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Research Paper

Impact of sea defense structures on downdrift coasts: The case of Keta in Ghana

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ABSTRACT

Coastal structures are used in coastal defence schemes with the objective of managing shoreline erosion and preventing flooding of vulnerable areas. This approach becomes necessary when coastal erosion threatens infrastructure and coastal resources. Constructing series of defence structures to protect beaches can however be expensive for developing countries like Ghana. This paper assesses the impacts of the Keta Sea Defence Project (KSDP) on the down-drift shoreline. The KSDP, which became necessary when the historic erosion rate reached about 8 m/yr and threatened to inundate the entire Keta township, combined both hard (groynes and revetment) and soft (nourishment) engineering methods. Six different sets of shoreline positional data were obtained from various sources that include digital topographic map (1974); Landsat imagery (1986, 1991, 2001); aerial photographs (2005); and *in situ* mapping of the shoreline in 2011 using RTK- DGPS. Changes were statistically analysed using linear regression and end point rates methods. Wave regime analysis was also done to assess its impact on the shoreline. It was revealed that swell wave moves mostly in the south-westerly directions (210°-240°) at a modal angle of 45° to the coast, with mean period and significant wave heights of 10.91 s and 1.4 m respectively. The wave direction results in generating longshore currents that transport sediment from west to east. Surge levels along the coast were found to be low between 0 and 0.6 m. The study revealed that the defence structures have resulted in increased erosion from about 3.2 m/yr (pre-construction period) to about 17 m/yr (post-construction). Although, the defence structures appear to have facilitated effective management of erosion in Keta, their impact on the down-drift coast through trapping of sediment in the littoral drift is significant. This suggests that the policy of hard engineering structures to manage coastal erosion in Ghana should be reevaluated.

Key words: Coastal defences, shoreline change, Keta, Ghana, coastal erosion.

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INTRODUCTION

Natural and anthropogenic impact on the dynamic shoreline position has resulted in accelerated migration of the shoreline inland in several coastal nations. Discussions of erosion problems have assumed a global dimension where it is estimated that about 70% of the world's sandy beaches are eroding (Bird, 1996). Shoreline morphological change within a coastal zone is assisted considerably by the geology, geomorphology, bathymetry, orientation of the shoreline and the level of human interference. These factors enable the ocean waves to break closer inland and generate currents that transport sediment along or across shore. The situation results in loss of sediment in a particular coastal area and gain of sediment in other areas. Human activities such as reclaiming of coastal lands for development, beach sand mining and over harvesting of coastal vegetation create the favourable conditions that facilitate inland movement of the shoreline position. The imbalance in sediment budget, which results, is a major source of instability in the dynamic shoreline position.

Coastal zones are among the well-developed areas globally and serve as sources of revenue generation for most coastal nations. According to Al-Tahir and Ali (2004), about twenty five percent of global productivity occurs within the coastal zones, where it is estimated that about thirteen percent of the world's urban areas are located (McGranahan et al., 2007). About fourteen of the world's seventeen largest cities are located in the coastal zone, while two-fifths of cities with populations of one million to ten million people are located near coastlines (Tibbetts, 2002). The coastal zone is home to over fifty percent of the global population (Van den Bergh and Nijkamp, 1998; Woodroffe, 2002) and this is predicted to increase by about thirty two percent by 2025 (Duedall andMaul, 2005) due to the availability of rich resources to produce goods and services. The near coastal population has average densities that are nearly three times higher than the global average density (Small and Nicholls, 2003). Coastal tourism is considered as one of the fastest growing forms of tourism in recent decades (Hall, 2001). Its economic impact is benefitting coastal economies significantly (Rivera-Arriaga and Villalobos, 2001), and is a major source of income generation for coastal nations (Duedall and Maul, 2005), offering employment opportunities to coastal dwellers.

Coastal erosion threatens coastal investment, destroys habitats and infrastructure, damages sources of livelihood of coastal dwellers, affects coastal ecology and negatively impacts the coastal environment. According to McGranahan et al. (2007), about ten percent of the world's population lives within low elevation coastal zones that are highly vulnerable to increasing sea level rise. It is estimated that approximately thirty eight percent of Africa's coastal ecosystem is highly threatened, while in some parts of South Sahara Africa, erosion rates are estimated to range between 23 and 30 m annually (Ibe and Quelennac, 1989). In Australia, about a quarter of a million homes could be uninhabitable by the end of this century due to the dangers of coastal erosion and rising sea levels, while some communities have already begun to demolish luxury homes which have been built on vulnerable coastlines (Bryant, 2009).

Losses associated with coastal erosion can be minimized with appropriate long term management scheme. Such planning strategies provide large-scale assessment of the risks associated with coastal processes and present a long term policy framework to reduce these risks to people and the developed, historic and natural environment in a sustainable manner (Defra, 2002). The strategic management options include 'hold the shoreline', 'retreat the shoreline', 'advance the shoreline' and 'do nothing' (Defra, 2002). Adopting a particular method is informed by the prevailing geophysical conditions, availability of funds, social, economic and political factors.

Coastal fore-dune areas, which represent a natural reserve that facilitates managing extreme events, have had their land use and land cover changed to accommodate industrial and population growth. The situation leaves little option but to undertake costly protective measures when coastal erosion and sea level rise threaten. The 'holding the shoreline' approach by using coastal defence structures has been adopted to stabilize beaches and control erosion in many parts of the world (Woodroffe, 2002). Structural hard engineering techniques, which involve using permanent concrete and rock constructions, are used to define the shoreline position and protect the assets located behind. This static engineering response strives towards achieving a dynamic equilibrium in the shoreline system.

Although varying degrees of success have been achieved, none has been able to stabilise sandy beaches that are being eroded (Ontowirjo and Istiyanto, 2003; Davis, 2005). This is because the engineering defence structures do not avoid intensification of the sequential erosion and often cause devastating effects on the down-drift shores or other parts of the coast. The most commonly used coastal defence structures include groynes, detached breakwaters, revetments and sea walls (Özhan, 2002). The basic function of these structures is to provide shelter to the segment of the shoreline which they protect, and to redistribute sand along and across the beach profile or to prevent further erosion. The protection is therefore limited to this segment of the coastline. Another approach that is gaining popularity is the sediment cell approach (Boateng, 2006). This approach is used to reduce the chance that measures taken within one sediment cell will impact adjacent cells (Eurosion, 2004). Through continuous monitoring of the shoreline position and beach sediment volume change, the effectiveness of the defence structures adopted can be assessed as well as their impact on the adjoining shorelines – especially on the down-drift coast. This is important

