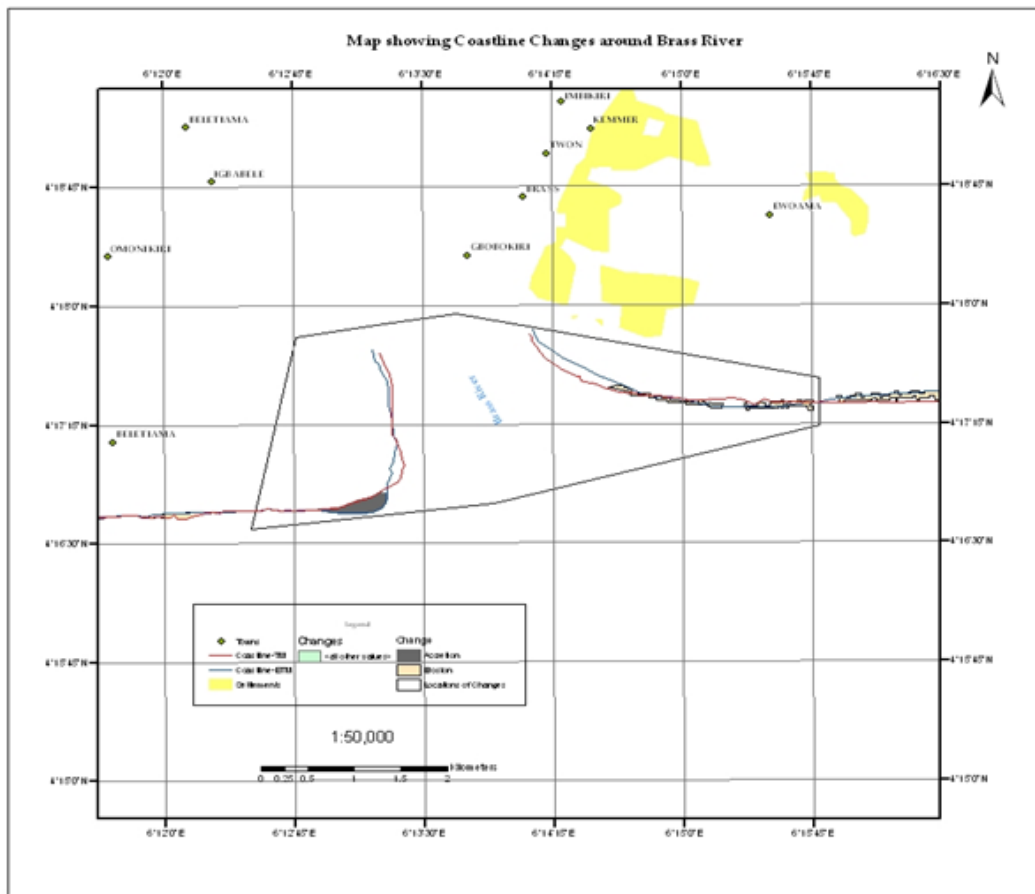


Figure 19. Map of Brass River and coastline

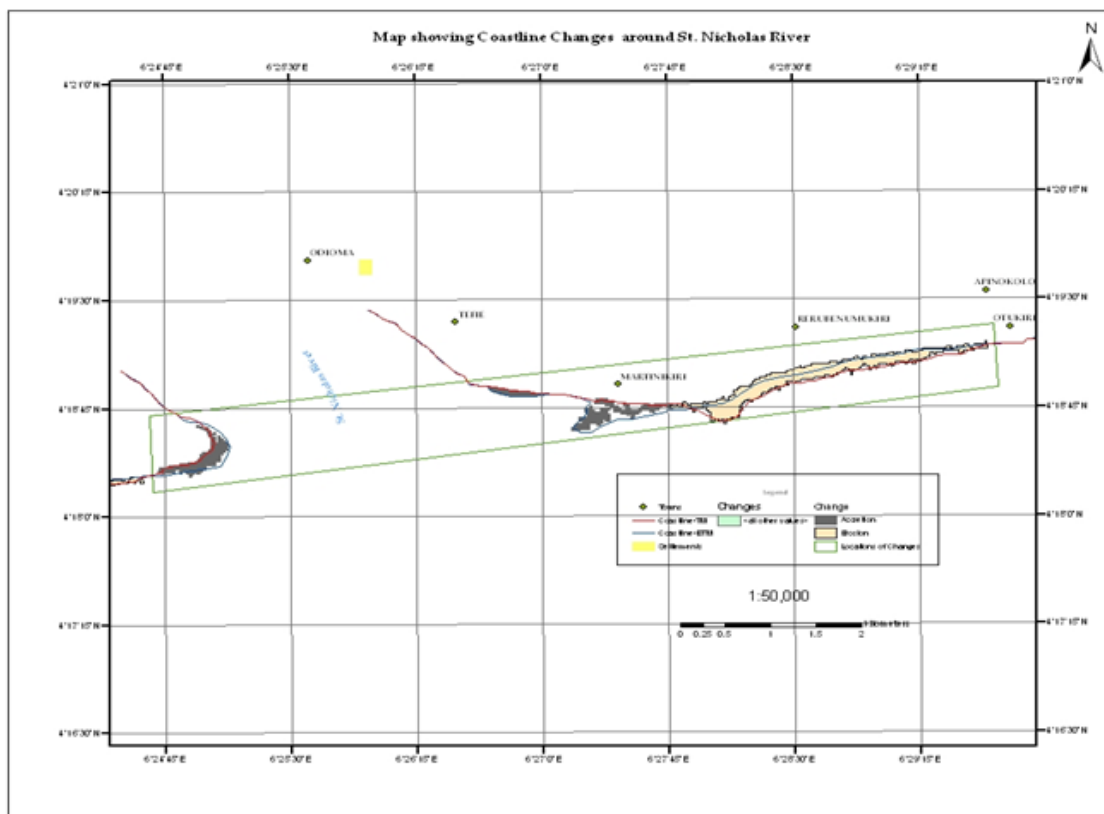


