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Research Article

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Analysis of Shoreline and Erosion Changes along the West African Coast from 1980 to 2020

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Abstract
The manifestations of climate change in coastal areas may represent a serious threat to livelihoods and lives. In West Africa, where many capital cities are located with a high concentration of people, shoreline changes have been studied in some port cities and beaches. This study investigates the changes along the coastline of West Africa from 1980 to 2020 at a regional scale including twelve countries. Spatial technique, remote sensing and GIS were employed in the assessment and analysis and monitoring of the shoreline changes from Mauritania to Nigeria. The findings revealed noticeable decadal changes with the most significant change evident from 1980 to 1990. The study further indicates that the coasts of Senegal and Guinea and Guinea Bissau experienced significant shift in the shoreline as it moved landward from 1980 to 1990. The results of the geospatial analysis indicates that erosion and accretion trends were dominated by loss of coastal land totaling 17372.45 km2 from 1980 to 1990 with erosion rates higher than areas gained through accretion. The difference between erosion and accretion rates between 1980-1990 period is 15,769.8 km2 with erosion rates on the increase. Study has provided to demonstrate decadal changes of coastal erosion and shoreline changes that characterize the West Africa coast from 1980-2020 highlighting its vulnerability. The study recommends concerted effort by relevant authorities in the region in mitigating against the adverse the consequences of sea level rise at a regional scale.

Keywords: Shoreline Change, Remote Sensing, Coastal Erosion, Accretion, West Africa

1. Introduction
The shoreline is the interface between the land and the sea and the immediate position of the land–water line. Shoreline changes depicts the way in which the position of the shoreline moves with time (WIOMSA, 2010). Therefore, coastal zones the world over remains major centers of economic development attracting huge population concentration [1]. The coast is rich with natural resources that provides communities with both ecological and economic services such as food, clean water, jobs, recreation, and protection from storms, commerce, trade, and transportation. Others include beaches and shorelines that offer recreational values and wetlands that are pivotal for fisheries growth and development. In addition, the ecological services provided by coastal regions support flood mitigation strategies which and often act as natural defense from coastal storms [2].

In West Africa, coastal areas are home to 31% of the population and provides 56% of the sub region's GDP. Despite these enormous contribution, coastal regions particularly those in West Africa are daily confronted with various hazards such as storm surges, flooding, coastal erosion, salinization of land and coastal waters and depletion of fish stocks all threatening socio-economic livelihoods and human survival. These manifestations are projected to intensify given the current scale of human and natural forcing (The World Bank, 2016). Boak and Turner, asserts that the dynamic nature of shorelines largely due to the geology, geomorphology and tidal waves further subject it to constant changes resulting in erosion of coastal areas or accretion of sediments, depending on the dominant processes acting on the coastline [3,4].

Other natural processes that contribute to shoreline changes include tectonics (plate movement and volcanism, the nature and structure of the rock and biological factors. These processes have tremendous impact in altering the nature, location, and temporal dynamics of the shoreline. The West African coast like the rest in Africa is also grappling with the impact of sea level rise which is accelerating shoreline changes and thereby aggravating coastal erosion. Evidence in the geomorphology and climate literature posits that Africa is highly susceptible to sea level rise and it is expected to experience some of its deleterious impact particularly in the West. While the global sea level rise averages 3-4mm, recent sea level rise measurement in Eastern Africa particularly the Indian ocean is now 5mm per year. The immediate and long term impact of Sea level can be felt in disruptions in economic cycles, increase in shoreline erosion, poor water quality leading to incidence of water and borne disease which will interact with other factors and trigger human displacement [5].

Climate change is currently having varied impact on coastal regions leading to shoreline changes in the subregion. Changes in climatic systems such as waves, currents, tides, changes in atmospheric pressure and ice cover also influences shoreline changes areas in which the coastal communities has now emerged recently as the focus of most of the impacts of climate change with a call to scale up adaptation and build resilience [6,7].

