E3 Journal of Environmental Research and Management Vol. 4(11). pp. 0359-0367, December, 2013
Available online http://www.e3journals.org
ISSN 2141-7466 © E3 Journals 2012

Full Length Research Paper

Impacts of shoreline morphological change and sea level rise on mangroves: the case of the keta coastal zone

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Accepted 10 December, 2013

Mangroves are faced with the challenge of coping with rising sea levels globally. They face the threat of being completely inundated should sea levels rise beyond levels they are unable to cope with.This is largely due to their location in wetlands that are constantly flooded by the sea at high tides. Many shorelines are facing the challenge of erosion and Anyanui in the Keta coastal zone in Ghana is no exception. Anyanui has a relatively large extent of mangrove cover, which apart from the pressure of human exploitation faces the threat of being inundated should sea levels go high. This study investigated the effect of sea level rise and shoreline recession on the mangroves at Anyanui, using geospatial data and modelling techniques. The local trend in rising sea level was analysed using data from a tide gauge station in Ghana. The End point rate of change method of estimating shoreline rate of change in Digital Shoreline Analysis System (DSAS), an extension in GIS was used for the shoreline change analysis, while the mangrove cover was estimated using ENVI. The results indicate that Keta coastal zone is eroding at a rate of about 2.32m/yr and the sea level is rising at a historic rate of about 3mm/yr. The study revealed that increasing sea level rise will enable the shoreline to migrate about 8 km inland in the next 100 years, which could pose a severe threat to the mangrove forest. It also emerged that there is a significant increase in mangrove cover between 1986 and 2002. Effective measures should be adopted to manage the expanding mangrove forest.

Keywords: Sea level Rise, Shoreline Change, Mangroves, Climate change, Keta, coastal erosion

INTRODUCTION

Recent findings on global acceleration in sea-level rise indicate that upper projections are likely to occur (Church and White, 2006). Projections suggest that the rate of sea level rise is likely to increase during the 21st century, although there is considerable controversy about the likely size of the increase (Climate Institute, 2010).It is estimated that the average global sea level was about 120-130m below the present levels as recently as 10,000 BC (Clough, 1994). Since the mid-19th century, sea level has been rising primarily as a result of human-induced climate change. According to the Climate Institute (2010), during the 20th century sea level rose about 15-20 centimeters, with the rate at the end of the century greater than the early part of the century. The range of projections for global sea-level rise from 1980 to 1999 to the end of the 21st century (2090–2099) is 0.18–0.59m (Solomon et al., 2007).

Sea level rise will affect mangrove forests by eliminating or modifying their present habitats and creating new tidally inundated areas where some mangrove species may shift (IPCC, 2001).Globally, mangroves are faced with the challenge of coping with rising sea levels. This is mainly based on the fact that they are located in wetlands that are constantly flooded at high tides. Mangroves face the threat of being completely inundated should sea levels rise beyond levels they are unable to cope with (Kathiresan et al. 1996). According to Kjerfve& Macintosh(1997), mangroves are likely to shift landwards as a result of rising sea levels. This migration may,

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*Corresponding authors: E-mail: Kappeaning-addo@ug.edu.gh however, be inhibited by human settlements at the landward boundary resulting in a “land squeeze” situation. Hence, the width of the mangrove forests is likely to decrease under sea level rise.

The effects of sea level rise on any mangrove habitat will be influenced by local conditions such as the wetland type, geomorphic setting and human activities in the wetland. It is predicted that the sea level rise may range from 45 to 65 cm /100 year (Stewart etal., l990). Many shorelines are migrating landward under the influence of sea level rise in the more vulnerable areas, which will significantly impact the coastal environment including mangrove forests (Appeaning Addo, 2013).

