Shoreline Change Analysis Using End Point Rate and Net Shoreline Movement Statistics: an application to Elmina, Cape Coast and Moree Section of Ghana's Coast

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Abstract

Most coastlines in the world are under the threat of erosion. As such many developed nations have instituted long-term measures to control the rate of change. However, along most developing nation coastlines, little attention is given to coastal erosion management. Ghana like most developing countries has little commitment to ensure the effective monitoring and management of coastal erosion. Consequently, many of its coastal communities and important historical monuments are now under severe risk to sea erosion. This study focuses on the shoreline evolution that occurred along the Elmina, Cape Coast and Moree coast of Ghana during a thirty-eight year period using available datasets that allowed the authors to discern what happened between 1974 and 2005, and in the most recent years, between 2005 and 2012. Shoreline data from 1974, 2005 and 2012 were incorporated in Geographic Information System (GIS) using ArcGIS for analysis. The net shoreline movement and end point rate statistics were generated by ArcGIS together with Digital Shoreline Analysis System software extension. The study identified that in all the three epochs considered, there were a general erosion trend in the shoreline changes. This study has provided valuable and comprehensive baseline information on the state of the coastline in the Elmina, Cape Coast and Moree area which can serve as a guide for coastal engineers, coastal managers and policy makers in Ghana to manage the risk.

Keywords: Coastal erosion management; shoreline change monitoring; GIS; beach sand mining; Ghana

1. Introduction

Historically, humans have preferred to put up residences close to the coast because of the many services the area provides. Currently, most of the world's population are residing close to the coast, with about 44% of the world's total population living within 150 km of coastlines (Syvitski et al. 2005). Leatherman et al. (2003) describes the coastward migration of the world's population, which is occurring in tandem with rising sea level and shoreline recession as a collision course.

The coastline is a highly dynamic area with constant sediment movement, creating new morphological features and changing positions (Absalonsen and Dean 2011). Xue et al. (2009) observed that coastal erosion and retreat is one of the major threats to life and property in their studied coastal zone. While many factors contribute to shoreline recession, sea level rise is the underlying driver, accounting for the nearly ubiquitous coastal retreat (Leatherman et al. 2000). Other shoreline recession factors include tectonic instability and subsidence, climatic change and numerous human activities (Carter 1988) that contribute to negative sediment budgets (Dillenburg et al. 2004). On account of the huge investments humans have made along most sections of the world's coast, effective long-term monitoring, planning and management regimes are required to ensure the sustainability of the coastal space.

Along the coast of most developing countries, issues of coastline retreat and erosion are gradually gaining prominence; however, coastal managers have been limited by sparsely available data on coastal processes and historical erosion trends in many areas (Appeaning Addo et al. 2008). Along Ghana's 550km coastline, erosion has been observed to be a serious problem since the early 1970s (Dei 1972), and continues to threaten many historical monuments, tourism facilities, communities and many important social infrastructure (Boateng 2009; 2012). The threats posed by Ghana's retreating coastline cannot be overemphasized; as several communities especially along the eastern coast continue to experience rapid erosion of beaches, sometimes up to several meters per day. Erosion along Ghana's coast are being influenced by factors such as high wave energy, storms, soft geology of some areas, uncoordinated management interventions, poor facility siting and coastal sediment mining (Boateng 2012; Jonah and Adu-Boahen 2014; Jonah 2015; Jonah et al. 2015a).

The need for adequate coastline management regimes has now become critical in Ghana, as the country strives to attain economic and social development. Effective and efficient management of the coastal zone indirectly implies the management of the many assets that are located within the coastal zone. In response to this need, the Ghana government has in recent years spent huge sums of monies to protect vital assets and communities along areas which are threatened by high rates of coastline erosion, including the ongoing 60 million Euro 25 km 'Ada Coastal Protection Works' and the recently completed 60 million dollar 'Sakumono Sea Defence Project', both in the Greater Accra Region. According to Boateng (2006; 2012) there has been little commitment to the concepts of integration of management interventions with wider natural processes and longer-term sustainability. The 'ad hoc' management interventions regimes in Ghana have classically succeeded in stabilising the coastline at the protected section and aggravated the erosion situation down-drift ("knock-on effects"). The presence of accelerated erosion, disappearing beaches, increased frequency of flooding and degraded ecosystems along Ghana's coast, may be indicative of an inability to provide competent coastal management. Moreover, accelerated sea level rise resulting from global climate change is expected to worsen current coastline erosion trends (IPCC 2014), meaning that sensible management strategies are increasingly required to deal with the risks arising from coastal erosion (Appeaning Addo et al. 2008).

In order to achieve sustainable coastal management, coastal engineers and coastal managers require a holistic understanding of the physical processes that evolve the coast, key elements of the coast as a system and the ability to detect the historical shoreline change and predict future shoreline change over different time scales (Davidson et al. 2010). Predicting future shoreline change entails a monumental task of modelling the shoreline over the entire spectrum of temporal and spatial scale (Miller and Dean 2004).

Only portions of Ghana's coastline has been studied to determine historical shoreline change trends. Previous shoreline change studies in Ghana (Figure 1) have focused on historical shoreline change of different section of the coast (Ly 1980; Appeaning Addo et al. 2008; Boateng 2012). It can be seen from Figure 1 that no previous study has covered significant portions of Ghana's coast including this paper's case study area. Elmina, Cape Coast and Moree are important historical towns in Ghana where the first encounter with Europeans (Portuguese explorers) occurred in 1471. These towns have a lot of historical buildings and heritage like the Elmina and Cape Coast Castles that are under severe threat of erosion. It is therefore important to assess the historical shoreline changes in this study area so as to predict future shoreline positions for proper management. This paper uses Geographic Information System (GIS) tools to identify coastline changes that has occurred in the Elmina, Cape Coast and Moree area from 1974 to 2012. Major coastal erosion contributing factors in this area are also identified.

2. Study area

2.1 Location and Geology of Study Area

This study was conducted on the Elmina, Cape Coast and Moree coastline, within the Central coast of Ghana, on the Gulf of Guinea (Figure 1, 2). Their geographic locations are latitude 05º07'50.0"N and longitude 001º38'20.0"W (Elmina) and latitude 05º 13'91.2"N and longitude 001º19'07.4"W (Moree), representing the western and eastern limits of the study area respectively. The studied shoreline is approximately 25 km in length. This area is made up of medium energy waves averaging 1m in the surf zone (GHAPOHA 2015), with net direction of longshore waves in the easterly direction (Boateng 2006).

