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Vulnerability of Coastal Communities to Sea Level Rise in Brass Local Government Area, Nigeria

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ABSTRACT

Coastal communities are continuously under threat of survival due to sea level rise, which has increased their vulnerability to inundation resulting to loss of livelihood, property and land area. Hence, this study investigated the vulnerability of the communities in the Brass coast to the impacts of sea level rise. Three communities (Twon-Brass, Okpoama and Diema) located within 0 – 1.2km from the shoreline, and where economic activities are prominent were purposively selected for the study. To assess the level of vulnerability of these communities to sea level rise, the coastal vulnerability index method comprising of six variables (topography, geomorphology, relative sea level rise rate, annual shoreline erosion rate, proximity to coast and population growth rate) were adopted. Landsat imageries at 10years interval for the period 1999 to 2019 were acquired to analyze the Brass shoreline dynamics. The results revealed that for a period of 20 years (1999-2019), the Brass coast has experienced a net land loss of 364.0km^2 and a projected land loss of 910km^2 by 2050, based on the current scenario. The study further revealed that Twon-Brass and Okpoama communities have high risk of inundation due to sea level rise with a calculated coastal vulnerability index values of 23.1 and 25.3, respectively; while Diema community had moderate risk of being inundated with a coastal vulnerability index value of 21.9. The study recommends the development of an integrated mitigation and adaptation strategy that would increase the resilience of the coastal communities to withstand the threat of sea level rise.

Keywords: Coastal communities, Brass, sea level rise, shoreline change, vulnerability index

1.0. Introduction

Coastlines are complex systems, where different deposition and erosion features such as caves, cliffs, beaches and mudflats exist. Coastal areas are rich in natural resources, which have made them to become important habitats for significant percentage of the world's population (Bird, 2008). Although no generally accepted threshold have been adopted to define the coastal zone, however, irrespective of the adopted definition, the population size is significant in relation to the world population. For example, estimates given by Center for International Earth Science Information Network (2012, 2013) as cited in (Bukvic *et al.*, 2020) show that the population of the coastal zone ranges from 323 million at 0–5m elevation above mean sea level (MSL), to 1.1 billion at 0–20m MSL, to 2.5 billion within 100km of the coast.

In spite of the high population already living in this delicate zone, future population projections have it that the rate of growth in coastal areas will outpace inland areas (Merkens *et al.*, 2016), which will attract further development and subject the cities and communities in the coastal zones to serious socioeconomic and environmental pressures. Stuart *et al.* (2020) noted that coastal communities are currently being faced with climate related emergencies, such as erratic weather events, increasing temperatures and sea level rise (SLR), which have further exacerbated the environmental challenges confronting coastal cities. This situation could cause serious stress on the population, resulting to human suffering, slow socioeconomic activities, loss of property, health challenges and loss of lives.

Despite the current situation in most coastal communities in the Niger Delta, future predictions of SLR are quite disturbing. For example, IPCC (2019) projected a rise of 0.18–0.5m of sea level by 2100, if the current situation remains unchanged. This scenario could cause severe effects for coastal areas, such as flooding, which would further aggravate the already challenging situation in most coastal communities in the world, especially along the Brass coast, where the impacts of SLR is already being felt. For example, the remains of an Anglican church built in 1850 by the British Missionaries are now underwater and about 200m away from the coastland in Twon-Brass, one of the studied communities. In addition, the frequent floods and erosion experienced in the Brass coast have washed away houses and ancestral graves, polluted cropland and groundwater aquifers through salt water intrusion. These are clear evidences that the Brass coast is vulnerable to SLR.

Vulnerability has been used in different context, leading to different interpretations (Rocha *et al*, 2020). However, for this study, coastal vulnerability shall mean the susceptibility of the coastline to the impacts of SLR. Several coastal vulnerability studies have been conducted in the past using different approaches. For example, Gornitz *et al.* (1991) designed a coastal vulnerability index (CVI), which comprised of seven selected proxy indicators of physical vulnerability to SLR. The indicators include geomorphology, tidal range, relief, wave height, lithology, erosion/accretion and relative sea-level changes. These indicators were each rated on a scale of 1-5 to determine their respective contributions to coastal vulnerability; where the values of 1 and 5 represent lowest and highest vulnerability, respectively. Based on the given scale, the indicators were integrated and analyzed. The corresponding calculated CVI was used to assess the level of vulnerability to SLR.

