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Coastal Shoreline Variability, Erosion and Climate Change Dynamics in Bonny Island, Niger Delta, Nigeria

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ABSTRACT

Spatio-temporal analysis of coastal shoreline dynamics of Bonny Island of Rivers State, Nigeria was evaluated using Landsat ETM of 2000, 2005, 2010, and Landsat 8 OLI of 2015 and 2020 spanning a period of 20 years. The satellite images with a resolution of 30m by 30m were digitized as polylines in geo-processing steps using ArcGIS 10.7 and bands (red, blue and green) of each image combined using Erdas Imagine 9.2. The shoreline of 2000 was superimposed on 2005 shoreline, 2005 shoreline on 2010, 2010 on 2015 and 2015 on 2020. Thereafter, overlaid maps were converted to polygons using features to polygon module. The polygons were grouped to advanced (accretion) or retreat (erosion) with which spatial query was applied. The result revealed that Bonny Island lost 1.37 km^2 (61.99%), 0.05km^2 (2.04%), and 2.55km^2 (59.72%) of land from 2000 to 2005, 2005 and 2010 and; from 2010 to 2015 respectively while 1.05 sq km (24.08%) was gained between 2015 and 2020. On the whole, 2.04 km^2 (50.75%) of land was lost from 2000 to 2020. The study concluded that Bonny Island shoreline experienced more erosion than accretion from 2000 to 2020. The study recommends periodic monitoring of the coastal area on monthly and yearly bases; establishment and enforcement of development setbacks, implementation of development control measures as well as the introduction of integrated coastal zone planning and management within the Niger Delta region to reduce hazards and protect the beautiful sand beaches.

Keywords: Shoreline, GIS, Satellite imageries, Erosion, climate change impacts

1. INTRODUCTION

Climate change induced eustatic rise in sea level is estimated at a rate of 1.6 mm/year and 0.6 mm/year respectively since the mid-nineteenth century and the previous two millennia (Church et al. 2011; Kemp et al. 2011). Climate change escalates environmental forcings such as extreme weather conditions and associated storm surges, wave attacks, episodic flooding, sea level rise and coastal erosion which exacerbate coastal hazards such as ground subsidence, landslide and cliff collapse. 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, 2008; Dolan et al., 1980). Coasts, coastlines, and coastal systems are highly dynamic under hydrodynamic forcings driven by wave energy flux (Abija et al. 2020) and are therefore areas of constant movement (Boak & Turner, 2005) under climate change impact. 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 long-shore currents (Carter and Woodroffe, 1994; Pidwirny, 2006). Coastal sediment transport processes result in erosion and or accretion due to the effect of external processes such as tide and wave-driven currents, wind generated waves and currents, or directly by inducing aeolian sediment transport and dune development (Abija, 2019). Coastline changes often result in erosion of coastal areas or accretion of sediments, depending on the dominant processes acting on the coastline (Pidwirny, 2006). Coastline change is a global phenomenon; it has been in operation for as long as the ocean and land existed. Coastal vulnerability to geohazards is escalated by climate change dynamics (Abija, 2024) which impact is seen varying degrees along most segments of the Nigerian coastline and around the globe with some areas more vulnerable to these changes than others. Nigeria is not spared from these global phenomena it has had its own share from the time past. The processes are still in operation till date. The construction of energy infrastructures such as oil wells and associated processing facilities, refineries, gas and oil transportation pipelines, storage tanks around and along the coast without sufficient setbacks and with not coastal defense infrastructure such as breakwaters have been a main cause for erosion in the coastal areas of Nigeria (Abija, 2025). The retreat of Nigerian shorelines threatens most of the coastal settlements, recreational grounds and oil export handling facilities which are almost invariably located in coastal towns such as Brass, Bonny, Ibeno-Eket, and Forcados (Ibe and Antia, 1983). The rates of erosion at 10 stations established along the Nigerian coastline, was determined by NIOMR in 1995. Erosion was found to be most dominant at Bar Beach, Victoria Island, with rates ranging between 25 and 70 metres per annum. Awoye beach on the low-lying Mahin mud-beach in Ondo State recorded 27 metres of erosion. Slight accretion was recorded at the Ugbogoro/Escravos beach.

The erosion rate for Bonny was also recorded it was quite high ranging between 2035metres per annum near the LNG site (NIOMR, 1995). Ibe further confirmed the erosion rate at Bonny station to be ranging between 20-24metres annually. The primary causes of coastal land loss include both natural processes and human activities. These primary causes determine where land will be lost whereas other factors, such as shoreline characteristics, control the rate of land loss. Some agents affecting land loss, such as wave energy, are common to all coasts, whereas other agents, such as vegetative cover, are only of local importance. In most coastal settings, the exact causes of land loss are uncertain, so it is necessary to evaluate all reasonable causes in order to predict what the coast might look like in the future and to understand how land loss will impact coastal communities. Physical agents affect land losses in all coastal environments, but wetlands are also subject to biochemical reactions and altered water circulation patterns. Most exposed coasts lose land primarily as a result of erosion, the wearing away or removal of the land surface by mechanical, chemical, and biological agents. Landward retreat of the shore is commonly the result of this erosion. Coastal erosion is initiated by the movement of water in the form of high waves and strong currents. Breaking waves erode the coast by suspending sediment particles or dislodging rocks. Ice, chemical weathering, and mechanical abrasion also aid the erosion of some rocky headlands and sea cliffs. Beach cobbles and sand act as tools that repeatedly strike the rocks and gradually wear them down. Powerful storms rapidly raise water levels and accelerate coastal currents causing the most rapid losses of land and perhaps most of the permanent land losses worldwide. Land loss during storms depends on many things, including distance from the storm center, storm-surge heights, wave characteristics, direction of storm movement, angle of wave approach, forward speed and duration of the storm, and tidal stage during storm landfall. Storms that strike the coast at high tide, and especially at spring high tide, tend to cause more damage because the storm surge superimposed on the high tide causes greater flooding and over wash. In areas where the tide range is small, tidal stage is of little consequence to storm surge heights, but it is often important where the tidal range is large. Land loss and property damage can increase when a peak storm surge coincides with high tide. The most damaging coastal storms are either extra tropical cyclones (winter storms) or extra tropical cyclones (winter storms) or extra tropical cyclones tropical cyclones (hurricanes) that form around centers of low barometric pressure (Morton, 1988). Cyclones winter storms derive their energy from the atmosphere, whereas the ocean is the principal energy source for summer hurricanes. Although the two storm systems are quite different, their influences on water bodies and near shore environments are similar. Both generate high, steep waves and strong currents that introduce new sediment into the littoral system and redistribute pre-existing sediments over large areas of the shore face and continental shelf. 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, 1988; Pandian et al., 2004). Coastal erosion has been reported by (Allen, 1965, Adegoke et al. 2010, Eludoyin et al. 2002) and Abija, (2019, 2024) noted that coastal erosion in the region is a major geological hazard visible in several coastal communities as retreating coastlines. and beach hazards have been identified in terms of the vulnerability of coastal areas to damage with regard to loss of property or infrastructure. 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 (Obowu, et al., 2014), historical coastline mapping, and comparison of beach profiles over a period of time (Ibe, 1988). Other more recent methods include simulation of coastline changes using numerical models. Bird, (2008) carried out a study on shoreline changes along the Bonny coastline over the past 30 years, using geospatial techniques, the study revealed that the shoreline has been found to be eroding away at an annual rate of 10m-30m along the Finita-Singi beach area.