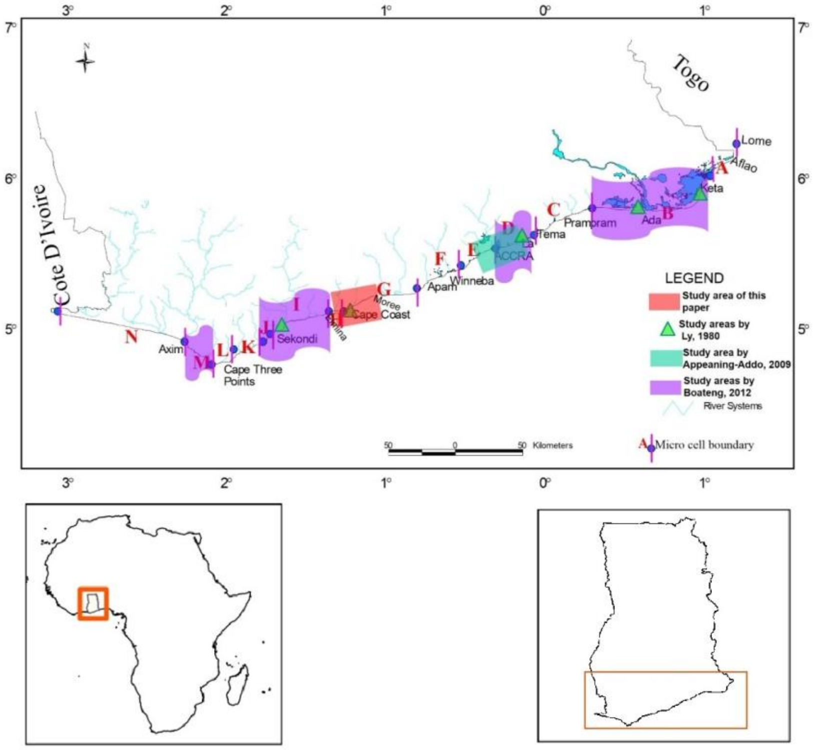

Figure 1: Coverage of shoreline change studies along Ghana's Coast

Ghana's coastline lies along an Afro-trailing edge type continental margin (Inman and Nordstrom 1971; Wiafe et al. 2013). The geology of Ghana include Precambrian formations of the Birrimian and Tarkwaian and the more recent unconsolidated Quartenary formations of the Sekondian and Accraian formations, commonly found near the coastal areas (Boateng 1970; Wiafe et al. 2013). Specifically, the Elmina zone is composed of sandstones and grits, the Cape Coast zone made up of granitiods and a few sandstones while the Moree zone comprises of phyllite and schist (Minerals Commission Ghana 2011). All the zones share similar vegetation cover (grasslands & coastal thickets) and soil type (acrisols).

Jonah et al. (2015a) identified that coastal sand and stone mining is widely practiced along the coast of Elmina, Cape Coast and Moree. Such activities are known to interfere with the coastal sediment budget. Most of the mined sand and stones are used to support the high housing demand within communities close to the coast. Population in the study area is on the rise, due to large numbers of people migrating to the area to find employments. Cape Coast has experienced a doubling of its population since 2000; an increase from 82,291 in 2000 to 169,894 in 2010 (Ghana Statistical Service 2013). With this population increase, there has also been a high demand for cheap residential facilities. In order to meet this demand, building contractors have largely depended on readily available beach sand and stones. Indigenous populations living along the coast have also solely relied on beach sand for their construction activities. As a result, beach sand mining has become a lucrative venture for most youths in the area, even though the activity is regarded as illegal.

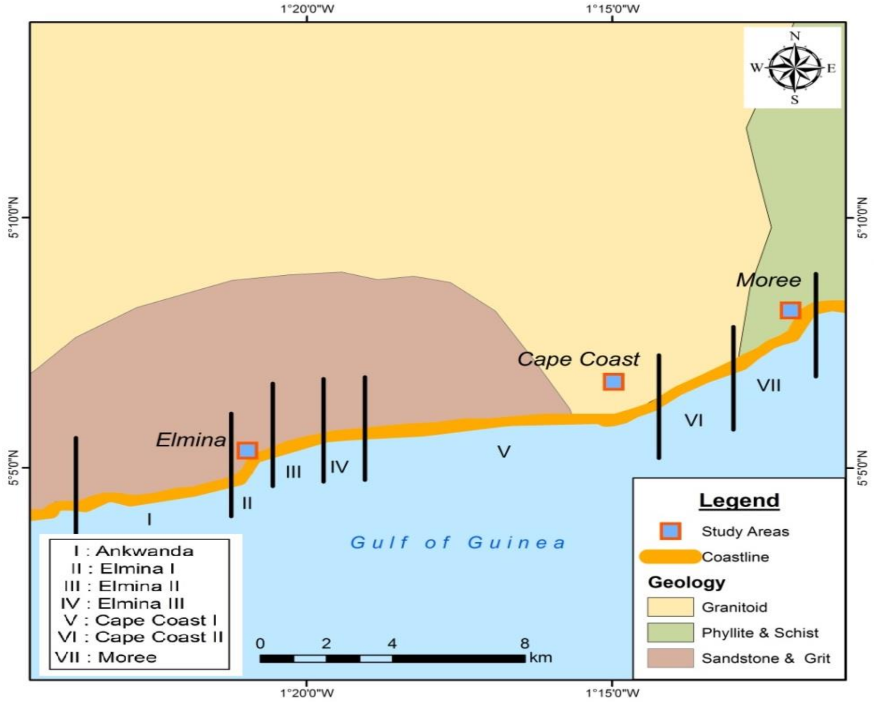

Figure 2: The Elmina, Cape Coast and Moree area showing the geology and coastline segments used during this study

2.2 Morphology and Description of Beach Segments

During this study, the study area was divided into seven study segments based on the shoreline morphology, orientation, geology and human activities (Figure 2). These are described as follows:

2.2.1 Ankwanda

This shoreline segment is located on the westernmost section of the study area, from the Ankwanda village through to the western side of the Elmina Castle (Figure 4). This shoreline segment extends the most into the Atlantic Ocean in the study area. It is approximately 4km in length and is made up of sandy beaches interspersed with hard rock outcrops in five areas. The longest of these rocky areas is about 0.56km while the shortest is about 0.08km. The longest sandy beach length is about 0.93km with the shortest being about 0.33km. The main structures along a 1.4km stretch of the western section of this shoreline segment are three well-known beach resorts. One of these has been protected with a rock revetment sea defence wall to control erosion. Jonah *et al.* (2015a) identified intense commercial beach sand mining activities at two locations within this shoreline segment, at about 200m to the east and west of this protected beach resort. Small-scale beach sand mining operations are also carried out along the remaining sections of this shoreline, which is mainly backed by residential structures. This shoreline segment is highly exposed to the incoming waves because of its orientation.

2.2.2 Elmina I

This shoreline segment extends about 2km, from the western side of the Elmina Castle through the beach stretch fronting the main Elmina township to the sandy beach on the western side of the Elmina Beach Resort (Figure 5). The Elmina Castle is protected by a hard rock coast on the western side and fronted by a 150m sandy beach on the eastern coast. Just adjacent the Elmina Castle is a fishing port built on the inlet of the Benya lagoon with two 200m long jetties constructed on each side of the inlet. One of the jetties was constructed during the initial dredging and development of the lagoon into a fishing port in 2005 while the second jetty was recently constructed, in 2015, during the construction of a fish processing plant near the lagoon inlet. A 100m rock revetment sea defense wall extends from the latter jetty, meant to provide additional protection to the fish processing plant. The remainder of the segment is made up of a dome shaped sandy beach stretch backed by residential facilities and a road. A fish market immediately follows the processing plant with the remainder of the shoreline backed by residential facilities and a road. About half a kilometer of this segment has been protected with a concrete sea wall, meant to protect the town road from the sea. The waves reaching this shoreline segment is mostly reduced due to the concave shape of the segment as well as the jetties.

