Journal of Sustainable Development in Africa (Volume 11, No.4, 2009)
ISSN: 1520-5509
Clarion University of Pennsylvania, Clarion, Pennsylvania

DETECTION OF COASTAL EROSION HOTSPOTS IN ACCRA, GHANA

By: K. Appeaning Addo

ABSTRACT

The coastline, which is defined as the physical interface of land and water, is constantly changing as it seeks to achieve and maintain equilibrium among many opposing natural and human induced forces in the coastal zone. Coastline change, which is a natural phenomenon that follows the variations in relative sea level, climate and ecosystems, may be exacerbated by human activities in recent times.

Information about where the coastline is and where it has been in the past is therefore important, since it can be used to derive quantitative estimates of the rate of coastline change (erosion or accretion), which in turn can be used to identify areas of extensive erosion problems. This knowledge serves to provide a basis for the implementation of sound coastal zone management strategies, coastal environmental protection policies and sustainable coastal development and planning schemes.

Ghana’s Accra coast, in common with those of the rest of the world, has changed over millions of years in response to changes in their natural environment. Such changes have occurred over a wide range of temporal and spatial scales, and are presently influenced by human activities. The lateral changes in the coastline position have resulted in coastal erosion, which has destroyed the coastal environment, affected the social economic life of the local population, threatened cultural heritage and hindered coastal tourism development.

Previous studies have cited different erosion rates in Accra’s coastline, which ranges from 2m to 10m per year. The inconsistency in the published recession rates makes it difficult to detect the erosion ‘hotspots’ along the shore. Accra’s coastline historic rate of erosion terms was statistically calculated using Digital Shoreline Analysis System. Available geospatial data, which includes a bathymetric map from Ghana Ports and Harbour Authority produced in 1904, topographic maps produced by the Survey Department of Ghana in 1974 and 1996, and a map of Ghana produced by CTK Aviation in 2002 were used to create a database in ArcGIS. Orthogonal transects were generated along which historic recession rates were calculated using linear regression.

This paper will describe how historic rates were determined and how the erosion hotspots were detected accounting for identified sources of uncertainty.

Keywords: coastal erosion, erosion hotspots, rate of change, uncertainty, climate change.

INTRODUCTION

Coastline retreat has resulted in over 70% of the world's beaches experiencing coastal erosion (Anthony, 2005). The erosion trend is expected to increase under the scenario of rising sea level as a result of climate change. This presents a serious hazard to many coastal regions, where it is estimated that about 25% productivity occurs and 60% of the human population lives (Al-Tahil and Asim, 2004).

Effective management strategies are required to deal with the risks arising from coastal erosion. These strategies rely on observations of historic coastline locations and movement through time, and on the level of vulnerability of the identified erosion 'hotspots'. There is increasing recognition that such quantified geomorphic understanding should be built at large scales, e.g. tens of kilometres and over years to centuries, in order to plan sustainable and spatially integrated measures (Appeaning Addo et al, 2008). Ground-based surveys of dynamic (particularly eroding) large scale landscapes are inherently problematic and often prohibitively expensive. For this reason much of the world's coastline morphology has not been properly quantified, particularly in developing countries, which has significantly influenced detection of erosion 'hotspots'. In the mean time coastal morphology may be quantified by coupling remotely sensed data with information on historic coastline position from historic aerial photography and other sources.

Coastlines are dynamic in nature. Accurate mapping of the instantaneous coastline position has as a result been always associated with significant uncertainty. This situation arises because at any particular time the coastline position is influenced by the short-term effects of tide and long term relative sea level rise. It is also controlled by the actions of rip and long shore currents, which results in cross-shore and alongshore sediment movement respectively in the littoral zone. This affects the accuracy of computed historic rates of change and therefore the reliability of any identified erosion ‘hotspots’. The science of coastline mapping has changed over the past 70 years (Crowell, 2006) due to advances in technology and the need to reduce uncertainty. Although the changes have resulted in improvement in coastal data processing and storage capabilities, the frequent change in technology has prevented the emergence of a standard method of coastline mapping (Moore, 2000). The various methods have their unique capabilities and shortcomings, and therefore the use of any particular method is influenced by the data sources and resources available.