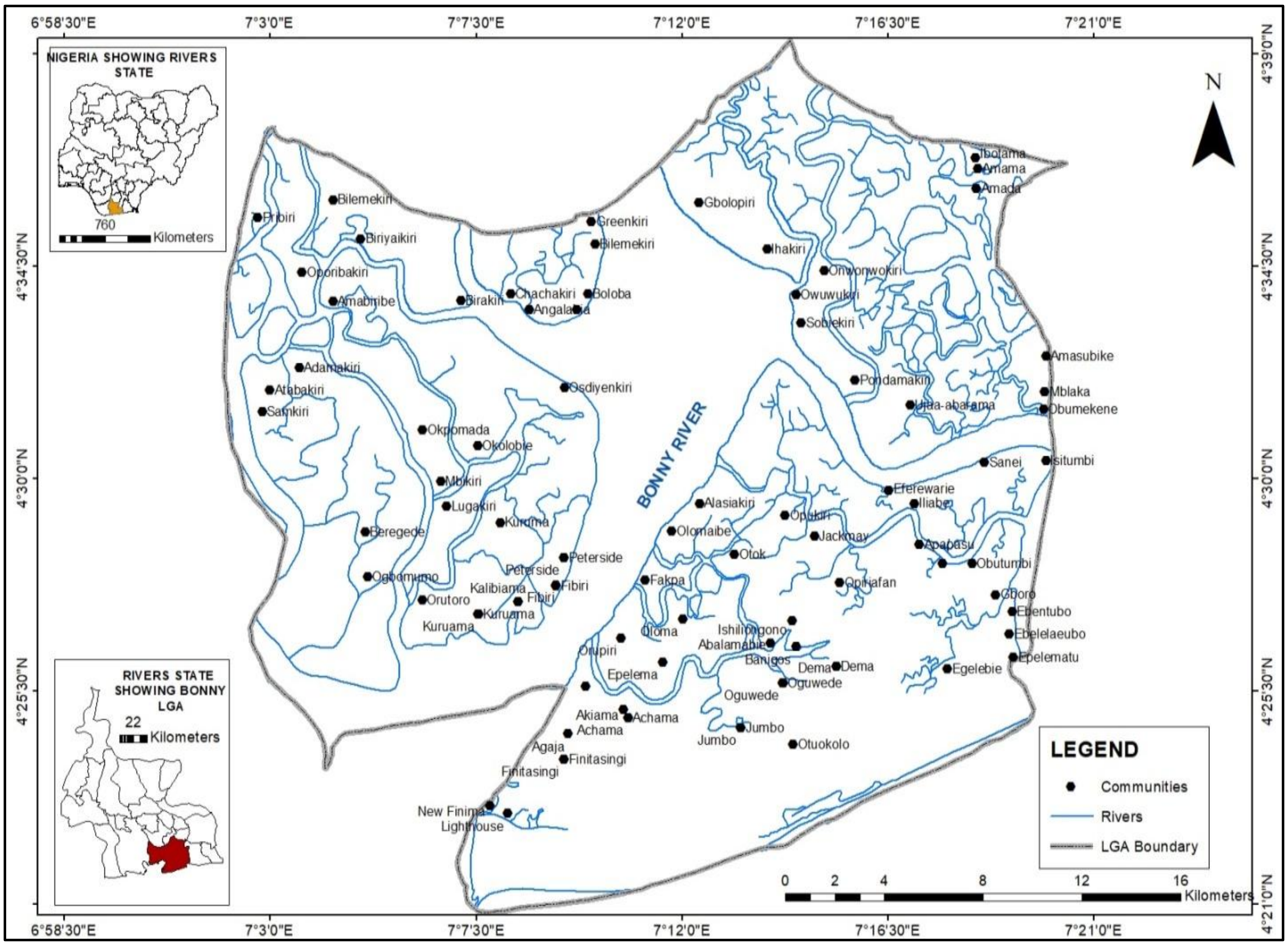

Figure 1: Study map of Region of Interest

Study Area

The study was carried out in Bonny Island. This is an island lying in between Latitude 7°3′0″ 90 and 7°16′30″ and Longitude4°21′0″ and 4°30′0″ near the edge of the southern part of Rivers State in the Niger Delta region of Nigeria, on the edge of the Atlantic Ocean with an estimated land coverage of 61364.04 Hectares (Figure 1). It serves the traditional seat of the Bonny kingdom with a traditional trading center of fishes, palm oil, palm kernel and salt and an importation port for shipping timber, beeswax, palms and ivory also it is home many Oil and Gas companies. Hydrologically, the Niger delta is dissected by a dense network of rivers and creeks draining the area and transporting water and sediments from the hinterland to the Atlantic Ocean. The driving force of ecological problems in the region stems from the network of surface water dynamics which have created a complex and fragile ecological region divided into smaller ecological zones distinguished by variation of the hydrological characteristics (Abija et al., 2020). Tectonically, the Niger Delta is an extensional basin which evolved by triple junction rifting (RRR) along Cretaceous equatorial fracture zones, opening of the South Atlantic and separation of Africa from South America (Abija et al. 2020). The delta basin is an arcuate structure with shared tectonic stratigraphic mega sequences during the Late Jurassic Early Cretaceous parallel to the direction of plate motion. These fracture zones are the Chain and the Charcot and the Ascension (Lehner & De Ruiter, 1977). Rift extension transcends into the Benue trough, a failed arm of the triple junction which started opening in the Late Jurassic and persisted into the Middle Cretaceous (Kulke, 1995). Rifting and opening into the continent was accompanied by gravity tectonism as the primary deformational process and induced deformation in response to shale mobility (Abija et al. 2020).

2. MATERIALS AND METHODS

The longitudinal research design was adopted for the study. This study made use of satellite images of the study area. Landsat ETM of 2000, 2005, 2010, 2015, and 2020 of 30m by 30m were acquired for the study from the United States Geological Survey (Morton, 1988). The satellite images 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 10.7. The colour composite facilitates the interpretation of multi-channel image data by human eye. 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 10.7 as POLYLINES which is a vector format of spatial data representation. The digitized shorelines of each year were subjected to spatial analyses using OVERLAYING METHOD. The shoreline of 2000 was overlaid on that of 2005, shoreline of 2005 was overlaid on 2010, 2010 on 2015 and that of 2015 on 2020. This is called overlay analysis. Thereafter, overlaid maps were converted to polygons using FEATURES TO POLYGON module. The result of the map then revealed those areas that were advanced or gained into the sea (Accretion) and retreated or lost to the sea (Erosion). However, the area in square kilometers of either advanced or retreat of overlaid map was calculated and inputted into the relational database. The database was then queried using QUERY BUILDER (SQL) of ArcGIS 10.7 in order to group the polygons into advanced and retreat and the total sum of the area in square kilometers of the advanced (gain) and retreat (loss) were determined. Thereafter, the percentage gain or loss of land was also calculated for the overlaid maps (2000 and 2005; 2005 and 2010; 2010 and 2015; and 2015 and 2020). The results of the analysis were presented in tables, maps and charts. Descriptive statistics in form of spatial extent of the erosion, accretion and the percentages of the extent was used. Inferential statistics such as analysis of variance was used to test the hypotheses at the significant level of $p<0.05$.

3. RESULTS

Shoreline Changes in Bonny Coastal Zone

The data on shoreline changes along section of the Bonny Coastline is presented in four different epochs. The extent of shoreline changes was determined through image analyses and field measurement carried out along the 12 transect points established along the shoreline of the Bonny Beach Area. Below are the results of the analysis carried out in the study area within the 2000-2020. Table 1 represents shoreline changes and change rate from 2000 to 2020. Figures 2, 3, 4, 5, and 6 represent the shoreline for 2000, 2005, 2010, 2015 and 2020 respectively while Figure 7 displays the entire shoreline from 2000 to 2020. The shoreline status depicting the erosion or loss and accretion or gain is displayed in Figures 8, 9, 10 and 11 for the period between 2000 and 2005, 2005 and 2010, 2010 and 2015; and 2015 and 2020 148 respectively. The analysis shows that the shoreline shifted seaward (advanced) with 0.42 km^2 while the shoreline shifted landward (retreated) with about 1.79 km^2 between 2000 and 2005. However, as a result, 61.99% of land was lost. During the period between 2005 and 2010, the shoreline shifted seaward with 1.20 km^2 while the shoreline shifted with about 1.25 km^2, thus 2.04% of land was lost. Between 2010 and 2015, the shoreline there was an accretion of 0.86 km^2 while 3.41 km^2 were eroded. This shows that 59.72% of land was lost during this period. Furthermore, between 2015 and 2020, the shoreline there was an erosion of land with about 1.65 km^2 while the shoreline shifted seaward with 2.70 km^2.