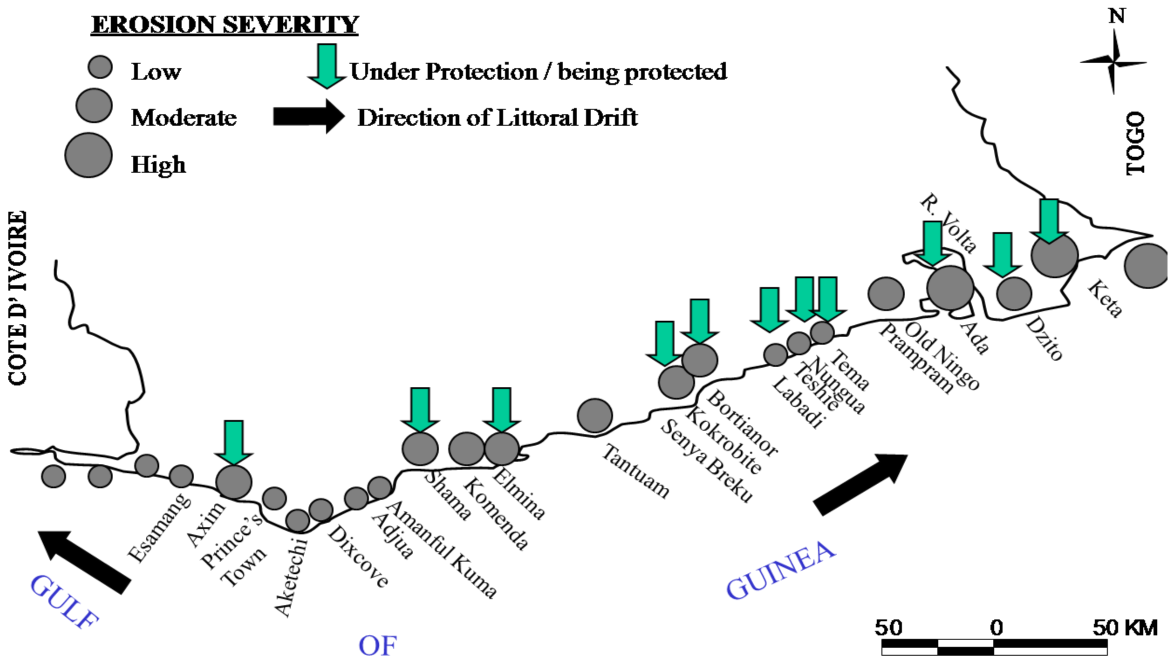

Figure 1. Erosion hot spots along Ghana coast (source: Armah and Amlalo, 1998).

because the presence of coastal defence structures is mostly accompanied with accelerated down drift erosion. This paper seems to address the importance of such structures in managing the near shore zone.

This paper, thus, assesses the impact of the Keta Sea Defence Project (KSDP) on the down drift coast in Ghana by using shoreline modelling techniques. After the introduction, the background of the study was discussed follow by the study area and then the results section: Pre-defence structure construction shoreline erosion rates were computed and compared with the post-defence erosion rates to identify rates of change. Wave regime parameters such as directions, energy densities and power along the coast were analysed by determining the correlation between the parameters and their percentage of occurrence. Analysis of these wave parameters along the coast gives insight into how they influence the strength and effectiveness of the longshore currents that drive erosion along the coast. And finally discussion section follow by conclusions and suggestions.

BACKGROUND

Coastal erosion in Ghana has assumed a chronic dimension. The increase in coastal erosion is as a result of human activities such as dam construction and sand mining, and in recent times increasing sea level rise due to global climate change. The high erosion rates threaten coastal infrastructure, cultural resources and the coastal environment. Coastal communities are losing their sources of livelihood as the sea destroys the local fishing and salt industries - the major source of income for most coastal dwellers (Akyeampong, 2001; Awadzi et al., 2008; Kufogbe, 1997). Coastal erosion has also resulted in the loss of cultural and archeological sites, destruction of future development sites and reduced public access to the shore (Appeaning Addo et al., 2008). Attempts to manage the spread of erosion along the Ghana coast have not been conducted in a systematic fashion due to lack of reliable historic rates of change information (Appeaning Addo et al., 2008). This has influenced predicting future coastline evolution trend and developing pragmatic as well as sustainable management strategies (Amlalo, 2005). The adhoc measures adopted to manage erosion problems are implemented with little regard for the adjoining coasts (Boateng, 2006; Amlalo, 2005).

About 25 coastal erosion hotspots (Figure 1) have been identified along the Ghana coasts that are undergoing various forms of morphological changes (Nai, et al., 1993). The worst affected area is Keta along the eastern coast of Ghana, which is eroding at a rate of about 8 m/yr (Ly,

Figure 2. One of the six groynes along Keta shoreline (source: Google map).

1980). Shortage of littoral sediment created when the Akosombo dam was built on the Volta River in 1961 is a major cause of increased erosion in Keta (Ly, 1980). It is estimated that the dam construction reduced sediment supply from the Volta River from about 71 million m^3/a to about 7 million m^3/a (Boateng, 2009; Ly, 1980). The erosion process in Keta has been exacerbated by the prevailing wave climate and the submarine topography (Appeaning Addo et al., 2011). The relatively high rate of erosion and the threat to life and property resulted in the over US$90m Keta Sea Defence Project (Boateng, 2009).

The defence project consists of revetment, groynes and beach fill. Figure 2 shows one of the groynes constructed along the shoreline in Keta and the nourishment around it. The aim of the project was to construct a 9 km road/causeway to reestablish a link that was lost to erosion; construct a new flood control structure to provide relief from extreme flooding conditions during high tides; construct sea defense works combining various approaches to prevent the spread of erosion as well as reclaim about 122 hectares of coastal land. Thus the project seeks to protect the eroding beach, minimize impacts on the down drift shoreline through bypassing the historic supply of sand and compensating for part of the sand budget deficit, as well as allowing for continued seine-net fishing.

Although the objectives for the project appear to have been considerably achieved, sediment starving of the down-drift coast has resulted in increased erosion between Kedzi and Hlorve. The situation threatens the local coastal communities and infrastructure. This fact goes against the background that appropriately designed and constructed groynes are able to hold limited volume of sediment and allow the excess sediment to move on through the system (Khazai et al, 2007).

THE STUDY AREA AND METHOD

Ghana's coastal zone represents about six and half percent of the land area of the country, yet houses twenty five percent of the nation's population and hosts about eighty percent of the industrial establishments (Armah and Amlalo, 1998). The 550 km long shoreline is divided into three zones (Figure 3): the western coast, the central coast and the eastern coast (Ly, 1980). The Eastern coast, which is about 149 km, stretches from Aflao (Togo Border) in the East to the Laloi Lagoon west of Prampram.