Modern data sources have come about as a result of recent developments in remote sensing technologies using air/spaceborne and land based techniques. They present the coastline in a data format ripe for analysis in GIS. Archived data sources, which are usually hardcopy maps and aerial photographs, provide historic records not available from modern data sources and can be digitally exploited in GIS following either manual digitising or scanning. These data sources create a good database for compilation of coastline positional information to detect change and facilitate determining erosion ‘hotspots’. Calculated coastline rates of change and their statistics reflect a cumulative summary of the processes that have impacted the coast through time. This information is influenced largely by the method adopted. Statistical methods generally assume coastline change is linear through time. Any non-linearity is attributed to behaviours that are not linear such as relative sea level rise, storms and sediment transport (Appeaning Addo et al., 2008). Numerous statistical methods have been developed to reduce the complexities of calculating coastline rates of change. The common analysis techniques include end point rates, average of rates, linear regression, jack-knife and weighted linear regression methods (Morton et al., 2004).

Many difficulties can be encountered in accurately detecting coastal erosion ‘hotspots’, based on sparse datasets and limited data, spanning a short period. The lack of dataset that span a long period of time introduce uncertainties in the estimated rates of change. Studies by Crowell et al. (1993) demonstrated the importance of using data sets spanning 60-80 years or more to determine the long term trend of erosion for identifying erosion ‘hotspots’. Such long term data are needed because the cycle of coastal erosion and subsequent recovery of the coastline are associated with coastal events such as storms that can obscure the underlying trend of erosion for decades. Modelling coastline changes to detect erosion ‘hotspot’ is therefore a big challenge to coastal regions where coastline data are scarce, especially in the developing countries like Ghana’s Accra coast.

This paper presents analysis of the historic rate of change to detect erosion hotspots in a region of coastline in which prior data is sparse and contradictory. The study area, the Accra coast in Ghana, is described in Section 2. Section 3 describes the various methods used to establish coastline position, analyse historic rates of coastline change and identify the erosion ‘hotspots’. The results are presented and discussed in Section 4.

STUDY AREA

This study investigates the coast around Accra, the political and economic capital of Ghana (Figure 1), which is on the Gulf of Guinea at latitude 5.626^0 N and longitude 0.1014^0 W. The coast faces approximately 250 degrees (south-west) and is approximately 40 km long.

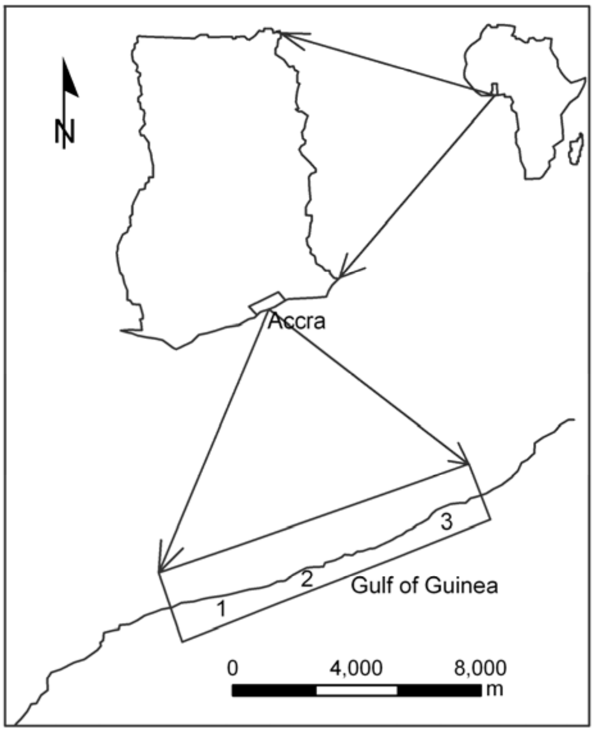

Figure 1: Location of the Study Area Showing Division of the Coastal Zone into Eastern (1), Central (2), and Western (3) Regions

Source: Survey Department of Ghana

The climatic condition that prevails along the coast of Accra is the equatorial type, characterised by wet and dry season, and the wind is a southwest monsoon. Significant wave height for 50% of the time is reported to be 1.2 m, with relatively long wave periods of between 10 – 15 seconds and a prevailing direction from the south-southwest (AESC, 1980). The neap and spring tidal ranges are 1.3 m and 0.6 m, respectively. The potential for alongshore sediment transport due to the wave action is estimated to be between 400,000 m^3/yr and 750,000 m^3/yr (Appeaning Addo et al., 2008). Detection of the erosion 'hotpots' along the Accra coast of Ghana has been undermined by a scarcity of geospatial data and great inconsistency in reported rates of change, which vary between 1.5 and 10 m/yr (Ly, 1980; Mensah, 1997; Kohli, 2003; Norley, 2006). It is evident that erosion has affected the social and economic life of the local population, threatened cultural heritage (forts and castles) and hindered coastal tourism development (Norley, 2006). According to Campbell (2006), 17 coastal inhabitants have lost their buildings to coastal erosion within a 26 year period in the western region of Accra. Problems associated with coastal erosion in the 'hotspots' are expected to increase as the coastline advances through more developed areas. Figure 2 illustrates a typically hazardous situation in the central region of Accra, with buildings situated on the tops of soft eroding cliffs.