Table 1: Spatio-Temporal Analysis of Shoreline Changes from 2000 to 2020

Period	Accretion or Gain (sq km)	Erosion or Loss (Sq km)	Total (Sq km)	Shoreline Difference (Sq km)	Percentage Loss or Gain (%)
2000-2005	0.42	1.79	2.21	-1.37	-61.99
2005-2010	1.20	1.25	2.45	-0.05	-2.04
2010-2015	0.86	3.41	4.27	-2.55	-59.72
2015-2020	2.70	1.65	4.36	1.05	+24.08
2000-2020	0.99	3.03	4.02	-2.04	-50.75

A total gain of land mass with about 24.08% was experienced during the period. In total, from 2000 to 2020, it was observed that 0.99 km^2 was gained seaward while 3.03 km^2 of land mass was eroded in Bonny Island. Periodical description of shoreline in Bonny Island reveals that between 2000 and 2015, there was a significant record of erosion with much being recorded between 2000 and 2005 and between 2010 and 2015 (Figure 12, Figure 13, Figure 14). The study area began to gain more landmass seaward between 2015 and 2020 (Figure 12, Figure 13, Figure 14). Meanwhile, the total shoreline analysis reveals that Bonny Island has experienced much erosion overtime from 2000 to 2020.

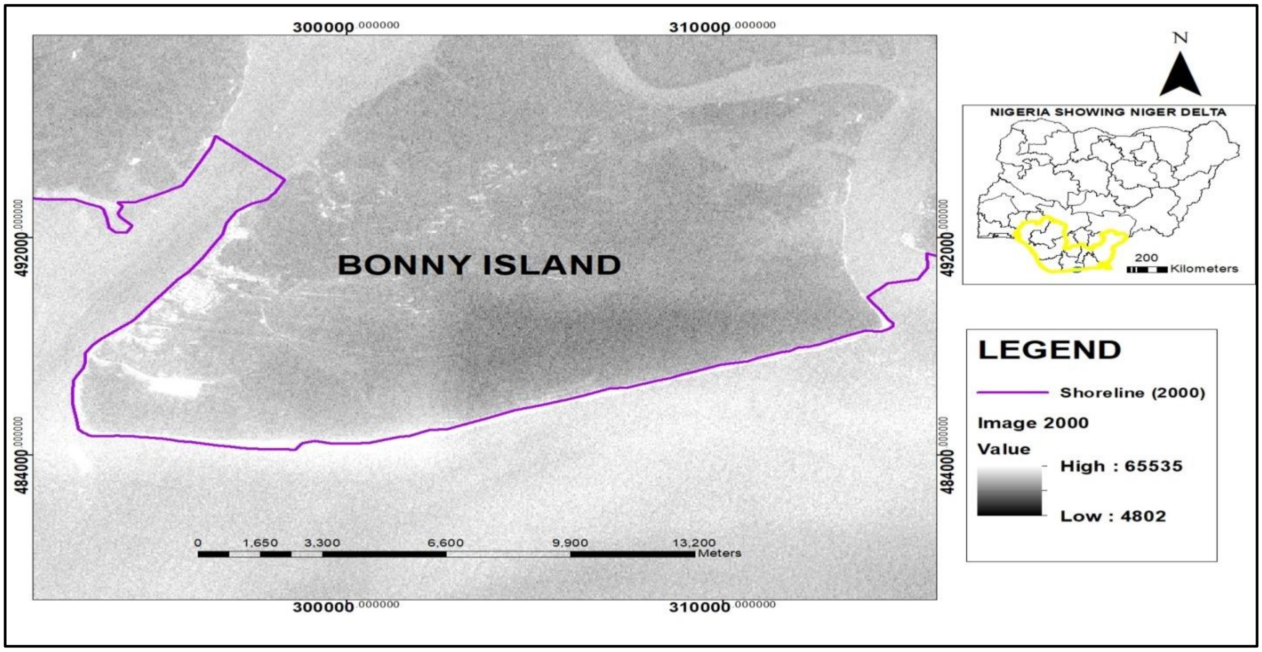

Figure 2: Landsat Imagery and Digitized Shoreline of Bonny Island in 2000

