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ASSESSMENT OF SEA INCURSION AND FLOOD SUSCEPTIBILITY FACTORS IN AYETORO FISHING COMMUNITY OF ONDO STATE, NIGERIA

OLAKUNLE, G. W[1], M. Salami[1], A. A. Osinowo[2].
[1]Nigerian institute for oceanography and marine research, no.3, Wilmot point, Victoria Island Lagos,
[2]Federal University of Technology, Akure, Ondo state, Nigeria.
Corresponding author, Email: gideolak@yahoo.com, gideonwole@gmail.com

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ABSTRACT

Ayetoro, a coastal fishing community in Nigeria is currently confronted with a major environmental hazard threatening its existence. This study assesses the vulnerability factors, using geographical information system (GIS), remote sensing techniques, historical data series and literature review to asses flood risk index and indicators. Indicators were rated on a scale from 1 to 5 reflecting "very low" to "very high" vulnerability to create coastal vulnerability and sea level rise index (CVSLRI). Extreme wave events for 2yrs, 5yrs,10yrs, 25yrs, 50yr and 100yrs return periods were obtained using the Gumbel distribution scheme, based on a 40-year (1980-2019) wave hind-cast. Ayetoro is situated within the mahin mud coast with soil composition of 12% sandy mud, 34% silty mud and 54% clayey mud. Vegetation cover reduced from 1990-2020 by 36.7%, while built- up area grew by 41.7%. CVSLRI indicates high vulnerability to rising sea levels due to low slopes, low topography, high mean wave heights, receding vegetation cover and proximity to some coastal installations. The overall annual forecast of storm surge revealed that extreme significant wave height (SWH) will rise to 1.29m, 1.54m, 1.59m,1.91m, 2.12m and 2.27m respectively for 2yr, 5yr, 10yr, 25yr, 50yr and 100yr return periods. Wave direction is predominantly Northeast (NE). Education, Bioremediation, and Shoreline protection that is environmentally friendly will reduce vulnerability and increase resilience.
Keywords:Climate change, Hazards, Spatial Data, Remote Sensing.

Introduction

Life is sustained by the earth because it provides an environment and atmosphere that has enabled living organisms, humans inclusive, to evolve and thrive on its surface, in its oceans, and in its air. The atmosphere is the main reason life thrives on the planet, at least for humans. The air we breathe, the water we drink and the warmth from sunlight that enable us to grow our food are all made possible by the atmosphere (Archer, 2011). However, the last few decades had witnessed a disequilibrium in the planet-earth in form of sea level rise, increase in atmospheric temperatures, unusual fires and snows, hurricanes and tornados which are all indicative of increase energy in the atmosphere occasioned by climate change. Within the last few decades, the atmospheric and sea surface temperatures have been rising and climates worldwide are changing. Increases in sea surface temperatures cause thermal expansion, which increases the water level of the sea surface (IPCC, 2013), thereby moving the shoreline farther inland. The warming of the atmosphere causes melting of mountain glaciers and polar ice sheets, thus increasing the rise in sea levels. Based on historical data, eustatic sea level changes between 1950 and 2009 were on average 1.7mmyr^{-}1. In recent years, satellite altimetry measurements (between 1993 and 2003) have shown an increase in this rate to over 3mmyr^{-}1 (IPCC, 2007a). Hazards birthed by Global warming and climate change had become exacerbated by anthropogenic activities like Excessive exploitation of mineral resources, poor waste management, increased volume of pollutants, unregulated urbanization, mining, industrialization etc. The situation is worse in developing countries like Nigeria due to lack of environmental education, infrastructural deficit, weak implementation of planning laws and systemic corruption.

Ayetoro is a major fishing community in Ilaje Local Government of Ondo State, Southwest of Nigeria , located within Latitudes 05°16 & 06°301 North and Longitudes 004°451 and 005°451 East of the Greenwich Meridian. The community is known for its richness in seafood like, crabs, periwinkles, crayfish and diverse species of fish. Therefore, seawater incursion, flooding and land degradation in the community is a national and global food security and public health concern (Olatunji-Ojo et al., 2019). Sea incursion and displacements due to high tides and extreme waves with the accompanying negative effect on the livelihood of residents can lead to high economic loss due to the reduction of agricultural products such especially fishing, which is the primary occupation of Aiyetoro community. Over 30 per cent of land in Ayetoro community and its environs had been abandoned and approximately 2km distance along the Ilaje coastal waters had already been affected by sea incursion and flooding. Incessant sea incursion with its resultant flooding and erosion had become a familiar hazard of the last few decades. This study aims at assessing the vulnerability factors that predispose this community to sea incursion, erosion and flood using geographical information system (GIS) and remote sensing (RM) techniques aided with historical data series and literature.

The study site is situated in an area consisting of several tributaries of the Niger River and ending at the edge of the Atlantic Ocean. It consists of several creeks and estuaries as well as a stagnant mangrove swamp and approximately 2.0 km of coastline. Land subsidence lowers the topography of Ayetoro area relative to the sea and making it vulnerable to sea level rise. For coastal areas, the relative sea level rise value is much more important than the eustatic sea level rise. In addition to the global average eustatic SLR of 3mmyr1, the relative sea level rise in Niger delta area of Nigeria and environ includes subsidence levels of 25–125mmyr^{-1}, which makes the study area highly vulnerable to floods. Climate change, generally will produce waves of higher energy which act on the coast. Consequently, ocean surges occur as a result of periodic spilling and plunging of sea waves extreme that inundate communities situated at the sea shores. Therefore, Oceanographic engineering solutions need to take into consideration wave patterns and height.