The sea level in Ghana is rising at a rate of between 2-3mm/yr (Appeaning Addo et al., 2008; Addy-Sagoe and Appeaning Addo, 2013) which conforms to the global trend (Armah et al., 2005). It is predicted to increase to about 6mm/yr in the next 100 years (Appeaning Addo et al., 2008). The direct impact of the rising sea level on the coast is the inundation of previously dry areas by the sea and the introduction of high energy waves on the shoreline, increasing offshore loss of sediment; increasing salinity of estuaries and aquifers; raising water tables; and exacerbating coastal flooding and storm damage (IPCC, 2007). It will also impact the shoreline evolution trend by increasing the rate of erosion and thus threaten the prevailing ecosystems.

Shoreline changes occur over a wide range of time scales (Appeaning Addo, 2009). These changes are mainly associated with waves, tides, winds, periodic storms, sea-level change, and the geomorphic processes of erosion and accretion, as well as human activities (Van and Bihn, 2008). While there is no doubt that shorelines are changing, the nature of change is complex and the magnitude is uneven and varies from one point to another (Camfield and Morang, 1996). The detection and measurement of shoreline changes are, therefore, important tasks in environmental monitoring and coastal zone management (Van and Bihn, 2008, Appeaning Addo et al., 2008).

The coastline of Ghana has about 70% of its shoreline being sandy (Armah and Amlalo, 1998). Coastal erosion, flooding and shoreline retreat are serious problems along the coast of Ghana (Jayson-Quashigah et al., 2013). Past human impacts, inappropriate management interventions, climate change and sea-level rise have been identified as major contributory factors (Armah, 1991). According to Ly (1980), the eastern coast of Ghana has been identified as the most erodible stretch with rates as high as 4m/year prior to the construction of the Akosombo Dam on the River Volta. This paper presents results of a study to investigate the effect of sea level rise on the mangroves in the Keta coastal zone of Ghana, using geospatial data and modelling techniques.

Study area

The study area is on the eastern coast of Ghana and it lies to the eastern side of the Volta River estuary (Figure 1). The shoreline generally falls within the Keta Municipality. The area falls between latitudes 5°25' and 6° 20' north and between longitude 0 ° 40' and 1 ° 10' east.Temperatures are high with mean monthly temperature of about 30ºC in the warmest month, March and about 26ºC in the coldest month, August. The average minimum diurnal temperature is about 25ºC and average maximum is about 33ºC (Dickson and Benneh, 1995).The average wave height for the area is about 1.39m and the average period is about 10.91s. The semi-diurnal tide that is prevalent along the coast has an average range of about 1m and therefore only able to generate weak tidal currents.

Coastal erosion in the study area is reported by Boateng (2009) to be about 2-4m/yr, while Ly (1980) estimated it to be about 4-8 m/yr before the construction of the Akosombo dam. However, Philip-Jayson et al. (2013) estimated the average rate of erosion to be about 2 m/yr after the of the Keta sea defense project. Although the coastal ecosystems are adapted to the environment of waves, shifting sediments, freshwater inflows, etc, increasing sea level rise could result in inundation. This will shift the species inland and result in loss of species that cannot migrate.

METHODOLGY

Materials used in this study include GPS data from field work, orthophotographsobtained from the survey department of Ghana as well as medium resolution (15m-30m) satellite imagery obtained from USGS glovis website.

The manual method was explored for the extraction of the shorelines. Band ratio between the mid infrared was used to identify the water-land boundary for the Landsat images except the 2011 image due to the gaps in the data. This was used to reduce the level of subjectivity in delineating the shoreline. For this study, band ratio was implemented using the band ratio model in the ENVI software, thus b5/b2.In ArcMap, the extracted shorelines were overlaid on the Landsat image. The output vector, however, consisted of other water/land boundaries such as those of creeks and lagoons and could not be directly used for change detection. To extract the target sections, the extracted vector shorelines were overlaid on the colour composites and used as guide to digitize the target shoreline.