2.2.3 Elmina II

This stretch of shoreline is about 2.5 km in length, stretching from the Elmina Beach Resort to the Kakum River Estuary (Figure 6). The entire shoreline segment is comprised of hard rocky coasts with only three sandy beach pockets within. This segment has the Elmina Beach Resort and a few other residential facilities backing the coastline. The 200m sandy beach that fronts the Elmina Beach Resort has been partially protected with a wire mesh revetment to reduce coastal erosion, while the other two sandy beach pockets averages about 70m in length. As a result of this segment’s rocky nature, less energetic waves makes it to the shore.

2.2.4 Elmina III

This coastline stretch extends about 1.6km from the Kakum River Estuary towards Cape Coast (Figure 7). The adjoining community is known to occasionally flood as a result of overwash during storms and flooding from the terrestrial side due to overflowing of the Kakum River. A 200m long sandbar about 150m from the estuary is fronted by rock outcrops that extends about 50m into the sea. About 1.3km of this shoreline segment has been protected with a rock revetment sea wall, obviously to protect the highway and the adjoining community. The remainder of the segment is unprotected but has rock outcrops along the low tide area. This shoreline is exposed to the incoming waves along the coast because of it straight orientation.

2.2.5 Cape Coast I

This segment is made up of a stretch of continuous open ocean sandy beach and is the longest stretch of sandy beach in the study area (extends about 7.5km) (Figure 8). This stretch of shoreline extends along the main Cape Coast-Elmina road, interspersed with two short hard rock sections (50m and 140m in length) along the last 1km stretch separating 320m and 530m of sandy beaches. Along the main beach stretch, the Cape Coast-Elmina road separates the beach berm from facilities, including a District Hospital, a number of Schools, including a teacher training college, a Senior High School and three Basic Schools, offices for the Ghana Health Services and several coastal communities. The beach berm along the shoreline ranges from about 40m to about 95m in width, covered with coconut trees, grasses and coastal thicket. The sandy beaches along this segment show signs of erosion including pronounced erosion scarps, exposure of underlying rocks in some areas and falling-over of coconut trees. Small-scale beach sand mining activities are carried out along several sections of this shoreline segment, particularly along communities (Jonah et al. 2015a). The last 1km stretch of shoreline are backed by several infrastructure including a Basic School, office and residential facilities for the Police Service, a community assembly park and three tourist facilities. Small-scale sea defense measures have been used to protect some of the facilities in this area, including gabions and a concrete seawall to protect the School and one of the tourist facilities. As a result of the orientation and composition, the Cape Coast I shoreline segment has high exposure to incoming waves, allowing beach sediments to be easily transported by alongshore currents.

2.2.6 Cape Coast II

This segment stretches from the rocky western side of the Cape Coast Castle to the base of the rocky cliff just beyond the sandy beach at Ekon community and has a length of about 3.5km (Figure 9). The shoreline is backed by the heavily-populated residential facilities of the main Cape Coast township. This shoreline segment is the most diverse in the study area. Several sections contain both sandy beaches mixed with rocky shores, a mix of hard and soft cliff sections, hard cliff-backed sandy beaches and several sandy beach stretches separated by hard cliffs. Several forms of sediment mining activities are carried out within this shoreline segment, including both commercial and small-scale beach sand mining, beach gravel mining and coastal stone quarry (Jonah et al. 2015a). It is the most intensely mined shoreline segment within the study area with one of the commercially mined beaches exhibiting a 5m high erosion scarp. The Cape Coast II shoreline also has a concave orientation, combined with its cliff and rocky coasts, it is less exposed to incoming waves as compared to Cape Coast I.

2.2.7 Moree

This segment starts from the cliffs of Ekon to the sandy beaches beyond the Moree township. It is about 4km in length and is also mostly backed by the Moree town (Figure 10). The shoreline length is made up of a diverse mix of promontories, hard rock cliffs separating short sandy beaches, and a mix of rocky shores and sandy beaches, as well as a longer stretch of sandy beaches. The towns of Ekon and Moree are located on hard rock cliffs and promontories overlooking the Atlantic Ocean. Both commercial and small-scale beach sand mining activities are practiced within this segment (Jonah et al. 2015a), with evidence of erosion such as scarps and degrading coastal vegetation evident along several sections of the shoreline. The Moree segment just like the Cape Coast II segment is less exposed to incoming waves as a result of its shoreline composition.

3. Methodology

3.1 Analysis of shoreline data

Quantification of the rates and extent of shoreline changes in the Elmina, Cape Coast and Moree area were accomplished using available shoreline data extracted from a 1974 digital topographic map, 2005 orthophotograph and 2012 satellite image (all obtained from the Department of Geography and Regional Planning, University of Cape Coast) and a ground survey. The 2005 shoreline dataset was obtained through carefully tracing the shoreline at a scale of 1:1500 while the 2012 shoreline was obtained through a field traverse along the coast with a Tremble Juno SD GPS.

The high water line (HWL) proxy was used to define shoreline positions in all datasets. The HWL is the most commonly used shoreline indicator (Boak and Turner 2005) and is the highest run-up of the last high tide, identifiable on orthophotographs and on the beach by the visually discernible wet/dry line (Smith and Zarillo 1990; Pajak and Leatherman 2002). The HWL proxy is generally deemed as a valid indicator of shoreline position (Gorman et al. 1998) and may sometimes be the only indicator available, especially in highly developed coasts where the beach is backed by a seawall, riprap revetment or other artificial structure (Del Rio and Gracia 2012).

All the shorelines were projected into the same coordinate system using the Ghana Metre Grid projection, along with the World Geodetic System 1984 (WGS, 1984) datum which enabled appending to be done and comparisons made (Figure 3). A detailed description on operating shoreline change analysis using DSAS has been provided by Thieler et al. (2009). The net shoreline movement (NSM) and end point rate (EPR) statistics were generated to describe the shoreline changes in the study area.