Significant wave height (SWH) is defined as the average height of the highest one-third waves in a wave spectrum. Extreme wave analysis is pivotal to design and construction of coastal and offshore structures (Goda *et al*., 2010). Remediation experts and marine engineers must be abreast with extreme waves with return periods of 50 or 100 years in order to proffer enduring and sustainable solutions. Therefore, understanding the extreme situations of wave is of benefit not only to researchers, but also of economic importance to the government and industry. Evaluation of design wave height corresponding to a return period has been carried out by many studies, among which are Vledder *et al*., (1993); Dong and Ki-Cheon, (2006). Unprecedented destruction of livelihood and failure of marine structures have been attributed to extreme waves. Therefore, a scientific understanding of the interrelatedness of global climate change patterns and their influence on extreme wave events is indispensable to providing mitigation and remediation solutions. (Caires *et al*., 2006; Grabemann & Weisse 2008; Mori *et al*., 2010; Semedo *et al*., 2013; Vanem 2015).

The average values of a time series of wave heights are useful in evaluating the existence of a trend over a long period of time. A time series data of extreme values is used to obtain the probability of extreme events at specific return periods. Analysis of extreme waves are vital tools required by marine engineers to evaluate and predict the threat of damages to offshore infrastructure based on analysis of past and future trends in the wave fields (Lionello *et al*., 2007), also based on diverse emission states (Nakicenovic *et al*., 2000). A better understanding of the significance of wave field on coastal locations is gained by evaluating the occurrence and trend pattern of significant wave height (SWH) and extreme waves over certain return periods.

Understanding the extreme situations of wave is of benefit not only to researchers, but also of economic importance to the government and industry. Evaluation of design wave height corresponding to a return period has been carried out by many studies, among which are Vledder *et al*., (1993); Dong and Ki-Cheon, (2006). Extreme waves can bring devastating effects on the coasts (e.g. through erosion) and cause failure of marine structures. Therefore, there is wide interest for the observation of such events in the context of climate change with an excellent understanding of the pattern that global climate changes can influence the appearance of extreme wave event (Caires *et al*., 2006; Grabemann & Weisse 2008; Mori *et al*., 2010; Semedo *et al*., 2013; Vanem 2015). Significant wave height (SWH) is defined as the average height of the highest one-third waves in a wave spectrum. Extreme wave analysis is vital in coastal and offshore construction for choosing design wave heights (Goda *et al*., 2010). In designing a marine structure, the engineer must be knowledgeable in extreme waves with return periods of 50 or 100 years. The average values of a time series of wave heights are useful in evaluating the existence of a trend over a long period of time, an example of a time series of extreme values is used in getting the probability of extreme events at specific return periods. The analysis of extreme waves can be utilized by coastal engineers to evaluate the threat of damages to offshore infrastructures or by marine engineers to compute past and future trends in the wave fields (Lionello *et al*., 2007), also based on diverse emission states (Nakicenovic *et al*., 2000). The trends in significant wave height with the evaluation of the occurrence of extreme waves at certain return periods, give a better understanding on the significance of wave field on coastal locations. However, results rely on the preliminary data with chosen statistical techniques (Mathiesen *et al*., 1994). Consequently, return values got for a particular location and from different researchers can be different (e.g. Bulteau *et al*., 2013a) thus, giving a difficult interpretation.

CVSLRI rankings and ranges of variables are not the same across different systems, depending on the measured values. Three to five classes of ranking are found in the literature. Kumar and Kunte (2012) use three classes (i.e. low, medium, high), Yin et al. (2012) use four (low, medium, high, very high), while Dinh et al. (2012), Pendelton et al. (2010), Ozyurt and Ergin (2009), Thieler and Hammer-Kloss (1999) and Gornitz (1991)

Materials and Method

Study area.

Ayetoro is a major fishing community in Ilaje Local Government of Ondo State, Nigeria, located within Latitudes 05°16 & 06°301 North and Longitudes 004°451 and 005°451 East of the Greenwich Meridian.