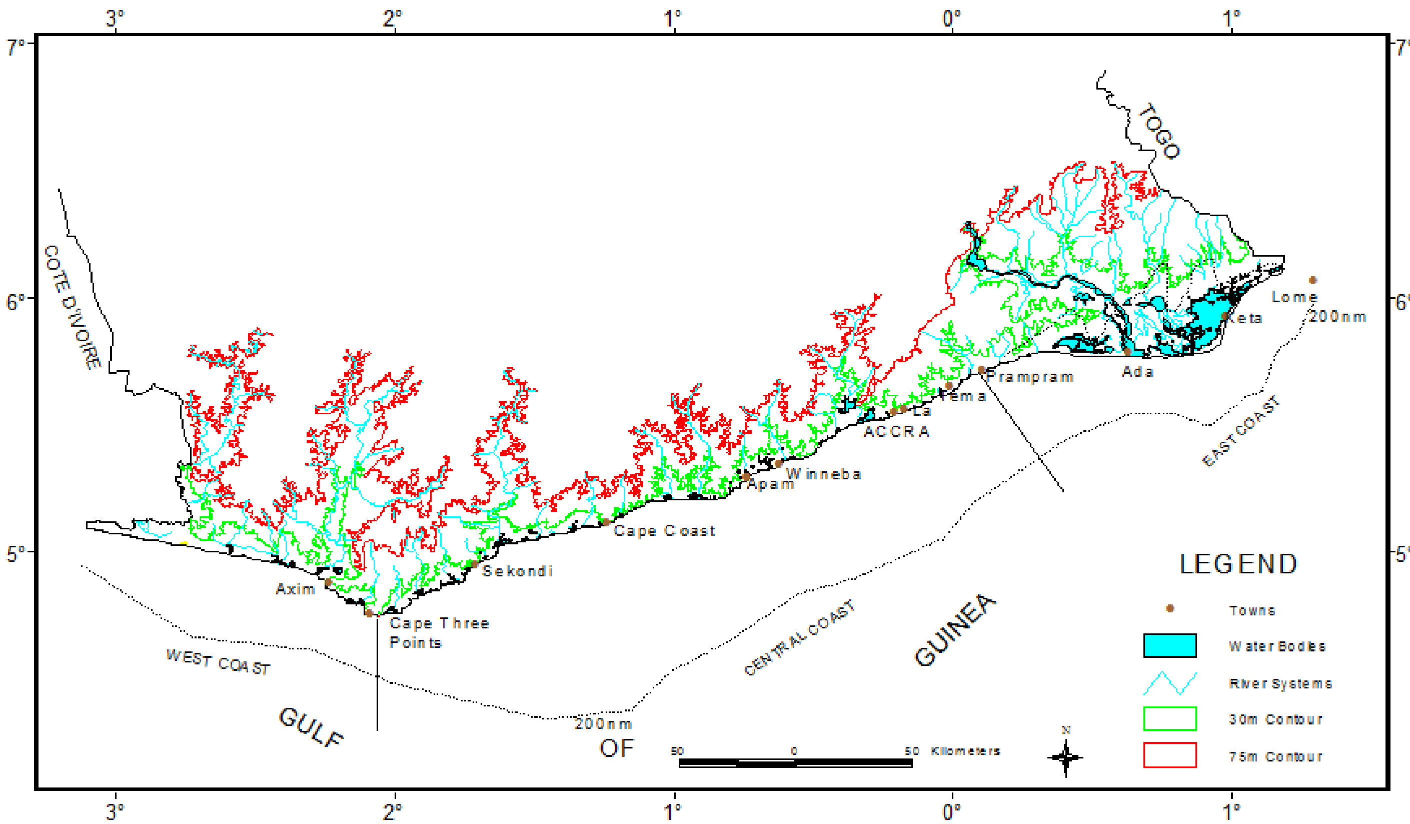

Figure 3. The three sections along the coast of Ghana (source: Boateng, 2009).

The study area (Figure 4) is the shoreline between Kedzi (label B) and Hlorve (label A) and is about 2.5 km long. The area generally 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 (label D) surrounded by marshy areas with a sandbar (sand spit) separating the lagoon from the Gulf of Guinea (label C) and a number of creeks along the coast. The sand spit is narrow; barely more than 2.5km at its widest point with a general elevation up to 2 m above mean sea level (Awadzi et al., 2008; Boateng 2009). The geology comprised of Quaternary deposits made up of clay, loose sand and gravel deposits (Akpati, 1978) that allows erosion by wave and ocean current actions. It is a relatively high energy beach with wave heights often exceeding 1m in the surf zone and characterised by erosion (Ly, 1980; Boateng, 2009). The tidal range in the area is estimated to be about 1.0 m (Sorensen et al., 2003).

The Volta River System, which is 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 (Figure 4). Bathymetric mapping of the sea bed topography reveals the presence of numerous canyons from the shelf all the way to the deepwater (Manu et al., 2005). The climate is dry equatorial (Awadzi et al., 2008). The main rainy season is between May and July with a minor rainy season between late August and early October and November to April being a dry season (Awadzi et al., 2008). The winds in the study area are due to the southwest monsoon with a prevailing direction from the southwest, and north east trade winds (AESC, 1980). The monthly average wind speed ranges between 1.7 and 2.6 m/s (Sorensen et al., 2003). The major currents along the coast include the longshore current, the Guinea current and a relatively weak tidal current (Appeaning Addo et al., 2008).

Data sources and positional accuracy test

Data used for the study are presented in Table 1. These include wave data obtained from Svašek Hydraulics (2006)

Figure 4. Coastline between Kedzi (label B) and Hlorve (label A) (source: Google Map).

Table 1. Data sets.

Data type	Data date	Source of data
Wave data	1997-2006	NOAA global wave model 4°N 1°W
Shoreline data	1974	Aerial photographs
Shoreline data	1986	Landsat Images TM
Shoreline data	1991	Landsat Images TM
Shoreline data	2001	Landsat Images ETM+
Shoreline data	2005	Ortho photographs
Shoreline data	2011	RTK-GPS Survey

based in Rotterdam in the Netherlands and historical shoreline data obtained from the survey and mapping division of Ghana Lands Commission. The 1974 shoreline position was extracted from a digital topographic map, the 2005 shoreline position was digitized from an orthophoto map, while the 1986 – 2001 shoreline positions were digitised from satellite imageries. The 2011 shoreline position was obtained *in-situ* by running RTK-GPS survey along the coast between Kedzi and Hlorve.

