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Coastal Vulnerability Index to Sea Level Rise in Ghana

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Abstract - Coastal zones are under severe threat from sea level rise. Areas with relatively low elevations will experience either temporal or permanent flooding, while other areas will experience increased coastal erosion. Sea level rise and other factors within the coastal environment combine to drive coastal erosion. Quantifying the risk levels of these variables enable the vulnerability index of a particular location to be estimated. This study divided the coast of Accra into three regions based on the geomorphology. Vulnerability index was estimated for the three geomorphic regions by determining their relative risk levels. The 'square root of product mean' (CVI_5) method was adopted for this study. The results indicate that the coastal vulnerability index for the entire coast of Accra is 7.07, which falls within the medium category. The western geomorphic region is more vulnerable to sea level rise followed by the eastern and the central geomorphic regions. Inundation in the western region will result in displacement of the local population, destroy their sources of livelihood and flood the Densu wetlands – a RAMSAR site. Sustainable management strategies should be adopted by the government to manage the situation.

Keywords - Coastal Vulnerability Index, Ghana Coast, Coastal Erosion, Coastal Inundation, Sea Level Rise, Coastal Management

1. Introduction

Coastal areas are dynamic and integration of complex multi-function systems. A wide number of often conflicting human socio-economic activities occur in these areas. Economic activities coupled with the complex oceanic processes result in morphological changes that influence the coastal environment considerably. Human impacts in the coastal zone exacerbate the natural stress from wave and tidal forces. While the natural oceanic processes results in a cyclic event, human activities usually create a long term effect if not properly managed (Appeaning Addo, 2013). Such activities prevent the cyclic behavior of the oceanic systems resulting in increased erosion or flooding in vulnerable areas.

Several factors combine to drive morphological changes in the coastal environment. The task of ranking the relevant factors and apportion their contribution to change on a particular coast require investigation of both past and present patterns of beach change and the process systems operating along the coast (Bird, 2000). Since the past two decades concerns have been expressed about the possible impact of sea level rise on the coastal environment and its influence on the landward migration trend in the shoreline position. These concerns have become necessary because coastal ecosystems are also particularly sensitive to the increase in coastal erosion and flooding.

Climate change has led to a rise in the earth's average surface temperature by about 0.7^0 C over the past 100 years (Gornitz, 2000). The resultant thermal expansion of the ocean and the increased melting of the glaciers have facilitated sea level rise in the oceanic system. According to IPCC (2007), the sea level is rising at a historic rate of about 2 mm/yr and this is expected to increase to about 6 mm/yr in the next century. Although the rate of sea level rise differs from one location to another as a result of possible isostatic adjustment of the mantle, their impact on the coastal zone is significant. It threatens vulnerable coastal areas with flooding, frequent storms and increased erosion as the shoreline moves more inland enabling waves to break and dissipate energy closer to the shore. The accelerated landward migration of the shoreline results in loss of life and properties, collapsing of coastal businesses, loss of revenue to both local and national governments, and a general environmental catastrophe. The prevailing situation of increasing vulnerability on the already highly vulnerable coastal areas calls for concerted effort in addressing the threats. Critical assessment of coastal vulnerability to sea level rise is therefore a key issue for several coastal nations.

The vulnerability of coastal systems to sea-level rise and to other drivers of change is determined by their sensitivity, exposure and adaptive capacity (Nicholls and Klein, 2005). It is specific to a given location, sector or group (Hinkel and Klein, 2007). Its assessment takes into account several factors that respond to forces that drive changes in the coastal area and requires different tools at different spatial and temporal scales (ETC-ACC, 2010). CVI provides numerical basis for ranking sections of coastline in terms of oceanic forcing, geophysical parameters and physical developments. These factors when identified, combined and quantified determine the resilience of the coastal environment. Coastal vulnerability index (CVI) may be used to identify areas that are at risk to erosion or inundation. Regions with high index values will tend to have low reliefs, erodible substrates, histories of subsidence and shoreline retreat, and high wave and tide energies (Gornitz et al., 1991). Critical assessment at the local scale enables understanding into the complexities of the coastal system, which allows identification of more specific vulnerable areas that could support policy decisions for management interventions.