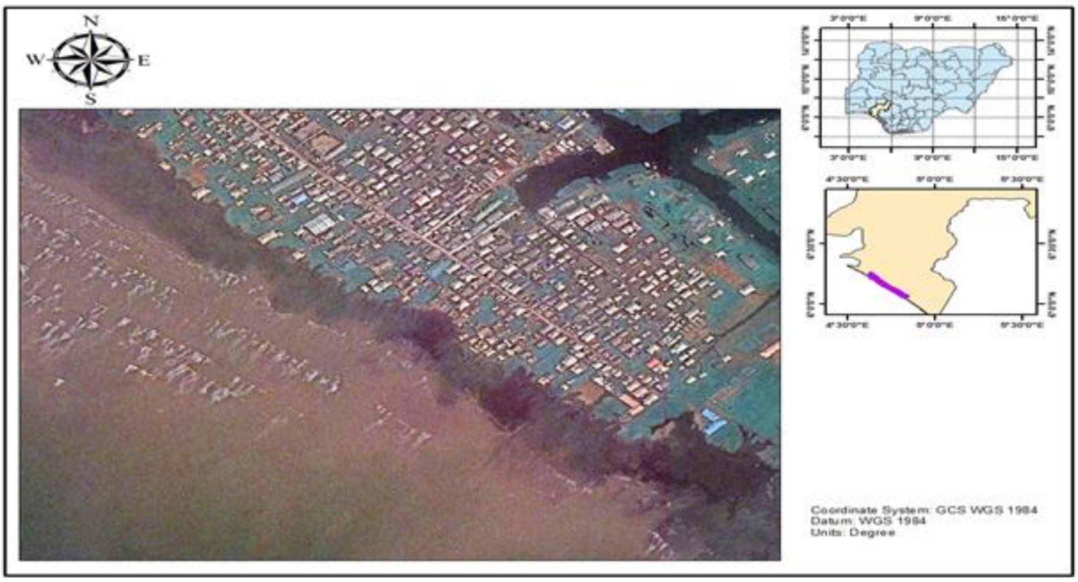

Figure 1. High resolution image of Aiyetoro community

Methodology

Data used were extracted from available satellite (ASTER Global DEM of 15 m and 30 m resolution and SRTM of 30 m resolution). SRTM, which was flown in February 2000, covers about 85% of the Earth's surface, and was obtained through Synthetic Aperture Radar interferometry of C-band signals. SRTM is available in 30 and 90 m spatial resolutions, with a vertical accuracy of about 3.7 m and greater gentle slopes than on steep slopes (Syvitski et al. 2012, Jarihani et al. 2015). First, each of the imageries was georeferenced in ArcGIS (10.4version). The DEM values were extracted from each of the SRTM and ASTER datasets. The analysis was achieved with the 'Raster analysis' option (in Spatial analyst extension) of the Hydrology toolbox of ArcGIS. First, the Fill option in the toolbox was used to improve the quality (sink) of the DEM. the Fill operation assigns values to raster cells within flow path that hitherto did not have associated drainage value based on defined interpolation procedure. Subsequently, flow direction and accumulation were extracted, using relevant operation tool in the 'toolbox' (MaDGIC 2014). Landsat imageries, were afterward georeferenced to ensure local compatibility with the coordinate systems of the study area and adjusted for inherent radiometric errors. The analysis was achieved with the 'Raster analysis' option (in Spatial analyst extension) of the Hydrology toolbox of ArcGIS and the Fill option in the toolbox was used to improve the quality (sink) of the DEM values.

Thieler and Hammer-Kloss (1999) and Gornitz (1991) approach was used in CVSLRI ranking of the study area. The classification ranges from very low to very high and ranked 1(very low), 2(low), 3(moderate), 4(high) and 5(very high). considering that such a refined classification will reduce considerably the uncertainty in computation of vulnerability. Tables 1 show the ranges of values of exposure, susceptibility and resilience variables respectively, as considered in the present research, as well as their ranking from 1 (very low) to 5 (very high). The exposure indicators are selected based on their influence on coastal flooding, inundation, sea water intrusion to groundwater sources and coastal erosion. All the chosen variables are physical properties of the coast, except "proximity to coast", which is a human-related variable.

Wave data was obtained using version 3.14 of the third-generation spectral wave model WAVEWATCH III ^{TM} (WW3), was used to simulate ocean wave parameters over the mid-Atlantic Ocean. A two-dimensional (2D) wave energy spectra model was obtained at each grid point with time period spanning from 1st January, 1980 to 31st December, 2019. The model provides output of wave parameters including wave spectra, SWH (4√ E), mean wavelength ($2\Pi\ k^{-1}$), mean wave period ($2\Pi\ k^{-1}2\pi$), mean wave direction, peak frequency, and peak direction. The simulation provided a six-hourly time series of SWH and other wave parameters over a box extending from 30°S to 40°N and 80°W to 15°E which contains nearshore and offshore locations. Results over water are extracted over 60°W, 10°S, 15°E and 20°N which contains the study location defined by coordinates 4.77°E, 6.1°N.

Result

Ayetoro is sandwiched between Dangote refinery and Escravos and Forcados Rivers with some oil and gas installations upstream (fig.2) considerably increasing the effect on waves splashing at the shore. (Fig1). The community is situated within the mahin mud coast with a soil composition of, 12% sandy mud, 34% silty mud and 54% clayey mud thereby making the area vulnerable to erosion (Table2). Land use land cover (LULC) map 1990, 2000, 2020 (fig 10,11,12) had shown a serious deforestation that has reduced the vegetation cover from 1990 to 2020 by 36.7%. At the same period the built-up area had grown by 41.7% due to population growth. (Fig. 6,7). The Average elevation of Aiyetoro as extracted from SRTM DEM data is between 0 and 5m above sea level, which is ranked low , the delineation and classification of the coastline slope ranges from 0 to 89.3%, the classification range of the slope is 0.001–71.1%, ("very high") while the geomorphologic zone is characterised by deltaic, sandy beach, and estuarine landforms. Evaluation based on CVSLRI ranking results indicate that Ayetoro is 95% vulnerable to rising sea levels, because the area characterized by high slopes, low topography, high mean wave heights, proximity to the coast and geomorphology characterized with sandy beach, delta and estuaries. (Figures 2,3,4 & 5). These factors make Aiyetoro susceptible to flooding due to river inflow and storm surges coming from the sea.