The reliability of the data set was checked by determining their positional accuracies against the 1974 shoreline position. The 1974 shoreline position was used as the reference because its reliability has been checked and commented on by previous studies (Appeaning Addo et al., 2011; Appeaning Addo et al., 2008; Boateng, 2006). The extracted shoreline positions in rocky areas on the satellite imageries were compared with the extracted shoreline positions of the same areas on the 2005 orthophoto maps. This was based on the assumption that the shoreline in the rocky areas did not experience significant change. The results increased confidence in using the data for the change detection and analysis. Both the high and low water marks were mapped during the field survey to reduce the uncertainty in determining the shoreline position. The high water line (HWL) was adopted as the shoreline proxy to ensure consistency and compatibility with the archived data available for change detection (Appeaning Addo et al., 2008, Boak and Turner, 2005).

Shoreline mapping

Various methods were adopted to map the shoreline positions from the data sources. The onscreen digitising method of mapping the shoreline proxy was used to extract

Table 2. Summary of parameters of wave data.

Statistic	Hs(m)	Tp(s)	Wave Direction(°)	Wind speed(m/s)	Wind Direction(°)	Wave speed(m/s)
Mean	1.39	10.91	194.21	4.65	213.04	17.02
Max	2.82	19.68	330.64	11.00	358.94	30.70
Min	0.0	3.11	46.37	0.00	1.10	4.85
Mode	1.26	11.07	206.51	4.96	224.99	17.27

shoreline positions from the satellite imageries, the orthophoto map and the digital topographic map in a GIS environment. Each shoreline position was mapped three times to reduce uncertainty in the mapping processes.

The 2011 shoreline position was surveyed by identifying the HWL on the ground and mapped using RTK-GPS technique, (Boak and Turner, 2005). The equipment used included two SOKKIA GSR2700 ISX Differential-GPS, a monocycle to facilitate movement of the rover station along the shoreline proxy and the beach face, and an allegro (data logger) to record and store the field data. An established ground control point with known coordinates was used as the base station after its reliability had been checked. The RTK-GPS method enabled fast and accurate positional measurement of the shoreline positions, intertidal and other morphological features.

Wave data analysis

Historical wave data from 1997 to 2006, obtained from Svašek Hydraulics (2006), included the significant wave height ranging from 0 to 2.82 m with average height of 1.32 m, wave periods from 3.11 to 19.68s, dominant wave direction of 206.51°, wind speed and wind direction. A summary is presented in Table 2.

Ocean energy comes in a variety of forms such as marine currents, tidal currents and waves. Ocean waves transfer energy over a fetch distance with little energy loss. Waves are therefore a regular source of power with an intensity that can be accurately predicted (Vining, 2005). The following models were adopted to compute the wave energies, surge levels and power densities from the wave data based on Vining (2005).

$$E_{density} = \rho_w g H^2/8 = \rho_w g A^2/2 \quad (1)$$

$$P_{density} = E_{density}/T = \rho_w gA^2/(2T) \quad (2)$$

$$\tau = \rho C v^2; \quad (3)$$

$$\text{Surge levels} = \tau/(2g\rho_w)(L/h) \quad (4)$$

where T is the period in seconds, P is the power density in joules per second, E the energy in joules, ρ_w is the density of the sea water, ρ_a is the density of the air, H the significant wave height in meters, A is the wave amplitude, C is drag coefficient, h is depth of water, L the length of the coast and τ is the stress of the wind force.

From the relations above, it is evident that the higher the energy density available the higher the power density. This relationship is significant since wave energy contributes considerably to shoreline morphological changes through transporting sediments along the coast. Hence the amount of sediment transported depends on the energy of the incoming waves.

Computing erosion rates

The historic shoreline rates of change were computed statistically using the Digital Shoreline Analysis System (DSAS). DSAS is an extension to ArcGIS that enables shoreline rates of change to be calculated. The extension contains three main components that define a baseline, generate orthogonal transects at a user-defined separation along the coast and calculate rates of change (linear regression, endpoint rate, averages of different time periods, weighted linear regression and jack-knife). It utilizes the avenue code to develop transects and rates, and uses the avenue programming environment to automate and customize the user interface (Morton et al., 2004). The software also enables the reliability of the calculated rates of change to be established. Linear regression and end point methods were adopted for the rates of change estimation. The linear regression method was selected due to its consistency in giving better long term forecasting results than other techniques (Dean and Dalrymple, 2002), while the end point rates method is simple and requires only two shoreline positions to obtain a rate of change. The end point rate was used to compute the rate of change between two shoreline positions, while the linear regression (LR) method facilitated computing the rates of change for all the combined different date shoreline positions. The shorelines

Table 3. Uncertainty error on shorelines.

Shoreline	Digitised	HWL	Scale	Total
1974	±1.0	±4.0	-	±4.35
1986	±15.0	±4.5	±3	±19.5
1991	±15.0	±4.5	±3	±19.5
2001	±15.0	±4.5	-	±18.6
2005	±1.0	±3.5	-	±4.5
2011	±1.00	±0.02	0.0	±1.0

were exported into a geodatabase and a baseline developed by mimicking the outer shoreline. Orthogonal transects were cast at 50 m intervals to cross the shorelines positions, which was used to compute the rates of change. The end point rate method was used to estimate the erosion rates between 1974-1986, 1986-1991, 1991-2001, 2001-2005 and 2005-2011.

Uncertainty quantification

Various sources or errors were identified and the uncertainty quantified. Apart from the 2011 data which was collected *in-situ*, the remaining data had plausible sources of errors due to registration, digitisation, scale and the shoreline identification. Accuracy of the horizontal distance obtained by the RTK-GPS method is between 1 and 3 cm. A summary of the estimated uncertainty values are presented in Table 3. The values were annualised to provide error estimation for the shoreline rate of change at any given transect using the equation:

$$E_a = \sqrt{(E_1^2 + E_2^2 + E_3^2 + E_4^2 + E_5^2 + E_6^2)}/T \qquad (5)$$

where T is the period and E_1, E_2, E_3, E_4, E_5 and E_6 are the various total uncertainties. The annualised error Ea, for all the shorelines was estimated as ±0.9 m/yr.

RESULTS

Six shoreline data sets were available for the shoreline change analysis. The shorelines of 1974 and 2005 covered the entire coast of Ghana while the rest covered mainly the study area. Transects were cast at 50 m intervals perpendicular to the shorelines which helped to generate points for shoreline change analysis. This is indicated in the lower panel of Figure 5, which shows two shoreline positions and the transects casted perpendicular to be used for the rates of change computation. The black arrow on the upper panel indicates Hlorve and the dotted red arrow, Kedzi, as the towns bonding the shoreline.