The aim of this study is to utilize a relatively simple and objective method to identify portions of the Accra's coast in Ghana that are at risk to sea level rise and the nature of the risk. This study assesses and estimates the vulnerability index of the Accra's coast by identifying all the various factors that can be influenced by sea level rise to drive changes in the coastal environment. It involves two phases. The first phase involves creating a database of geologic and environmental variables (Gornitz and White, 1992). The variables included in this database are geology, geomorphology, elevation, relative sea-level rise rates, shoreline recession rates, tide range and mean wave height. The second phase of the study is in two parts. The first part entails assessing the potential impacts on the shoreline based on these variables, while the second part involves quantifying the relative vulnerability of the different sections of Accra coastal environment to sea level rise.

2. Study Area

Accra lies along the Gulf of Guinea and it is the political and economic capital of Ghana. It is part of the Greater Accra region of Ghana and the shoreline is about 40 km long. The region is the smallest in Ghana but densely populated with about 3,909,764 inhabitants based on the 2010 population census figures (GSS, 2011). It is estimated that about 60% of major industries, urban settlement, tourism, heritage and conservation are located in the coastal zone (Amlalo, 2006). Accra is located at latitude 5.626^0 N and longitude 0.1014^0 W (Figure 1). The study area is generally a low lying area with successions of ridges, slopes and occasional rocky headlands. The coastal region is underlain by a gentle, mature topography that slopes towards the shore. Along the shoreline, sandy platforms are associated with lagoonal inlets and river deltas. The coastal zone is defined as the edge of the continental shelf on the seaward side and the thirty meter contour on the landward side (Armah and Amlalo, 1998). However, for this study the landward side is restricted to the berm of the beach.

The coastal area experiences significant differences in the amount and seasonal distribution of precipitation. It has two rainy seasons with the major season between April and July, and the minor one between September and November. Sediment transport to the littoral zone is high during the rainy season as the rivers discharge their sediment from the upland catchment areas into the sea. Inversely, sediment transport reduces during the dry season when temperatures are over 30^0 C resulting in the drying up of most of the rivers.

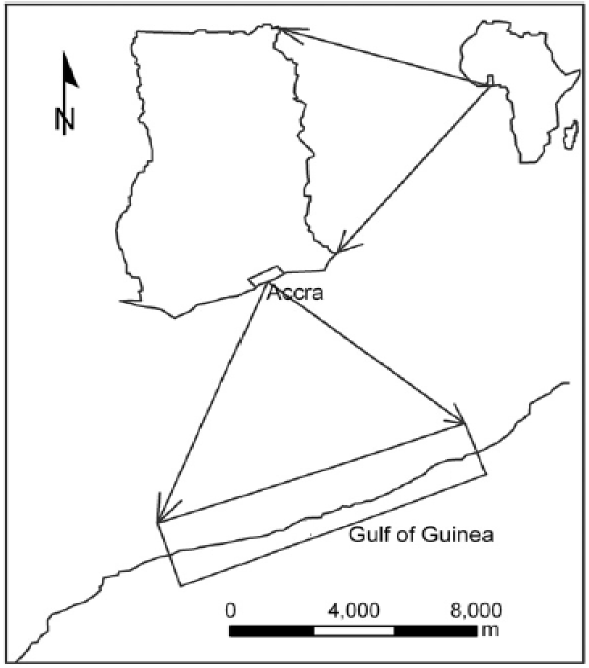

Figure 1. Location of the study area along the Ghana coast (Appeaning Addo, 2009)

Waves approach the open coast from the south-southwest direction. Currents that transport sediment include the longshore current, the Guinea current that can measure up to 0.5 m/s during raining season but is weak most of the year and the tidal current (Wellens-Mensah et al., 2002). Various sizes of lagoons exist along the coast with some associated with rivers and rivulets. Some of the lagoons remain closed until opened by high river flows due to heavy rains. The drainage pattern in Accra coastal zone is dendritic and the gradient of the streams towards the ocean are very gentle. The catchment areas of the drainage systems are small, and therefore most rivers are ephemeral. Only a few large rivers are perennial. The vegetation found along the coast of Accra includes grasses, herbs, shrubs and different kinds of mangroves usually located around the lagoons.