Apart from the natural processes, anthropogenic activities such dredging, construction of breakwater infrastructure, physical development; mineral exploration, ports construction, removal of backshore vegetation, construction of coastal control works among others continue to exert enormous pressure on the shoreline of many regions including West Africa [8].

The attraction of the coast to human habitation has resulted in rapid expansion of economic activities and tourist resorts with concomitant impact on increasing migration of people to coastal regions. Studies on urbanization asserts that Sixty percent of the world's 39 metropolises with a population of over 5 million are located within 100 km of the coast, including 12 of the world's 16 cities with populations greater than 10 million. The impact of rapid urbanization on shoreline changes have been more significant over the past century and includes drainage of coastal wetlands, deforestation, reclamation, and discharge of sewage, fertilizers, and contaminants into coastal waters [9].

Over the years several methods have been deployed to study and analyze shoreline changes including methods that incorporate local observations and basic surveying techniques. The most recent method includes satellite remote sensing techniques and geographic information systems (GIS) for the identification, mapping and analyses of shoreline changes which have gained prominence in recent years as high resolution satellite data have become readily available. Although several methods such as the geomorphologic and sedimentary techniques have been employed in the past in studies of shoreline changes in West Africa, remote sensing and GIS remains the dominant technique. Previous studies of shoreline changes along the West African coast include the pioneering work of Ibe, Ibe and Anita, and most recently Alves et, al and Dada, et.al [10-15].

Studies of shoreline changes are carried out for several reasons including coastal erosion assessment and to gain insight on the temporal and spatial trends of coastal erosion and accretion rates triggered by natural and human impacts [16].

Therefore, understanding the process driving shoreline changes and the rate of change at a given time is imperative for better coastal area management. This research provides further analysis of shoreline changes along the West African coast and the drivers of shoreline erosion and accretion and this is where the research derives its relevance.

2. Study Area

The subject area is a coastal region located between the latitudes 4° N and 22° N and the longitudes 9° E and 18 W. It is the coastal region of twelve countries from the north to the south: Mauritania, Senegal, the Gambia, Guinea Bissau, Guinea, Sierra Leone, Liberia, Côte d'Ivoire, Ghana, Togo, and Benin, Nigeria (figure 1). Only three West African countries are landlocked countries, and so are excluded in this study.