Shoreline change results

The shoreline rates of change for the study area calculated using the linear regression method are presented in Table 4 for both the pre-defence and post-defence periods. Columns 1-4 are the results for the pre-Keta sea defence era while columns 5 – 8 are for the post-Keta sea defence period. Columns 1 and 5 represent the average rates of change computed for the two periods. The results include the standard Error of linear regression (LSE), the R-squared of linear regression and the confidence interval of linear regression for period 1974 – 2001 (pre) and for the period 2001-2011(post). The mean of the R-squared (square of the correlation coefficient) was found to be 0.8 (see columns 2 and 6 of Table 4). The maximum and minimum changes before the defence structures constructed in Keta were 0.22 and -5.13 m/yr respectively. Similarly for the post defence period, -10.77 and -22.98m/yr were the minimum and maximum estimated rates respectively along transects.

The average rates of change for the 48 transects was -3.20 and -17.0m/yr for the two periods respectively. Table 5 shows the minimum, mean and maximum rates obtained using the linear regression. Between the years 1974 and 2001, minimal erosion was computed along the beach.

For the shoreline change rates computed using the end point rate method, the summary of all the change rates are tabulated below in Table 6. This method was used for computing only two shorelines positions.

The changes in the shoreline position between the years are shown in Figure 6. It shows that the rates of erosion were high around some transects relative to the others. It also shows the variation in shoreline change interannually

Before the construction of the defence structures in 2001, the extreme point of the landward movement of the shoreline occurred around transect 14 (a horizontal distance of about 700 m from the last groyne). However,

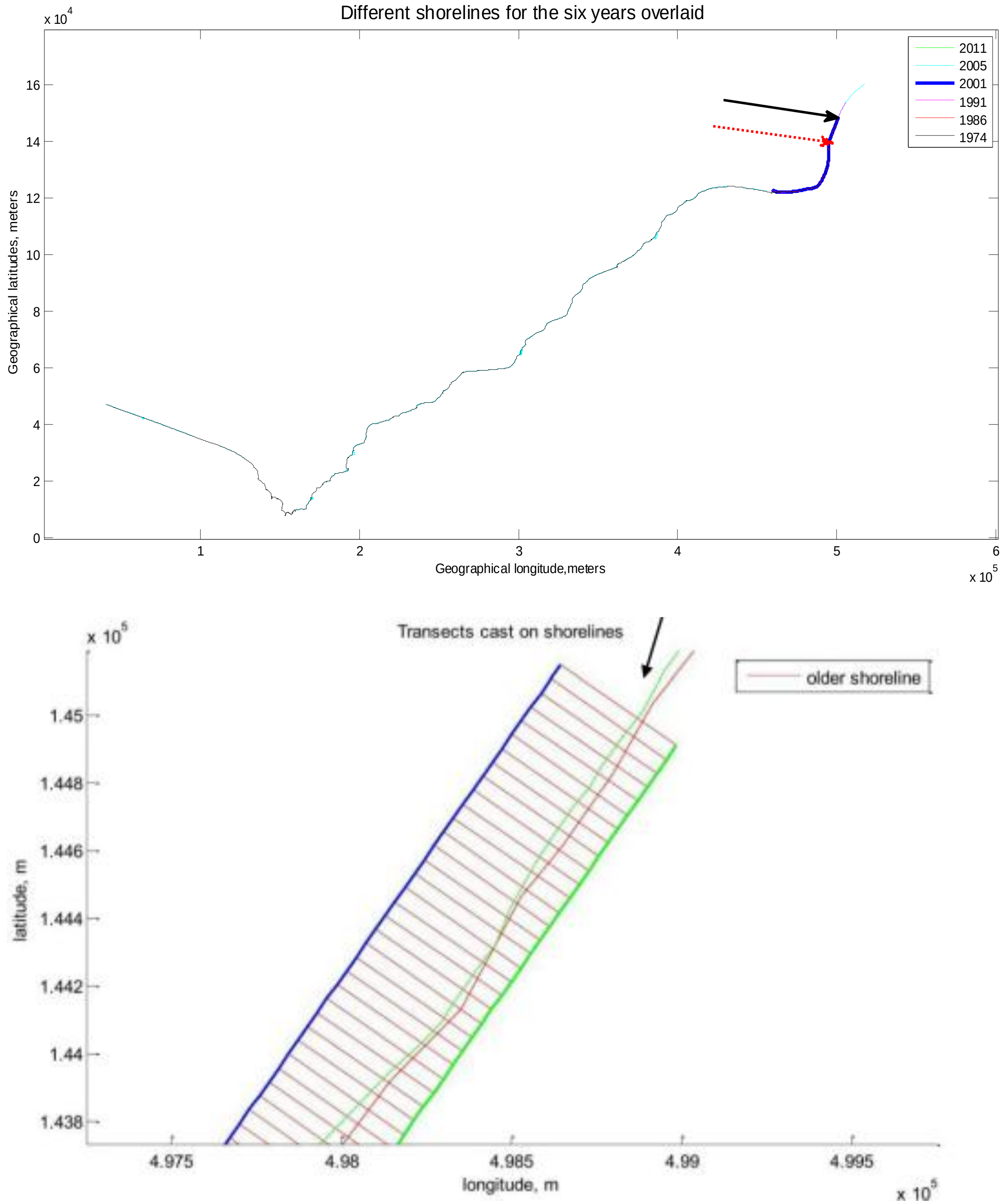

Figure 5. Upper panel:Shoreline of Ghana, study area between Kedzi (red dottted arrow) and Hlorve (black arrow) with the six set of data overlaid and, Lower panel:Transects cast at an interval of 50 meters on shorelines.

Table 4. Erosion rates for Pre- and Post-Keta sea defence project.