Coastal erosion hotspots have been identified along the Accra coast (Appeaning Addo, 2009), where about 80% of the shoreline is eroding and the remaining 20% is either stable or accreting (Appeaning Addo et al., 2008). Causes of erosion in Accra are as a result of natural and anthropogenic forcing factors, which interact at varying intensity and energy to initiate or exacerbate erosion.Previous study by Appeaning Addo et al. (2008) divided the study area into three (3) regions based on the geomorphology (Figure 2). These include the western (14.8km) which extends from Bortianor to Jamestown; Central (12.4 km) covering the distance between Jamestown and Teshie; and the Eastern (12.6 km) which starts from Teshie to the Sakumo lagoon. This study adopted the division by Appeaning Addo et al. (2008) for the study area.

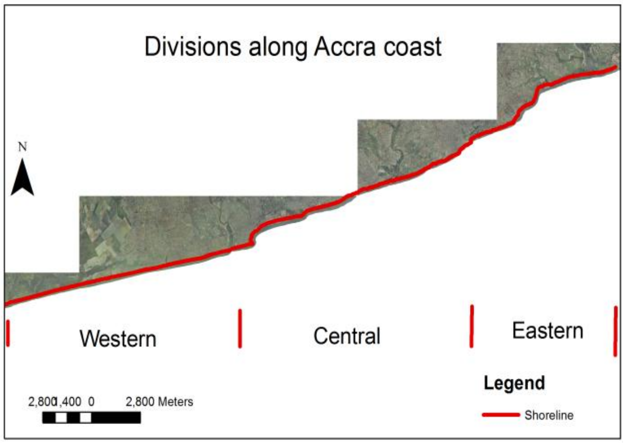

Figure 2. Three regions with similar features (based on Appeaning Addo et al., 2008)

3. Methodology

In order to develop a database for a local-scale assessment of coastal vulnerability for the Accra coast, relevant data were gathered from various sources. These include government agencies, journal articles and newspaper scripts. The maximum significant wave height was obtained from AESC (1980) that gives indication of the wave energy in transporting sediment; mean tidal range which is linked to episodic inundation hazards and local subsidence rate were derived from Takoradi tide gauge station data obtained from the Survey and Mapping Division of the Lands Commission of Ghana; mean shoreline displacement and relative elevations were obtained from Appeaning Addo et al. (2008). The geomorphology variable, which expresses the relative erodibility of different landform types, were derived from available 2005 orthophoto maps obtained from the Survey and Mapping Division of the Lands Commission of Ghana. Information on the geology which shows the different types of rocks along the Accra coast was obtained from Muff and Efa (2005).

The manipulation process was simplified by classifying the geologic and environmental data variables into new "risk" variables based on ETC-ACC (2011). Risk for this study refers to hazard or susceptibility. The method involves identification of key variables representing significant driving processes influencing coastal vulnerability and coastal evolution as well as quantifying the variables. Quantification of the variables is based on the definition of semi-quantitative scores according to a 1-5 scale (Hammer-Klose and Thieler, 2001), where 1 indicates a low contribution to coastal vulnerability of a specific key variable and 5 indicates a high contribution. Afterwards, key variables are integrated in a single index. Although McLaughlin and Cooper (2010) framework for determining coastal vulnerability index involves coastal characteristics, coastal forcing and socioeconomic factors, this study considered only the physical characteristics of the coast and the coastal forcing since they are the critical factors that significantly drive changes in the coastal zone of Ghana (Ly, 1980; Appeaning Addo et al., 2008). The thresholds for the physical and coastal forcing variables were based on Appeaning Addo et al., (2008). Elevations threshold for this study is 0.5m and rate of erosion threshold is 1.5 m/yr. The risk assignments for mean elevation, mean shoreline displacement, local subsidence trend, mean tidal range, and maximum significant wave height developed for this study are given in Table 1. The risk assignments for geology and geomorphology adopted for this study (see Gornitz et al., 1991) are also given in Tables 2 and 3 respectively. The factor levels developed for this study are the dominant issues that influence changes in the coastal zone and are similar to what pertains in other parts of the world (e.g. Dwarakish et al., 2009).