Figure 20. Map Showing St. Nicholas River and Coastline

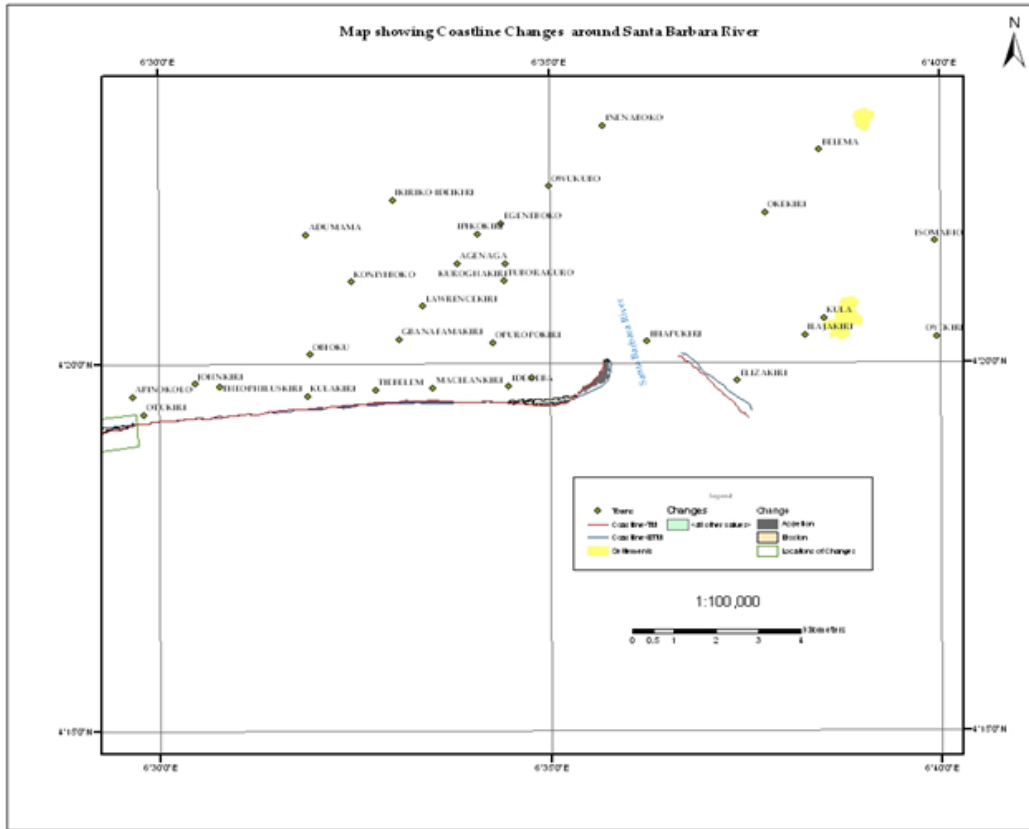


Figure 21. Map Showing Santa Barbara