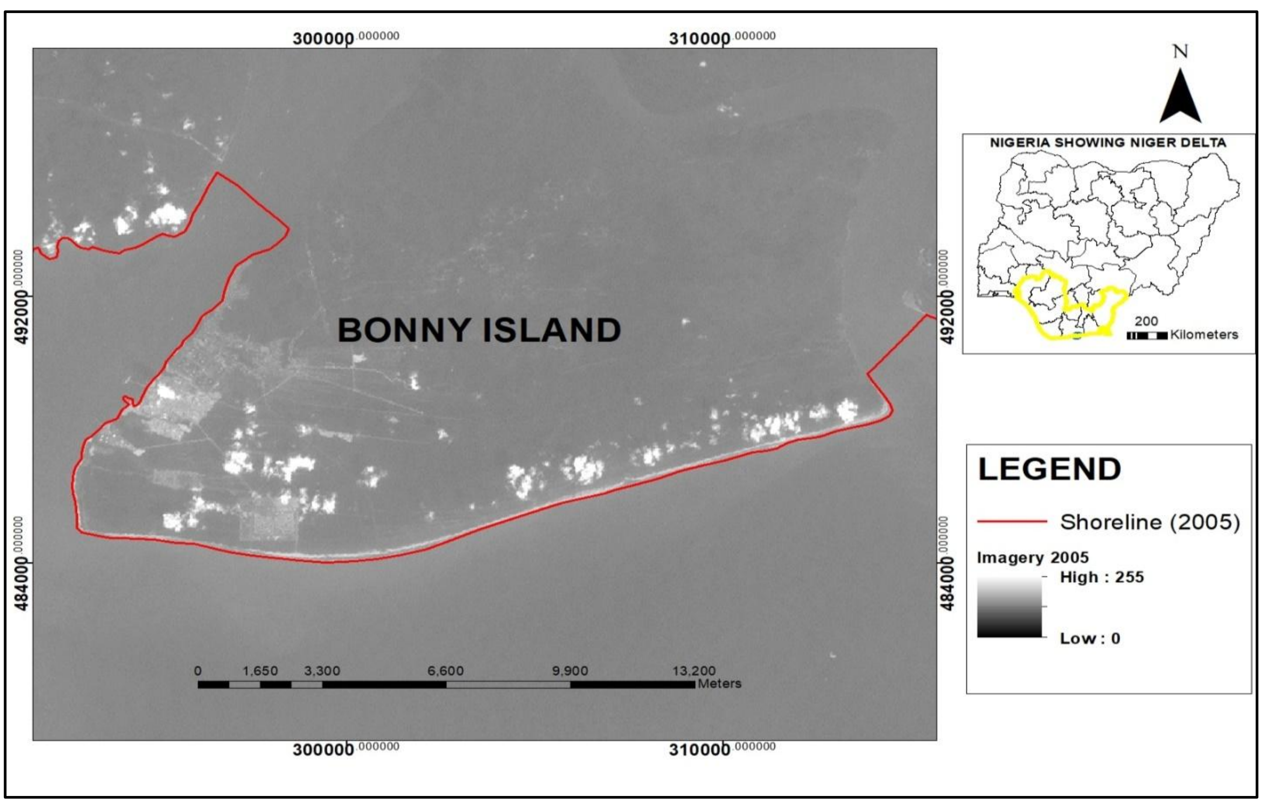

Figure 3: Landsat Imagery and Digitized Shoreline of Bonny Island in 2005

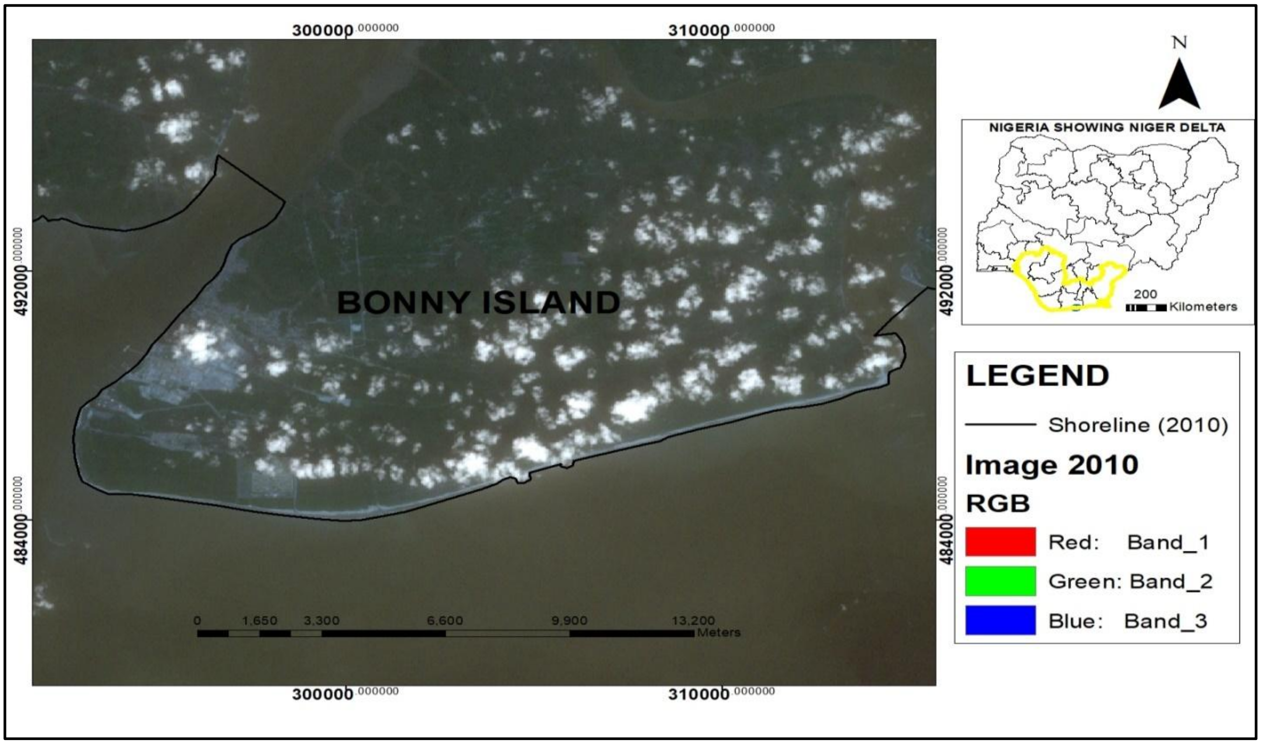

Figure 4: Landsat Imagery and Digitized Shoreline of Bonny Island in 2010

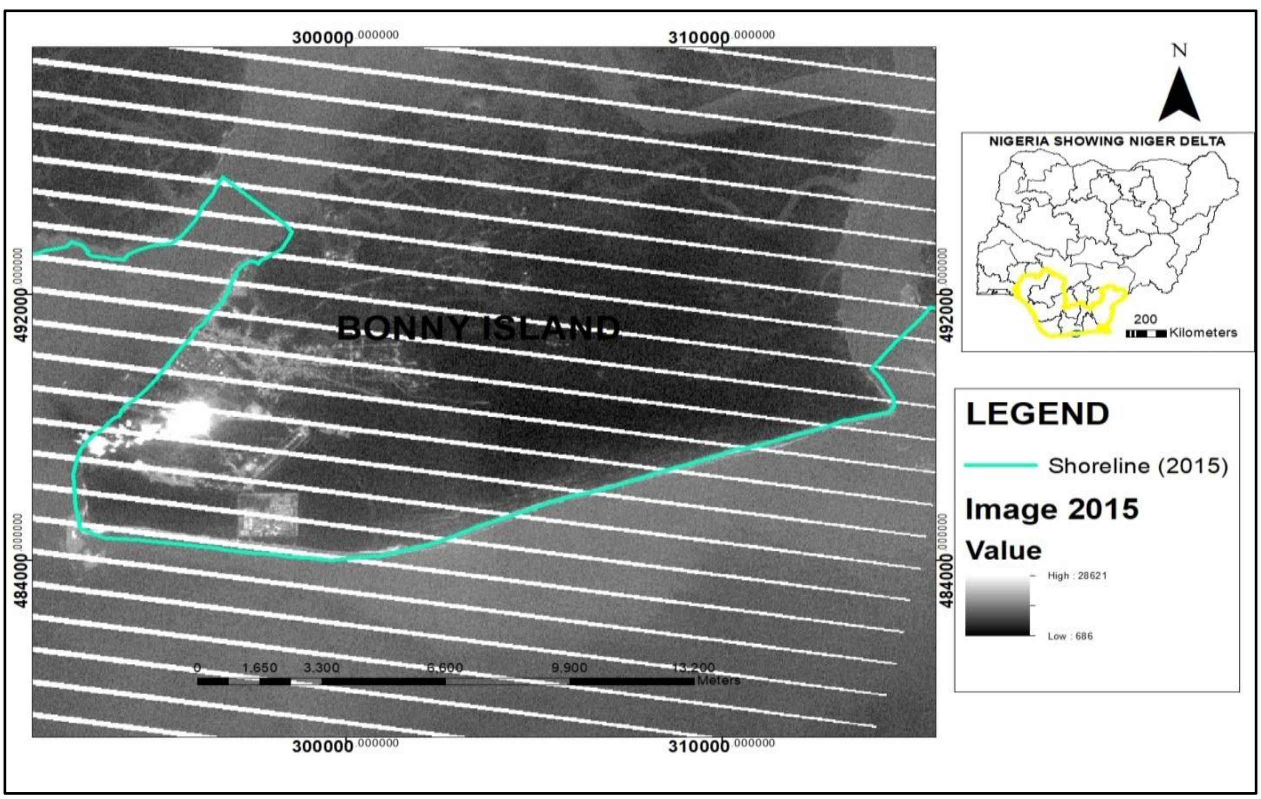

Figure 5: Landsat Imagery and Digitized Shoreline of Bonny Island in 2015

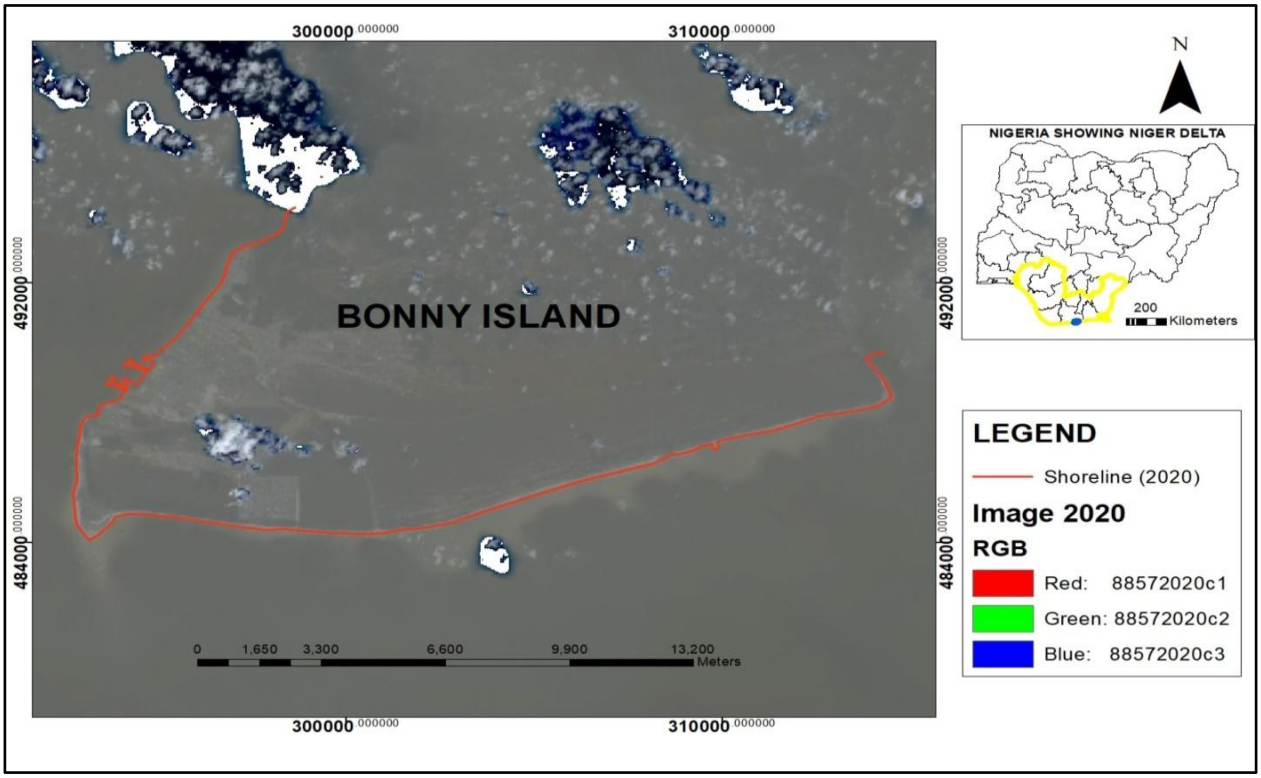

Figure 6: Landsat Imagery and Digitized Shoreline of Bonny Island in 2020

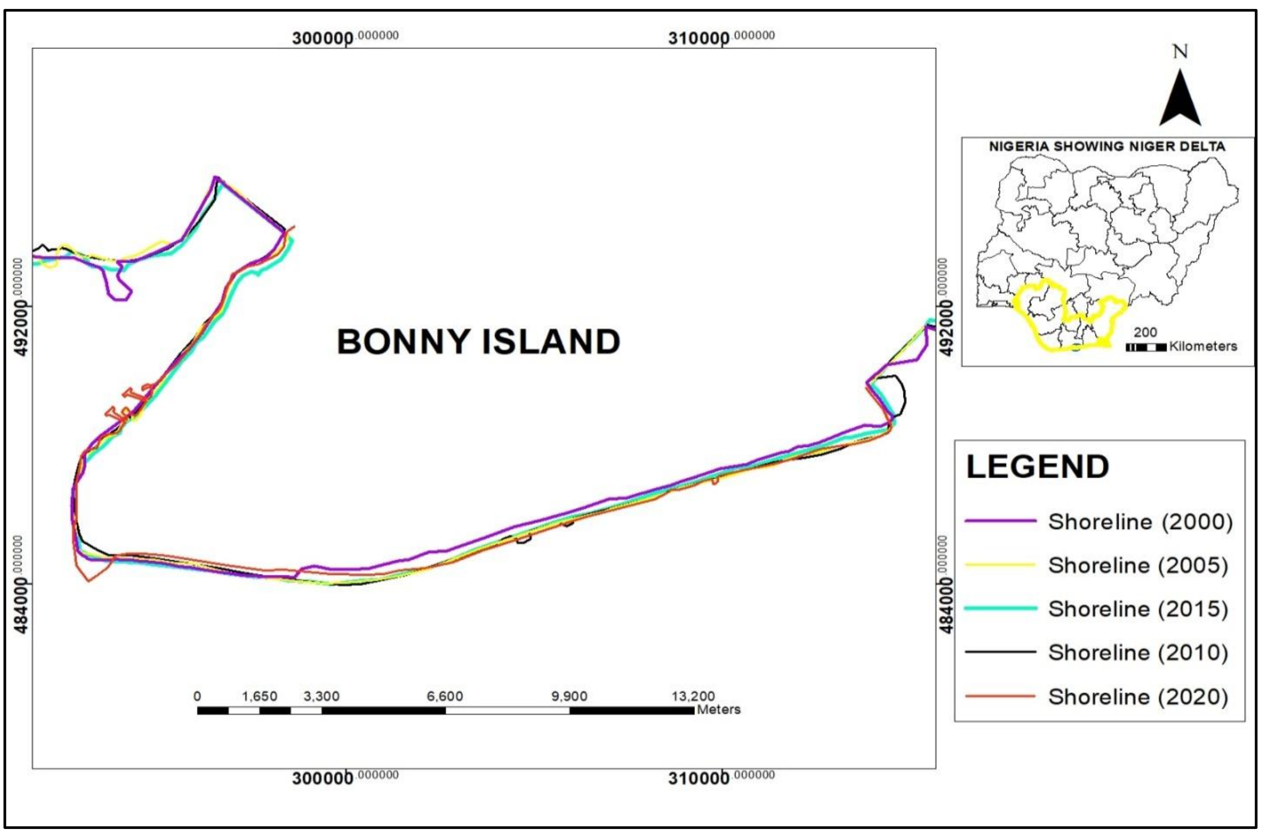

Figure 7: Shorelines from 2000 to 2020

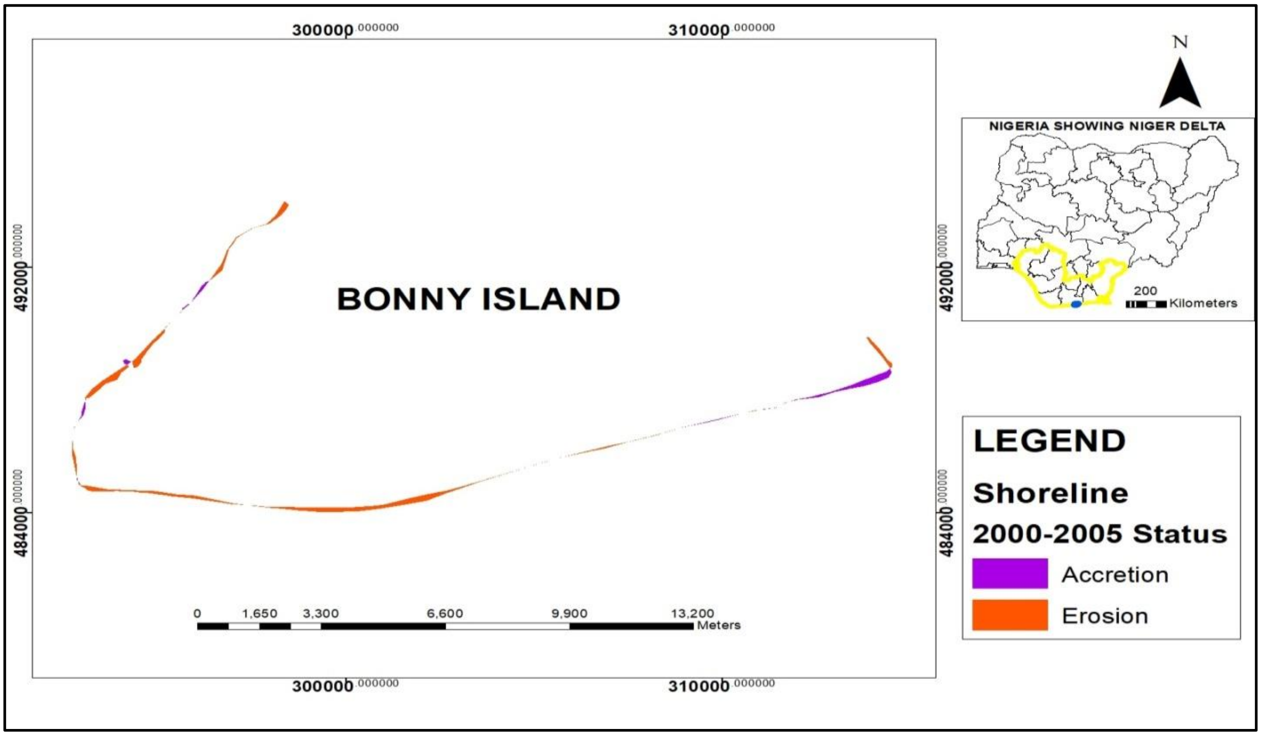

Figure 8: Shoreline Status between 2000 and 2005

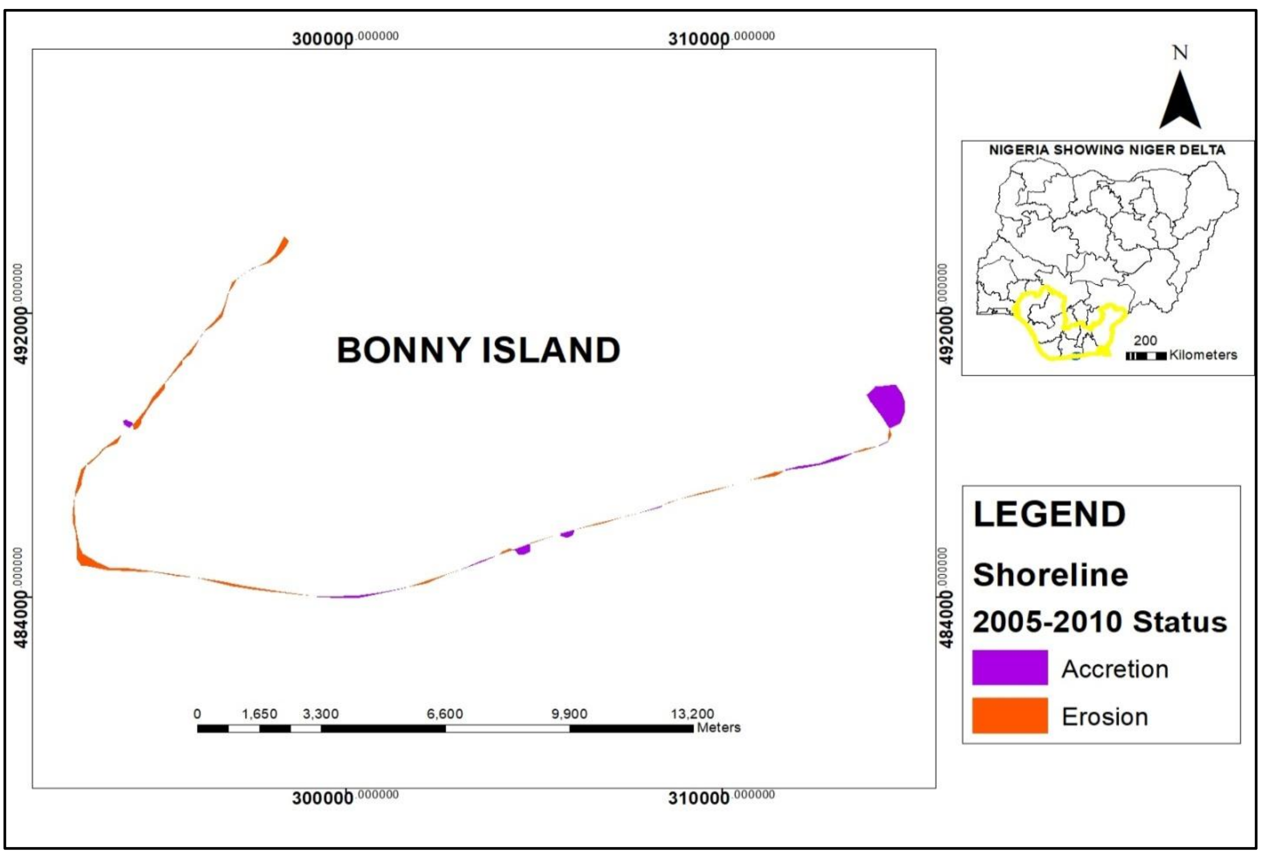

Figure 9: Shoreline Status between 2005 and 2010

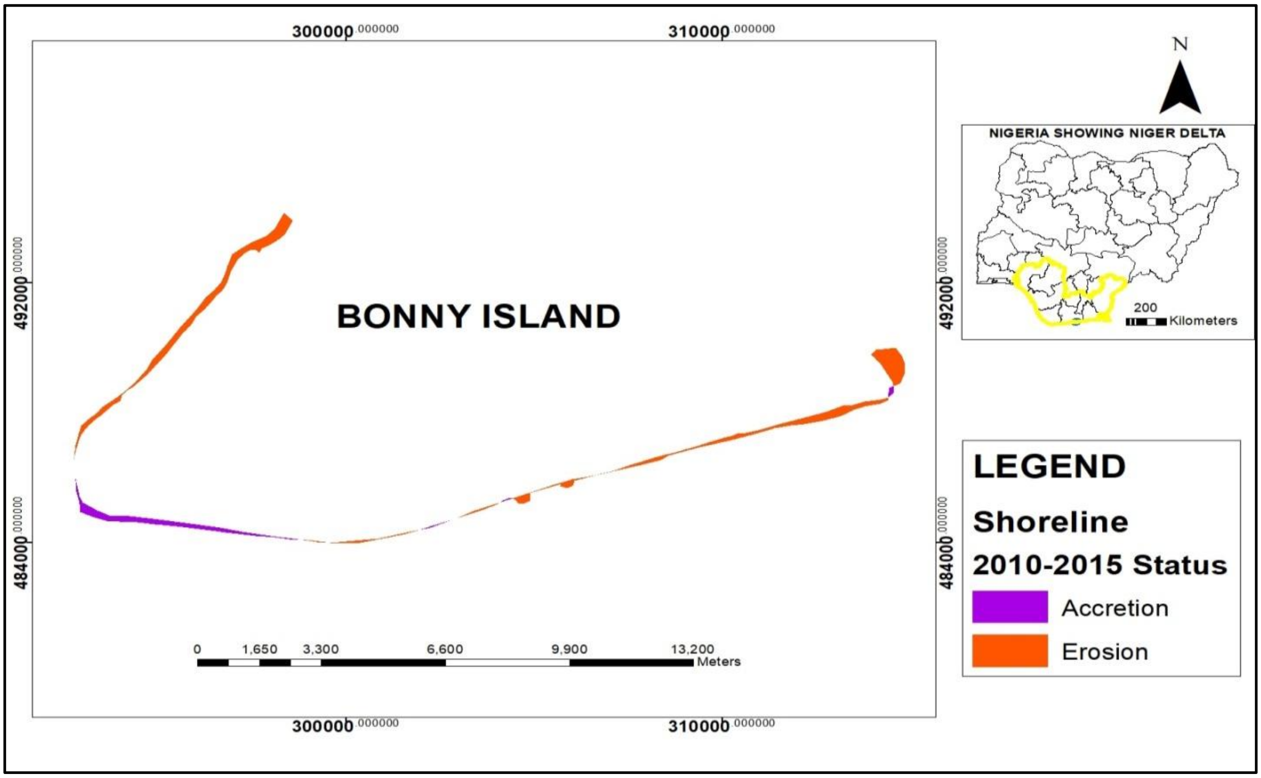

Figure 10: Shoreline Status between 2010 and 2020

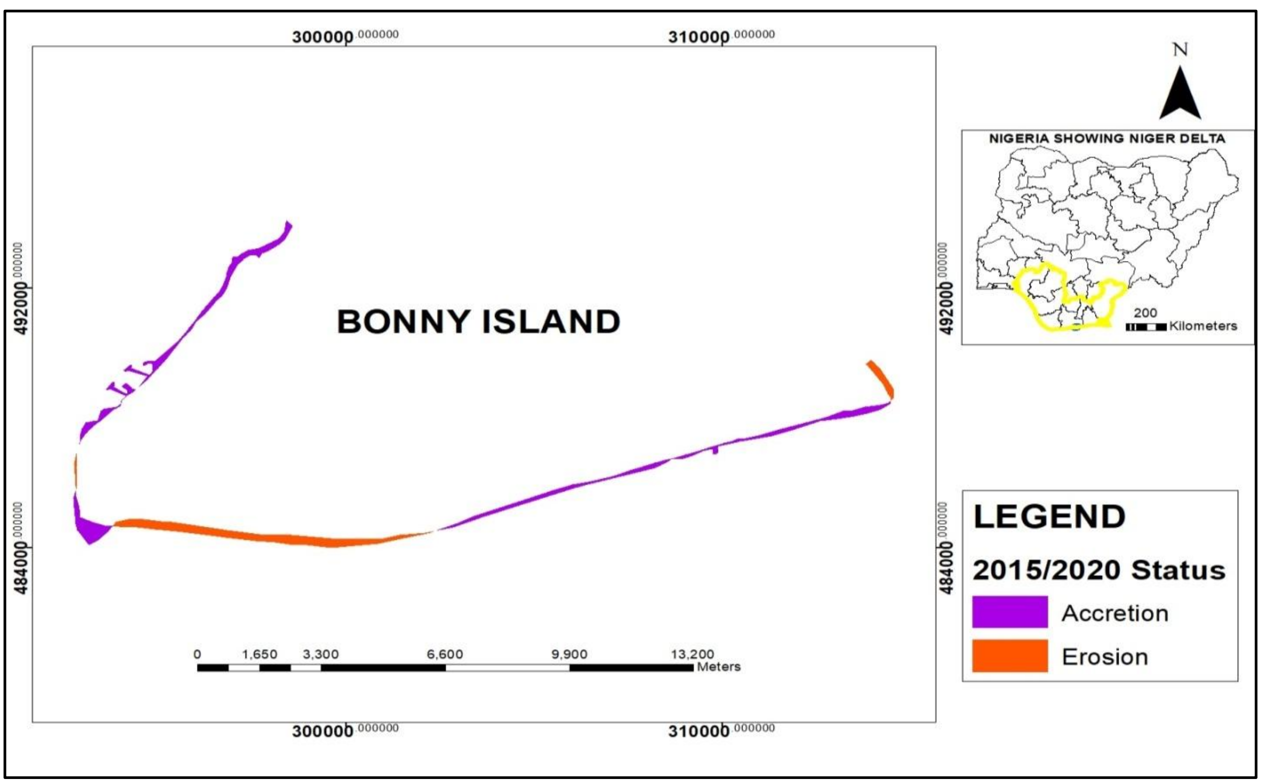

Figure 11: Shoreline Status between 2010 and 2020

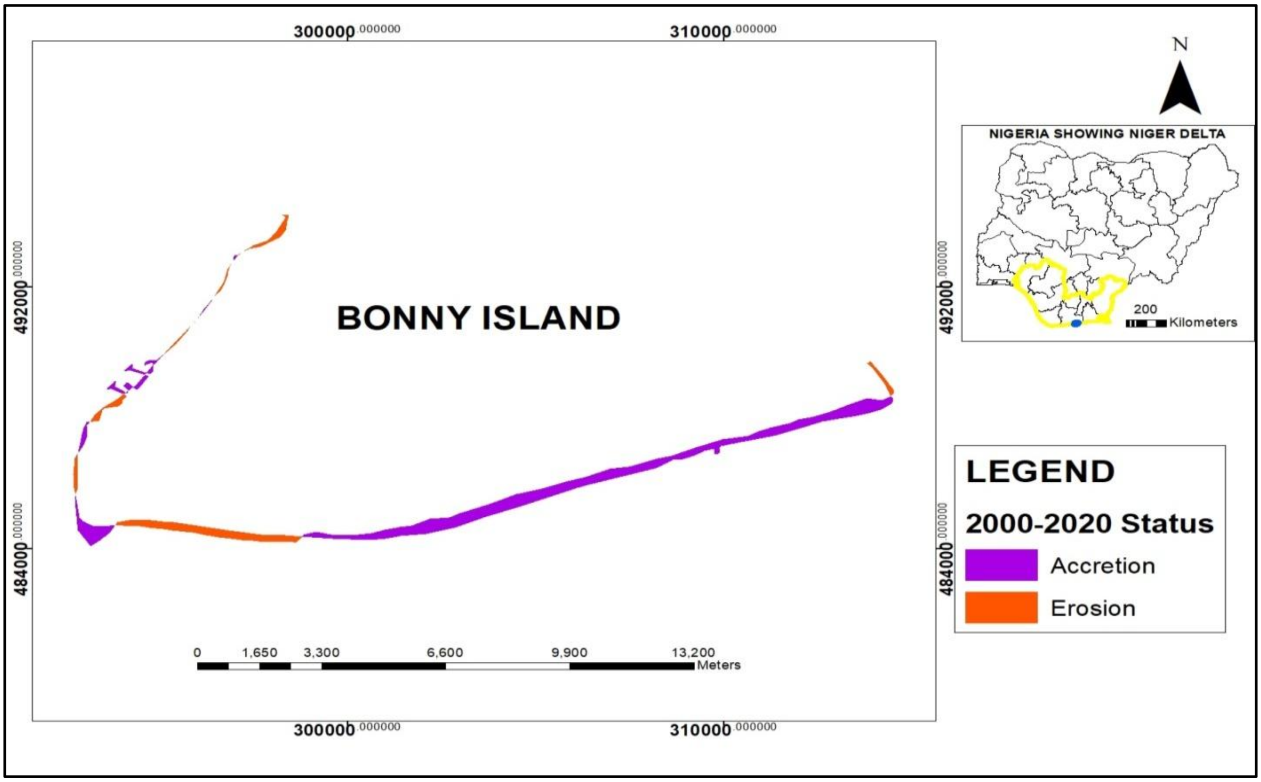

Figure 12: Total Shoreline Status between 2000 and 2020

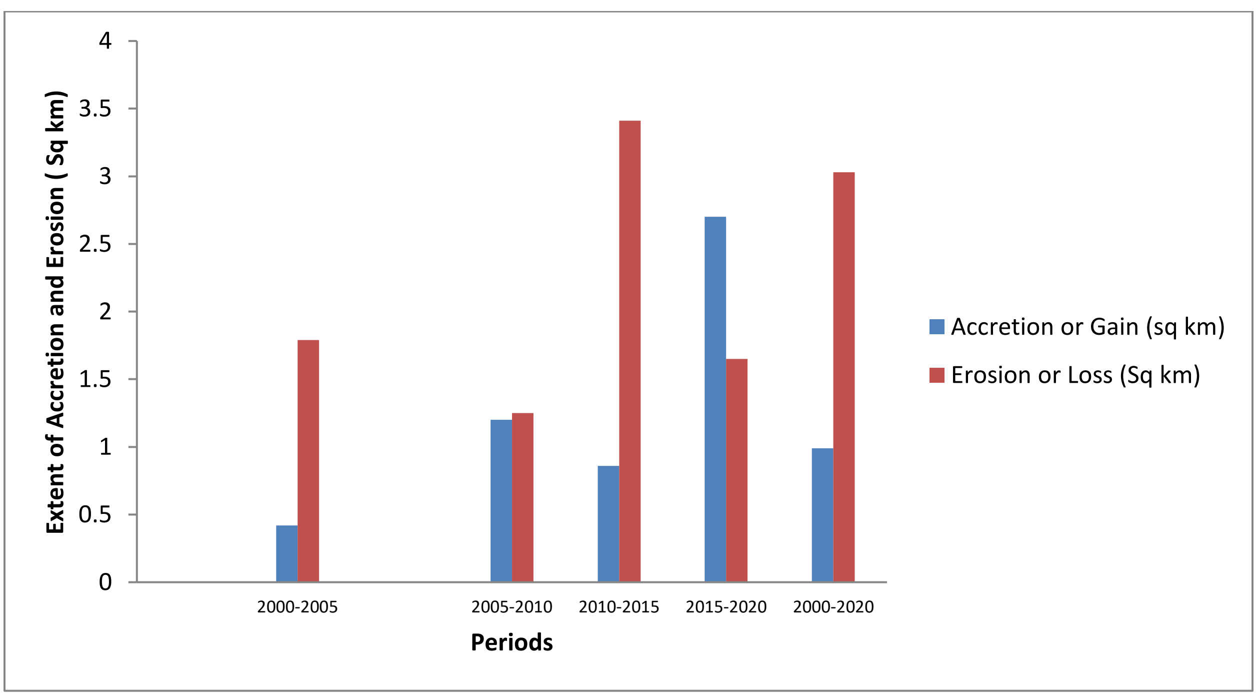

Figure 13: Shoreline Accretion and Erosion between 2000 and 2020

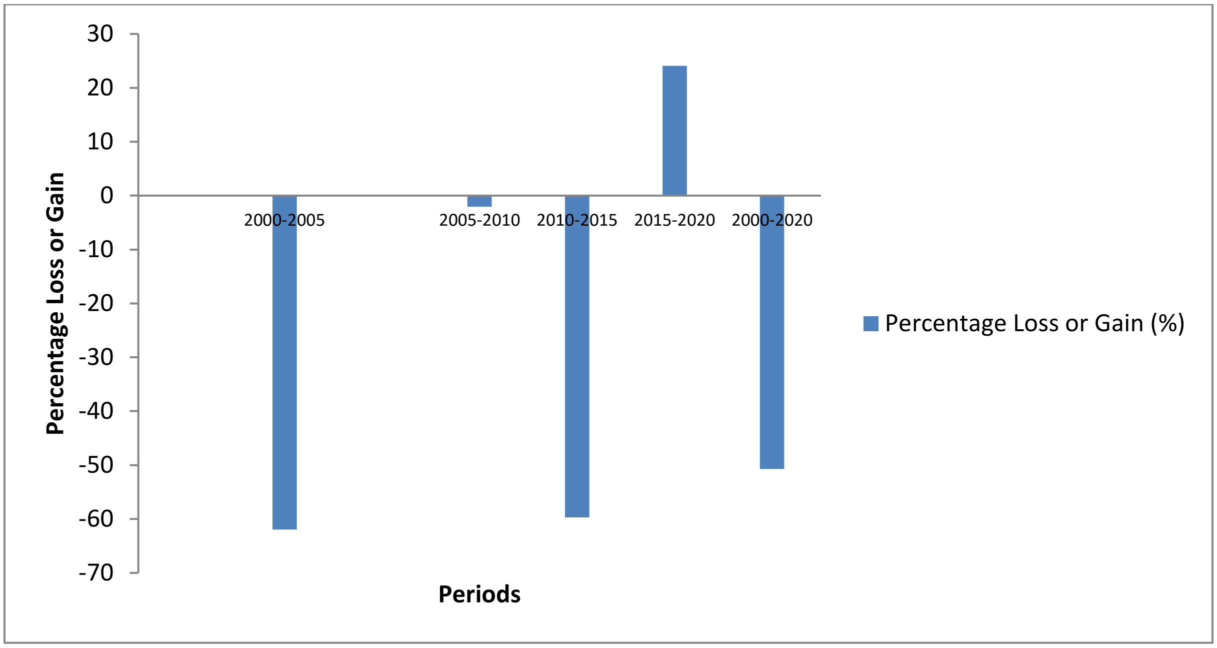

Figure 14: Shoreline Accretion and Erosion between 2000 and 2020