The CVI approach has since become one of the most effective and commonly used approaches for the study of coastal vulnerability to SLR. Several studies (Balica *et al*., 2012; Oyegun *et al.*, 2016; Weis *et al.*, 2016; Jana and Hegde, 2016; Tano *et al.*, 2018; Cogswell *et al*., 2018; Pantusa *et al*., 2018; Koroglua *et al.*, 2019; Rocha *et al*; 2020; Hereher *et al*., 2020; Hzami, *et al.*, 2021; Vandarakis *et al.*, 2021) have used this approach. Some of these studies adopted or modified the CVI physical indicators as proposed by Gornitz *et al.* (1991), while others modified the indicators by including socioeconomic variables. In all these studies, the fundamental motive was to use a tool that has the capacity to reveal the current level of risk coastal communities are exposed to, and perhaps make projections of the future state of risk based on given scenarios of SLR.

Despite the exposure of the Brass coast to SLR, there is dearth of baseline data on the level of vulnerability of the communities. Hence, this study was carried out to assess the degree of vulnerability of the communities to SLR. In addition, the study would provide baseline information that would guide policy makers on the development of effective management strategies for the Brass coast to prevent future hazard. The study adopted the CVI approach based on six indicators (topography, geomorphology, annual shoreline erosion rate, proximity to coast, relative sea level rise rate, and population growth rate) to assess the level of vulnerability of the coastal communities in Brass Local Government Area to SLR.

2.0. Methodology

2.1. The study area

Brass is a Local Government Area in Bayelsa State, Nigeria, located between latitudes 4°1951.78N and 4°2130.08N and longitude 5°5704.66E and 6°3039.55E as shown in Figure 1, with a 2016 projected population of 246,100 persons (NPC, 2016). Twon-Brass, located on the Brass Island is the headquarters of Brass Local Government Area. Other communities located along the Brass coastline are Sangana, Okumbiri, Opuakassa, Liama, Okpoama, and Diema. The major landforms in the Brass coastline are beach ridge barriers and tidal flats. The beach ridge barrier is formed by a sequence of longitudinal sandy ridges with a dominant dip. They were formed by the conflicting activity of the Niger River pushing sediments seaward and the Atlantic Ocean currents hugging on the shoreline. Geographically, the region is made up of geomorphic units of strand coast, Delta flank and Arcuate Delta (Oyegun, 1994).

Coastal Brass is primarily made up of mangrove swamps and ridge beaches, and is dominated by tidal activity that extends a kilometre inland. The study area experiences two major seasons, the dry and wet, which span from November to March, and April to October, respectively. The mean annual rainfall is about 3000mm and daily average temperature of about 30^{O}C. The heavy precipitation experienced in the area has also helped to sustain the rising sea level, which has constituted flood risk to the communities along the Brass coastline.