LRR1	LR2	LSE 5	LCI9	LRR1	LR2	LSE	LCI95	Transect ID
-3.45	0.89	16.6	3.66	-15.07	0.9	36.01	62.35	1064
-3.5	0.89	17.21	3.8	-10.77	0.78	41. 92	72.59	1065
-3.51	0.87	18.64	4.11	-13.05	0.7	62.41	108.06	1066
-3.61	0.87	19.03	4.2	-15.07	0.9	36.01	62.35	1067
-3.3	0.87	17.26	3.81	-16.29	0.65	87.49	151.48	1068
-2.86	0.85	16.29	3.6	-16.78	0.61	97.46	168.74	1069
-3.06	0.85	17.72	3.91	-16.13	0.63	90.28	156.31	1070
-3.31	0.91	14.6	3.22	-15.49	0.69	76.66	132.73	1071
-3.32	0.9	15.47	3.41	-14.06	0.72	64.34	111.4	1072
-3.15	0.84	19.05	4.21	-14.39	0.76	58.56	101.39	1073
-3.6	0.88	18.74	4.14	-14.83	0.78	57.18	99.01	1074
-3.8	0.95	12.46	2.75	-17.31	0.79	66.34	114.86	1075
-3.95	0.99	6.67	1.47	-19.46	0.77	78.1	135.23	1076
-3.98	0.99	4.61	1.02	-20.51	0.75	87.85	152.1	1077
-3.84	0.99	5.49	1.21	-21.86	0.76	89.63	155.2	1078
-3.68	0.98	6.62	1.46	-22.6	0.76	92.1	159.47	1079
-3.57	0.98	6.73	1.48	-22.98	0.79	85.76	148.49	1080
-3.73	0.92	14.75	3.26	-21.65	0.82	74.34	128.72	1081
-3.72	0.88	18.94	4.18	-20.72	0.85	62.68	108.52	1082
-3.58	0.82	23.08	5.09	-18.5	0.86	53.82	93.19	1083
-3.56	0.78	26.2	5.78	-18.02	0.89	47.09	81.54	1084
-3.81	0.86	21.51	4.75	-18.36	0.9	43.89	75.99	1085
-4.6	0.95	14.1	3.11	-19.89	0.92	42.8	74.1	1086
-5.01	0.96	13.27	2.93	-21.03	0.91	48.63	84.21	1087
-5.13	0.97	11.43	2.52	-20.69	0.9	50.12	86.79	1088
-4.68	0.96	12.91	2.85	-19.87	0.85	60.25	104.31	1089
-4.21	0.88	21.11	4.66	-19.09	0.83	63.08	109.21	1090
-4.07	0.82	26.37	5.82	-18.24	0.83	60.76	105.2	1091
-3.96	0.77	29.75	6.57	-17.36	0.82	59.71	103.39	1092
-3.87	0.77	29.19	6.44	-16.81	0.81	59.56	103.13	1093
-3.81	0.81	25.28	5.58	-16.34	0.8	59.69	103.35	1094
-3.5	0.8	23.96	5.29	-16.31	0.78	64.18	111.13	1095
-3.03	0.75	24.45	5.4	-16.47	0.79	62.8	108.74	1096
-2.85	0.71	25.13	5.55	-15.45	0.77	61.12	105.83	1097
-2.75	0.74	22.27	4.92	-14.67	0.78	56.58	97.96	1098
-2.55	0.74	20.71	4.57	-13.83	0.76	57.46	99.5	1099
-2.3	0.69	21.06	4.65	-13.66	0.79	52.13	90.26	1100
-2.41	0.74	19.49	4.3	-14	0.7	67.43	116.75	1101
-2.4	0.73	19.87	4.39	-15.02	0.68	75.52	130.77	1102
-2.65	0.79	18.54	4.09	-16.43	0.76	68.34	118.33	1103
-2.85	0.83	17.79	3.93	-16.54	0.78	65.19	112.88	1104
-2.66	0.79	18.83	4.16	-17.7	0.83	57.91	100.27	1105
-2.29	0.67	21.95	4.85	-16.28	0.81	57.65	99.81	1106
-1.85	0.45	27.91	6.16	-14.67	0.77	58.92	102.02	1107
-1.34	0.22	34.91	7.7	-16.92	0.86	50.71	87.8	1108
-0.88	0.08	41.41	9.14	-12.41	0.71	58.39	101.1	1109
-0.3	0.01	44.4	9.8	-13.42	0.78	52.75	91.33	1110
0.22	0.00	46.35	10.23	-15.26	0.85	46.54	80.58	1111

Table 5. Summary of change rates using linear regression.

Period	Minimum	Mean	Maximum
Before Defence	-5.13	-3.20	0.22
After Defence	-22.98	-17.00	-10.77
Total 1974-2011	-9.74	-7.76	-4.92

Table 6. Summary of change rates using the end point method.

Before Defence	**1974-1986**	**1986-1991**	**1991-2001**	**Average**
Change rates ±0.31m/yr	-1.54	-3.21	-2.24	-2.33
After Defence	**-**	**2001-2005**	**2005-2011**	**Average**
Change rates ±0.31m/yr	-	-3.99	-2.88	-3.44

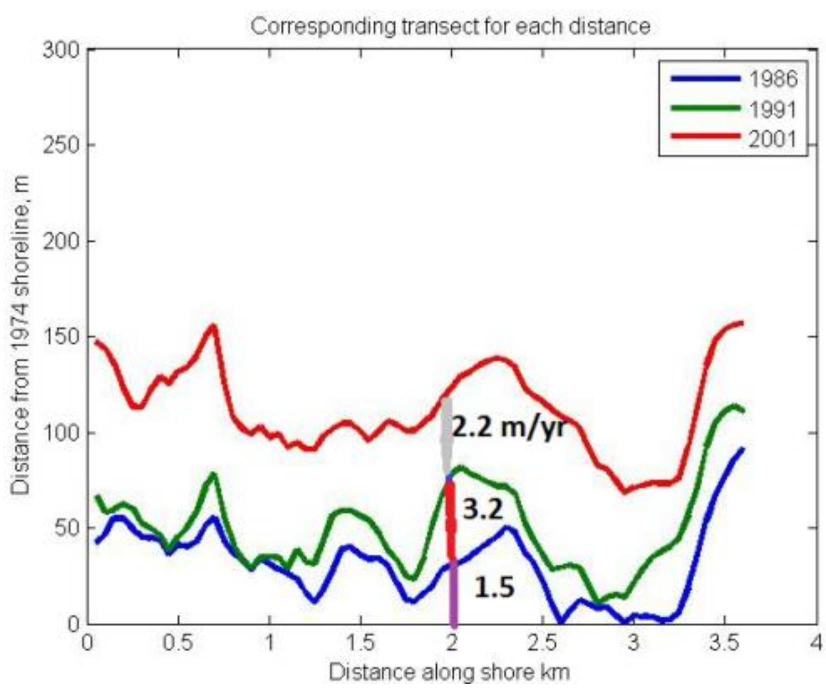

Figure 6. Shoreline profile before the defense construction with the rates of change between 1986 and 1991, and 1991 and 2001.

after the construction in 2001, transect 14 (that is, at a horizontal distance of 700 m from the last groin) experienced least landward movement of the shoreline as shown in Figure 6. The area that appeared to be eroding more is around transect 40 (that is, horizontal distance of about 1.5 km). This is evident in Figure 7 which has the widest gap between shorelines 2005 and 2011. It also indicates that near the defence structure at Kedzi, there is minimal erosion as compared to the further eastern side of the coast at Hlorve.

