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Medium resolution satellite imagery as a tool for monitoring shoreline change. Case study of the Eastern coast of Ghana

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ABSTRACT

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Shoreline change analysis provides important information upon which most coastal zone management and intervention policies rely. Such information is however mostly scarce for large and inaccessible shorelines largely due to expensive field work. This study investigated the potential of medium resolution satellite imagery for mapping shoreline positions and for estimating historic rate of change. Both manual and semi-automatic shoreline extraction methods for multi-spectral satellite imageries were explored. Five shoreline positions were extracted for 1986, 1991, 2001, 2007 and 2011 covering a medium term of 25 years period. Rates of change statistics were calculated using the End Point Rate and Weighted Linear Regression methods. Approximately 283 transects were cast at simple right angles along the entire coast at 200m interval. Uncertainties were quantified for the shorelines ranging from ±4.1m to ±5.5m. The results show that the Keta shoreline is a highly dynamic feature with average rate of erosion estimated to be about 2m/year ±0.44m. Individual rates along some transect reach as high as 16m/year near the estuary and on the east of the Keta Sea Defence site. The study confirms earlier rates of erosion calculated for the area and also reveals the influence of the Keta Sea Defence Project on erosion along the eastern coast of Ghana. The research shows that shoreline change can be estimated using medium resolution satellite imagery.

ADDITIONAL INDEX WORDS: *Coastal Erosion, Landsat, ASTER, DSAS, Keta Sea Defence Project*.

INTRODUCTION

Coastal zones are facing intensified natural and anthropogenic disturbances including sea level rise, coastal erosion, over exploitation of resources among others. Over 70% of the world's beaches are experiencing coastal erosion and this presents a serious hazard to many coastal regions (Appeaning Addo et al., 2008). According to Zhang (2010), awareness of the quality of global coastal ecosystems being adversely impacted by multiple driving forces has accelerated efforts to assess, monitor and mitigate coastal stressors. Monitoring temporal–spatial changes of coastal environments can help understand among others, the spatial distribution of erosion hazards, predicting their development trend and supporting the mechanism research on coastal erosion and its countermeasures.

The shoreline, which is defined as the position of the land-water interface at one instant in time (Gens, 2010) is a highly dynamic feature and is an indicator for coastal erosion and accretion. The processes of erosion and accretion affect human life, cultivation and natural resources along the coast. Rapid shoreline changes can create catastrophic social and economic problems along populated strands. Design of viable land-use and protection strategies to reduce potential loss is necessary and this requires comprehension of regional shoreline dynamics (Blodget et al., 1991; Chu et al., 2006).

Remote sensing techniques provide a synoptic vision of the Earth that is not possible to obtain other than by exhaustive and expensive field evaluations. Data from remote sensors allow analysis of a region with sufficient accuracy in an efficient, rapid and low-cost way (Berlanga-Robles and Ruiz-Luna, 2002). It also helps in analysing areas that are poorly accessible or rapidly changing (Chu et al., 2006). The use of remote sensing data is therefore increasingly becoming a more effective option for monitoring shorelines. Over the years, geomorphologists, oceanographers and geologist have developed interpretation keys for mapping coastline geomorphic features using aerial photographs; however, few studies of this type have used images generated by remote sensing orbital instruments (Kawakubo, 2011). Though the use of aerial photographs tends to be effective in this case, the frequency of acquisition, cost and coverage presents a challenge (Appeaning Addo et. al., 2008). Furthermore, the spectral range of these sources is minimal and may introduce errors in shoreline interpretation (Alesheikh et al., 2007).

On the other hand, multispectral remote sensing satellites provide digital imagery in various spectral bands, including the near infrared where the land-water interface is well defined. Furthermore this approach has advantages: less time consuming, inexpensive to implement, large ground coverage, and the

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capability for repeat data acquisition and monitoring (Van and Bihn, 2008). The principal limitation of satellite images is arguably their low spatial resolution when compared to photographs taken from aircraft (Kawakubo, 2011).

Coastal Zone of Ghana

According to Armah and Amlalo (1998), Ghana's coastal zone represents about 6.5% of the land area of the country, yet houses 25% of the nation's population. This small strip of land now hosts 80% of the industrial establishments in Ghana. Over 70% of the shoreline of 550km is sandy. Coastal erosion, flooding and shoreline retreat are serious problems along the coast. According to Ly (1980) the eastern coast 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. The construction of the Dam in the early 1960's has supposedly reduced sediment supply to this coast offsetting the balance between the sediment lost to longshore drift and replenishment. Erosion rates increased reaching as high as 8m/year around 1970.