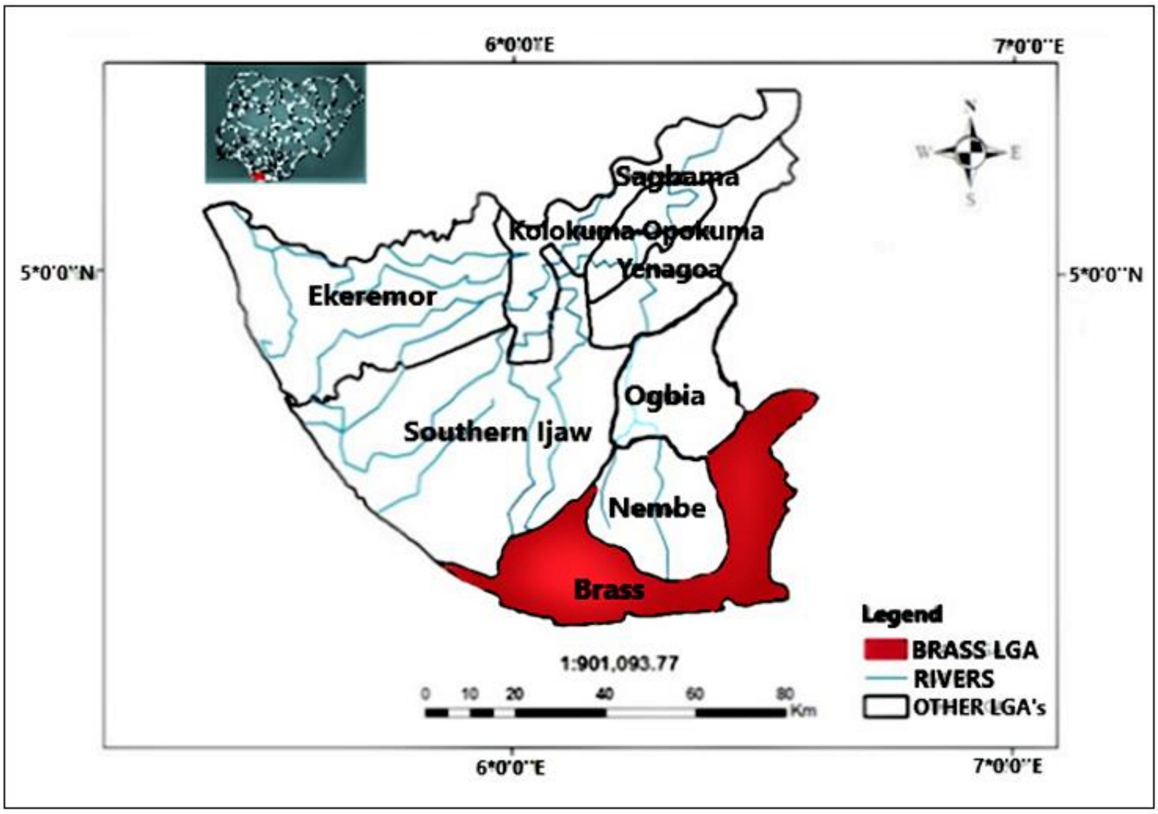

Figure 1: Bayelsa State showing Brass Local Government Area

2.2. Data collection and treatment

The study used the quasi-experimental design, which involved the assessment of the level of vulnerability of the coastal communities in Brass Local Government Area to SLR, using the CVI, based on six indicators (topography, geomorphology, relative sea level rise rate, annual shoreline erosion rate, proximity to coast and population growth rate), which were ranked on the scale of 1-5; where 1, represents (least) and 5 (highest) vulnerability to SLR. Spot heights were taken in the study area at random intervals with the aid of a global positioning system (GPS), and a digital elevation model (DEM) was designed to map and classify the vulnerable areas. Changes in the shoreline were measured using Landsat TM imageries of 1999, 2009 and 2019. These images were processed in the ArcGIS 10.0 environment, and were overlaid on each other to ascertain the amount of land lost and land gained due to erosion and accretion over a 20-year period.

2.2.1. Coastal Vulnerability Index (CVI) Variables

The CVI has been used widely to assess coastal vulnerability to SLR, based on defined variables. Its choice is based on the fact that it integrates selected variables which produce a numerical value that can be used to rank the vulnerability of coastal areas to inundation. The CVI variables used in this study are: topography, geomorphology, annual shoreline erosion rate, proximity to coast, relative sea level rise rate and population growth rate. For the calculation of the CVI of the selected communities, the ranking of the respective variables in Table 1 was adopted, where the value of 1 represents very low risk and 5, very high risk. Thereafter, the respective values of each of the variables for each community were integrated into the CVI equation:

$$CVI = \sqrt{\frac{Rx_1.Rx_2.Rx_3.Rx_4.Rx_5.Rx_6}{Count\ var.}} \quad (1)$$

where: CVI = Coastal vulnerability index, R = rated value, x_1= topography, x_2=geomorphology, x_3 = relative sea level rise rate, x_4 = annual shoreline erosion rate, x_5 = proximity to coast, x_6 = population growth rate, Count var = the sum of the variables under consideration

Table 1: Ranking of coastal vulnerability index variables for the Brass coastline

Variable	Rank of variable				
	Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)
Topography (P)	>10m	8-10m	6-7m	3-5m	0-2m
Geomorphology (P)	Rocks	Cliffs	Vegetated coast	Lagoon estuaries	Barrier island, beaches, deltas
Relative sea level rise rate (P)	0-1mm	1-2mm	2-3mm	3-4mm	>4mm
Annual shoreline erosion rate (P)	0-1m	1-5m	5-10m	10-15m	>15m
Proximity to coast (HI)	>800m	600-800m	400-600m	200-400m	100-200m
Population growth rate (SO)	0%	<1%	1-2%	2-3%	>3%