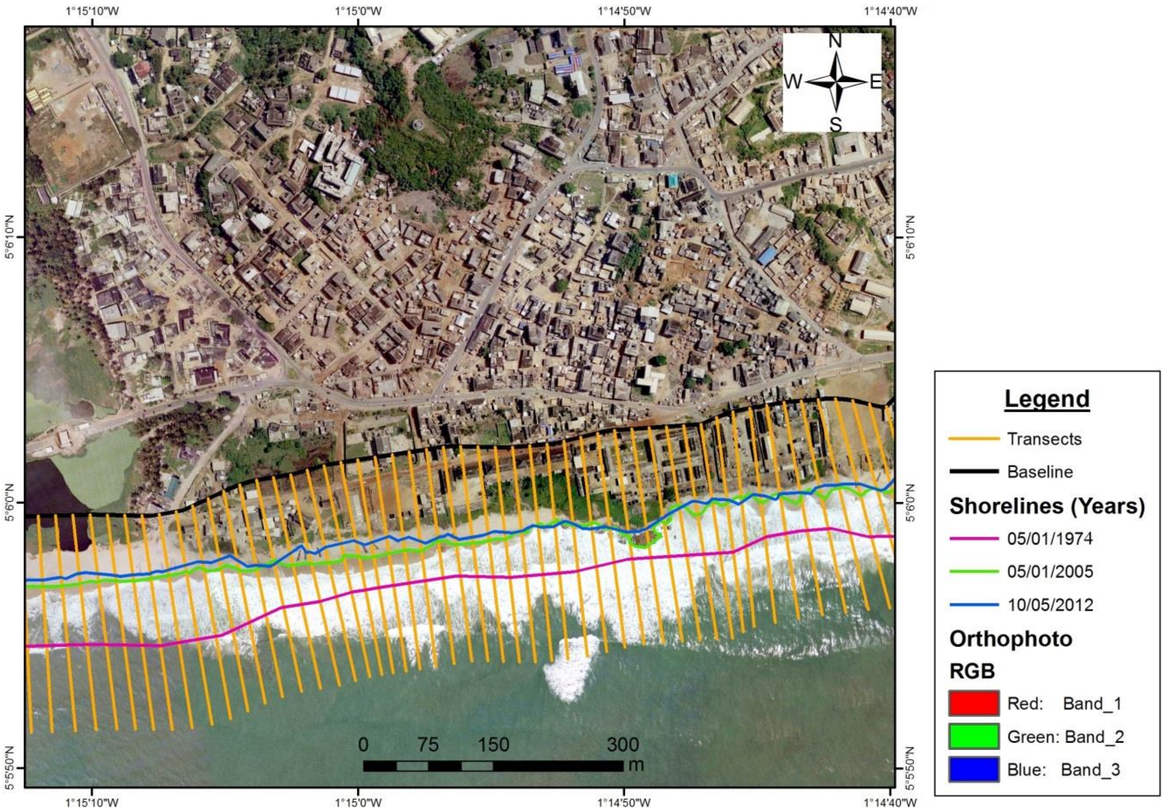

Figure 3: An output from DSAS analysis in ArcGIS showing an area in Cape Coast with historical shoreline positions and transects that enabled the calculation of shoreline change statistics

3.2 Estimating Associated Coastline Errors

According to Morton *et al.* (2004), documented trends and calculated rates of shoreline change are only as reliable as: (1) measurement errors that determine the accuracy of each shoreline position, (2) sampling errors that account for the variability of shoreline position, and (3) statistical errors associated with compiling and comparing shoreline positions. This study used error estimates based on Hapke et al. (2010). We deemed four uncertainty terms from Hapke et al. (2010) to be relevant to this study: georeferencing uncertainty (U_g), digitizing uncertainty (U_d), aerial photo uncertainty (U_a), and the uncertainty of the high water line at the time of survey (U_{pd}). These values are presented in Table 1 to show how each error contributes to uncertainty in the rates of change. In addition to these, we associated another uncertainty value, GPS device spatial accuracy (U_s), to the 2012 shoreline.

For each shoreline position, U_p, the total uncertainty is found as the square root of the sum of squares (Hapke et al. 2010) of the relevant uncertainty terms (Equation 1). Specific shoreline uncertainty errors are also presented in Table 1. These individual uncertainty values were used to calculate annualized uncertainty values at each transect. The uncertainty of a single transect's end point shoreline change, U_E rate is found as the quadrature addition of the uncertainties for each year's shoreline position, divided by the number of years between the shoreline surveys (Equation 2).

$$U_p = \sqrt{U_g^2 + U_d^2 + U_a^2 + U_{pd}^2 + U_s^2} \quad \text{.....................(Equation 1)}$$

$$U_E = \frac{\sqrt{U_1^2 + U_2^2}}{year2 - year1} \quad \text{.............................(Equation 2)}$$

Where U_1 and U_2 are the total errors associated with each shoreline position.

This approach carries the reasonable assumption that the component errors are normally distributed (Appeaning Addo et al. 2008). The calculated annualized errors for each epoch are presented in Table 2.

Table 1: Errors associated with the datasets used in this study.

Measurement errors (m)	Digital map (1974)	Aerial photo (2005)	GPS field survey (2012)
Georeferencing uncertainty (U_g),	4	-	-
Digitizing uncertainty (U_d),	1	1	-
Aerial photo uncertainty (U_a)	-	3	-
Uncertainty of the High Water Line (U_{pd})	4.5	4.5	4.5
GPS device spatial accuracy (U_s)	-	-	3
Total shoreline position uncertainty (U_p) (m)	6.10	5.5	5.41

Table 2: Calculated errors at each transect for the medium- and short-term periods

Period	Annualized error (m/yr)
1974-2012	± 0.22
1974-2005	± 0.26
2005-2012	± 0.96

In addition, ground truthing of the entire study area was conducted over one week period. The aim was to collect more data and information from the field through field observation and anecdotal information from local people. Residents were asked about the status of the shoreline in relation to previous years. The evidence observed from the field and the responses obtained from the local people agreed well with the GIS analytical findings.

4. Results

4.1 Summary of shoreline evolution: 1974 to 2012

The analysis of the shoreline changes between 1974 and 2012 indicated that the Elmina, Cape Coast and Moree coastline has been eroding at a rate of 1.22 m/yr±0.22m with an average of 49.13 m of land lost across shore face over the period. The highest and lowest values in NSM and EPR of the shoreline evolution during the 1974 to 2012 period is presented in Table 3. Overall the Cape Coast I segment experienced the highest and most consistent erosion while the Moree segment experienced the lowest erosion trends (Table 4) Overall trends indicated that sandy shoreline sections had significantly higher rates in contrast to rocky and cliff sections where erosion was minimal; with some cliff sections experiencing almost no erosion in the entire analysed period. Figures 4 – 10 illustrates the total shoreline evolution along each studied shoreline segment in the Elmina, Cape Coast and Moree area during the 1974 - 2012 period.

Table 3: The highest and lowest values in shoreline changes within the seven study shoreline segments during the 1974 to 2012 period.

	Net Shoreline Movement (m)		***End Point Rates (m/yr)***	
Shoreline Segment	High	Lows	High	Lows
Ankwanda	-79.59	-4.31	1.97	0.11
Elmina I	-61.96	-9.41	-1.37	-0.17
Elmina II	-74.26	-4.03	-1.84	-0.13
Elmina III	-70.62	-20.9	-2.03	-0.55
Cape Coast I	-94.34	-21.5	-2.48	0.57
Cape Coast II	-120.5	-2.66	-3.17	-0.07
Moree	-42.9	-7.6	-1.13	-0.2