Figure 2: Urban Development along the Eroding Accra Coast

Geomorphology

The study area encompasses three geomorphic regions, termed here as 'western' (14.3 km from Bortianor to Jamestown), 'central' (12.7 km from Jamestown to Teshie) and 'eastern' (11.3 km from Teshie to Sakumo lagoon) represented on Figure 1 as 1, 2 and 3. The western region consists of unconsolidated and poorly consolidated sediments rendering it extremely vulnerable to erosion. The central region consists of soft sandstone layers and the eastern region is made up of hard rocks overlain with soft rocks, which are moderately sensitive to erosion. Parts of the central and eastern regions have been engineered to prevent erosion using revetment and groynes. The western limit of the study area is the Densu wetland, which is important industrially, for salt extraction, and is a Ramsar site of international ecological importance as a habitat for approximately 35,000 waterfowl (BirdLife International, 2005). A barrier ridge separates the wetland from the sea. The sea level along the Accra coast is rising in conformity to the global trend at a historic rate of approximately 2 mm/year, but this is expected to increase to approximately 6 mm/yr (IPCC, 2007).

METHODOLOGY

Data

Data for this study, spanning a period of 98 years, include a 1904 bathymetric map obtained from Ghana Ports and Harbours Authority and mapped using planetable surveys (onshore) and echo sounding (offshore, last revised in 1992), 1974 and 1996 digital topographic maps obtained from the Survey Department of Ghana, and a 2002 digital map and near-vertical stereo film aerial photography of Accra obtained from CTK Aviations. The 1974 data was mapped using analogue photogrammetric method, the 1996 was mapped using stereo model and the 2002 was mapped using digital photogrammetric method. The scales of all maps are 1:50,000.

The high water mark (HWM) proxy was used to define all the coastline positions on the different date maps, which also have a common datum (Clarke 1880_RGS spheroid) and projection (Transverse Mercator). The coastlines were therefore compatible for comparison. The 1904 map, which was in hardcopy format, was digitised manually using a Calcomp 3400 digitising tablet with a resolution of ±0.127mm, which for a 1:50,000 scale map results in an uncertainty of 6.3 m on the ground. The 2002 map was used as reference to check the positional accuracy of the remaining maps. A Global Position System (GPS) survey was performed in 2005 to validate the coastline position on the 2002 map by using the mean of the reported historic rates of change to define an error ellipse. The positional accuracy of the remaining maps was assessed by comparing the planimetric coordinates of 20 identified conjugate features on all the maps, and determining their root mean square error (RMSE) relative to the 2002 map, which was presumed to be the most accurate of the coastline data available. The planimetric positional error for the 1996 and 1974 maps was found to be 0.17 and 0.18 m respectively at the 95% confidence interval. Only 11 identical features were identified for the 1904 map that gave a relatively high RMSE of 9.9 m at the 95% confidence interval. Vertical accuracy of the maps was not validated since the emphasis of the study is on linear change.

Historical Coastline Analysis

The coastline positions were compiled in ArcGIS using the metric Ghana Metre Grid coordinate system and each was coded with 6 attribute fields that included ObjectID (a unique number assigned to each transect), shape, shape length, ID, date (original survey year) and accuracy. Accuracy of ± 10 m was adopted as default that encompassed the uncertainty in the 1904 data. All coastline features were then merged within a single line on the attribute table, which enabled the multiple coastline files to be appended together into a single shapefile to prepare for calculating coastline change rates with Digital Shoreline Analysis System, DSAS (Thieler et al., 2005). Historic rates of coastline change were generated in ArcGIS using DSAS version 3.0, an extension to ESRI ArcGis V.9^{+} developed by the USGS in corporation with TPMC environmental services. This extension, which leads the user through the major steps of coastline change analysis, contains three major components that define a baseline, generate orthogonal transects at a user defined spacing along the coast, and calculates rates of change (using linear regression, endpoint rate, average of rates, jack-knife and weighted linear regression). It utilises the avenue code to develop transects and rates, and the avenue programming environment to automate and customise the user interface (Morton et al., 2004).