Source: Adapted from Musa *et al.*(2014)
P: physical; SO: social; HI: human influence

The six ranked coastal vulnerability index variables are defined as follows:

i. **Topography**: The height of an area above MSL determines the degree of its impact by SLR, because low-lying areas are more susceptible to inundation during storm surges and flooding (Van *et al*., 2012). Height measurements were carried out randomly in the study locations (using hand held GPS with 95 per cent accuracy); this was then compared with the SRTM (Shuttle Radar Topography Mission) digital elevation map (DEM).

ii. **Geomorphology:** The landform composition of a coast influences its level of susceptibility to erosion and the degree of resilience to wave actions (Pendleton *et al*., 2010). The Niger Delta geomorphology comprises of deltaic, sandy beach and estuarine landforms (Oyegun, 1993), which are easily erodible as they offer less resistance to wave actions.

iii. **Relative sea level rise rate:** The annual relative sea level rise rate at a local level, is the measurement of the sea height above a given datum, which is averaged over a year and measured with the aid of tide gauges (Yin *et al*., 2012). Rosmorduc (2017) reported that satellite altimetry measurements for (2010–2016) in the Niger Delta coast show eustatic SLR rise rates of 3.03– 3.39 mm yr−1.

iv. **Annual Shoreline erosion rate:** Coastal area erosion rate determines its response to SLR. Hence, coastal areas with high level of erosion will be more vulnerable to SLR than areas experiencing accretion (Kumar and Kunte, 2012). The Niger Delta values for annual erosion as published by the Nigerian Institute of Oceanography and Marine Research (2016) are 20–25mm yr−1 (Escravos), 16–20mm yr−1 (Forcados), 15–20mm yr−1 (Brass), and 10– 14mm yr−1 (Bonny).

v. **Proximity to coast:** The distance of a settlement to the coast influences its susceptibility to the impact of SLR such as wave actions, storm surges, erosion and floods. This study adopted a distance of 0-1.2km from the shore using the 2012 Nigeria SatX satellite imagery (Musa *et al.,* 2014).

vi. **Population growth rate:** High population growth of coastal areas exerts serious pressure on the environment in diverse ways. Hence, highly populated coastal areas face higher environmental challenges (UNFPA, 2009) and more prone to the impact of SLR. The Niger Delta inter-census for (1991– 2006) show a population growth rate of 2.9–3.1 % (NPC, 2006).

2.2.2. Materials used

Three communities (Twon-Brass, Okpoama and Diema) located within 0 – 1.2km from the shore, where economic activities are prominent were purposively selected for the study. The population figure available for these communities was that of the 1991 population census, which was projected to 2019, using the geometric method of population projection at 3% annual growth rate, the formula is:

$$P_p = P_1(1+r)^n \quad (2)$$

Where: P_p= Projected population; P_1 = population as per the recent census; r = annual rate of increase or decrease of population; and n = number of years. The total projected population for the three sampled communities was 98,911 persons, which comprises of 57,786 (Twon-Brass), 38,199 (Okpoama) and 2,926 (Diema).

Data in the form of maps and figures were used in the study. Coordinates and spot heights were acquired from the study area using a GPS device that has an accuracy level of 95 per cent, which was considered adequate for the study. This was stored in the computer and finally processed in the ArcGIS 10.0 environment. This data was used to develop a DEM of the study area. Landsat imageries of the shoreline for the periods of 1999, 2009 and 2019 were acquired and processed with the ERDAS IMAGINE 2018 software. Data on relative sea level rise rate, population growth rate, geomorphology and annual shoreline erosion rate of the study area were gotten from Rosmorduc (2017), National Population Commission (2006), Oyegun (1993) and Nigerian Institute of Oceanography and Marine Research (2016), respectively. Maps of the study area were obtained from Federal surveys, Rivers State and Google earth. These were also processed in the ArcGIS 10.0 environment.