4. DISCUSSION

This study was concerned with the analysis of coastal shoreline change in Bonny using GIS based assessment to gather all data. It is evident from the result of analysis that both coastal erosion and accretion are revealed in Bonny Island coastline. The coastline has been subjected to erosion especially between 2000 and 2015. It has been reported that scientists from the Nigerian Institute for Oceanography and Marine Research (NIOMR) have reported widespread erosion and flooding of the Bonny Islands and the Niger Delta (Ibe et al 1984, Awosika 1993) created erosion resulting from deficit of sand due to natural and anthropogenic activities varies in intensifies from area to area along the coastline. Notable among the natural causes of coastal erosion are vulnerable soil characteristically topography and occurrence of off shore canyons. Anthropogenic cause includes destruction of coastline dredging and dams of rivers. The impact of the intensity of wave affects the sedimentation level along the coast. The sedimentation transport makes shoreline to protrude and erode (Li and Chen, 2003). The issue of human activities was evident in the study area as the Western part of Bonny Island was greatly found to be retreating inland in all the periods considered. Hart et al., (2008) submitted that sediment loss caused by erosion may eventually breach causing loss of another lagoon environment. Thus, if absolute care is not taken the seaport in the area will soon be flooded and rendered unusable and less functional. The net effect of shoreline changes in Bonny Island is to cause a high level of frustration and misery because people and businesses would need to relocate and new infrastructure would need to be provided. The finding of the study reveals that there have been a lot of significant changes that have occurred in the last 20 years from 2000 to 2020, the rate of urbanization in the community was relatively slow due to the poor awareness and knowledge on the natural resources available, crippling lots of commercial activities and leaving other activities that contributes majorly to growth of and development dormant. The increase in accretion in the recent times may be due to waves that are less steep and farther apart which tend to bring sediment onshore. Also, there may be some human activities that may result to sand filling and the place is being acquired by some people.