Table 1. Assignment of relative risk factors for elevation, shoreline displacement, local subsidence trend, tidal range, and wave height

Variable	**Very low 1**	**Low 2**	**Moderate 3**	**High 4**	**Very high 5**
Mean elevation (m)	>30m	20-30m	10-20m	0.5-10m	≤0.5m
Mean shoreline displacement (m/year)	>0.5	0 to 0.5	0 to-1.5	-1.5 to 2.5	≤ -2.5
Local subsidence trend (mm/year)	<-1 (Land rising)	-1 to1	1-2	2-4	> 4.0 (Land sinking)
Mean tidal range (m)	<1.0 (Microtidal)	1-2	2-4	4-6	> 6.0 (Macrotidal)
Maximum significant wave height (m)	≥ 0	0-1	1-2	2-3.5	≥ 3.5

Table 2. Risk factors for geology

Variable	**Very low 1**	**Low 2**	**Moderate 3**	**High 4**	**Very high 5**
Sandstone		■			
Unconsolidated soil				■	
Lagoonal/fluvia sediment					■
Metamorphic		■			
Sand					■
Clay				■	
Gravel				■	

Table 3. Risk factors for geomorphology

Variable	Very low 1	Low 2	Moderate 3	High 4	Very high 5
Beaches poorly developed		■			
Marine with wave erosion			■		
Non-marine (land erosion)			■		
Barrier coast					■
Delta environment					■
Embayed non-rocky coast				■	

Based on the information in Tables 1, 2 and 3, the risk factors for the variables identified along the Accra coast in the three geomorphic regions are present in Table 4.

Table 4. Risk factors for identified variables in the three geomorphic regions

Variable	Western region	Central region	Eastern region
Mean elevation (m)	5	4	5
Mean shoreline displacement (m/yr)	3	3	4
Local subsidence trend (mm/yr)	2	2	2
Mean tidal range (m)	1	1	1
Maximum significant wave height (m)	1	1	1
Geomorphology	5	3	3
Geology	4	2	3

The relative risk variables contained within the database created in GIS environment were used to formulate a coastal vulnerability index (CVI). Gornitz and White (1992) and Gornitz *et al*. (1997) proposed and tested (in terms of sensitivity analysis) different formulas (considering 7 key variables) for the derivation of the final CVI. The studies (Gornitz and White, 1992 and Gornitz *et al*., 1997) identified that the methods were adequate for the task when the number of risk factors that are missing data, for a given location, are less than three. Various methods have also been discussed extensively in ETC-ACC (2011) for determining CVI. They include product mean (CVI_1), modified product mean (CVI_2), average sum of squares (CVI_3), modified product mean (2) (CVI_4), square root of product mean (CVI_5) and sum of products (CVI_6). The CVI formulation based on the square root of product mean (CVI_5) was used for determining the CVI for the Accra coast.

Square root of product mean: $vCVI_5 = CV_1^{\frac{1}{2}}$ (1)

Where CVI_1 (Product mean): $= \frac{x_1 * x_2 * x_3 * x_4 * \ldots\ldots x_n}{N}$ (2)

(n =variables present, x_1=mean elevation, x_2=local subsidence trend, x_3=geology, x_4=geomorphology, x_5=mean shoreline displacement, x_6=maximum wave height and x_7=mean tidal range).