2.2.3. Data analysis

Gornitz (1991) developed three (3) risk classes (high, moderate and low) based on 33 percentile ranges. CVI results with values >22 were classified as high risk, moderate risk values range from 11-22 and low risk values are < 11. The shoreline change analysis of the Brass coast was carried out using Landsat satellite imageries of 1999, 2009 and 2019. From the imageries, the land gain and loss in square kilometres were calculated from 1999-2009, 2009-2019 and 1999-2019 over the digitized shoreline, which show the direction of change. Positive value of change indicates land gain, i.e. land encroaching seaward; while negative value indicates land retreat and water advancing, resulting in a submarine environment.

3.0. Results and Discussion

3.1. Topography of the study area

A GPS was used to obtain spot heights in the three selected communities for the study and a DEM was created using the elevation figures obtained. The DEM reveals the topography of the three communities being studied (see Figure 2). Using the ranking of coastal vulnerability index variables as presented in Table 1, the elevation of each of the studied communities where classified based on the following scale: >10m (very low vulnerability); 8-10m (low vulnerability); 6-7m (moderate vulnerability); 3-5m (high vulnerability) and 0-2m (very high vulnerability).

Using the elevation classification, Twon-Brass, with a height of 0-3m was considered very highly vulnerable to SLR, as shown with light and dark green colours in Figure 2. The dark green section has an average height of 0-1m, while the light green section has an average height of 2-3m above sea level. Due to the low elevation of Twon-Brass, it is easily susceptible to flooding during high tides, which inundates a large portion of land in the area making the people to use sandbags as water barriers and construction of wooden bridges to adapt to the rising waters. The brown patch section where Okpoama is located has an average elevation of 4-5m, which is classified as being highly vulnerable to SLR. This area is also affected by flood especially during the yearly spring tide. Heavy rainfall also contributes to the flooding of this area as it increases the inflow from the sea. The purple patch section where Diema community is located has an average elevation of 6-7m above sea level and was classified as moderately vulnerable to SLR. This is a clear indication that the elevation of the studied communities has exacerbated their vulnerability to SLR.