Shoreline position data was digitised from 2005 orthophoto using the arc map component of ArcGis;1974 digital topographic map; Landsat TM of 1991, 2001 and 2011 at 30m resolution. For change detection, Digital Shoreline Analysis System (DSAS 4.3), which is an

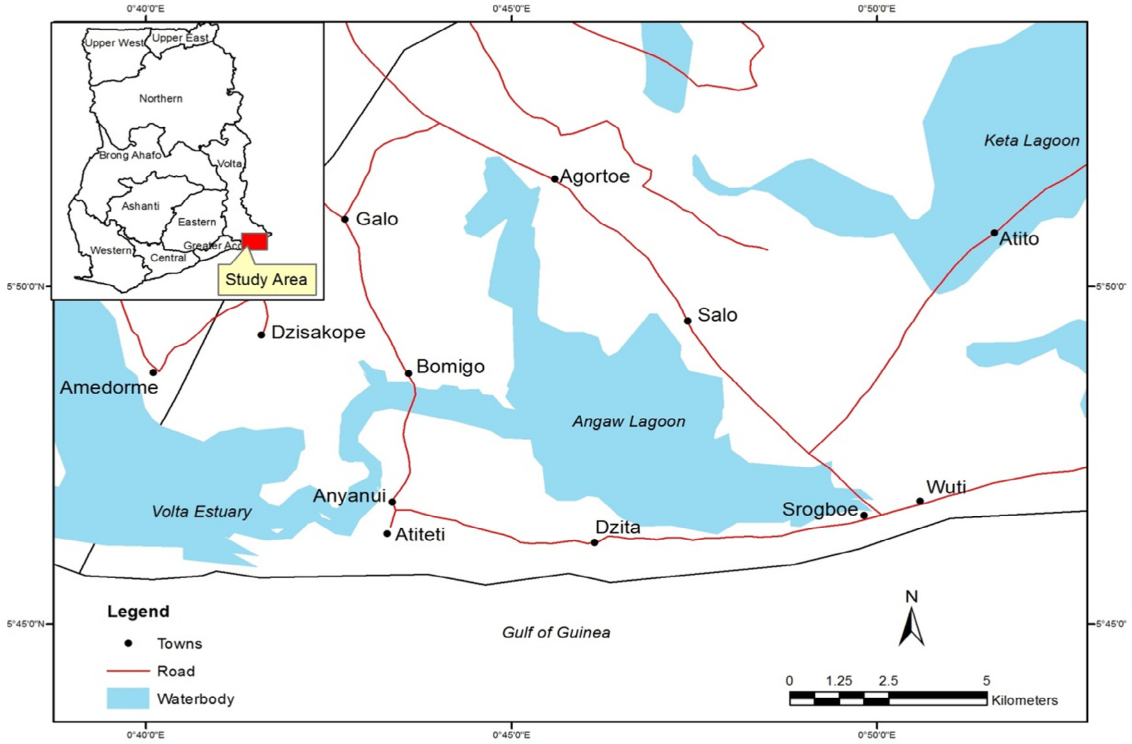

Figure 1: Map of the study area

extension for ArcGis and developed by the USGS (Himmelstoss, 2009), was used. DSAS computes rate-of-change statistics for a time series of shoreline vector data using user specified intervals along the shoreline using different methods.

The End point rate of change method was adopted to estimate the historic rates of erosion using the Digital Shoreline Analysis System (DSAS) in ArcGis because of its simplicity.

Mangrove cover was extracted from satellite imageries (Landsat TM 1986 and Landsat ETM 2002) using ENVI 4.7. This software was selected because it allows the analysis of vegetative areas in satellite images.The mangrove cover was also estimated using ENVI by classifying the vegetative areas on the satellite image from the other areas.The unsupervised classification of the image was done using ENVI 4.7 software. The K-means clustering algorithm was used for creating thematic maps. This map showed areas on the image that had vegetation by distinguishing them from bare land and water. This was vital as it provided the needed guidance for the ground-truthing in terms of areas that had the likelihood of being mangrove vegetations.