River and Coastline

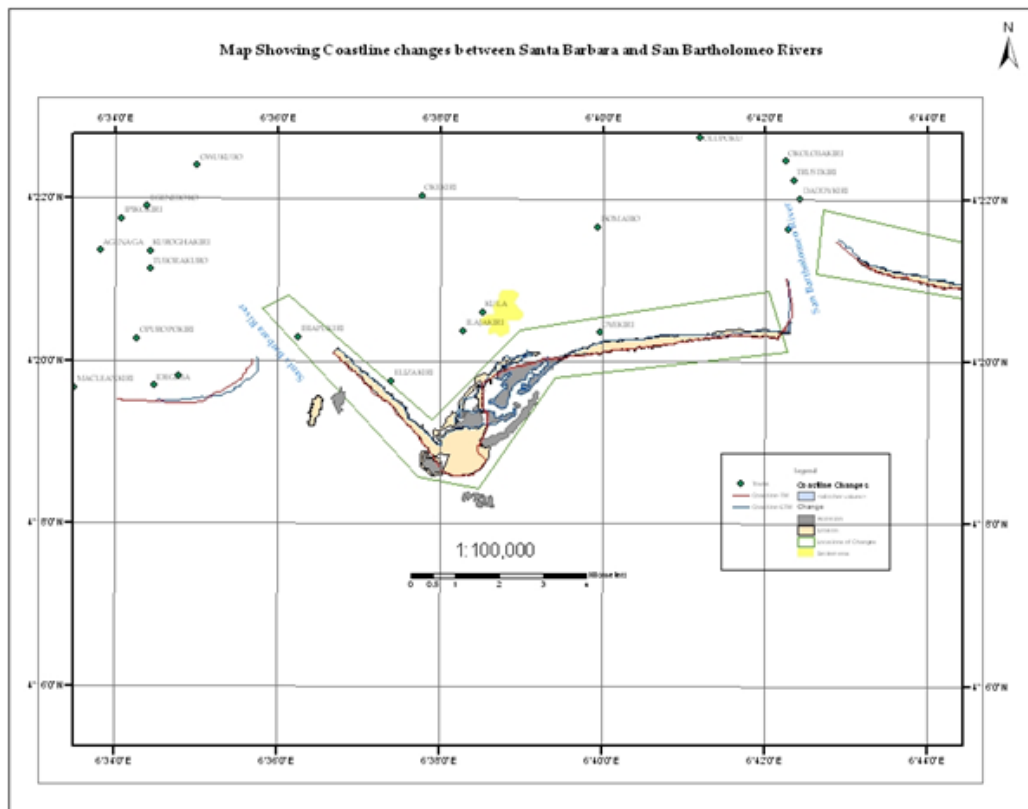


Figure 22. Map Showing Santa Barbara and San Bartholomeo Rivers and Coastline