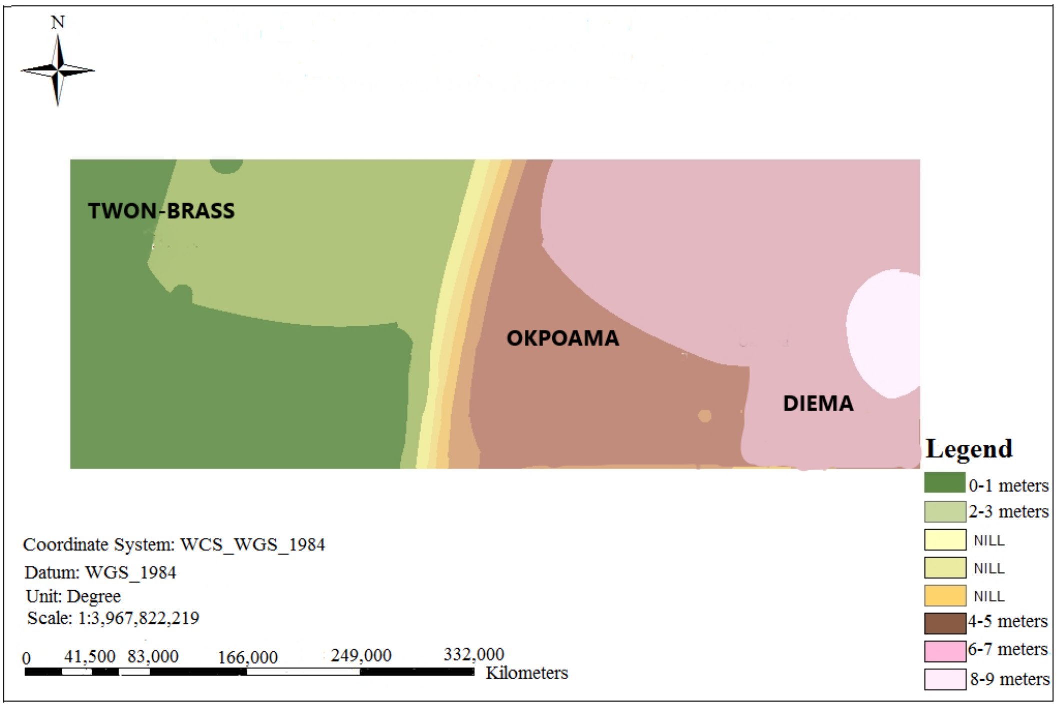

Figure 2: Digital Elevation Model of the study area

3.2. Geomorphology of the study area

Pendleton *et al.*(2010) noted that a major determinant of coastal resilience to wave actions and level of susceptibility to erosion is the nature of its landforms. The geomorphology of the study area and the entire Niger Delta is characterized by deltaic, sandy beach and estuarine landforms (Oyegun, 1993), which is known to have weak resilience to erosion and wave action. Based on the classification of geomorphology as stated in Table 1, the three studied communities (Twon-Brass, Okpoama and Diema) have very high vulnerability to SLR, as the landform underlying the area is weak in resisting ocean surges and erosion of the coast. This situation has led to loss of the little available land for agricultural practices, valuable properties and disruption of socioeconomic activities in the studied communities.

3.3. Relative sea level rise rate of study area

The relative sea level rise rate of the Niger Delta, where the study area is located ranges from 3.03-3.39mm/yr (Rosmorduc, 2017). Based on these values the studied locations (Twon-Brass, Okpoama and Diema) were considered highly vulnerable to SLR. Although the three studied communities' relative sea level rise rates were equally rated, however, Twon-Brass with the lowest elevation (0-3m) is expected to experience more inundations as rising sea waters overflow the banks. A further increase in sea level would cause severe consequences in the studied communities as coping with the current SLR is already taking its toll on the communities.

3.4. Annual shoreline erosion rate of study area

The annual shoreline erosion rate for the Brass coast is 15-20m, which is considered high to very high vulnerability to SLR. The probable reason for this high rate of shoreline erosion is the weak underlying deltaic, sandy beach and estuarine landforms that characterize the area (Oyegun, 1993). These landforms have low resistance to wave actions and ocean surges, which wash away valuable portion of the land. Residents living in the studied communities, especially those living very close to the coast are often threatened by the advancing sea as part of their land is swept away by erosion.

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3.5. Proximity to coast of study area

The proximity of a community to the coast is a major determinant of its vulnerability to SLR. The closer a community is to the coast; the higher its level of vulnerability, as it can easily be reached by storm surges, wave actions and floods. The three communities selected for the study are within 0-

1.2km of the coastline. However, Twon-Brass is within 0.6-0.8km (600-800m) from the coast, with a classification rating of low vulnerability to SLR. On the other hand, Okpoama and Diema communities are within the range of 0.4-0.6km (400-600m) to the coast and are classified as being moderately vulnerable to SLR (see Table 1). The implication is that, ocean surges and flood waters would take longer time to reach Twon-Brass when compared to Okpoama and Diema communities, all things being equal. Similarly, flood waters may also recede faster in locations farther away from the coast. With the increasing population of the study area and poor availability of land, more people may be tempted to locate closer to the coast, which would exacerbated the already high exposure of the communities to SLR.

3.6. Population growth rate of study area

The impact of SLR may be more severe in areas that are highly populated, as population growth exerts more pressure on environmental resources (UNFPA, 2009) and infrastructure. In spite of the threat of SLR in the studied communities, they have witness steady growth in population. The inter-census (1991-2006) population growth rate was 2.9-3.1% (NPC, 2006). The population rating in Table 1 shows that the population growth rate of the studied communities is considered highly vulnerable to SLR. In the event of flooding, more people and infrastructure will be affected as the population increases.

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3.7. Shoreline change analysis

To validate the fact that SLR is being experienced in the coastal communities of Brass Local Government Area, a shoreline change analysis was carried out. The shoreline of Brass Local Government Area was analyzed using Landsat imageries of 1999, 2009 and 2019 as shown in Figures 3, 4 and 5, respectively.