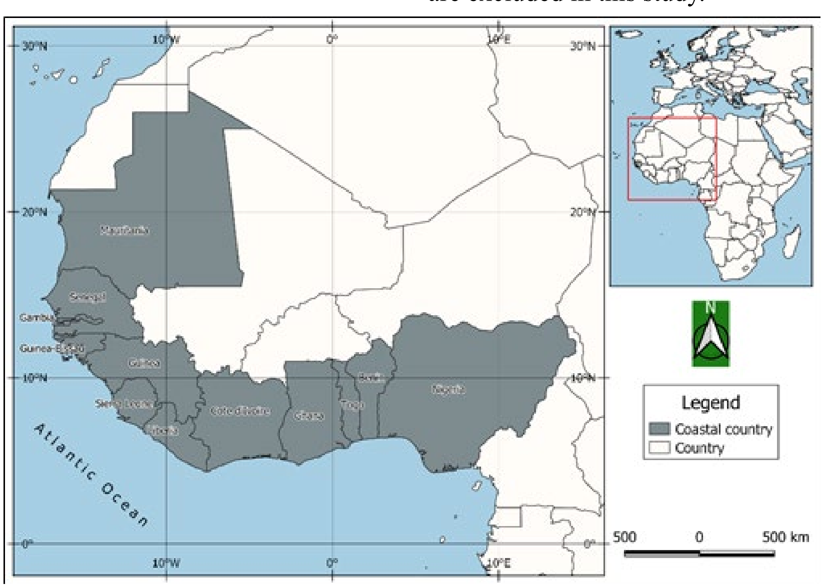

Figure 1: Location of the countries of the study area

The study area is a low-lying stretching from Mauritania to Nigeria. It comprises thee sectors: northern, western, and Gulf of Guinea. The northern sector includes Mauritania, Senegal, and the Gambia. Its continental shelf is narrow, with a width of 30 km on average [17]. The landform is mainly characterized by sand dunes and narrow spits delineating the river arms. The western sector is the coast from Guinea-Bissau to Sierra Leone. It is a sector of sand and mud. The estuaries are rich in mangroves. The continental shelf is wide (200 km on average), which amplifies the tides [17,18]. The Gulf of Guinea from Liberia to Nigeria has a narrow shelf. Furthermore, the barrier of sandy beach is narrow with river inlets, marshes, and lagoons [18,19].

The continental shelf is marked by some important submarine accidents: Kayar canyons in Senegal to the north of the Cape Verde Peninsula, and a deep canyon ("Bottomless Hole") cutting into the shelf off Abidjan in Côte d'Ivoire [17].

In general, the West African coastline is essentially sedimentary, mobile and dynamic. Indeed, in this coastal line, rocky coastlines constitute less than 3% of the coastline (for the parts directly exposed to the ocean), formed by rocks that are often altered and fractured, sometimes not very coherent, and prone to rockfall and erosion, as observed on the cliffs of Dakar for example [17]. The rest of these coastlines, essentially composed of sedimentary basins, are divided between: very dynamic, unstable and mobile coastlines, and dynamic sedimentary coastlines.

As such, the West African coasts are very susceptible to marine water penetration due to their highly sandy nature and low altitude. The IPCC estimates that in these low-lying areas, a 50 cm rise in sea level would result in deep inland water penetration [20]. According to projections, a vast majority of sandy coasts in Africa will experience shoreline retreat through the 21st century [21].

The climate in West Africa is under the control of two winds. Their influences vary with the north-south movement of the Intertropical Convergence Zone (ITCZ). From November to February, hot dry continental air originates from the high-pressure system above the Sahara Desert and gives rise to the dusty Harmattan winds. From March to October, moist equatorial air originates from the Atlantic and brings annual monsoon rains [22].

Rainfall is one of the most important elements in characterizing the different types of climate in this region. From north to south, seasonal cumulative rainfall ranges from 100 mm at Nouakchott latitude to more than 4,000 mm in Conakry, Monrovia or Roberts field [23].

Urbanization in the coastal region of West Africa is twice as high as in the hinterland. It is densely populated. The average density is 260 inhabitants per km [17]. In fact, some 85% of the population of West Africa is concentrated in the twelve coastal countries [24]. Furthermore, the population will increase from 36 to 80 million between 2020 and 2050. Economic activities on the coast are of paramount importance. It accounts for 56% of the GDP of West Africa [17].

3. Methodology

Data were obtained from secondary sources. The shorelines were directly captured digitally from the Google search engine through the historical settings of 1980, 1990, 2000, 2010 and 2020.
The shorelines were digitized to show the geometry of their inward and outward changes which were thereafter analyzed into erosion and accretion along the coastline. The captured polylines were closed to form polygons and thereafter were overlaid to compute the erosion and accretion levels for the two years and most often those that are close to each other i.e. 1980 and 1990; 1990 and 2000; 2000 and 2010; 2010 and 2020. Generally, the level of accretion and erosion was also monitored between 1980 and 2020. The levels of erosion and accretion were computed in ArcGIS 10.7 and measured in square kilometers and the trend was arithmetically obtained by subtracting the erosion value from the accretion value. The percentage change of the trend was also calculated.