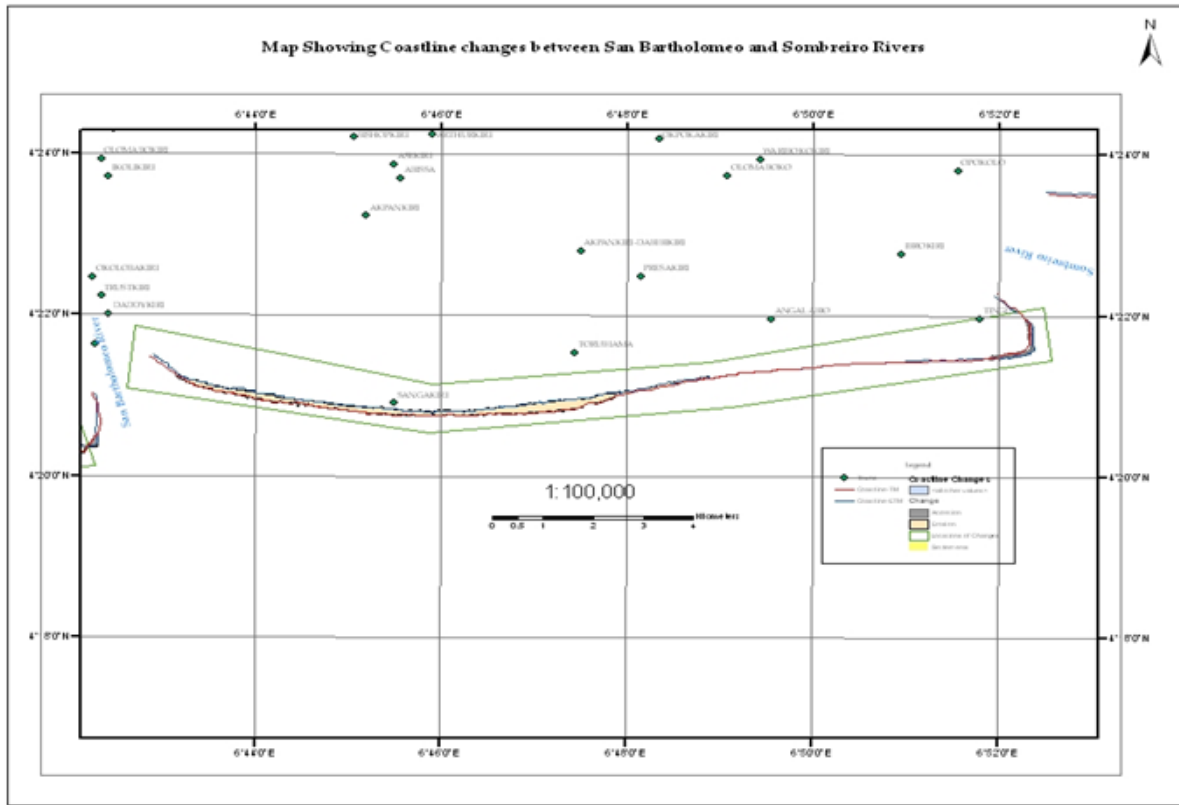


Figure 23. Map showing San Bartholomeo and Sombreiro Rivers and Coastlines