The annual mean SWH stands at 0.37m, while the seasonal means stands at 0.23m and 0.47m respectively for winter and summer. The predominant wave direction at Aiyetoro is North-East (Fig 9a,b,c). The mean wave heights have peak values of 0.68m and 0.67m respectively in July and August. Minimum values of 1.8m and 1.9m occur in December and January. In a temporal linear trend analysis, declining or negative trends are observed in the annual and summer mean SWH and extreme SWH. Inclining or positive trends are only observed at winter. Furthermore, the sharp decrease in SWH and Extreme SWH between years 1998 and 1999 is as a result of a strong El Ni˜no phenomenon between these years causing the weakening of the West African Monsoon. The significant increase in SWH and Extreme SWH from year 1992 to 1993 is also as a result of a strong La Ni˜na phenomenon accompanying the strengthening of West African Monsoon. For the different return periods, extreme SWH ranged between 1.29m and 2.27m. Larger values of seasonal mean extreme wave heights occur during summer and ranges between 1.28m and 2.32m consecutively for all the return periods.

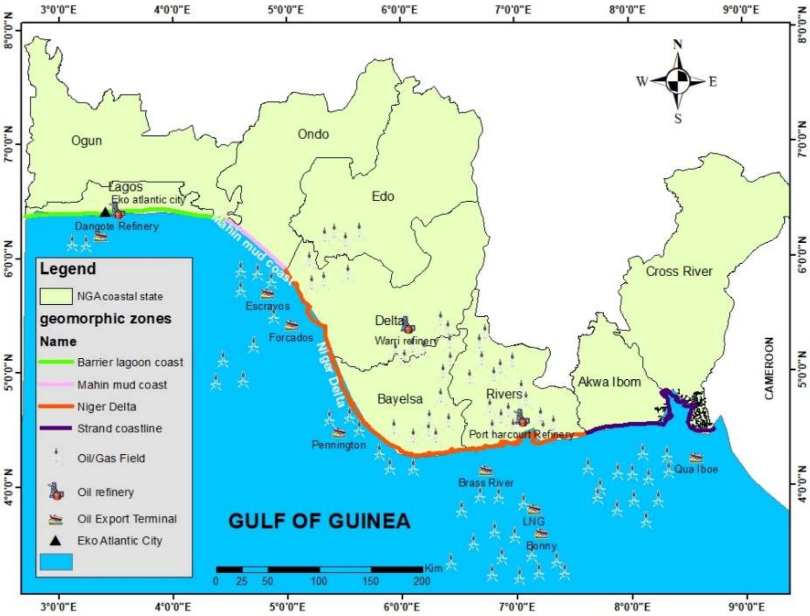