2.1 Image Geo-Processing for Land use Change and Percentage Change

The study made use of multi-spectral satellite images of Landsat 4 and 5 Thematic Mapper of 1980, Landsat 7 Enhanced Thematic Mapper of 2000, and Landsat 8 OLI/TIRS of 2020 for the landuse/land cover analysis. All the imageries were of 30m x 30m spatial resolution and cloud free. Other information of the imageries are found in Table 1. The bands of each scene were stacked together using COMPOSITE module of the ArcGIS 10.7. Thereafter, the staked layers were mosaicked to cover the entire study area. A boundary shapefile layer of about 500 km from the coastline of West Africa to hinterland was captured and this was used to delineate the imagery of each year under consideration. Unsupervised classification was used to classify the imagery into major landuse as guided by different agencies. The landuse/land cover classification was guided by the information obtained from West Africa: Land Use and Land Cover Dynamics and available at https://eros.usgs.gov/westafrica/data-downloads. The area of each landuse class was computed in ArcGIS 10.7 which was used to compute the landuse change and percentage change in squared kilometers.

2.2 Digital Elevation Model

The digital elevation model (DEM) of the study area was obtained from the Shuttle Radar Topography Mission (SRTM) imagery of 2020. This is being obtained to have the topographic information concerning the along the West African Coastline. The imagery was in Geotiff format and easily compatible to process in the ArcGIS environment. The imagery was thereafter clipped to the boundary of the shapefile being used for this study and further spatial analysis was performed.

2.3 Method of Data Analysi

The study employed the use of descriptive statistics involving the use of spatial extent in terms of landuse/land cover analysis, minimum, maximum and mean in terms of climate data and spatial coverage in terms of shoreline changes. Zonal statistics in GIS environment were adequately employed to extract the minimum, maximum and mean values of total precipitation and air temperature which were used for further statistical analyses. Results of analysis were presented in tables and graphs.

3. Results and Discussion

3.1 Decadal changes along the West African Coast from 1980 to 2020

The geospatial analysis of the Landsat images allowed us to appreciate the degree of changes on the shoreline along the West African coast within the four decades that constitutes the study period (1980 to 2020). In sum, the study of the dynamics of the West African coastline shows a regressive evolution at the of -2.78 m/year as shown in (Figure 2).

The causative factors that have been implicated in the driving mechanism of the observed erosion and shoreline changes are Westerly and easterly wind, waves, littoral drift caused by built-up structures and anthropogenic influences play a dynamic role in the shoreline process.

