Assessing Coastal Vulnerability Index to Climate Change: the Case of Accra – Ghana

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Assessing Coastal Vulnerability Index to Climate Change: the Case of Accra – Ghana

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ABSTRACT

Coastal zones are under severe threat from climate change and its associated sea-level rise. Areas with relatively low elevations will experience either temporal or permanent flooding, while other areas will experience increased coastal erosion. Several factors within the coastal environment combine to drive coastal erosion. Identifying these variables and quantifying their risk levels enable the vulnerability index of a particular location to be estimated. This study divided the coast of Accra into three sections based on the geomorphology. The vulnerability index was estimated for the three sections by determining their relative risk factors. The ‘square root of product mean’ (CVI) method was adopted for this study. The results indicate that the coastal vulnerability index for the entire coast of Accra is 7.7, which falls within the moderate risk category. The western section is more vulnerable to sea-level rise followed by the eastern and the central sections. Inundation in the western section will result in displacement of the local population, destroy their source of livelihood and flood the Densu wetlands – a RAMSAR site.

INTRODUCTION

The dynamic and complex multi-functional coastal environment is constantly changing due to natural and anthropogenic driving factors. These changes affect a number of often conflicting human socio-economic activities that occur in these areas. The human induced influences generally tend to exacerbate the natural stress from wave and tide climates on coastal resources. Climate change, as a result of the shifts in the mean state of the climate or in its variability, has led to a rise in the earth's average surface temperature (Gornitz, 2000). The resultant thermal expansion of the ocean and the increased melting of the glaciers have facilitated sea-level rise at a rate of about 1-2 mm/yr (IPCC, 2007). Accelerated sea-level rise represents a significant coastal management challenge to coastal nations, especially in developing nations where there is scarcity of geospatial data. Sea-level rise has resulted in increased erosion, inundation of vulnerable areas and more frequent storms in Accra (Amoani et al., 2012). These developments threaten coastal life and properties. There is therefore the need to critically assess coastal vulnerability to climate change.

Vulnerability assessment of the coastal zone takes into account several factors that drive changes in the coastal zone. These factors when identified, combined and quantified determine the resilience of the coastal environment to these forces. Information on the effectiveness of the factors driving erosion enables the vulnerable state of a coastal area to be quantified. Vulnerability assessments are specific to a given location, sector or group and it depends on the local ecological and socio-economic characteristics (Hinkel and Klein, 2007). 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). A more detailed vulnerability assessment at the local scale enables understanding into the complexities of the coastal system at a localized scale in a specific area.

Shoreline erosion in Accra has been reported by previous studies (Anokwa et al., 2005; Campbell, 2006; Appeaning Addo et al., 2011). It is estimated that about 80% of the shoreline is threatened by erosion, while the remaining 20% is either stable or accreting (Appeaning Addo et al., 2008). Coastal erosion has affected the social and economic life of the local population, threatened cultural heritage and hindered coastal tourism development (Sagoe-Addy and Appeaning Addo, 2012). According to Boateng (2012), substantial amount of houses has been lost to coastal erosion in the past and the trend continues in some areas along the coast. In the western part of the Accra coast, 17 coastal inhabitants in two coastal communities have lost their buildings to coastal erosion over 26 years (Campbell, 2006). A study by Appeaning Addo et al. (2011) estimates that about 85 houses will be lost to erosion in three communities in the western part of Accra by 2025 under increasing sea-level rise, which will displace over 2000 coastal inhabitants.

Causes of erosion in Accra are as a result of natural and anthropogenic forcing factors (Appeaning Addo et al., 2011). These driving forces of varying intensity and energy interact within the Accra coastal area to initiate or exacerbate erosion. Anokwa et al. (2005) identified the varying geological constituents along the coast as a major driver of erosion. Beach sand/gravel mining and general lack of enforcement of laws banning beach sand mining have been identified by Appeaning...
Addo et al. (2008) as a major cause of increased erosion in Accra. Appeaning Addo (2012) identified the unplanned physical infrastructure development, population increase and increasing tourism development in the coastal zone as a cause of increased erosion. Coastal vegetation is cleared and wetlands are drained for infrastructural development (Alvarado, 2003).

The Coastal Vulnerability Index (CVI) is one of the most commonly used and simple methods to assess coastal vulnerability to sea-level rise, in particular due to erosion and/or inundation (Gornitz et al., 1991). CVI provides numerical basis for ranking sections of coastline in terms of their potential for change as a result of several factors such as sea-level rise, geology, wave climate and geomorphology. It enables coastal managers to identify regions where risk may be relatively high and develop appropriate management strategies.