Supervised classification was done after the ground-truthing of the study area had been carried out to ensure that the actual surface cover types present in the image are the ones used for the classes in the classification. This was done by first training the image by delineating areas of the study area into three categories, that is, land, water and vegetation and assigning particular colours to each of them. The Parallepiped method of classification in ENVI was then used to categorise the features into these classes.

This was done after the supervised classification of the image. The classified images of the two years (1986 and 2002) were used in this analysis using the ENVI software. This process compared the two images and the various classes and then calculated the change that had occurred and represented the result in the form of statistical variables. The change map was then drawn for each of the classified images.

Future erosion rates were calculated using the Bruun model. The prediction was based on the EPR results for the 1991 and 2001 shorelines as well as the historic and future sea level rise.

The calculated values were then imported into ArcGis and used to generate the future shoreline positions in ArcGis as points. The points were then overlaid on the baseline shorelines and digitized into a line shapefile. This was then overlaid on the orthophoto and a Landsat image, to give a visual interpretation of the position of the shoreline at the dates used for the prediction. It also helped to assess the impact of shoreline recession on mangrove colonies.

Table 1: Average Erosion and Accretion Rates

Period	Erosion Rate Ave(m/year)	Accretion Rate (m/year)
1974-1986	-0.04	0.05
1974-1991	-0.16	0.03
1991-2001	-6.88	1.48
1974-2000	-0.09	0.11
2001-2007	-4.89	0.74
Average	-2.41	0.48

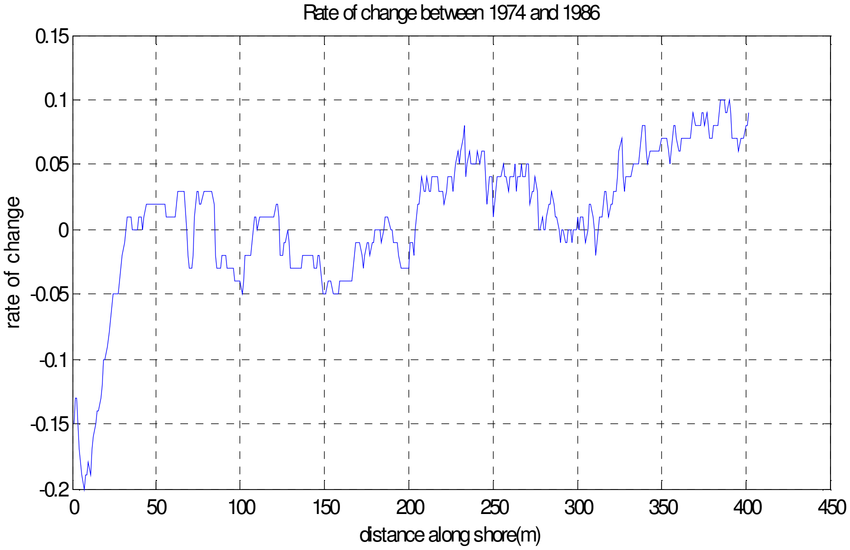

Figure 2: Erosion and Accretion rates between 1974 and 1986

RESULTS

The rate of the rising level was found to be 3.2mm/yr which is slightly higher than the estimated global level of 2mm/yr. Results from this study revealed that the Keta coastal zone is eroding at a rate of 2.4m/yr and an accretion rate of 0.48m/yr. The results show that both erosion and accretion were actively occurring at the Keta coastal zone, with erosion rates higher than the accretion rates (Table 1).

Over all rates of shoreline change

The end point rate method was employed for the calculation of shoreline change.The positive values show accretion whilst the negative values show erosion. Change rate were calculated for periods between1974 and 1986,1974 and 1991, 1974 and 2005, 1991 and 2001, and 2001 and 2007.The general pattern observed is a high rate of erosion from the first to about the hundredth transect, after which a small rate of accretion occurs. This pattern was observed for almost all the periods under observation.