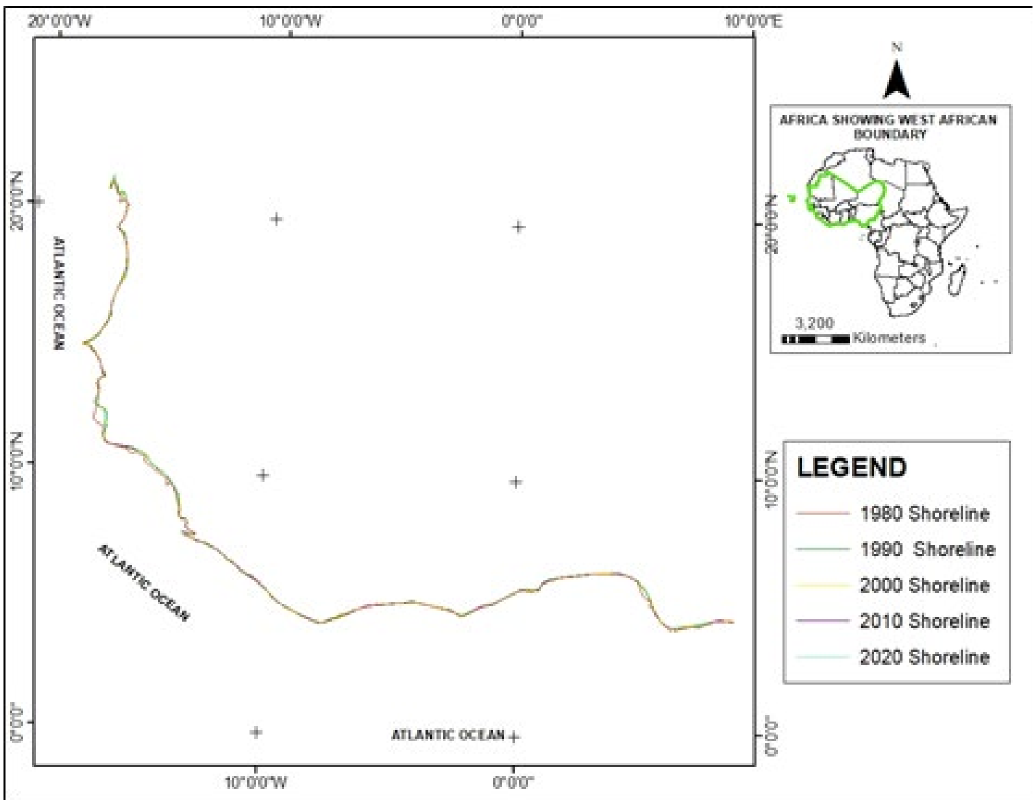

Figure 2: Shoreline Changes along the West African Coast from 1980 to 2020

Coastal cities along the West African coast has over the years been characterized by shore like changes and coastal erosion driven by sea level. These twin hazards also pronounced in the Senegalese and Guinean coasts. Indeed, between 1980 and 2020, a significant retreat of the coastline was noted, as a consequence of the rise in sea level. However, increased erosion were more visible in 1990 and 2020. Also, erosion was more noticeable on the Guinean coasts located further south than on the Senegalese coasts located in the north. Similarly, along the Senegalese coast, erosion is more striking in the south than in the north as shown in (Figure 2). This shows a net spatial variability of sea level rise that is similar to the spatial variability of thermal expansion in West Africa, which becomes stronger going south as ocean waters are more warmed moving towards the Equator.

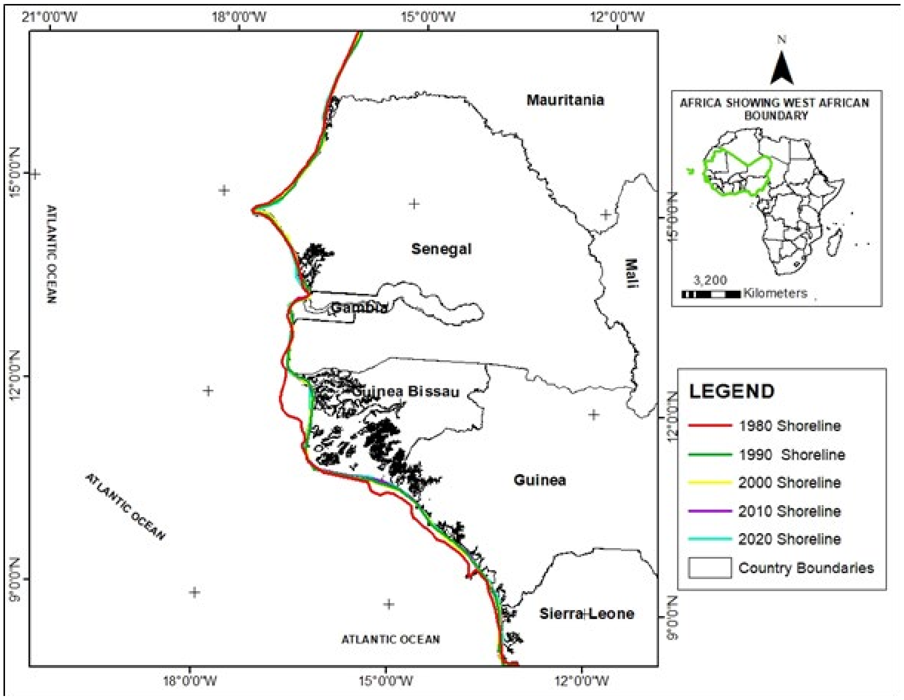

Figure 3: Evolution of the coastline along the Senegal and Guinea coasts from 1980 to 2020

The study also considered the analysis of the erosion trend along the West African coast from 1980 to 2020 and the result revealed the extent to which sea level rise has impacted the coastline of West Africa. Changes in the shoreline along the West African coast from 1980 to 2020 showed enormous erosion rates in 1990 and 2020 as shown in figure 3 as erosion rates outpaced accretion in the period under consideration.