This paper assesses and estimates the vulnerability index of the Accra coast by identifying the various factors that can be influenced by climate change to drive changes in the coastal environment. The study involves two phases. The first phase involves creating a database of geologic and environmental variables. The variables included in this database are geology, geomorphology, elevation, relative sea-level rise rates, shoreline recession rates, tide range and mean wave height (after Gornitz and White, 1992). The second phase of the study was conducted in two parts. The first part entails assessing the potential impacts on the shoreline due to these variables, while the second part quantified the relative vulnerability of the different Accra coastal environment to sea-level rise.

**STUDY AREA**

Accra lies along the Gulf of Guinea (Figure 1) 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 and housing census figures (GSS, 2011). Accra is located at latitude 5.626° N and longitude 0.1014° W, which influences the climatic conditions that prevail along the coast.

The study area is generally a low lying area (elevation ranges between 2 and 12 m) with successions of ridges, slopes and occasional rocky headlands. The coastal zone is underlain by a gentle, mature topography that slopes towards the shore (Muff and Efa, 2005). Along the shoreline, sandy platforms are associated with lagoonal inlets and river deltas. Figure 2 shows the underlain rocky beach and the devastating effect of coastal erosion along part of the western section in the study area.

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 (AESC, 1980). Inversely, sediment transport reduces during the dry season when temperatures are over 30°C resulting in the drying up of most of the rivers.

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 weak 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 vegetation found along the coast of Accra includes grasses, herbs, shrubs and different kinds of mangroves usually located around the lagoons. Clearing of coastal vegetation to put up shelter to accommodate the increasing population and the emerging coastal tourism business has resulted in a ‘land squeeze’ situation (Appeaning Addo, 2012).

This study adopted the division by Appeaning Addo et al. (2008) where the study area was divided into three (3) sections based on the geomorphology. These include the western (19.1 km) which extends from Boratian to Jamestown; Central (14.4 km) covering the distance between Jamestown and Teshie; and the Eastern (14.6 km) which starts from Teshie to the Sakumo lagoon (refer to results and Figure 3 for detailed description of the divisions).

**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. The sources include government agencies such as the Geological Survey Department and the Survey and Mapping Division of the Ghana Lands Commission as well as journal articles. The compilation of this data set is essential to mapping potential coastal changes due to climate change. According to Gornitz et al. (1991), a vulnerable coastline is characterized by low coastal relief, subsidence, extensive
shoreline retreat, and high wave/tide energies. The manipulation process was simplified by classifying the geologic and environmental data variables into new “risk” variables. Each risk variable ranges in value from 1 to 5 and indicates the region’s relative risk to erosion or inundation. The risk variables were based on ETC-ACC (2011). The risk assignments for mean elevation, mean shoreline displacement, local subsidence trend, mean tidal range, and maximum significant wave height adopted for this study are given in Table 1 (after Gornitz et al., 1991). The risk assignments for geology and geomorphology are also given in Tables 2 and 3 respectively where using the Likert scale with 1 being very low to 5 being very high.

Based on the information in Tables 1, 2 and 3, the risk factors for the variables identified along the Accra coast in the three sections are presented in Table 4. The maximum significant wave height was obtained from AESC (1980) that gives indication of the wave energy in transporting sediment; mean tidal range was obtained from Wellens-Mensah et al. (2002); local subsidence rate was derived from Takoradi tide gauge station data obtained from the Survey and Mapping Division of the Lands Commission of Ghana; mean shoreline displacement was obtained from Appeaning Addo et al. (2008); and relative elevations was obtained from Appeaning Addo (2009). The geomorphology variable, which expresses the relative erodibility of different landform types, were derived from 2005 orthophoto maps obtained from the Survey and Mapping Division of the Lands Commission of Ghana and information on the geology that shows the different types of rocks along the Accra coast was obtained from Muff and Efa (2005).

Table 1: Relative risk factors for elevation, shoreline displacement, local subsidence trend, tidal range, and wave height (after Gornitz et al., 1991).