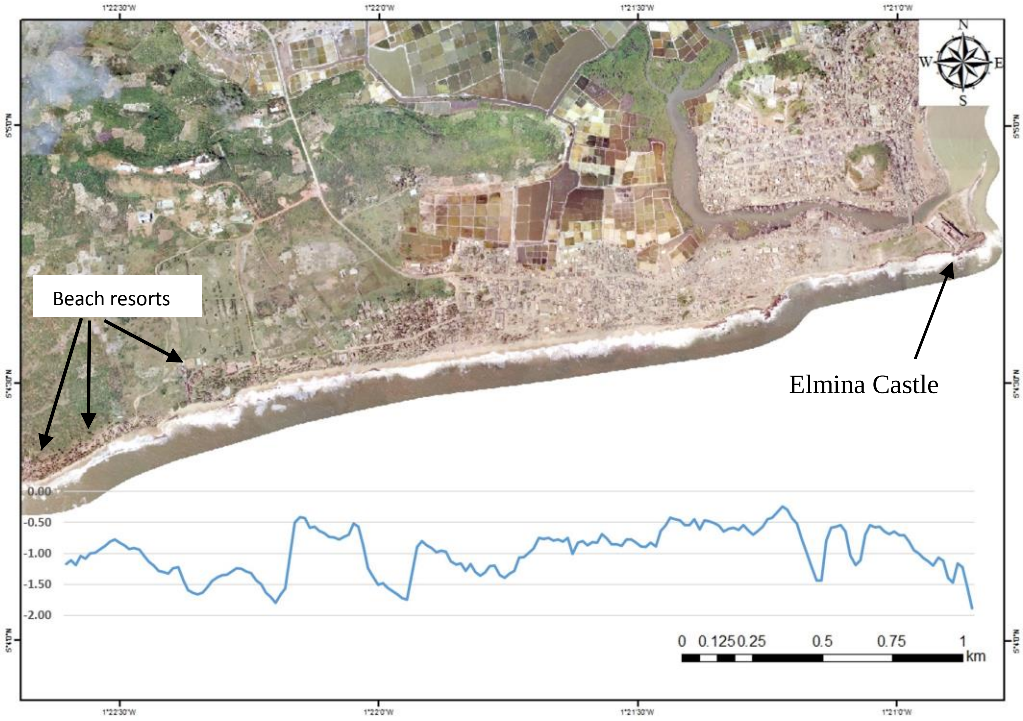

Figure 4: Erosion trends (m/yr) along the Ankwanda shoreline segment during the 1974 - 2012 period

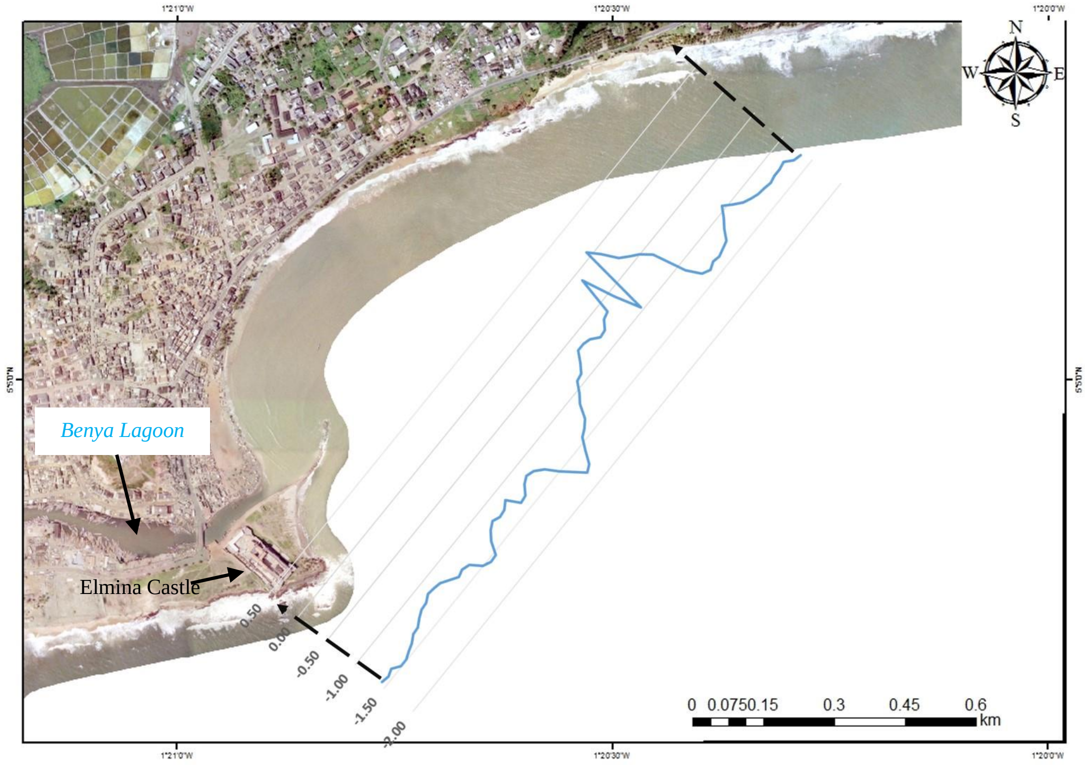

Figure 5: Erosion trends (m/yr) along the Elmina I shoreline segment during the 1974 - 2012 period

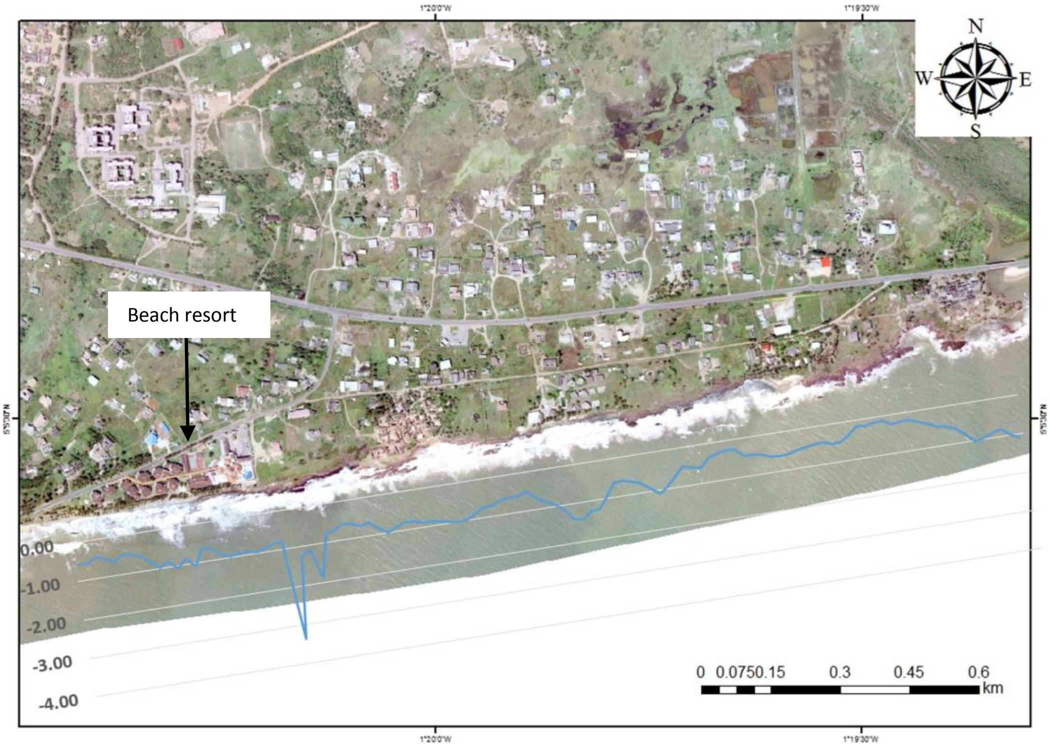

Figure 6: Erosion trends (m/yr) along the Elmina II shoreline segment during the 1974 - 2012 period