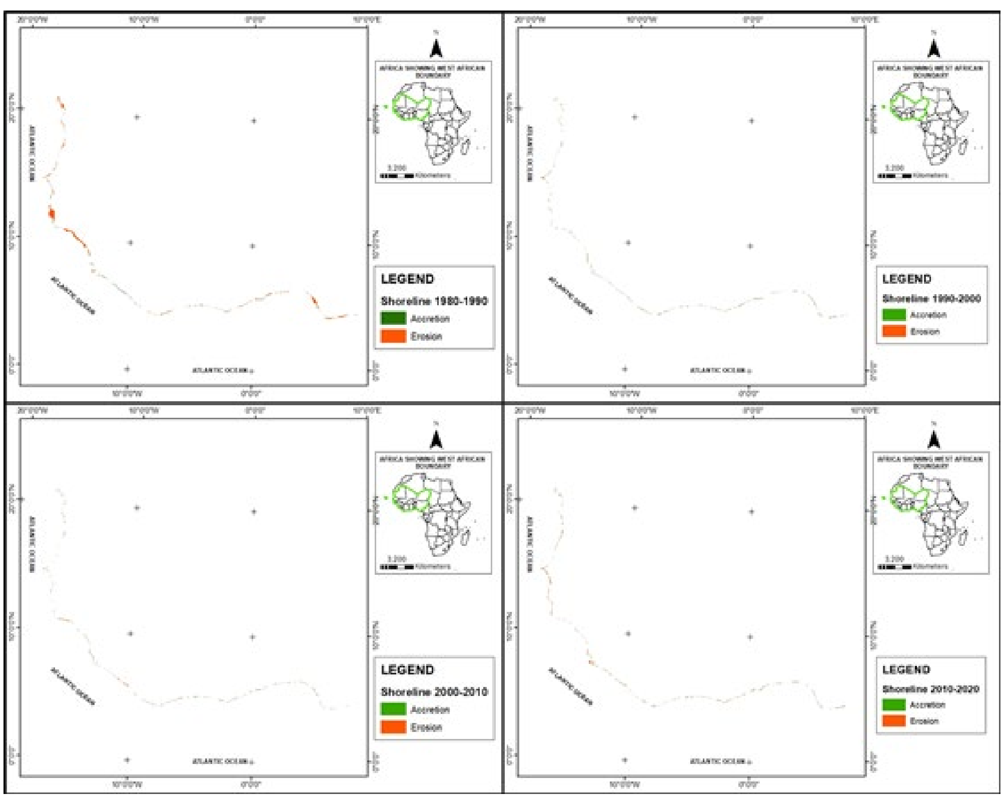

Figure 4: Shoreline changes along the West African Coast from 1980 to 2020

Analysis of decadal trend of both erosion and accretion rates along the West African coast between 1980 and 1990 is shown above in figure 4 with the result indicating that 17372.45 km2 of coastland was lost due to coastal erosion as captured in figure 3 above. It was the most significant land loss recorded in the study period 1980-2020. The accretion rate of (1602.64 km2) was not enough to compensate for the land loss. The difference between erosion and accretion rates was 15,769.8 km2 from 1980 to 1990. Erosion rates accounted for over 91% of land loss driven by erosion during this period. However, erosion rates were less pronounced between 1990 and 2000; only 5% of the eroded portion was lost. Ninety-five percent of the eroded area was counterbalanced by accretion.