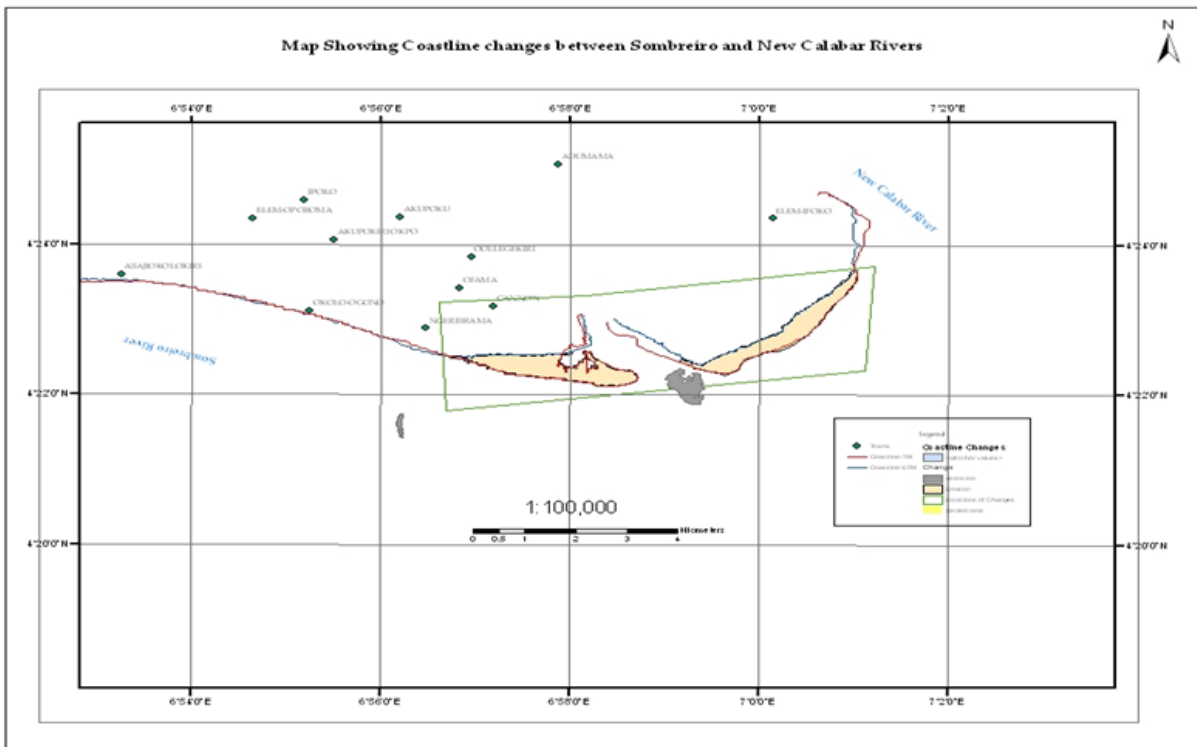


Figure 24. Map showing Sombreiro and New Calabar Rivers and Coastlines