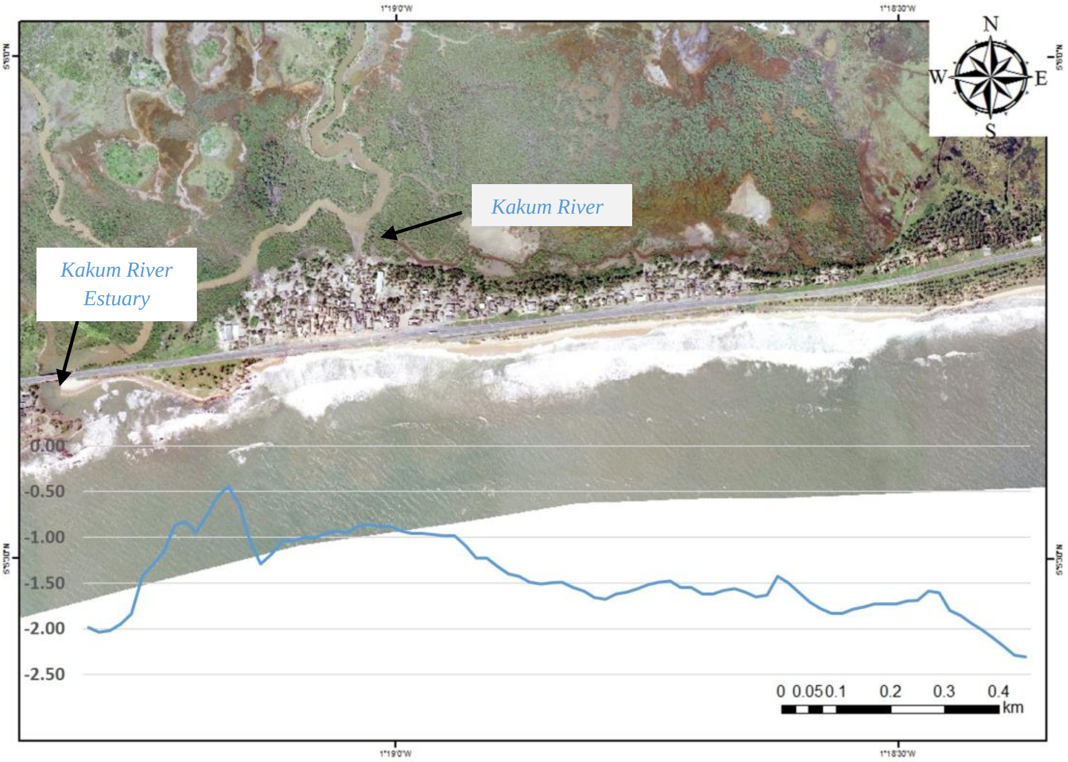

Figure 7: Erosion trends (m/yr) along the Elmina III shoreline segment during the 1974 - 2012 period

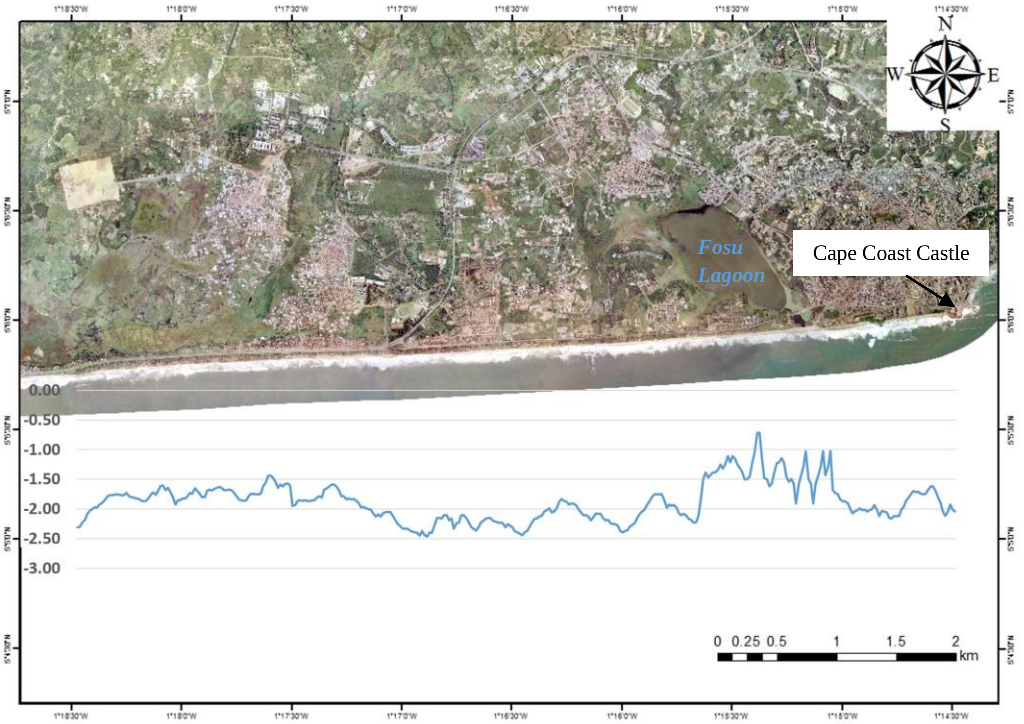

Figure 8: Erosion trends (m/yr) along the Cape Coast I shoreline segment during the 1974 - 2012 period

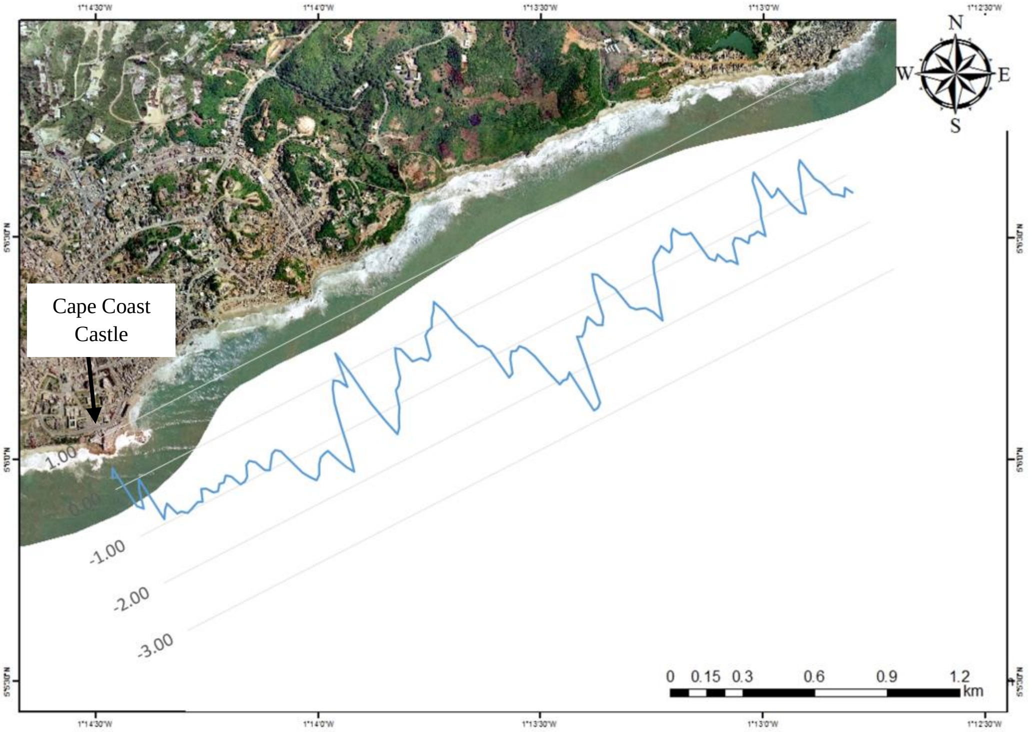

Figure 9: Erosion trends (m/yr) along the Cape Coast II shoreline segment during the 1974 - 2012 period