There have been interventions such as the Keta Sea Defence Project (KSDP) which involved stabilization of the shoreline with break water and groynes, construction of a flood control structure and land reclamation from the lagoon. The KSDP was completed in 2004 (GLDD, 2001). These among others have influenced the accretion and erosion patterns along this coast.

This paper explores the analysis of shoreline change using medium resolution satellite imagery including Landsat TM, Landsat ETM+ and ASTER imagery. Data for the study spans over a period of 25years and covers the period before and after the construction of the KSDP. Erosion and accretion patterns are compared before and after the sea defence to determine the influence of the KSDP on rates.

METHODS

Study Area

The coastal zone of Ghana is generally divided into three sections, the western, central and eastern based on the geomorphology (Ly, 1980) (Figure 1). The Eastern coast, which is about 149km, stretches from Aflao (Togo Border) in the East to the Laloi Lagoon west of Prampram. The shoreline studied covers about 52 km of this stretch, from the eastern side of the Volta estuary to Blekusu east of Keta. The area falls between latitudes 5°25' and 6° 20' North and between longitude 0° 40' and 1° 10' East. The landscape consists of a large shallow lagoon (Keta Lagoon complex) surrounded by marshy areas with a sandbar (sand spit) separating the lagoon from the Gulf of Guinea and a number of creeks along the coast. The sand spit is very narrow; barely more than 2.5km at its widest point with a general elevation up to 2m above mean sea level (Awadzi et al., 2008; Boateng 2009).

The geology of the area is soft and generally comprises quaternary rocks and unconsolidated sediments made up of clay, loose sand and gravel deposits (Akpati, 1978). The Volta River System, the main source of sediment supply to this basin, consists of a larger drainage basin, broad delta plain, narrow shelf, steep upper slope, and a large basin floor. Recent mapping of the sea bed topography reveals the presence of numerous canyons (valleys) from the shelf all the way to the deepwater (Manu et al., 2005).

Two types of wave approach this coast, the seas generated by the weak, local monsoon and the swell generated by storms in the southern part of the Atlantic Ocean. Average wave height for the area between 1997 and 2006 is 1.39m but may reach a height of about 3m. They normally arrive from the direction between south and south west with an average period of 10.91s which may reach a maximum of 19.68s (Svašek Hydraulics, 2006). Tides are semi-diurnal with an average range of about 1m (Appeaning Addo, 2009). The tidal currents caused by this tides are weak.

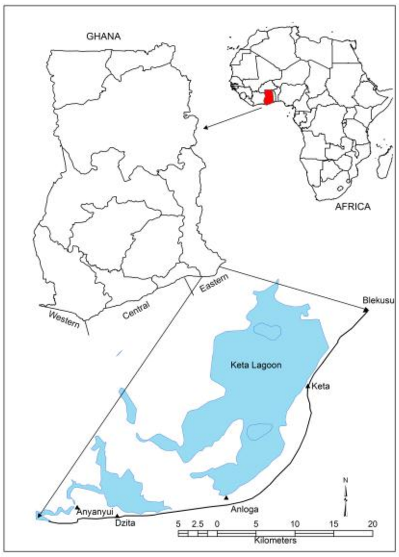

Figure 1. Location of the Study Area (after Ly, 1980; Ghana Survey Department)

Data and processing

Five imageries including Landsat and Aster (Table 1) were used for analysing shoreline change. The imageries span a period of 25 years and were acquired from the United States geological survey, earth resources observation and science centre.

The Landsat TM data was resampled using nearest neighbour and 1st order polynomial transformation to 15m. For the Landsat ETM+ data, the panchromatic band with a resolution of 15m was used to sharpen the six multispectral bands to obtain a new image at 15m. The Gram-Schmidt pan sharpening algorithm in ENVI which is based on principal component analysis was used.

The ASTER VNIR bands were already at 15m but were acquired at L1A (raw data), hence the need for geometric correction/rectification. The VNIR bands were co-registered (Image to image) to the Landsat 2001 ETM+ data using 30 visually interpreted Ground Control Points (GCP). The total root mean square (RMS) error was 0.35m.