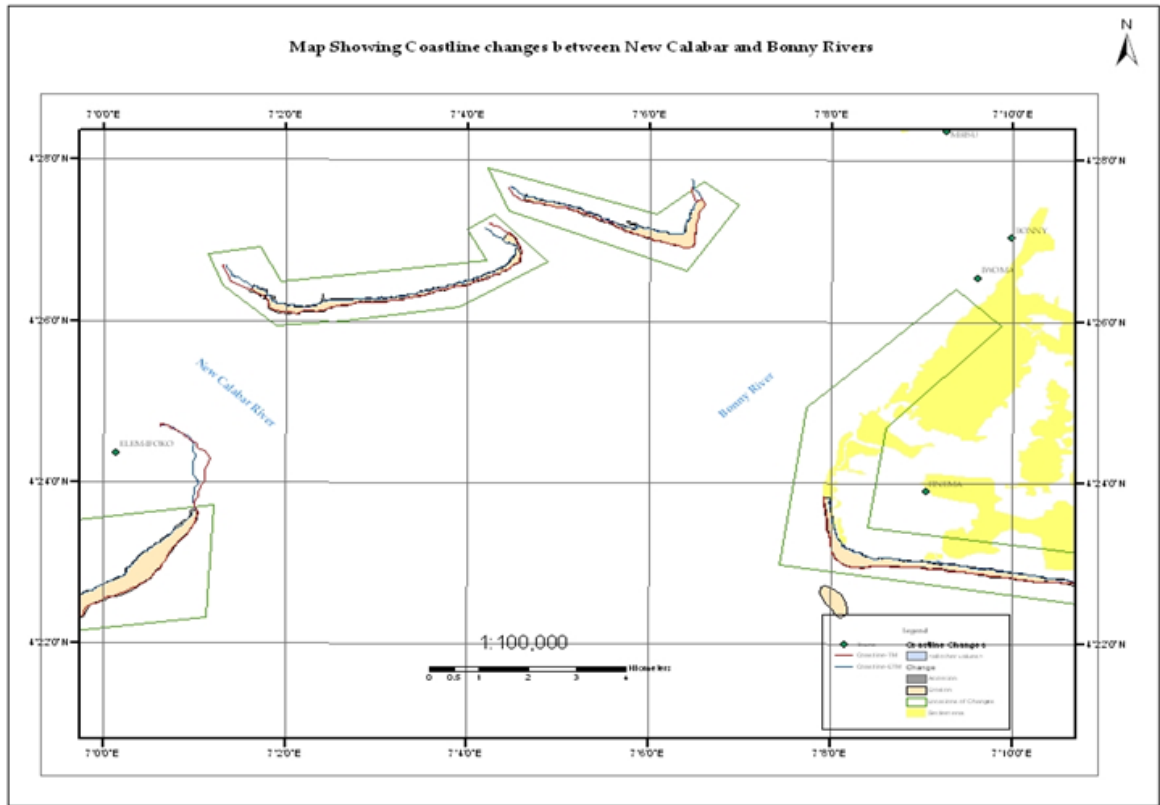


Figure 25. Map showing New Calabar and Bonny Rivers and Coastlines

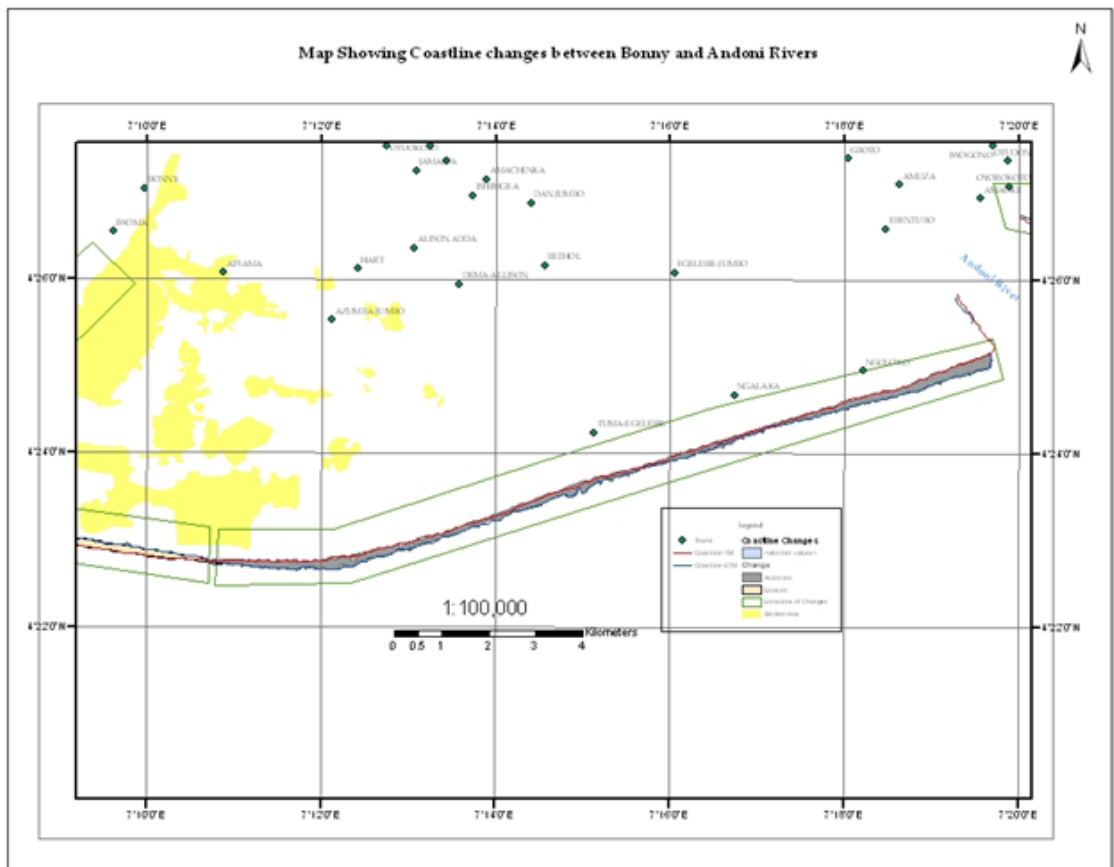