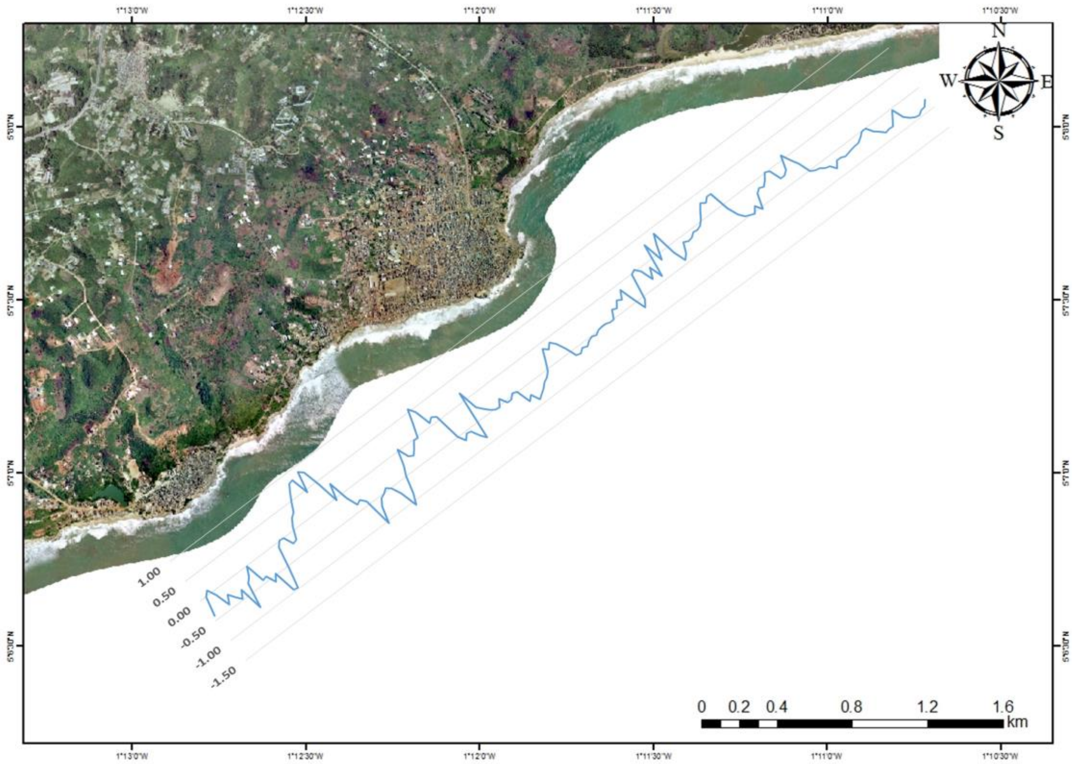

Figure 10: Erosion trends (m/yr) along the Moree shoreline segment during the 1974 - 2012 period

Table 4: Established End Point Rates and Net Shoreline Movement for the Elmina, Cape Coast and Moree segment during this study.

	End Point Rate (m/yr)			Net Shoreline Movement (m)		
Shoreline Segment	1974-2012	1974- 2005	2005-2012	1974-2012	1974- 2005	2005-2012
Ankwanda	-1.14	-1.19	-0.96	-39.21	-33.72	-7.15
Elmina I	-1.32	-1.53	-0.14	-46.07	-43.96	-1.04
Elmina II	-0.98	-1.04	-0.82	-34.28	-28.78	-6.11
Elmina III	-1.38	-1.54	-0.92	-51.1	-49.6	-6.82
Cape Coast I	-1.98	-2.13	-0.93	-73.06	-66.93	-6.88
Cape Coast II	-1.04	-1.21	-1.29	-37.68	-32.20	-9.56
Moree	-0.67	-0.58	-0.86	-21.88	-16.82	-6.39

4.2 Shoreline changes: 1974 - 2005

Results indicate that during this period shoreline erosion within the study segments were higher as compared to the overall erosion experienced within the 1974-2012 period (Table 4) with the exception of the Moree segment. The average erosion rate for the entire study area during this period was -1.32 m/yr±0.17m with an average NSM of -43.41 m across the face of the coastline. The highs and lows recorded within each shoreline segment during 1974-2012 period is given in Table 5.

Table 5: The highest and lowest values in shoreline changes during the 1974-2005.

	Net Shoreline Movement (m)		***End Point Rate (m/yr)***	
Shoreline Segment	High	Lows	High	Lows
Ankwanda	-61.45	-0.78	-1.98	-0.03
Elmina I	-42.16	-6.73	-1.36	-0.22
Elmina II	-57.36	-2.40	-1.85	-0.08
Elmina III	-82.02	-21.62	-2.65	-0.70
Cape Coast I	-92.95	-2.05	-3.00	-0.07
Cape Coast II	-93.68	-4.98	-3.02	-0.16
Moree	-38.67	-1.12	-1.25	-0.04

Average shoreline changes for the Elmina I segment were higher during the 1974 to 2005 period, compared with changes that occurred during the 1972-2012 period. The Elmina II segment experienced the greatest shoreline changes at the westernmost end with an NSM of -57.36 m and EPR of -1.85m/yr±0.17m. Erosion trends during this epoch conformed to the total shoreline evolution recorded in this study (1974-2012), where sandy beaches were more vulnerable to erosion than rocky or cliff sections.

4.3 Shoreline change: 2005 - 2012

Shoreline changes for this period were more variable with most of the coastline experiencing erosion with a few areas showing stability. The study area experienced an average EPR of -0.85 m/yr±0.77m and an NSM average of -6.28 m over this period. The recorded highs and lows in shoreline changes during this period is presented in Table 6. Figure 11 presents an example of local erosion that occurred within a small section of the study area during this period.

Table 6: The highest and lowest values in shoreline changes during 2005-2012.