A baseline was constructed onshore by closely digitising the direction and shape of the outer coastline, which was used as the starting point for all transects set at 50 m intervals. Historic rates of coastline change were calculated at each transect using linear regression applied to all four coastline positions from the earliest (1904) to the most recent (2002). The linear regression method was selected because it has been shown to be the most statistically robust quantitative method when limited numbers of coastlines are available, and it is also the most commonly applied statistical technique for expressing rates of change (Morton et al., 2004). The average historic coastline rate of erosion, based on 1904-2002 data, is 1.13 m/yr at the 95% confidence interval. Figure 4 shows a graph of the historic rates of change calculated using the four different date coastline positions. Sources of uncertainty that affect the accuracy of the computed rate were identified and computed as 0.17 m/yr. They include error from planetable method of surveying the coastline position, photogrammetric method of extracting the coastline position from aerial photographs and uncertainty for digitising the coastline position from the 1904 paper map.

Various studies (Crowell et al., 1991; Thieler and Danforth, 1994; Moore, 2000; Morton et al., 2004) provide estimates of typical measurement errors associated with mapping methods and coastline digitising. The largest errors were found to be positioning errors of ± 10 m, which were attributed to scales and inaccuracies in the original 1904 survey using the planetable method. Coastline position error due to photogrammetric method of mapping is ± 6.1 m (Crowell et al., 1991). However, according to Morton et al. (2004), the influence of large coastline position errors on long-term rates of change can be reduced if the period under analysis is so long, which is 98 years for this study. A total coastline positional error (E_n), equation 1, incorporates all the measurement errors by taking the square root of the sum of squares of field survey error (E_s), digitising error (E_d) and photogrammetric error (E_p) as they apply to specific date coastline data. The root mean square error (RMSE) was calculated as a realistic assessment of combined potential error since these individual errors are considered to represent standard deviations.

The maximum planetable error incorporates all of the errors associated with the mapping process including distance to rodded points, planetable position and identification of HWL (Morton et al., 2004**).** This is applied only to the 1904 map as the more recent coastlines were derived from aerial photographs. Digitising error, which reflects the maximum digitising error estimated was applied to the 1904 and 1974 maps originally produced in hard copy format. Photogrammetric mapping error, which represents the error involved in locating relative positions of coastlines taken from aerial photographs (Crowell et al., 1991), was applied to the 1974, 1996 and 2002 maps since they were all mapped using photogrammetric methods. The total coastline position error is thus expressed as:

$$E_n = \sqrt{(E_s^2 + E_d^2 + E_p^2)} \qquad (1)$$

where n = coastline number (1 – 4)

A separate total error (E_n) was calculated for each coastline and the results are provided in Table 1. The positional error for each period was then incorporated into an error for each transect. That value was annualised (Ea) to provide error estimation for the coastline change rate at any given transect and expressed as:

$$Ea = \frac{\sqrt{(E_1^2 + E_2^2 + E_3^2 + E_4^2)}}{T} \qquad (2)$$

where E_1, E_2, E_3, and E_4 are the total coastline position error for the various years and T is the 98 years period of analysis.

The maximum annualised error using best estimates for the study area is 0.17 m/yr (Table 1). The coastline historic rates of change computed at the transect points were used to identify the erosion ‘hotspots’.

Table 1: Estimated Measurement Errors for the Study Area

Measurement Errors (m)	**1904**	**1974**	**1996**	**2002**
Planetable survey error (E_s)	10	-	-	-
Digitising error (E_d)	6.3	6.3	-	-
Photogrammetric mapping error (E_p)	-	6.1	6.1	6.1
Total coastline position error (E_n) (m)	11.82	8.76	6.1	6.1
Annualised transect error (E_a) (m/yr)	± 0.17			

Detection of Erosion Hotspots

The extracted coastline positions of 1904, 1974, 1996, and 2002 were overlaid in ArcGIS. This enabled linear changes in the coastline positions over the 98 years period to be detected and the locations experiencing significant recession identified. The computed historic rates of change at the transect points facilitated erosion ‘hotspots’ in the Accra coastline to be determined. A threshold rate of change value of 1.50 m/yr was adopted. This threshold value was used since locations with rates lower than the threshold rate are assumed to be eroding in conformity to the average long term erosion rate estimated for the entire length of Accra’s coastline. Locations with historic rates of change greater than the threshold rate were therefore classified as the erosion ‘hotspots’.