Shoreline change between 1974 and 1986

The period between 1974 and 1986 experienced both erosion and accretion (Figure 2). About 40% of the erosion occurred between the first fifty transects whilst the rest the erosion occurred from transect number fifty (50) to two hundred (200). The rest of the transects experienced accretion. Erosion rate was relatively higher than the accretion rates. The erosion rates were from 0.01m/yr to 0.2m/yr and accretion rates were from0.01m/yr to 0.1m/yr.

Shoreline change between 1974 and 1991

The period between 1974 and 1991 experienced more erosion than accretion (Figure 3). About 70% of the transects experienced erosion whilst the remaining 30%

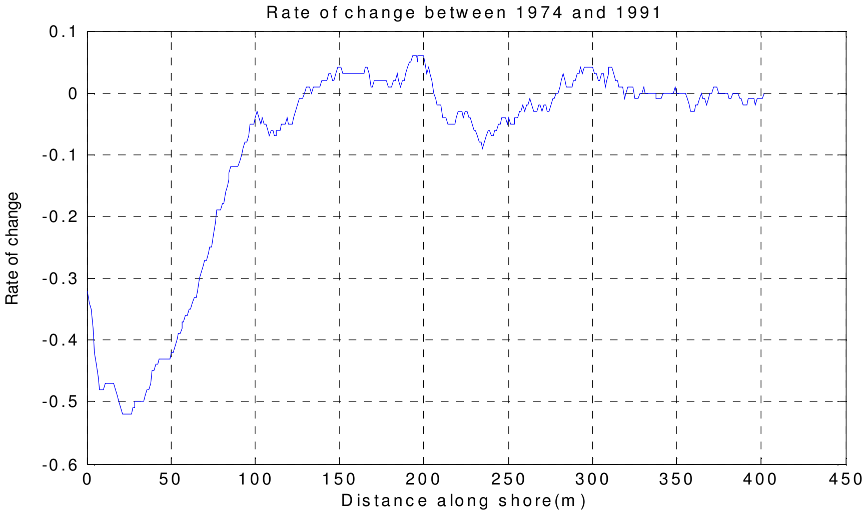

Figure 3: Erosion and Accretion rates between 1974 and 1991

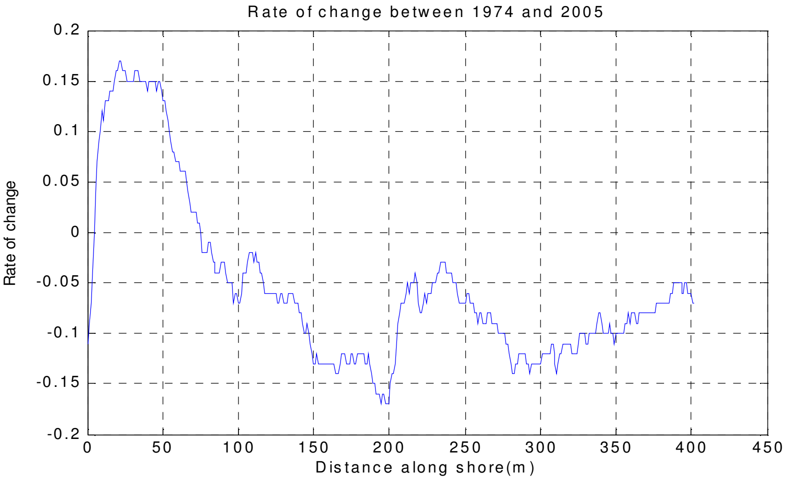

Figure 4: Erosion and Accretion rates between 1974 and 2005

experienced accretion. The erosion rates were quite high and ranged from 0.01m/yr to 5.2m/yr and accretion rates were from0.01m/yr to 0.06m/yr.