This approach was adopted for this study because it has been widely used in other applications at various levels, including local level (Gornitz *et al*., 1991; Gornitz, 1990; Gornitz, 1991; Thieler and Hammar-Klose, 1999; and Thieler *et al*., 2002).The number of risk factors identified in Accra's coast satisfies the use of this approach. CVI values were estimated for four locations in the western, six locations in the central and eight locations in the eastern regions of the Accra coast. These locations were selected based on erosion rates reported by Appeaning Addo *et al.* (2008) and critical assessment of the orthophoto map. The values obtained enabled the mean CVI values for each of the three regions to be determined as well as the mean CVI value for the entire Accra coast. The data values of the CVI_5 calculated for the three regions were used to construct a histogram. Based on the histogram, three risk classes were developed for the study area (i.e., low, moderate, and high risk based on 33 percentile ranges). Low risk class values are those values less than 5, moderate risk values range from 5 to 11, and high risk values are greater than 11. The mean CVI values were also estimated for the three geomorphic regions and the entire coastal zone of Accra. The results were mapped through a GIS system that enabled the most vulnerable areas to be identified.

4. Results

The three regions of the Accra coast have similar geological and physical features. The geology of the Accra coastal environment is made up of various types of rocks. They include unconsolidated sediments, sandstones, quartz and lagoonal sediment (Figure 3).

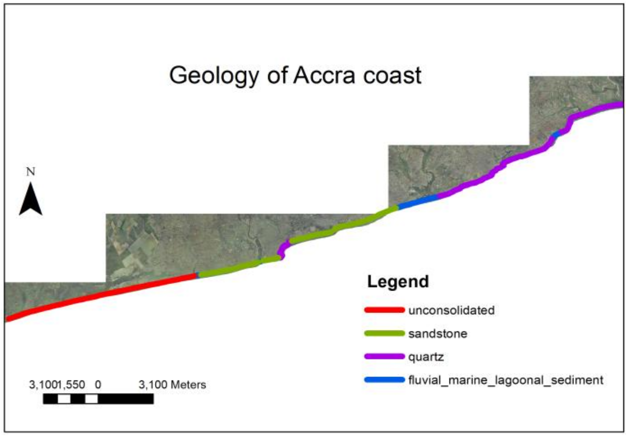

Figure 3. Geology distribution along Accra coast (based on Muff and Efa, 2005)

The western part is predominantly unconsolidated soil while the eastern part is more of quartz and little portions of lagoonal sediment. The central part is mainly sandstone and a little portion of quartz.

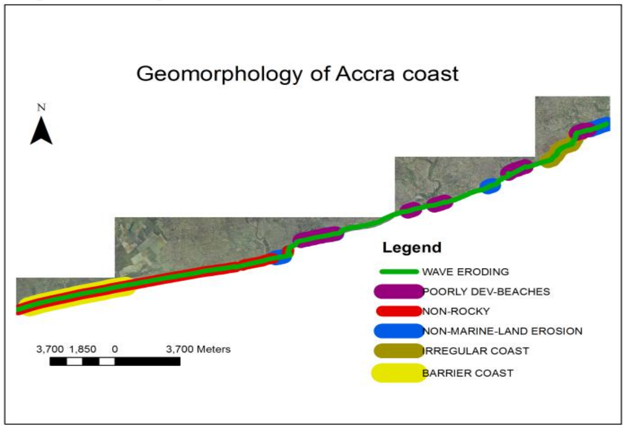

Figure 4. Geomorphic features along Accra coast

The landforms identified from the 2005 orthophoto maps included those formed by erosion and those formed by deposition. Several geomorphic features occur in all the three regions (Figure 4).

The CVI computed for the three regions in the study area indicate their vulnerability to sea level rise. The vulnerability index values range between 4.5 and 12.0 and they vary along the coast. A graph of the CVI_5 variations along the coast is presented in Figure 5.