Although the entire coast was eroding in the study area before the defence structures were constructed, the trend and intensity has changed after the engineering interventions. Figure 8 shows areas that are eroding or accreting in the study area. It shows that there is a marginal accretion in an area near Hlorve at a rate of about 0.22 m/yr during the pre-construction period (1974-2001). This occurred at about 2,400 m from the last groyne. Figure 8

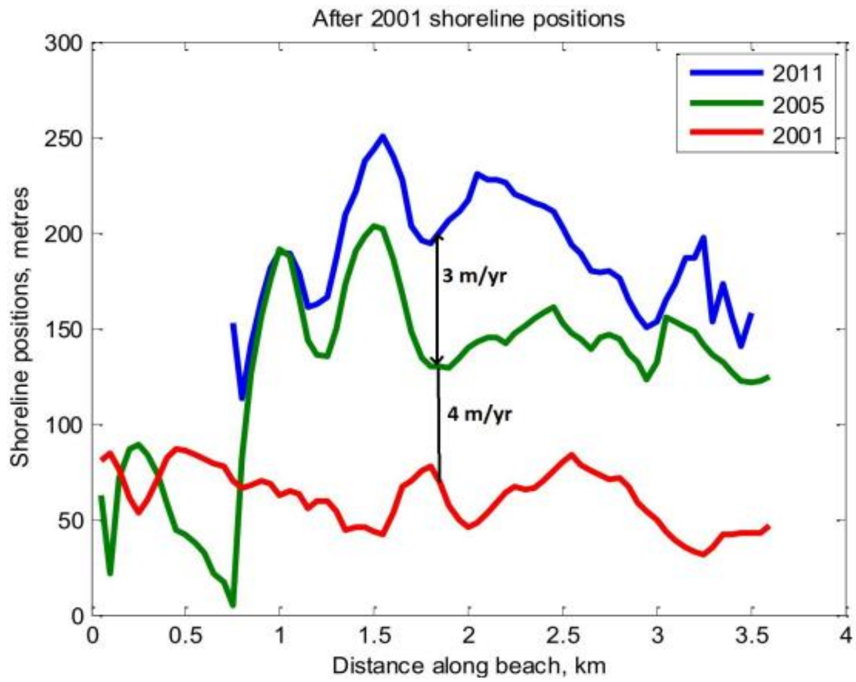

Figure 7. Shoreline profile after the defence construction indicating the rate of shoreline movement between 2001 and 2011.

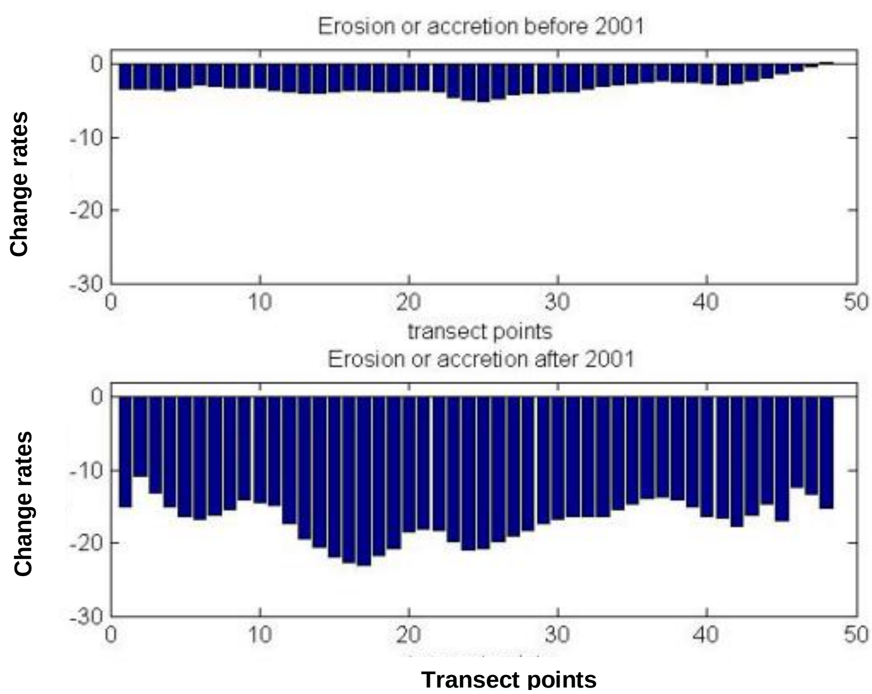

Figure 8. Erosion and accretion areas. Upper panel: Rates (m/s) before KSDP. Lower panel: Rates (m/s) after KSDP. The distance between Kedzi and Hlorve is from left to right.

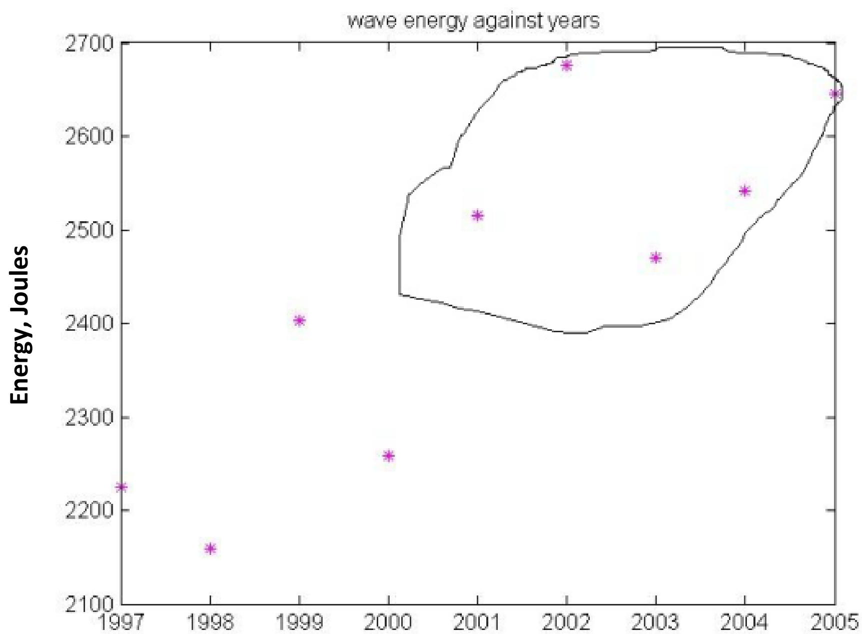

Figure 9. Wave energy variation between the years of 1997 and 2005.

(lower panel) also indicates that the entire area is experiencing erosion after the construction of the defence structures.