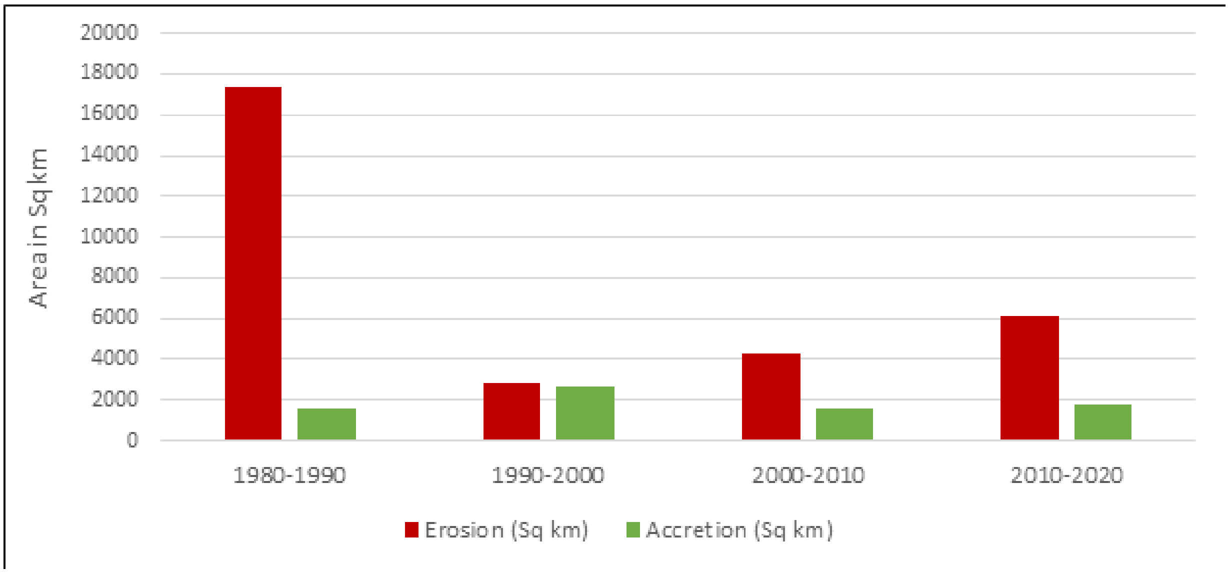

Figure 5: Erosion and accretion along the West African coast between 1980 and 2020

The overall trend of both erosion and accretion rates from 1980 to 2020 is shown above in figure 5 with 1999-2000 recording the lowest rate of both erosion and accretion while in 2000-2010 erosion rates was slightly higher (4000 sq km) and accretion about 1000 sq km than 1999-2000 rates. Consequently, the 2010-2020 decade was also characterized by increased erosion hazards as 6000 sq km of land was lost due to erosion rates while accretion remained at the same level obtained in 2000-2010 epoch. The countries where erosion rates were most pronounced are the coasts of Guinea, Sierra Leone, and Nigeria.

In terms of comparison, the 1980-1990 decade witnessed the highest rates of erosion throughout the period of the study as 16000 sq km of land was lost due to the menace of erosion while accretion was insignificant and negligible as captured in figure 5.

The shoreline changes along the West African Coast showed different situations. Some sections of the coast are more exposed to erosion than others. On the other hand, the counterbalancing mechanism of accretion is almost the same all along the coast. It showed no significant difference from the northwest to the southeast. It is less important than area of land lost through erosion. Therefore, the important amount of land lost because of erosion in 1990 has never been found again.

4. Discussion

Our findings indicates the presence of significant changes in the shoreline and erosion trend along the West African coast, especially in Guinea. It is important to highkight that between 2000 and 2021 most of the studies using geospatial technique in shoreline analysis along rivers and deltas are conducted on a small scale [25]. Studies in some sectors of the West African coast showed those changes at a local level. By using geomorphological methods, Guerrera et al. measured a 5 m/year erosion in some sectors of the coast of Togo in the last forty years [26]. Kaki et al. monitored by remote sensing a 10 m per year erosion between 1963 and 2005 on the coast of Benin [27]. In their review, Almar et al. found up to 5 m/year landward movement of the shoreline at the port of Cotonou in Benin [18]. In Saint-Louis (Senegal), Cisse et al. found an increase in flood risk between 1994 and 2015 caused mainly by sea level rise. In the all, the general trend as shown in this study is that erosion rates has been increasing since 1980 up to the present [28].