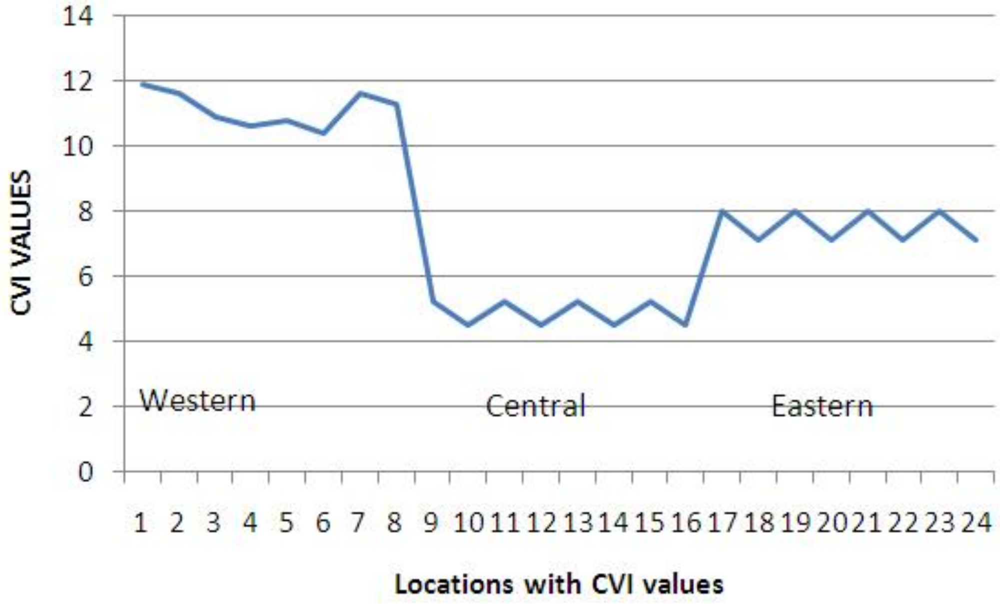

Figure 5. CVI_5variations along the coast

The highest and lowest CVI_5 values computed for the western region are 11.9 and 10.4 respectively; the central region has highest CVI_5 value of 5.2 and lowest CVI_5 value of 4.5; while the eastern region highest and lowest CVI_5 values are 8.0 and 7.1 respectively. The average CVI_5 values for the three geomorphic regions are western region 11.14, central region 4.85 and eastern region 7.55; while the mean value for the entire Accra coast is 7.07. Using the classification developed for this study, the computed average CVI values for the regions suggest that the western region is a high risk area to sea level rise; the eastern region is a medium risk area to sea level rise while the central region is a low risk area to sea level rise. The entire coastal zone of Accra can be classified as a medium risk area to increasing relative sea level rise (Figure 6).

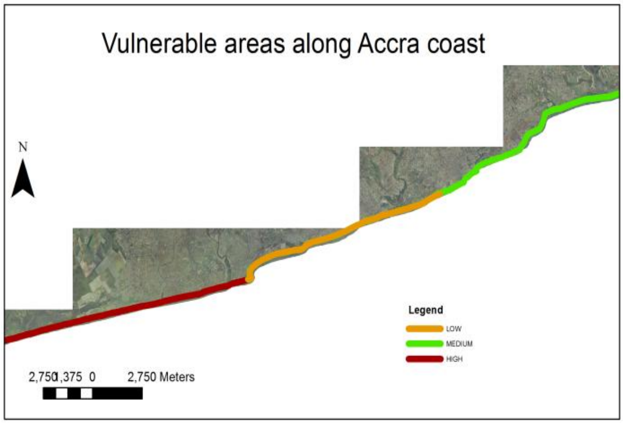

Figure 6. Vulnerable areas along the Accra coast

5. Discussion

Sea level rise will affect the three coastal regions of Accra differently. This is as a result of the level of resistivity of the geomorphological and geological features within the regions to oceanic forcing. Although wave and tide activities will drive change in the coastal region of Accra as the sea level continue to rise, their risk factors are very low (refer to Table 4). However, they are significant in driving sediment along and across shore (AESC, 1980). The shoreline orientation enables waves to break at an angle and generate longshore current which transports sediment alongshore from the west to the east. The intensity of wave activities will increase as the sea level rises, especially in the eastern region, where the bathymetry is relatively deep within the nearshore area (Appeaning Addo, 2009).