	Net Shoreline Movement (m)		***End Point Rate (m/yr)***	
Shoreline Segment	High	Lows	High	Lows
Ankwanda	-32.34	-0.26	-4.62	-0.04
Elmina I	-9.62	-0.76	-0.96	-0.11
Elmina II	-19.09	-0.59	-2.73	-0.08
Elmina III	-16.97	-0.40	-2.42	-0.06
Cape Coast I	-23.32	-2.94	-3.33	-0.42
Cape Coast II	-31.57	-0.63	-4.51	-0.09
Moree	-22.55	-1.28	-3.22	-0.18

Figure 11: Erosion of sandy beach at the Elmina Highway Bridge. (A) shows more sand at the Elmina Bridge in 2005 which was eroded by 2011, (B) with further exposure of underlying rocks, (C) shows section of the 1.5 km rock revetment sea defence near the Elmina Highway Bridge.

5. Discussion

5.1 Evidence of Coastal Erosion

The extent of coastal erosion, the causes and the consequences have been important issues in the Elmina, Cape Coast and Moree area in recent years, even though this has not culminated in a clear-cut management intervention. There is ample evidence to illustrate that coastal erosion is occurring and is having adverse impacts on the area; requiring immediate management interventions. Evidence from this study as well as other recent studies, including Jonah and Adu-Boahen (2014), Jonah et al. (2015a), Jonah et al. (2015b) and Jonah et al. (2016), clearly demonstrate the physical, social, economic and ecological consequences of the coastal erosion problem in the Elmina, Cape Coast and Moree area.

The net shoreline evolution showed that there were widespread coastal erosion during the 38 year period studied. In this study, sandy beach sections eroded at higher rates compared to the rates along rocky or hard cliff sections. These trends corroborate several other studies (such as Leatherman et al. 2003) that have suggested that open ocean sandy beaches are more susceptible to erosion compared to other coastal landforms. For instance, in this study the Cape Coast I shoreline segment is comprised of mainly a continuous stretch of sandy open ocean beaches and recorded the highest erosion rates while the other segments, composed of different shapes with both sandy sections and hard rock cliffs, recorded lower rates.

Several signs of coastal erosion are evident in the Elmina, Cape Coast and Moree area, including beach scarps and underlying hard rock exposures. As suggested by Leatherman et al. (2003), sea level rise and shoreline recession on one side and increasing human development and migration on the landward side, leading to a collision. In recent years, tourism facilities within the Elmina, Cape Coast and Moree area have been constructed closer to the coastline than before. In several instances, the response of property owners to erosion has been to armor their section of coastline (Figure 12A, D); in the long run the problem is either exacerbated or transferred onto to adjacent sections.

Figure 12: Some coastal defence structures in the study area. (A) Seawall to protect a beach resort in Cape Coast, (B) wire mesh revetment to control erosion near a school facility in Cape Coast, (C) section of a 1.5 km major sea defence project to protect a section of the Cape Coast-Takoradi highway, (D) boulder revetment used to prevent further destruction to a beach resort at a rapidly receding beach in Elmina.

5.2 Shoreline evolution in the Elmina, Cape Coast and Moree area

The shoreline is a time-dependent phenomenon that exhibits substantial short-term variability (Morton 1991). Spatio-temporal shoreline dynamics are caused by natural influences such as storms, marine currents and beach geomorphology (Gopinath and Seralathan 2005). As a result of global warming, the sea has been rising slowly over the last 150 years (Carter, 1991; Cai et al. 2009), contributing to the long-term recession being experienced along most of the world's coast (Leatherman et al. 2003; Pfeffer et al. 2008; Vaughan 2008; Cai et al. 2009). Humans aggravate these natural erosion occurrences through interferences with the natural coastal processes by undertaking activities such as coastal development, deforestation and coastal engineering (Wong 2003; Anfuso and Pozo 2009).

It is a fact that sea level rise in and of itself cannot move sand directly; a rise in the water level to which the beach profile must adjust requires shore recession, except where copious amounts of sand are available (e.g., where rivers deliver sediment directly to the sea) (Leatherman et al. 2003). According to Leatherman et al. (2003), sea level rise induces beach erosion or accelerates ongoing shore retreat in three main ways, (1) higher water level enables waves to break closer to shore and therefore, with more power; (2) deeper water decreases wave refraction and thus increases the capacity for longshore sediment transport;

(3) with higher water level, waves and currents act further up the beach profile, causing a readjustment of that profile.

Similarly, common human activities such as the widespread beach sand mining activities along the Elmina, Cape Coast and Moree area (Jonah et al. 2015a) allows waves and current to act further up the beach profile, accelerating natural shore recession and erosion. Beach sand mining acts by lowering the beach, allowing higher water volumes and levels up the beach profile. When this plays out for long periods, especially in areas with soft cliffs and erosion scarps, waves interact with and wear cliff toes increasing vertical erosion and shore recession rates. In the current study area, the widespread occurrence of beach sand mining most likely combined with the rising sea level (IPCC, 2014) has caused beaches to become more vulnerable to flooding during high tide and coastal storms, resulting in damage to properties and erosion of the coast.

The coastline of Elmina, Cape Coast and Moree has been eroding since the early 1970s, when rapid urbanization along the coast began (Dei 1972; Jonah et al. 2016). Results from this study show that coastal erosion was relatively higher during the 1974 to 2005 period in comparison with the rates observed during the 2005 to 2012 period. The most plausible explanation for the difference in erosion rates during the two epochs may be found in the type of shoreline evolution that occurred during each epoch.

In 1974, there were vast spans of coastal land buffer along the entire coast of Elmina, Cape Coast and Moree; characteristic of Ghana’s coast at that time (Boateng 2012). Most of these buffer land had eroded by 2005. Coastal segments predominantly composed of unconsolidated materials were most susceptible and eroded the most during this period; Cape Coast I segment being most affected, while Ankwanda, Elmina I-III and Cape Coast II also eroded significantly. There was less erosion along the hard cliff sections; quite obvious in the Moree segment which is most comprised of hard cliffs with few sandy beach sections.

By 2005, most of the sandy beaches had begun developing erosion scarps, changing the erosion dynamics in the area. Erosion scarps in the area were most likely caused by human activities, especially beach sand mining activities which is predominantly practiced in the area (Jonah et al. 2015a). As a result of lowering of beach levels through sand mining, high tide and storm water flows to the backshore hitting the toe of scarps, gradually eroding and causing beach recession. This change in shoreline recession dynamics most likely contributed to the reduction in erosion rates from 2005.

Conclusions

The coastal zone is known for its dynamic nature and is intensely used and populated by humans. The area is prized as a national asset as it provides a range of essential services and products. The intervention of humans in the coastal zone has a direct impact on the natural response of the zone. Open ocean sandy beaches experienced higher coastal erosion compared to rocky or cliff areas. This implies that holding all other factors constant, the coastline position could move over 50m further inland from the present position over the next 50 years. However, given the problem of climate change and associated sea level rise, the situation over the next 50 years could be worse than anticipated. There is the need therefore to develop sustainable engineering interventions to protect life and properties at the backshore.

Continued monitoring of shoreline changes is important to our understanding of the changes taking place on the coastline of Elmina, Cape Coast and Moree. Furthermore, studies that link land use patterns, human activities and other processes taking place in the coastal and marine areas are recommended. The results obtained in this study are vital for coastal managers, investors and for decision-making on issues such as coastal land use planning and development of a construction set-back. Geographic Information Systems techniques such as has been employed in this study is a useful and inexpensive means for monitoring the coastal environments especially for developing countries like Ghana.

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