Shoreline change between 1974 and 2005

The period between 2001 and 2005appears to have experienced high erosion with little accretion occurring (Figure 4). About 14% of the transects experienced accretion whilst the remaining 86% experienced accretion. The erosion rates were from 0.01m/yr to 0.18m/yr and accretion rates were from 0.01m/yr to 0.18m/yr.

Shoreline change between 1991 and 2001

The period between 1991 and 2001experienced both erosion and accretion (Figure 5). The erosion rates were from 0.01m/yr to 22m/yr and accretion rates were from 0.01m/yr to 4m/yr. The average erosion and accretion rate for the area was 0.04m/yr.

Shoreline change between 2001 and 2007

This period experienced high rates of accretion and relatively lower rates of erosion (Figure 6). About 6.3% of the transects experienced erosion whilst the remaining

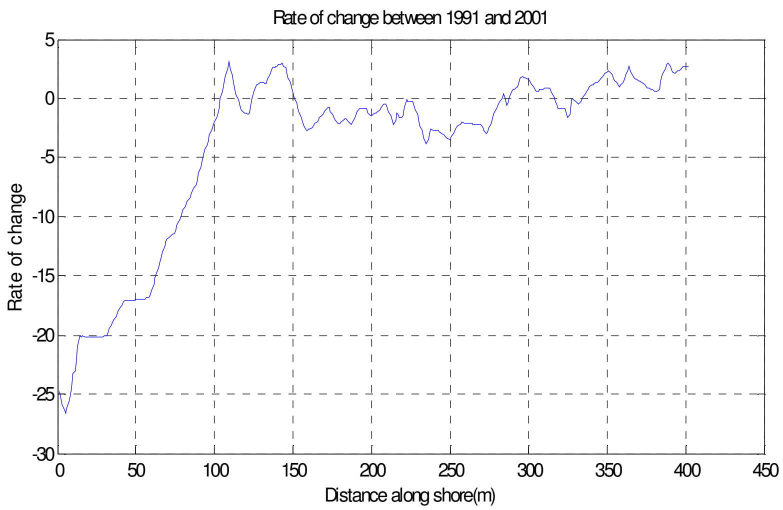

Figure 5: Erosion and Accretion rates between 1991 and 2001

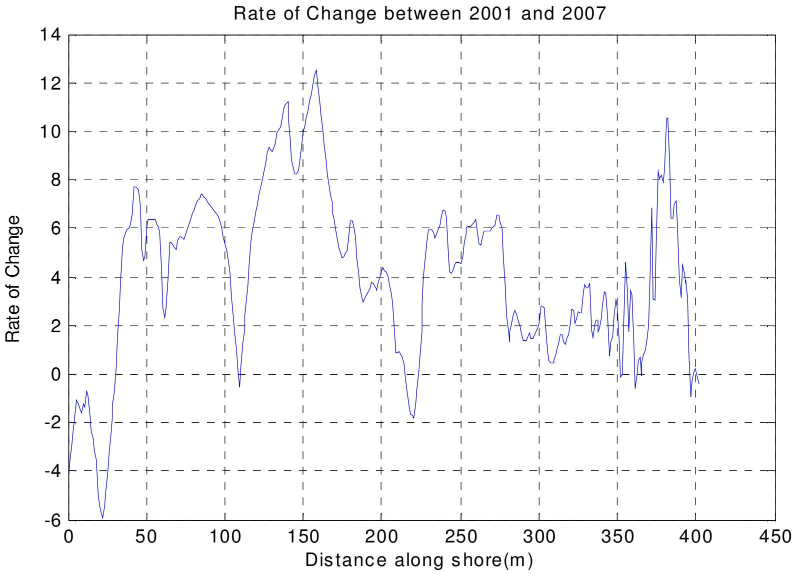

Figure 6: Erosion and Accretion rates between 2001 and 2007

93.7% experienced accretion. Erosion rates ranged from 0.1m/yr to 5.9m/yr and accretion rates were from 0.3m/yr to 12.5m/yr.