<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean elevation (m)</td>
<td>&gt;30</td>
<td>20 and ≤ 30</td>
<td>&gt;10 and ≤ 20</td>
<td>5 and ≤ 10</td>
<td>≥ 0 ≤ 5</td>
</tr>
<tr>
<td>Mean shoreline displacement (m/yr)</td>
<td>&gt; 2.0 accretion</td>
<td>&gt;1 and ≤ 2</td>
<td>&gt;1 and ≤ +1</td>
<td>&gt;2 and ≤ -1</td>
<td>≥ -2 and erosion</td>
</tr>
<tr>
<td>Local subsidence trend (mm/yr)</td>
<td>&lt; -1 land rising</td>
<td>≥ -1 and ≤ 1</td>
<td>&gt; 1 and ≤ 2</td>
<td>&gt; 2 and ≤ 4</td>
<td>&gt; 4.0 land sinking</td>
</tr>
<tr>
<td>Mean tidal range (m)</td>
<td>&lt; 1.0 microtidal</td>
<td>≥ 1 and ≤ 2</td>
<td>≥ 2 and ≤ 4</td>
<td>&gt; 4 and 6</td>
<td>&gt; 6.0 macrotidal</td>
</tr>
<tr>
<td>Maximum significant wave height (m)</td>
<td>≥ 0 and &lt; 3</td>
<td>≥ 3 and ≤ 5</td>
<td>5 and ≤ 6</td>
<td>&gt; 6 and ≤ 6.9</td>
<td>≥ 6.9</td>
</tr>
</tbody>
</table>

Table 2: Risk factors for geology (after Gornitz et al., 1991).

<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unconsolidated soil</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Lagoon/fluvial sediment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Metamorphic</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Risk factors for geomorphology (after Gornitz et al., 1991).

<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beach poorly developed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine with wave erosion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-marine (land erosion)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-glacial irregular coast</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Barrier coast</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Delta coast</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Embayed non-rocky coast</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Western section</th>
<th>Central section</th>
<th>Eastern section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean elevation (m)</td>
<td>5</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Mean shoreline displacement (m/yr)</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Local subsidence trend (mm/yr)</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Mean tidal range (m)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Maximum significant wave height (m)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Geology</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

The relative risk variables contained within the database created in GIS environment were used to formulate a coastal vulnerability index (CVI). CVI may be used to identify areas that are at risk to erosion or inundation. 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. These formulas were adopted for this study.

Product mean:

\[
CV = \frac{1}{n} \sum_{i=1}^{n} x_i = \left( \frac{1}{n} \sum_{i=1}^{n} x_i \right)^{1/2}
\]

Where: \( n \) = variables present

\( x_1 = \) mean elevation

\( x_2 = \) local subsidence trend

\( x_3 = \) geology

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X_4 = geomorphology \quad x_5 = \text{mean shoreline displacement}

X_6 = \text{maximum wave height} \quad x_7 = \text{mean tidal range}

The methods have been discussed extensively in ETC-ACC (2011). The CVI_3 formulation was used to determine the CVI for the Accra coast because it has been widely used in other applications at the local, regional and supra-regional level (Thieler et al., 2002; Thieler and Hammar-Klose, 1999; Gornitz et al., 1991, Gornitz, 1990; Gornitz, 1991a).

The results were mapped through a GIS system that enabled the most vulnerable areas to be identified. The data values of the CVI_3 calculated for the three sections were used to construct a histogram for this study. Based on the histogram, three risk classes were developed (i.e., low-, moderate-, and high-risk based on 33 percentile ranges) based on ETC CAA (2011). Low risk class values are those values less than 6, moderate risk values range from 6 to 9, and high risk values are greater than 9.

**RESULTS**

The three sections of the Accra coast (Figure 3) have similar geological and physical features. Most of these features that have been formed as a result of erosion are now also enhancing the effectiveness of erosion.

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 4). 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.

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 sections (Figure 5). The varied types of rocks in the study area and the prevailing geomorphic features informed the selection of these maps over the others.

![Figure 3: Three sections with similar features (based on Appeaning Addo et al., 2008).](image)

The western and eastern sections are eroding more relative to the central section (Figure 7). The rate of erosion for Accra is estimated as 1.13 m/yr ± 0.17 m/yr (Appeaning Addo et al., 2008). The western part is eroding at a rate of 1.30 ± 0.17 m/yr, the central part is eroding at a rate of 0.40 ± 0.17 m/yr and the eastern part is eroding at a rate of 1.50 ± 0.17 m/yr. This trend is expected to continue and possibly increase under influence of increasing sea-level rise.

![Figure 4: Geology distribution along Accra coast (based on Muff and Efa, 2005).](image)
The vulnerability index values computed for the Accra coast range between 4.5 and 12.0 and they vary along the coast. The average CVI values for the three sections are: western section 9.0, central section 4.8 and eastern section 7.3. The mean value for the Accra coast is 7.7 which fall within the moderate risk category. Based on the CVI values computed, the high risk area to sea-level rise is the western section; the eastern section is classified as a moderate risk area to sea-level rise while the central section is low risk area to increasing sea-level rise (Figure 8).