RESULTS AND DISCUSSION

The study has quantified the recession of the Accra coastline and identified the erosion ‘hotspots’ along the coast. It has been found that the average historic coastline rate of erosion, based on 1904–2002 data, is 1.13 m/yr ± 0.17 m. Although high, this value is significantly less than rates reported by previous studies. This study has found that 82% of the Accra coast is eroding, while the remaining 18% is either accreting or stable. The results demonstrate that all three coastal regions have, on average, retreated since 1904 as shown in Figure 3. The erosion ‘hotspots’, the shaded portions, (Figure 3) are located in the western and eastern regions. This confirms that the two regions are unstable in the long term as reported by Appeaning Addo et al. (2008).

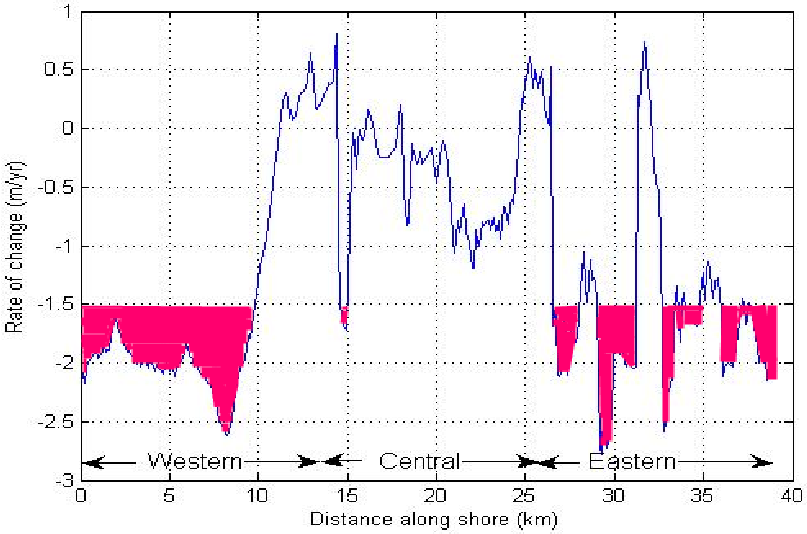

Figure 3: Calculated Historic Rates of Coastline Change and Erosion 'Hotspots' along Accra's Shore

The western and the eastern regions are eroding more (-1.7 and -1.9 m/yr respectively) compared with the central region (-0.2 m/yr). Whilst this is partly due to the prevailing geomorphic and geological features, engineering intervention (reclamation and construction of groynes and revetments) is responsible for some of the stabilisation and accretion. Construction of groynes in addition to the jetties at the defunct Accra harbour trap sediment in the littoral zone on the up drift side and the construction of revetments have prevented further movement of the coastline inland. Uncertainty rate quantified was reported in units of m/yr, which represents 95% confidence interval for the slope of the regression line i.e. with 95% statistical confidence that the true rate of coastline change falls within the range defined by the reported value plus or minus the error value.

Confidence in the analytical results is greatest because the historic rates of change estimated at the transect points are relatively high which indicate that erosion is occurring and they have persisted for decades as revealed by the 98 year span period. The erosion trend has been consistent for long stretches of the coast that indicate that rates along the transect points are reliable. Familiarity of the study area and GPS survey run in 2005 to validate the 2002 coastline position suggest that the historic rates of change presented in this study are accurate.

The result of this study is significant since it provides reliable recession information for policy makers in Accra, which will serve as the baseline for developing sustainable management strategies and policies to control the Accra coastal resources. It also serves as a baseline for future monitoring of changes in the coastline position as well as enables further studies into the coastline morphology. The information about the erosion ‘hotspots’ reveals locations along the Accra coast that need urgent attention to check the spread of erosion. The results of the study also facilitate analysis into erosion trends along the transects that are valuable information for further research work.

CONCLUSION

Various methods have been developed to quantify historic rates of coastline change. Linear regression statistical method, which enables all data to be used regardless of changes in trend or accuracy and also the most statistically robust quantitative method when limited numbers of coastlines are available, was adopted for this study. This method is particularly useful in geographic areas for which little geospatial data is available, particularly in developing countries like Ghana. Since linear regression consistently gives better long term forecasting results (Crowell et al., 2005) due to its robustness, it can be inferred that the average recession rate of change estimated in the Accra coastline and the locations identified as erosion ‘hotspots’ are reliable.