There are significant differences in shoreline changes in West Africa. In fact, some studies reported accretion sections on the coast of West Africa. On the Volta Delta in Ghana, the average accretion was 0.53 m/year [29]. Changes in erosion and accretion can be affected by defense structures, especially around ports and hotels. In the case of Keta in Ghana, groins changed the dynamic of erosion negatively [30]. The construction of three deepwater ports in the bight of Benin, Gulf of Guinea, resulted in shoreline destabilization with acute erosion threatening stretches of beaches in the port cities of Lomé, Cotonou and Lagos. Villages and coastal roads and other infrastructure are also under the threat of erosion exacerbated by port construction on the Gulf of Guinea [31].

Limitations of this study may be from the non-integration of the local impacts of man-made factors. In fact, this study did not take into account the local changes caused by coastal defense structures. Cross-profile comparisons with bathymetric surveys in Taiwan showed that because of jetty and groin construction, erosion as well as accretion are observed [32]. In combination with sediment budget calculations, satellite images, drone and local video cameras, Angnuureng et al. showed that no landward recession has been observed at Elmina beach in Ghana thanks to sea defense structures [33].

The scale (West African) does not allow the assessment of different behaviors of the different trends along the coast of West Africa. There can be significant differences from one section to another of the coastline. Between 1990 and 2012, on the Andhra Pradesh coast in India, 275 km of the shoreline showed erosion, 417 km showed accretion and 153 km was under stable condition [34]. On-site investigations of coastal erosion and accretion in the northeast of Taiwan carried out in 2006, 2012, 2013 and 2019 showed that erosion as well as accretion are reported [32]. In Qingdao, eastern Shandong province of China, three segments displayed three behaviors of the shoreline in the periods 2000-2010 and 2010-2019. For all segments, there was an accretional trend up to 11.64 m/year. There had been a net gain of coastal land [35].

In light of the limitations of the shoreline analysis along the West African coast from 1980 to 2020, an accurate measure of the trend in erosion can be estimated. In fact, this study showed a dynamic trend on the coastline of Guinea. Most of the studies are conducted on the Gulf of Guinea and some on the coast of Senegal. A West African scale made it obvious that the central segment of the coast is one of the most exposed to shoreline changes and erosion.

5. Conclusion

Shoreline changes can be analyzed in association with one of its main causes, which is the sea level rise. In forty years, from 1980 to 2020, the shoreline in West Africa, from Mauritania to Nigeria, showed noticeable changes. As shown by many studies, remote sensing and GIS are efficient tools for monitoring shoreline changes. On the coast of West Africa, the most significant change happened from 1980 to 1990. The midway sector, between Guinea-Bissau and Sierra Leone showed important movement of the shoreline in 1990. In fact, the coastal region of Guinea, especially Guinea-Bissau, recorded a landward movement of the shoreline stretching on large areas. The shoreline movement translated into erosion or accretion along the coast. Rosion rates were shown to be more prevalent than accretion in the study. The total extent of land lost to coastal erosion was 17,372.45 km2 between 1980 and 1990 with no sign of recovery. Studies on local scales found important erosion rates of up to 5 meters per year in some coastal countries of West Africa - Togo, Benin, and Senegal. Studies carried out in other places of the world found out different trends. Accretion and stable conditions were reported from coastal regions of Asia. Those conditions are from different natural features, but also from different adaptation measures.

This study showed that special monitoring and extensive analysis of the coasts of Guinea needs to be conducted. The regional approach to coastal erosion associated with shoreline changes evident in this study offer a unique opportunity to investigate the implication of sea level rise and their impacts through shoreline changes. Human interventions – ports, tourist resorts, defense structures needs to be factored in the regional manifestations of sea rise level for a better mitigation of the negative impacts and relevant adaptation options.

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Competing Interest

The authors declare no competing interest

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