Figure 3: Satellite imagery showing Brass shoreline in 1999

Figure 4: Satellite imagery showing Brass shoreline in 2009

Figure 5: Satellite imagery showing Brass shoreline in 2019

Table 2 shows the result of the shoreline change analysis carried out by overlaying the image of 1999 on 2009 and 2009 on 2019. From the analysis, encroachment of land seaward represents land gain; while land loss represents water advancing. The direction of change is determined by the difference between land gain and loss, which was calculated over the digitized shoreline in km^2 in each of the periods under consideration. From 1999 to 2009, only 96 km^2 of land was gained as opposed to 263km^2 land loss, which translates to shoreline difference of -167km^2. Similarly, from 2009 to 2019, shoreline loss was 197km^2, while cumulatively from 1999 to 2019, the shoreline loss has increased double fold to 364.0km^2. At this rate of land loss, if nothing is done to slow down this rate, by 2050 an estimated 910km^2 of the Brass land area might be lost. This estimate may be exceeded if the sea level increases beyond the current levels. Similarly, Antunes *et al.* (2019) in their study estimated that 903km^2 of the coast were potentially susceptible to flooding due to SLR. Ogoro (2014) in a study of Bonny shoreline in Nigeria also recorded land loss of 1,819.4km^2 for a period of 15 years (1986-2001). These studies show that the coastal communities in some parts of the world are vulnerable to flooding due to SLR.

Table 2: Analysis of shoreline change from 1999 – 2019

Year	Land gain (km^2)	Land loss (km^2)	Shoreline difference (km^2) ±
1999-2009	96.0	-236.0	-167.0
2009-2019	118.0	-315.0	-197.0
1999-2019	214.0	-578.0	-364.0

3.8. Calculated CVI of sampled communities

The CVI of each of the sampled communities in Brass was determined using equation 1, as shown in the method of study and the data range and ranking of CVI variables selected for the study as shown in Table 1. The calculated CVI values revealed that Twon-Brass has a value of 23.1, Diema, 21.9 and Okpoama 25.3, with a mean value of 23.43 as shown in Table 3. Based on the calculated CVI values of the three communities, their respective level of vulnerability was determined using Gornitz (1991) risk classification of low (with CVI value of less than 11), moderate (with CVI value of 11-22) and high (with CVI value of greater than 22). This shows that Twon-Brass with a CVI value of 23.1 and Okpoama with CVI value of 25.3 are highly vulnerable to SLR; while Diema with a CVI value of 21.9 is moderately vulnerable to SLR. The combination of the six indicators of vulnerability makes the Brass coast vulnerable to SLR. This exposes the communities to storm surges and frequent flooding, which have increased their susceptibility to various types of waterborne diseases such as diarrhea and cholera. Also, trauma associated with frequent flooding could cause hypertension. The level of vulnerability of the studied communities in the Brass coast is a clear indication that further increase in sea level could cause serious devastation to the communities, including loss of property and human life.

Table 3: Calculated CVI of sampled communities

Community	Rank of Variable						
	TOPO	GEO	RSLR	ASER	PC	PGR	CVI
Twon-Brass	5	5	4	4	2	4	23.1
Diema	3	5	4	4	3	4	21.9
Okpoama	4	5	4	4	3	4	25.3

Note: Topo = Topography, GEO = Geomorphology, RSLR = Relative sea level rise rate, ASER = Annual shoreline erosion rate, PC = Proximity to coast, PGR = population growth rate

4.0. Conclusions

The study has revealed that the Brass coastline is vulnerable to inundation due to SLR, as the analysis of the six selected variables show high risk rankings, which culminated in high calculated CVI values in the three communities studied. Twon-Brass and Okpoama have high risk of inundation due to SLR, with CVI values of 23.1 and 25.3, respectively; while Diema has moderate risk of being inundated with CVI value of 21.9. The high level of vulnerability of these communities to SLR is manifested in a total land loss of 364km^2 for a period of 20 years (1999-2019), while the projected land loss based on current scenario would be 910km^2 by 2050. Based on projected future increase in SLR, the level of land loss in the Brass coastline would even be higher than the current projected figures if the situation is not improved to enhance the resilience of the Brass coastline to inundation due to SLR.

The findings of this study can be used as a supplement to other data sources by decision-makers when developing mitigation and adaption strategies for the Brass coastline. Also, the study could assist in the development of specific intervention measures based on the local peculiarities of the studied communities and their respective degrees of vulnerability to inundation due to SLR. In light of the current high risk of inundation that the coastal communities are exposed to, there is a compelling need to design an integrated mitigation and adaptation strategy that would increase the resilience of the coastal communities to withstand the threat of SLR. Some of the basic issues that should be incorporated in the strategy are public education on the current dangers of inundation by locating close to the shoreline, encourage tree planting and reduce the rate of population growth of coastal communities.

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