Shoreline Extraction

The dry wet/boundary which approximates the high waterline (HWL) was extracted using semiautomatic and manual methods. Previous studies used the HWL as the shoreline proxy for change analysis in Ghana (Appeaning Addo et al., 2008; Appeaning Addo, 2009; Ly, 1980). Band ratio between the mid infrared (band 5) and the green (band 2) 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 so as to reduce the level of subjectivity in delineating the shoreline. These were edited and used for change analysis The ASTER and Landsat ETM+ 2011 were however directly digitized.

Table 1. Imagery Characteristics

Data	Path/Row	Date	Bands	Resolution	Level
Landsat TM	192/56	1986-01-13	6MS	30m	L1T
Landsat TM	192/56	1991-01-03	6MS	30m	L1T
Landsat ETM+	192/56	2001-01-30	6MS 1 Pan	30m 15m	L1T
ASTER	192/56	2007-11-06	3VNIR	15m	L1A
Landsat ETM+	192/56	2011-01-10	6MS 1 Pan	30m 15m	L1T

Shoreline Analysis

The shoreline positions were compiled and managed in ArcGIS 9.3. The Digital Shoreline Analysis System (DSAS 4.2) developed by the USGS in 2010 (Himmelstoss, 2009) was used for rate estimation. The DSAS uses measurement baseline method to calculate rate of change statistics for a time series of shorelines. The baseline is constructed to serve as the starting point for all transects cast by the DSAS application.

Transects were cast at simple right angles from the baseline at 200m interval. Historic rates of shoreline change were then calculated at each transect using end point rate (EPR) and weighted linear regression (WLR).

The EPR was employed where only two shoreline positions were available as was the case for the period between 2001 and 2007. The EPR is calculated by dividing the distance between the shorelines by the number of years that have elapsed.

$$R = Dm/T \qquad (1)$$

Where R is the rate, D*m* is the distance in meters between the two dates and T is the period between the two shoreline positions.

For the entire period the WLR method was used for calculating the rates. The method was also used to calculate changes for periods between 1986 and 2001 (period before the KSDP) and between 2001 and 2011 (the period during and after the KSDP). Both periods had more than two shoreline positions mapped. In computing WLR, more reliable data thus shoreline positions with smaller uncertainty, are given greater emphasis or weight towards determining a best-fit line. The slope of the regression line between the shoreline positions at each transect is reported as the change rate (equation 2).

$$y = mx + b \qquad (2)$$

Where y = distance from baseline; m = slope (rate of change) and b = y-intercept.

For this study, uncertainties were quantified using estimates based on studies such as Crowell et al. (1991) and Moore (2000) and Hapke et al., (2010). Additional errors, which were associated with the imagery used for this study, were estimated. Four main sources of error were identified to account for the uncertainties.

Errors resulting from image registration, digitization of the shoreline, position of HWL and differences in resolution were considered. Resampling the 1986 and 1991 images from 30m to 15m did not add any spatial information but rather added to the uncertainty. 15m was used as scale/resolution uncertainty for all images.

The tidal range (1m) of the area was negligible and therefore was not accounted for as a source of uncertainty due the resolution of the imagery used. A total shoreline positional error for each epoch (E_x) was therefore calculated using the following equation:

$$E_x = \sqrt{(E_s^2 + E_p^2 + E_r^2)} \qquad (3)$$

Where E_s is the error occurring from scale difference, E_p is the photogrammetric error and E_r is the registration error. This approach carries the assumption that component errors are normally distributed (Dar and Dar, 2009).

The total uncertainties were used as weights in the shoreline change calculations. The values were annualised to provide error (E_t) estimation for the shoreline change rate at any given transect and expressed as:

$$E_t = \sqrt{(E_1^2 + E_2^2 + E_3^2 + E_4^2 + E_5^2)} / T \qquad (4)$$

where E_1, E_2,... E_5 are the total shoreline position error for the various years and T is the 25 years period of analysis.

The maximum annualised uncertainty using best estimate for this study is ±0.44m/year.