Mean elevation changes from a risk factor of high and medium in the western and eastern regions respectively to low in the central region (refer to Table 4). The significantly low topography along part of the western region is expected to facilitate flooding of the Densu wetlands as the sea level rises. This is evident by the frequent experience of storm surge in some areas in recent times (Amoani *et al.*, 2012 and also confirms the conclusions by Appeaning Addo *et al.* (2008). The phenomenon will affect the small scale fishing industry by eroding natural fish landing sites and inundate saltpans for the large scale salt industry thereby increasing unemployment problems. It will also collapse buildings of the local inhabitants. Thus the situation will have dire social and economic implications on the local communities. Destruction of buildings will render a greater percentage of the population in the western region homeless.

The western region again has high and very high risk factors for geology and geomorphology respectively. The eastern and central regions have moderate and low risk factor for geology. However, they both have moderate risk factor for geomorphology (refer to Table 4). These risk factors in part explain the historic shoreline erosion pattern along the Accra coast as reported by Appeaning Addo *et al.* (2008). The varying strength of the prevailing coastal rocks explains why some areas are eroding more than others. The weak rock strength in the western region will offer little resistance to the impact of the rising sea level and facilitate increased erosion. Although the central and eastern regions have relatively stronger rock strength, the moderate risk factors for the prevailing geomorphology indicates that some portions are vulnerable to sea level rise. These sections may experience inundation as the sea level continues to rise. Already, the shorelines in the western and eastern regions are eroding at rates over 1.0 m/yr (Appeaning Addo *et al.*, 2008). This confirms the relatively high risk factors in these two regions as compared to the central region which has a moderate risk factor. The observed historic erosion trend is expected to continue under increasing sea level rise. However, the relatively strong rock strength in the eastern region may slow the rates down.

The mean CVI values computed for the three regions support the erosion trend observed by Appeaning Addo *et al.* (2008) who identified the western region as the highest eroding shoreline, followed by the eastern and the central regions. Again the average CVI value estimated for the entire Accra coastal zone also confirms the trend observed by previous studies (Appeaning Addo *et al.*, 2008; Anokwa *et al.*, 2005). Numerical modelling of future shoreline morphological change to sea level rise in Accra also revealed a similar trend (Appeaning Addo *et al.*, 2008). These results of erosion rates offer varied options for managing the coastal zone. However, the CVI values computed will offer reliable information for developing management strategies as they combine more factors that drive change in the coastal zone.

6. Conclusion

The study has demonstrated that the coast of Accra is vulnerable to increasing sea level rise and the risk level for the entire coastal area is medium. The study has revealed that the combined effect of several factors has resulted in the vulnerable state of the study area to sea level rise. Geology, geomorphology and relatively low elevation are the major factors that facilitate the high risk level in the western region. Although the risk factor associated with wave and tide actions are minimal in the study area, the presence of relatively deep bathymetry, especially in the eastern region (Appeaning Addo *et al.*, 2008), will facilitate significant impact from wave actions. This will result in weakening the geology and lead to increased erosion as the sea level continue to rise. The low risk area to sea level rise along the Accra coast is the central region.

Constructing revetment and groynes are the options currently being used in Ghana to manage coastal erosion and inundation. However, hard engineering structures, particularly revetments, as adequate to hold the beach have been thoroughly disproved by Cooper and Pilkey (2012). These artificial interventions, which are adopted to counteract natural processes usually, transfer the problem from one location to another. It is therefore important that management options should rather be implemented in tandem with the natural processes. Relocation of inhabitants in the more vulnerable areas could be adopted as a management option. Although this could have social implications on the inhabitants, it will enable the erosion processes to remain localized and the inhabitants to move to a safer environment. Beach nourishment approach could also be adopted to manage the vulnerable coastal areas as well as exploring the sediment cell concept management strategy. Additionally, a setback line could be introduced along the coast of Accra. This will prevent development of infrastructure closer to the beach. It will also prevent a ‘land squeeze’ effect, which will enable cyclic activities of the shoreline to occur within the given space and prevent conflict between coastal development and coastal processes (Appeaning Addo, 2013). It is further recommended that socioeconomic factors as a determinant of coastal vulnerability index should be examined to identify their risk level.

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