Historic rates of change of the Accra coastline, a developing country with sparse geospatial data have been presented. The observed erosion trend is expected to continue, if unchecked, under the influence of accelerated sea-level rise. It has been found that the coastline has receded at an average rate of 1.13 m/yr, which, although high, is significantly less than rates reported by previous studies. The western and eastern regions are eroding more than the central region.

The study has revealed that significant portions of the coastal lands have been lost thus leading to some portions been identified as ‘hotspots’. Coastal infrastructure, ecology, industries and the local population in the study regions are therefore under varying levels of erosion threat. This study has used the historic rates of change and erosion ‘hotspot’ results to greatly improve understanding of historic recession in Accra.

REFERENCES

AESC (1980). Architectural and Engineering Services Corporation, Hydrology Division: Report on investigation, coastal erosion and protection measures at Keta, Delft Hydraulics Laboratory (Ministry of foreign affairs of the Netherlands, directorate of international technical assistance). Pg 65.

Al-Tahil and Asim (2004). Assessing land cover changes in the coastal zone using aerial photography. Surveying and Land information. Volume 64, no.2. pp 107-112.

Anthony, E. J. (2005). Beach Erosion. Encyclopedia of Coastal Science. Ed Schwartz, M.L. Springer publishers. Pg 140-144.

Appeaning Addo, K., Walkden, M. and Mills, J. P. (2008). ISPRS Journal of Photogrammetry & Remote Sensing 63(2008): 543–558.

BirdLife International (2005). BirdLife's online World Bird Database: the site for bird conservation. Version 2.0. Cambridge, UK: BirdLife International. http://www.birdlife.org Accessed 29/4/2007.

Campbell, M.O. (2006). "The Sustainability of Coconut Palm Cocos Nucifera Linnaeus 1753 in Coastal Ghana". Journal of Coastal Research 22(5): 1118-1124.

Crowell, M., Letherman, S. P., and Buckley, M. K., (1991). Historical Shoreline Change: Error Analysis and Mapping Accuracy, Journal of coastal research. 7(3): 839- 852.

Crowell, M., Leatherman, S. P., and Buckley, M. K. (1993). Erosion rate analysis: long term versus short term. Shore and Beach, 61(2): 13-20.

Crowell, M., Leatherman, S. P., and Douglas, B. (2005). Erosion: Historical analysis and forecasting. Encyclopedia of coastal science. Ed Schwartz, M.L. Springer Netherlands. Pg 428-432.

Crowell, M., (2006). Historical shoreline mapping and analysis: An historical overview. An abstract submitted to shoreline change conference II: A workshop on managing shoreline change. Charleston, U.S.A. http://www.csc.noaa.gov/shoreconf/shoreline_change_conf_proceedings.pdf Accessed on 20/01/07.

IPCC (2007). Climate Change 2007: The Physical Science Basis (Summary for Policymakers). Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch/SPM2feb07.pdf. Accessed on 20/04/2007.

Kohli, K. **(**2003). [India-ej] ‘when logic doesn't wash’. http://www.hindustantimes.com/news/printedition/130603/detPLA01.shtml. Accessed on 02/03/2005.

Ly, C.K. (1980). “The role of the Akosombo Dam on the Volta River in causing erosion in Central and Eastern Ghana (West Africa).” Mar. Geol., vol. 37, pp.323 – 332.

Mensah, J. V. (1997). "Causes and effects of coastal sand mining in Ghana." Singapore Journal of Tropical Geography 18(1): 69-88.

Moore, L. J. (2000). Shoreline mapping techniques: Journal of Coastal Research, v. 16, p. 111-124.

Morton, R. A., Miller, T. L., and Moore, J. (2004). National assessment of shoreline change: Part 1: Historical shoreline changes and associated coastal land loss along the U.S. Gulf of Mexico: U.S. Geological Survey Open-file Report, 45pgs.

Norley, N. (2006). Agambila Alarmed At Sea Erosion. Ghanaian Chronicle. Accra: 8.

Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., and Miller, T.L., 2005. Digital Shoreline Analysis System (DSAS) version 3.0; An ArcGIS© extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2005-1304.

Thieler, E. R. and Danforth, W. W. (1994). "Historical Shoreline Mapping .1. Improving Techniques and Reducing Positioning Errors." Journal of Coastal Research 10(3): 549-563.