Figure 26. Map showing coastline between Bonny and Andoni Rivers

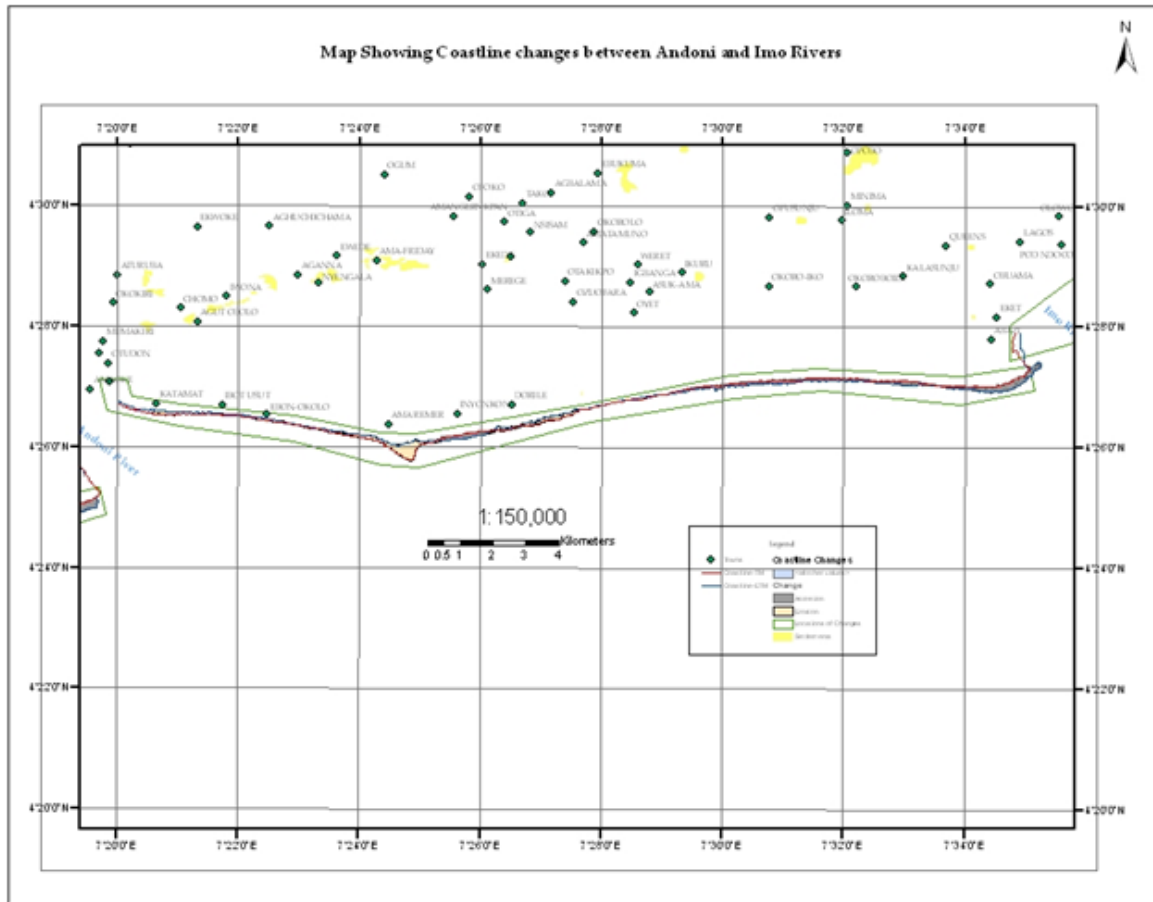


Figure 27. Map showing