RESULTS AND DISCUSSION

In all, 7 shoreline positions were extracted for change detection (Figure 2). Change rates were calculated for the period between 1986 and 2007 and then for 1986 to 2011(Figure 3). The results show that there have been significant changes along the entire coast for the 25 years period under study. For the period between 1986 and 2011, about 40% of transects were ignored due to the gap in the 2011 shoreline positions. This affected change rates especially near the estuary. However, overall rates show little variation when compared. The averages of the calculated rates are shown in Table 2.

Overall rates ranges from -12m/year to 18m/year where negative values represent erosion and positive values represent accretion (Figure 3). Using the 1986 to 2007 results as a reference, about 45% of the entire shoreline experienced erosion while the remaining have mostly accreted.

Accretion rates range from 0.1m/year to 19m/year with an average 2.50m/year while erosion rates were between 0.1 to 9.30m/year with an average of 2.38m/year. Both rates are significantly high.

The Keta area has been much accreting with rates reaching about 18m/year while the area between Keta and Blekusu has been eroding with rates at an average of 3.50m/year with some sections recording as high as 9m/year. Near the estuary there are extreme cases of erosion and accretion over the period and rates are as high as -11m/year and 17m/year respectively. For the entire shoreline, erosion and accretion rates average at 2m/year.

The period before the KSDP (1986 to 2001) revealed that erosion dominates the entire shoreline (Figure 4) with about 70% of the cast transects recording erosion. Erosion rates range from 0.1 to 15.40 m/year with an average of 3m/year and accretion rates ranging from 0.1m/year to 21m/year with an average of 5.90m/year. The higher erosion rates occur between Keta and Blekusu and around Atorkor and Anyanui while the area between

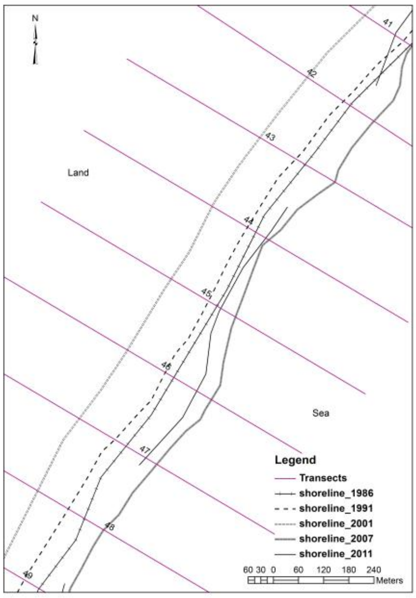

Figure 2. Extracted Shorelines

Keta and Anloga have experienced significant accretion. Close to the estuary there is evidence of both erosion and accretion over the period. Here erosion rates were as high as15m/year and accretion rates also at a high of 14m/year. These high rates have led to the destruction of coastal dwellings within the period. It is estimated that about 70% of the Keta Township now lies under sea (Fiadzigbey, 2005). Beaches as well as ecological and aesthetic

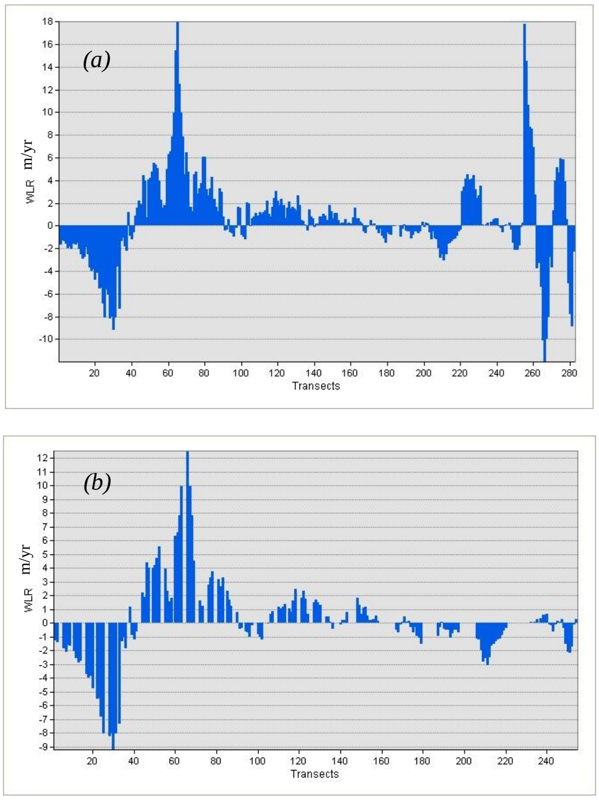

Figure 3. Rates of Change *(a) 1986-2007 and (b) 1986-2011*

Table 2. Average erosion and accretion rates

Period	*Erosion (m/year)*	*Accretion (m/year)*
1986-2011	1.91	2.04
1986-2007	2.38	2.77
1986-2001	3.10	5.17
2001-2011	4.52	5.59
2001-2007	4.68	10.04