Mangrove cover change

The results of the change statistics showed a value of 45203 points for the image difference. In this change statistics, a positive value indicates that the class size increased and vice versa, implying that mangrove cover had seen a positive change of about 40682700m^2.This can also be represented in percentage as 225.1%. This is illustrated in the (Table 2) below:

Predicted shoreline positions

It was observed that by the year 2101, the shoreline position at Atiteti(refer to Figure 1) will be at the current location of the mangroves in the study area. The shoreline would have moved landwards by a distance of about eight kilometres (Figure 7).

Though the mangrove cover appeared to have

Table 2: Change Statistics for Mangroves

	Mangroves [Green] 535 points	Bare land [Red] 499points	Water [Blue] 765 points	Row Total	Class Total
Unclassified	605	659	2953	4217	5956
Bare land [Red] 288 points	2128	11673	6733	20534	20830
Mangroves [Green] 261 points	17031	895	47146	65072	65281
Water [Blue] 429 points	314	953	36150	37417	37621
Class Total	20078	14180	92982	0	0
Class Changes	3047	2507	56832	0	0
Image Difference	45203	6650	-55361	0	0

Percentages

	Bare land [Red] 499 points	Mangroves [Green] 535 points	Water [Blue] 765 points	Row Total	Class Total
Unclassified	3.013	4.647	3.176	70.803	100
Bare land [Red] 288 points	10.599	82.32	7.241	98.579	100
Mangroves [Green] 261 points	84.824	6.312	50.704	99.68	100
Water [Blue] 429 points	1.564	6.721	38.878	99.458	100
Class Total	100	100	100	0	0
Class Changes	15.176	17.68	61.122	0	0
Image Difference	225.137	46.897	-59.539	0	0

Area (Square Meters)

	Bare land [Red] 499 points	Mangroves [Green] 535 points	Water [Blue] 765 points	Row Total	Class Total
Unclassified	544500	593100	2657700	3795300	5360400
Bare land [Red] 288 points	1915200	10505700	6059700	18480600	18747000
Mangroves [Green] 261 points	15327900	805500	42431400	58564800	58752900
Water [Blue] 429 points	282600	857700	32535000	33675300	33858900
Class Total	18070200	12762000	83683800	0	0
Class Changes	2742300	2256300	51148800	0	0
Image Difference	40682700	5985000	-49824900	0	0

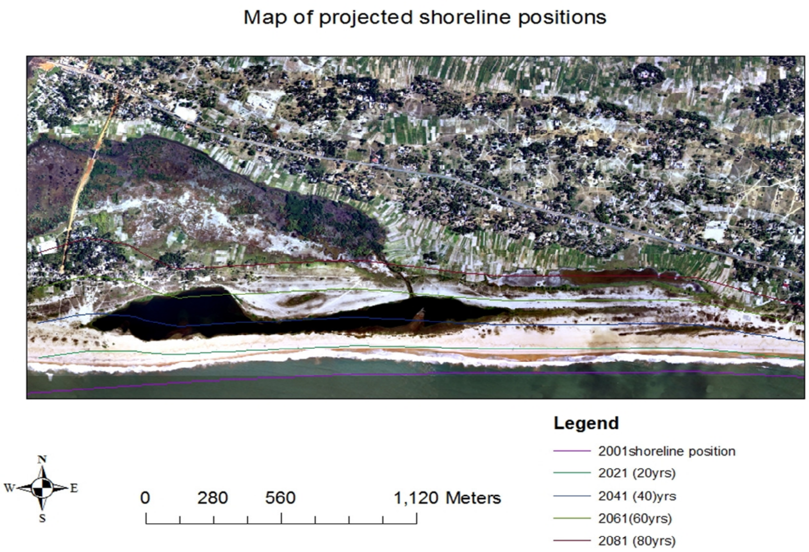

Figure 7: Map of projected shoreline positions

increased, the study revealed that mangroves in the area could be at risk of complete inundation with these rates of erosion and sea level rise based on the predicted future shoreline calculations.