5. CONCLUSION

The study concluded that Bonny Island shoreline experienced more erosion than accretion from 2000 to 2020. The only accretion was experienced between 2015 and 2020. It is recommended that coastal and marine processes should be monitored for integrated management of degraded ecosystems, climate change adaptative engineered systems (hard or soft), and public enlightenment programs should be organized periodically for the residents of Bonny Island to make them aware of the vulnerability of the area to sea level rise and adaptation measures that should be put in place. A constant monitoring of the shorelines through geospatial techniques should be setup in Nigeria. This would enable early detection of any unprecedented changes taking place along the shorelines thereby making it possible for early arrests of such changes. Hence a monitoring unit is recommended that would have it as its responsibility to monitor our shorelines. A concerted and conscious effort by the Regulatory authorities and government should be applied in the creation of legal bounds and laws to activities within the Nigerian coastal zones. Establishment of off-limits is necessary to checkmate where people are permitted to carry out developmental projects. Also, measures of protection of shoreline based on site specific assessment and hydrodynamics and morpho dynamic based design of hard engineering infrastructure such as coastal breakwaters, sheet piling, groynes, rip-raps or soft engineering approaches for protection of the climate vulnerable coastal areas from erosion. Routine monitoring of hydrodynamic forcings such as waves, tide and current, is recommended for updated of sedimentation models.

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Author Contributions

First Author conceptualized the research and carried out the analysis/ interpretations while second author advised and directed the research; and wrote the article.

Informed consent

Not applicable.

Ethical approval

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

Conflicts of interests

The authors declare that they have no conflicts of interests, competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Data and materials availability

All data associated with this study will be available based on the reasonable request to corresponding author.

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