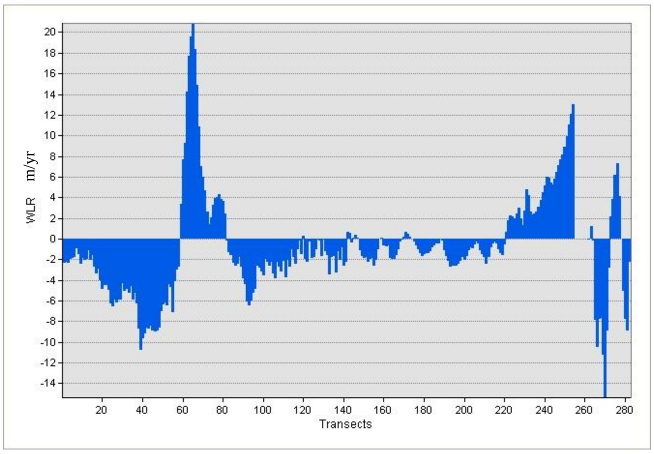

Figure 4. Erosion and Accretion Rates between 1986 and 2001

values were threatened. This led to the initiation of the KSDP which was completed in 2004. The project involved among others the establishment of groynes, revetments and beach nourishment.

The period between 2001 and 2011 which is considered the period after the KSDP shows a reversal of situations with the entire coast experiencing more accretion (about 80%) (Figure 5). However, erosion rates have remained high ranging from 0.1 to 17m/year with an average as high as 4.50m/year. Accretion rates also were high ranging from 0.1 to 26m/year and an average of 5.6m/year. The area between Keta and Blekusu (down drift of the KSDP) and the area near the estuary (up drift of the KSDP) remain high points of erosion over this period with rates reaching as high as 16m/year. This trend reveals the fact that, such 'ad hoc' management interventions like the KSDP classically tend to stabilise the shoreline at the protected section and aggravate the situation elsewhere along the shoreline ("knock-on effects").

Overall it is evident that most areas that experienced erosion between 1986 and 2001 have accreted between 2001 and 2007. The immediate vicinity of the Keta Township continues to accrete as well as areas around the estuary with values reaching 17m/year. Most portions of the Cape have also accreted.

Erosion trends

According to Ly (1980), erosion rates along the eastern coast have increased after the construction of the Akosombo dam in 1962. The rates reached as high as 8m/year as compared to the 4m/year high rates before the construction. The result of this study reveals high rates of erosion along the entire coast for the period under study from 1986 to 2011 thus an average rate of about 2m/year ±0.44m. This confirms the high rates of erosion in the area. The period before the construction of the KSDP marked intense erosion along the entire coast with rates reaching as high as 15m/year and an average of about 3.10m/year for the area near Keta and the Volta estuary. This has led to destruction of many coastal facilities and homes especially at Keta. It also confirms the assertion that the Cape has been retreating since the construction of the Akosombo Dam (Boateng, 2009).