DISCUSSION
Climate change and accelerated sea-level rise will affect the western, central and eastern coastal sections of Accra differently. The western section has a CVI value of 9.0, which makes it the highest risk area to climate change compared to the eastern (7.3) and central (4.8) sections. Although the entire Accra coast is considered moderate in terms of risk to climate change according to this study, the relatively high mean CVI value of 7.7 is considerably high. The value is not consistent with other parts of the world due to differences in the risk factor of variables used to estimate CVI. The level of resistivity of the geomorphological and geological features within the three sections to oceanic forcing account for the CVI values obtained.

The sea level, which is rising at a rate of over 2 mm/yr (Sagoe-Addy and Appeaning Addo, 2012) will facilitate waves to break closer nearshore and tides to flood low lying areas during very high tides. Although the risk factors for wave (significant wave height 1.4 m) and tide (tidal range 1 m) activities are very low (refer to Table 4), they are significant in driving sediment along and across shore (AESC, 1980). The longshore current moves along the coast from west to east transporting sediment that shapes the shoreline configuration. The resulting shoreline orientation influences the breaking pattern of waves and how they impact the shoreline. This in part explains the different CVI values obtained for the three sections.

The western section of Accra coast is highly vulnerable to climate change. Several factors account for the CVI value obtained for the western part. The area has a barrier coast, poorly developed beaches (refer to Table 3) and low mean elevation (refer to Table 1) relative to the other sections. The very low lying areas get flooded during very high tides and whenever there is a storm surge. Recent incidence of flooding in some coastal communities in the western section (e.g. Gleefe) can be attributed to sea-level rise as a result of climate change (Amoani et al., 2012). This section of the coast is also dominated by soft rock and unconsolidated sediment that are easily erodible. The shoreline in this section is eroding at a rate of about 1.30 m/yr, which is relatively high. The observed historic erosion trend is expected to continue under increasing sea-level rise as has been observed by Appeaning Addo (2009). These factors account for the high CVI value estimated for the western section of the Accra coast.

The central and eastern sections are dominated by soft and hard rocks that influence shoreline morphological change. The central section is eroding at a rate of about 0.4 m/yr which is relatively low and the eastern part is eroding at a significantly high rate of about 1.50 m/yr. The relatively deep bathymetry in the nearshore area of the eastern section (Appeaning Addo, 2009) enables waves to break closer to the shore and attack the shoreline, thereby eroding the softer part of the shoreline. Although the historic erosion rate is high in the eastern section, the presence of relatively hard rocks will slow the rates down. This in part explains the CVI value estimated for the eastern section. Non-marine erosion as a result of rain water runoff into streams and lagoons are dominant along the portions of the central and eastern coast (refer to Figure 5). The channels created enable the sea to move more inland during very high tide and contaminate the fresh water system. This has the tendency to affect fresh water fishing activities in the lagoons and streams. They can also affect crop farming in the coastal zone. Continuous widening of the channels will result to increased erosion problems which will lead to loss of coastal land and properties. The relatively low risk factor for the geomorphic features in the central and eastern sections partly account for the CVI values obtained for these two sections respectively.

The high risk state of the western section requires pragmatic measures to manage the coastal environment and resources. Although Oteng-Ababio et al. (2011) suggested relocating the inhabitants as a measure to manage the erosion problem in the western section, the residents are resolved to maintain their occupancy due to their strong cultural and social ties to the communities. The government has adopted constructing hard engineering structures, such as groynes and revetments, to manage coastal erosion in the critical areas along the coast. This approach is not sustainable as the erosion problem is simply transferred down-drift of the coast. There is therefore the need to explore the option of using soft engineering measures, such as beach nourishment which facilitate managing with nature, to manage the erosion problems in the western section. The measures if adopted
would preserve the source of livelihood of the inhabitants as well as their social life.

CONCLUSION
The study has demonstrated that the coast of Accra is vulnerable to climate change and its associated sea-level rise. The risk level for the entire coastal area can be categorized as moderate. The most vulnerable area is the western section where sea-level rise will result in increased erosion and inundation of the low lying areas, especially the Densu wetlands area. This confirms studies by Appeaning Addo et al. (2008) and Anokwa et al. (2005) that identified the western section is erosion prone. Increased erosion and flooding in the Densu wetlands will affect the habitats of migratory birds and destroy the ecology. The study has also revealed that the combined effect of several factors within the coastal domain places the risk factor to climate change at a higher level. Geology, geomorphology and relatively low elevation are the major factors that facilitate the high risk level in the western section. Generally, the risk factor associated with wave and tide actions will be minimal according to the standard risk categories adopted (refer to Table 1) but based on the Accra coastal conditions they will be significant. In the eastern section, the presence of relatively deep bathymetry (Appeaning Addo et al., 2008) will facilitate considerable 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 section. This confirms model simulations by Appeaning Addo et al. (2008).

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LITERATURE CITED