Figure 2: Costal facilities along the Nigeria coast

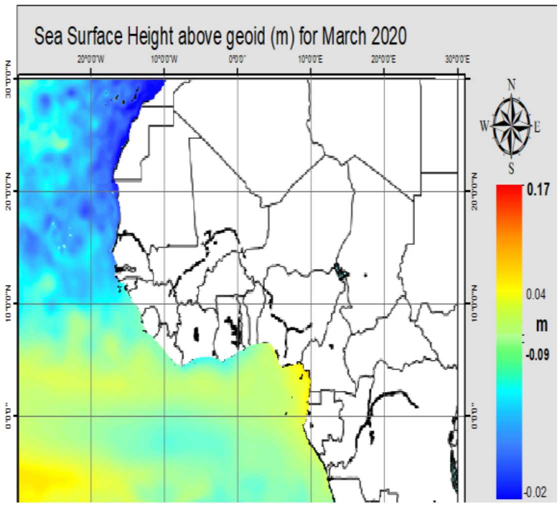

Fig. 3(a). Sea surface height, march,2020

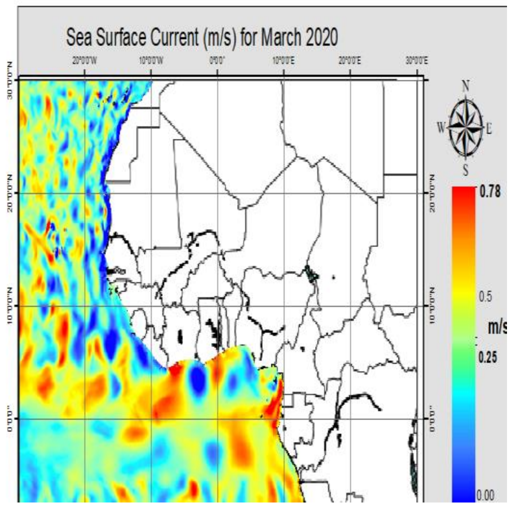

Fig.3(b). Sea surface current for March 2020

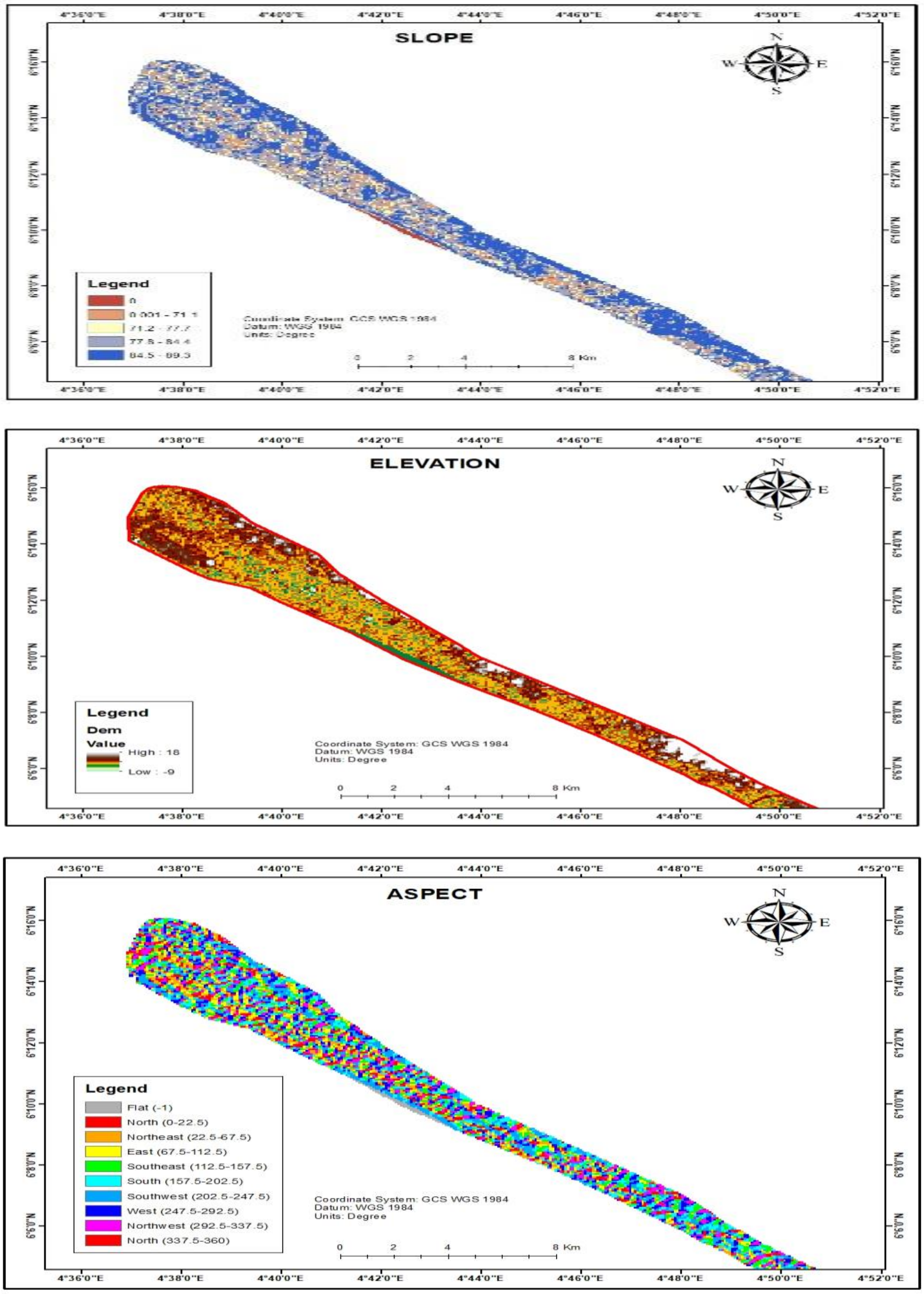

Fig 3: Topography-(a)Slope (b)Elevation (c) Aspect

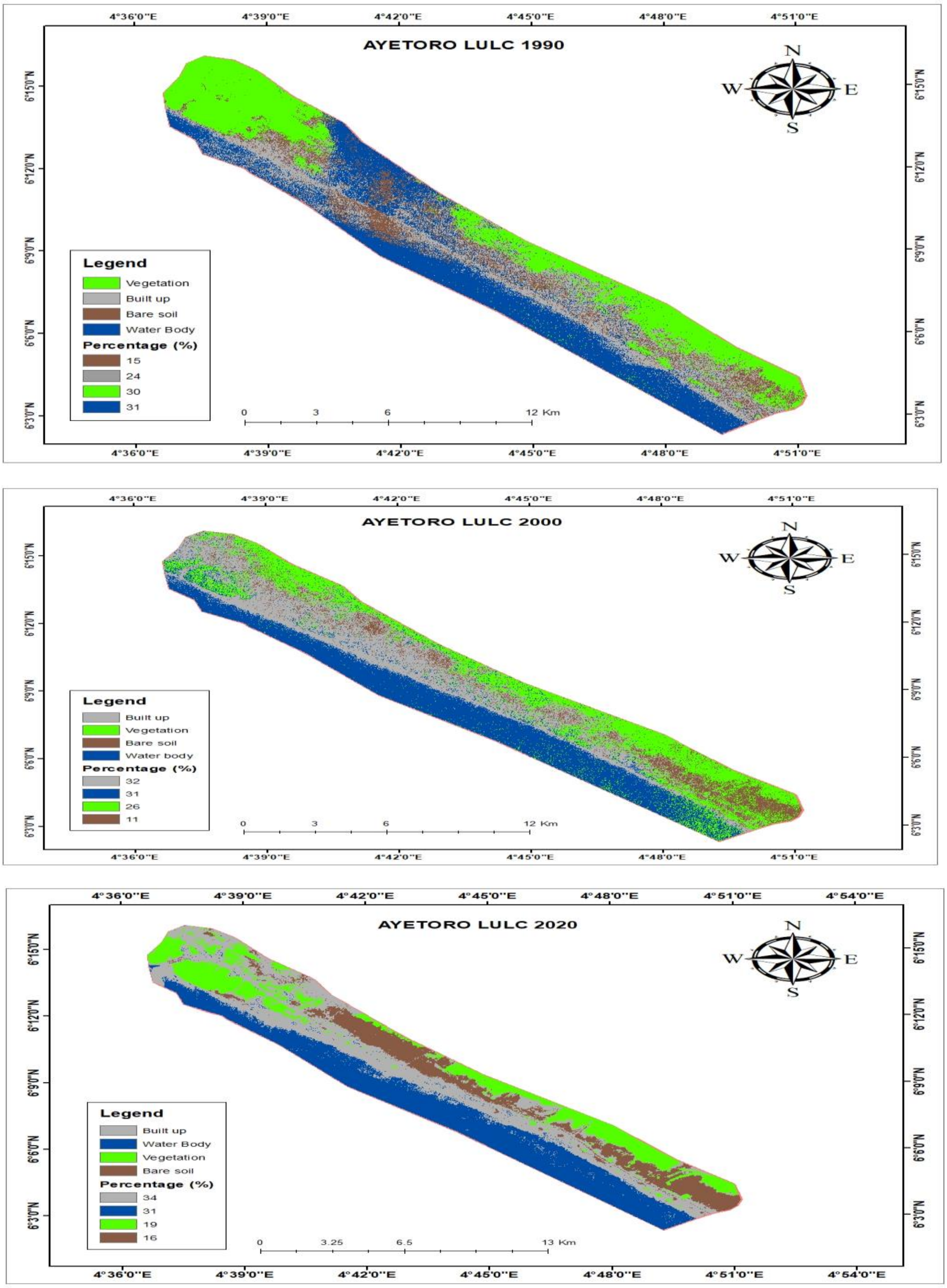

Fig 5: Land Use Land Cover (a) LULC 1990 (b) LULC 2000 (C) LULC 2020

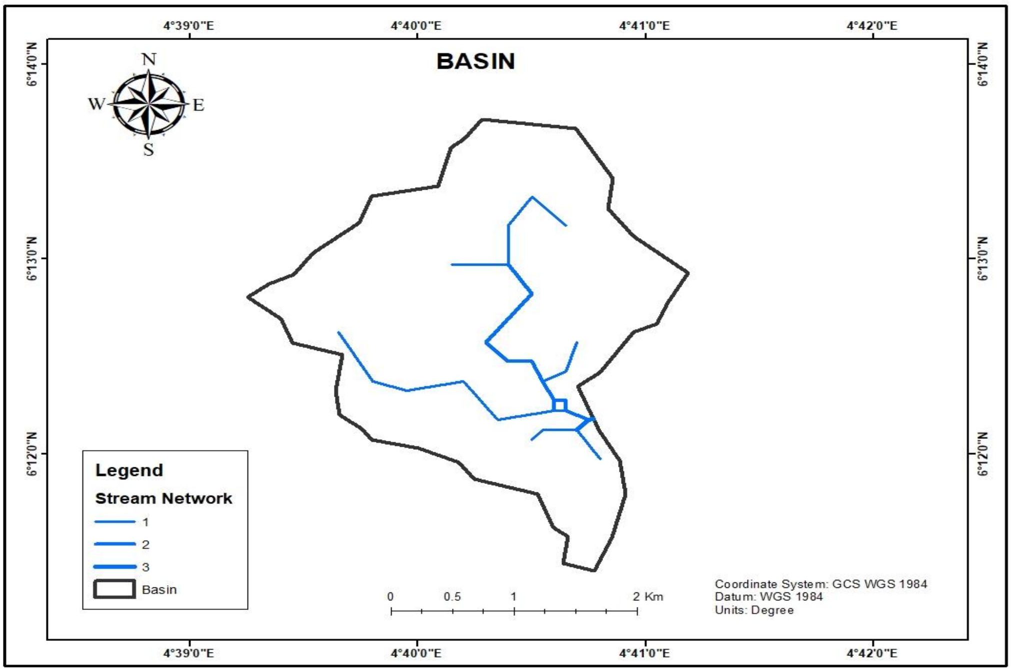

Figure 6(a): Aiyetoro Basin

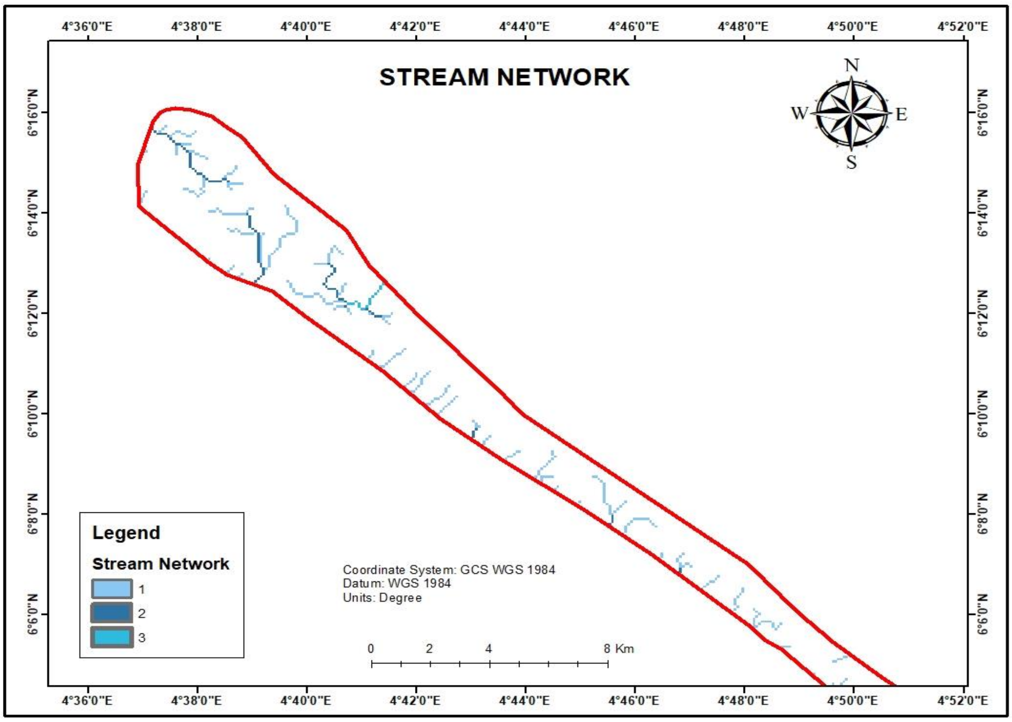

Figure 6(b): Ayetoro Stream Network