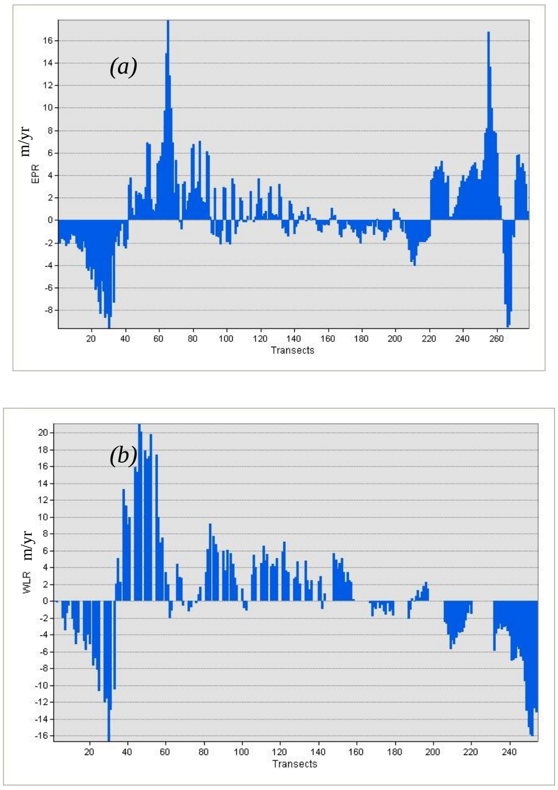

Figure 5. Erosion and Accretion Rates *(a) 2001-2007 (b) 2001-2011*

As part of efforts to curb the situation, the Keta Sea Defence project was initiated with work beginning in 2001. Thereafter, the rates indicate more accretion to the west of the site and erosion to the east. Erosion rates remain high averaging 4.52m/year while accretion rates were also as high as 5.50m/year. The high erosion rates in the east have led to the destruction of houses at Blekusu and its surrounding communities (Figure 6*a*). This situation confirms the knock-off effects by hard coastal protection measures.

Further down to the west (near the estuary) erosion rates had also increased leading to the destruction of homes and schools. As well the road linking Anyanui in the far west to Keta was completely cut off at Atorkor (Figure 6*b*). Efforts are underway to protect this area from further erosion.

Natural factors such as the high energy of waves in the area, soft geology and the orientation of the shoreline as well as sea level rise account for the high erosion in these areas. Topographic mapping of the sea bed around the estuary has also revealed canyons offshore which causes waves to break at higher speed and increase erosion in the area. These are however aggravated by human factors such as the construction of the Akosombo Dam on the Volta Lake in 1965 which led to reduction in sediment supply to the area, ad hoc interventions such as the Keta Sea Defence Project, sand mining and mangrove harvesting and development close to the shore (leading to land squeeze).

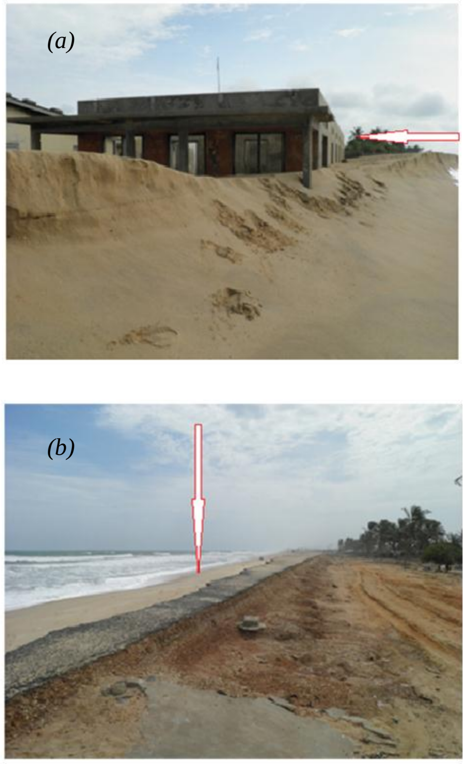

Figure 6. Destruction caused by sea erosion at *(a)* Blekusu and *(b)* Atorkor

CONCLUDING REMARKS

Results of this study have been useful in revealing the trends in shoreline change along the eastern coast of Ghana. Although aerial photographs are traditionally the main sources of data for shoreline monitoring, the study has shown that medium resolution multi-spectral satellite imagery can be used to map and monitor the large and dynamic shoreline this coast. The approach could also be replicated along the entire coast.

The findings generally confirm the high rates reported for this area after the construction of the Akosombo Dam. Average erosion rates are estimated to be 2m/year with the sections to the extreme east and west experiencing higher rates. Previous studies estimate erosion rates be 1.13m/year ±0.17 for the Accra shoreline (Appeaning et al., 2008) and Ly (1980) place estimates for the eastern coast between 4-8m/year. The current rates reflect this general trend.

The comparison of rates before and after the KSDP reaveals the structure is currently playing a role in the erosion and accretion patterns in the area. Erosion is now taking place down drift (Blekusu and beyond). However, the shoreline around Keta and Cape St. Paul has been experience accretion since the completion of the KSDP. This study confirms the ‘knock-on effects’ of ad hoc coastal hard protection along the coast of Ghana and supports the call for shoreline management planning (SMP).

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