coastline between Andoni and Imo Rivers

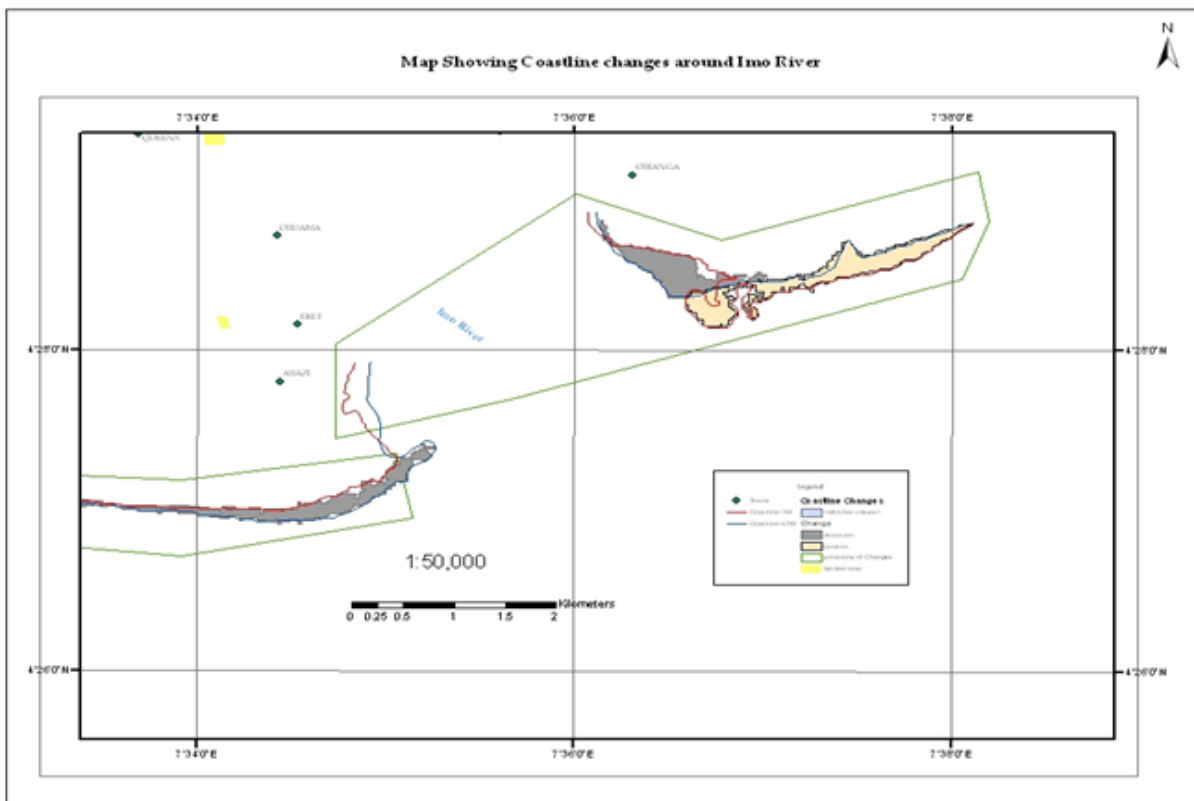


Figure 28. Map showing Imo River and Coastline