Table 1. Ranking of the exposure CVSLRI variables of Ayetoro.

Variables/Ranking	Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)
Topography	<5m				
Coastal slope					
Geo-morphology	Beaches			Lagoons estuaries	Barrier islands, beaches, deltas
Relative SLR rate				3–4mm	>4mm
Mean tidal range				1–2m	> 2m
Mean wave height				10–15m > 15m	
Annual shoreline				200–400m	100–200m

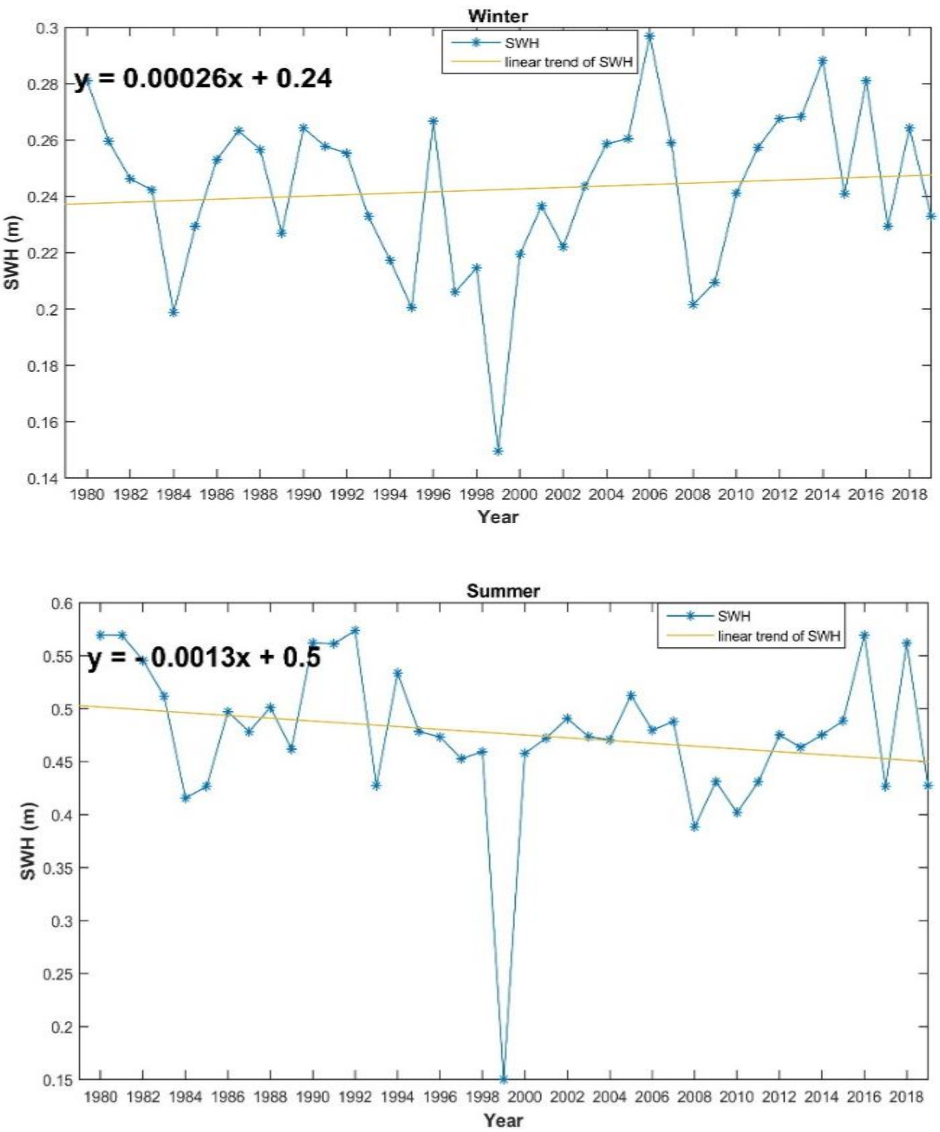

Fig7: (a) Long-term trend of annual mean and (b) Winter mean Extreme SWH

(c) Summer mean Extreme SWH (1980 to year 2019. Unit: myr−1. Only trends significant at the 95% level are shown)