DISCUSSION

Analysis of the tide gauge data showed that local sea level was rising consistently in conformity with global scenarios. The rate of the rising level was found to be 3.2mm/yr which is slightly higher than the estimated global level of 2mm/yr. The higher value could be attributed to an anomaly in the data that occurred between 1955 and 1960 due to faulty equipment. Aside the unusual occurrence between 1955 and 1960, the results showed a trend of gradual rise in sea level along the coast of Ghana. Rising sea level is known to have direct impact on shoreline. Thus, the rising trend in the sea level could have direct influence on the changes in the shoreline position that have been observed over the years and hence impact on the mangroves located there.

Rising sea level may also bring high energy waves closer to the mangrove areas that otherwise experienced only low energy. This is because as the waves move progressively into shallower water, they break and lose energy. Some of this energy is transferred into a shoreward momentum flux which acts to raise the mean sea level slightly close into shore. This may then exacerbate the erosion that is already occurring at the area, resulting in the removal of sediment and further retreat of the shoreline. Thus natural factors including wave, current actions and the shoreline orientation, as well as anthropogenic factors such as beachsand mining, play major roles in the observed shoreline changes.

The results show that both erosion and accretion were actively occurring at Anyanui, with erosion rates higher than the accretion rates. The estimated erosion rate is consistent with what has been reported by previous studies (Boateng, 2009; Jayson-Quashigah et al., 2013) and could be attributed to the local sediment budget, wave action as well as the intensive sand mining in the area. The highest rates of erosion occurred at Atiteti, which located is in close proximity to the estuary. These high rates could be the result of the hydrodynamics associated with the opening and closing of the estuary during low and high tide respectively.

Mangroves in Ghana have been under increasing pressure due to their economic importance to the coastal communities (Armah and Amlalo, 1998). The current study assessing the change in the mangrove colony revealed an increase in the mangrove between 1986 and 2002.The results of the study varied from that of Armah and Amlalo (1998), who stated that the mangroves were being lost gradually in some of the coastal localities. The increasing cover of mangroves could be the result of various programmes for sustainable management of the mangroves and education of the local communities on these practices (Armah and Amlalo, 1998).It was evident that the demand for mangroves was still high in the study area. Mangroves are cleared for timber, charcoal and firewood. Because of higher calorific value, the mangrove twigs are used as firewood. The mangrove wood is rich in phenols, making it highly resistant to deterioration, and is widely used as timber for construction purpose (Kathiresan and Rajendran, 2005). From the prediction, it was observed that by the year 2101, the shoreline position at Atiteti will be at the current location of the mangroves at the area. The shoreline would have moved landwards by about eight (8) km.

The implications of results are that, the shoreline in the study area is unstable. The top dying disease is believed to be caused by an array of factors such as increased soil salinity due to reduced water flow, reduction in periodic inundation, and excessive flooding.

CONCLUSION

The study has revealed that the Keta coastal zone is eroding at a rate of 2.32m/yr with a local sealevel rise of about 3.4mm/yr. With potential rising sea level, mangrove colonies around Anyanui and its environs will be inundated if they are unable to appreciably migrate inland and keep pace with it. This may result in the reduction of freshwater flow to the mangrove ecosystems. Increased salinity may affect the mangroves negatively by reducing growth (Kathiresan and Rajendran, 2005). There had been an increase in the mangrove cover at Anyanui between 1986 and 2002. It is therefore necessary for a continuous monitoring process in the study area to understand the rate of recovery of the mangroves after destruction to enhance developing policies for effective management of the mangrove forest. It will also help in the educating and sensitising the inhabitants against poor practices of mangrove conservation.

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