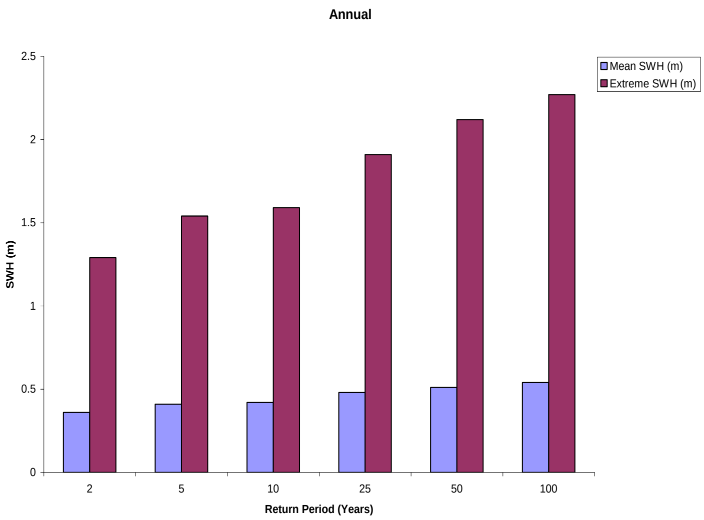

Fig 8 (a): Annual Mean SWH & Extreme SWH

Discussion

Life is sustained by the earth because it provides an environment and atmosphere that has enabled living organisms, including humans, to evolve and thrive on its surface, in its oceans, and in its air. However, the last few decades had witnessed a disequilibrium in the planet-earth which has posed an existential threat to life on the planet. Sea level rise, increase in atmospheric temperatures, unusual fires and snows, hurricanes and tornadoes have become common occurrences and indicative of increase energy in the atmosphere occasioned by climate change.

Hazards birthed by Global warming and climate change had become exacerbated by anthropogenic activities like poor waste management, increased volume of pollutants, unregulated urbanization, Industrialization etc. The situation is worse in developing countries like Nigeria due to lack of environmental education, deficit of infrastructure, weak implementation of planning laws and systemic corruption. The environmental hazard confronting Aiyetoro had been further exacerbated by ,construction of Eko Atlantic City and dams in the upstream, Dangote refinery at Lekki, Escavos and Forcados river which sandwich the community, all these are contributory to sea incursion. Aiyetoro is Situated Within the mahin mud coast that is replenished by upstream sediment supply, in a low-lying area thereby offering less resistance to inundation in times of flooding and sea surges. The mean elevation of Aiyetoro as extracted from SRTM DEM is between 0 and 5m above sea level, which is ranked low as defined in Table 1.

Coastal slope defined as the degree of steepness with reference to the surrounding land determines the minimum level of water that can penetrate and inundate an area; therefore, areas with lower or gentler slopes are more vulnerable to waves and tide action than areas with steeper slope. The delineation and classification of the coastline slope ranges from 0 to 89.3%. Figure 4 shows the classification of the slope and the fact that Aiyetoro has a slope of 0.001–71.1%, which gives it a “very high” vulnerability ranking, making it highly susceptible to inundation.

Aspect values indicate the directions the physical slopes face. We can classify aspect directions based on slope angle with a descriptive direction. An output aspect raster will typically result in several slope direction classes. If no slope exists, then the cell value will be -1. These are the grey cells in the aspect map (Fig . Where slope exists, aspect is measured clockwise starting north as 0°. It returns back as 360° north again. Finding the dominant vegetation types dependent on aspect and enhancing erosion modelling using aspect and vegetation to see how slopes will erode over time along with precipitation, temperature and growing periods. Also, land degradation by interpreting soil erosion and surface run off has been extensively modeled using aspect.

Geomorphology is the description of and processes that lead to the formation of landform patterns. The type of landform found on the coast determines its degree of vulnerability to erosion and its level of resistance to wave forces. Vulnerability ranking based on geomorphology is done such that cliffs and rocky areas have landforms with low vulnerability; lagoons and estuaries have high vulnerability, while beaches, deltas, and barrier islands have very high vulnerability. Aiyetoro geomorphologic zone is characterized by deltaic, sandy beach, and estuarine landforms. These characteristics give it a “high” to “very high” ranking and make it very susceptible to erosion and wave action.

The overall annual forecast of storm surge revealed that extreme SWH will rise to 1.29m, 1.54m, 1.59m,1.91m, 2.12m and 2.27m respectively for the 2yr, 5yr, 10yr, 25yr, 50yr and 100yr return periods. Seasonal analysis showed that for the different return periods, higher values of extreme SWH at summer suggest that storminess will be more severe during this season than during winter. The annual mean SWH stands at 0.37m, while the seasonal means stand at 0.23m and 0.47m respectively for winter and summer. The predominant wave direction is Northeast (NE) and swell occurred for 99.3% of the study period at the location. The mean SWH have peak values of 0.68m and 0.67m respectively in the months of July and August while least values of 1.8m and 1.9m are found in December and January. In a temporal linear trend analysis, declining or negative trends are observed in the annual and summer mean SWH and extreme SWH. Inclining or positive trends are only observed at winter. Furthermore, the sharp decrease in SWH and Extreme SWH between years 1998 and 1999 is as a result of a strong El Ni˜no phenomenon between these years causing the weakening of the West African Monsoon. The significant increase in SWH and extreme SWH from year 1992 to 1993 is also as a result of a strong La Ni˜na phenomenon accompanying the strengthening of West African Monsoon.

Conclusion

Results indicate that Aiyetoro is highly vulnerable to rising sea levels, with areas characterized by low slopes, low topography, high mean wave heights, and close proximity to the coast. Moreover, the CVSLRI analysis shows that Aiyetoro is highly vulnerable to rising sea levels and flooding due to its ranking. These findings will assist decision-makers to take appropriate adaptive measures to reduce Aiyetoro vulnerability and increase resilience to climate change impact.

Acknowledgement.

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