Results from wave regime along the coast

Waves reaching the shores of Ghana consist of swells originating from the oceanic area around the Antarctica and seas generated by locally occurring winds (Irvine et al., 2009). The wave energies for the different successive years from 1997 to 2006 were found to be (2.2247 2.1592 2.4031 2.2581 2.5155 2.6775 2.4693 2.5428 2.6443 1.7463) $*10^3$ kg/s^2. The year 2002 recorded the highest amount of wave energy, while the lowest wave energy was recorded in 2006 (Figure 9).

The dominant amplitude of waves in the region is 1.0 m. The wave period for the swells generally falls in the range of 3 to 20s. The swell has a mean period of 11s and a relatively regular averaged height between 1 to 2 m (Irvine et al., 2009). The dominant wave direction is from the south south-west. The mean wave height for each month was estimated to determine how they relate (Figure 10). August registered the highest mean significant wave height of 1.73 m. With these findings, future works are intended to look at the interactions between various hydrodynamic parameters and morphology nearshore at all scales.

The yearly amounts of significant wave heights, periods, wind speeds and surge levels from deep offshore towards the coast of Keta are presented in Figure 11. The magnitude of each parameter affects the quantity of sediment transport. Longer period of wind blow leads to large waves which break and facilitate transport of sediment along or across shore. Figure 11 show the undulations in these features.

The correlation between the wave parameters are presented in Figure 12. These correlations were determined for directions between 210°–240°. The periods, surge and wind speed have correlation coefficients of 0.36, 0.39, and 0.39 with the significant wave heights. The results reveal how the various parameters increase in relation to each other. Wind and wave directions (for all directions) increase in the same direction, but with a small correlation of 0.12. This low value is as a result of high swells along the study area.

The percentage occurrence of 30° wave-direction classes and 0.5 m significant wave heights was done to show the amount of waves that move towards ranges of directions. From Figure 13, it is evident that most of the waves come from the south-west (210°-240°) direction (top left). The peak values of the other parameters are shown in relation with the peak wave height. The same is done for the peak period (top right), mean surge (bottom left) and mean wind speed (bottom right).

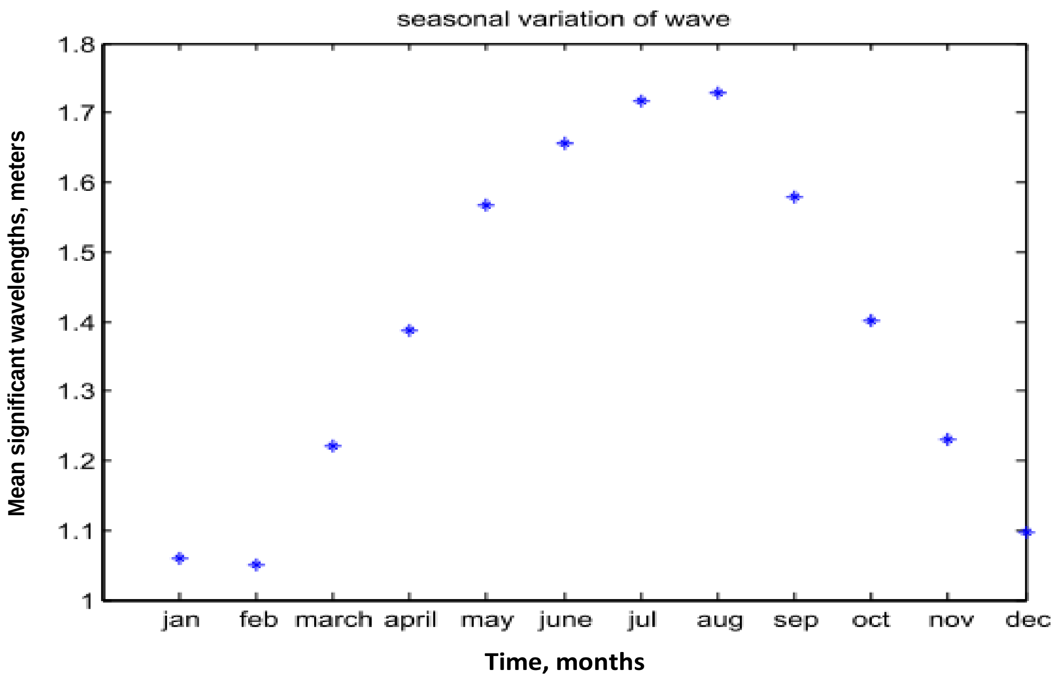

Figure 10. Monthly variations of mean wave heights.

DISCUSSION

The study has revealed the impact and ongoing threat that coastal erosion poses to the down-drift shoreline of the KSDP. Previous studies by Ly (1980) reported that the rate of shoreline retreat in Keta between 1923 and 1949 was about 4 m/yr; between 1959 and 1975 it was around 6 m/yr; and after 1964 the rate of erosion increased to between 8 and 10 m/yr after the construction of the Akosombo dam over the Volta River. This development resulted in the construction of the Keta sea defence structures in an attempt to reverse the trend in 2001. The groynes are trapping sediment and building the beach at Keta while the down-drift coast is being starved of sediment. Although the study area was eroding before the engineering intervention in Keta (refer to Figure 8), the rate has intensified after the defence work. The mean erosion rate before the construction was 3.20 ±0.3 m/yr which increased to about 17.00 ±0.3 m/yr after the construction of the defence structures (Table 5). Although this is relatively high, it confirms the observation by Appeaning Addo (2009) who reported a rate of about 15 m/yr.

Wave action has been identified as a primary agent in causing coastal erosion along several coasts (Brunel and Sabatier, 2009; Li, et al., 2001) and a dominant reshaping agent responsible for short term change (Backstrom, et al., 2008). Dominant wind direction towards the coast is south-west (210°-240°) at an angle of about 45° to the coast and approximately in the same direction with the waves (refer to Figure 13). This confirms observations by AESC (1980) who identified south southwest as the dominant wave direction. The approaching waves dissipate their energy as they approach the shallow shore as a result of depth-induced breaking.

The mean wind speed of about 4.96 m/s along the coast influences the approaching waves (refer to Figure 12). The oblique wave approach to the coastline generates longshore current when they break. This current is largely responsible for the net sediment transport from west to east. The results show that there is a correlation between the wave heights and the wind speed. With a mean wave height of about 1.4 m, Kedzi, would experience wave energy of 1750 kg/s^2 onshore. This energy could be severe enough to cause backwash and also carry sediment across shore resulting in erosion. The presence of an open coast with relatively narrow continental shelf provides minimum resistance to the oceanic forces.

Conclusion

This study establishes that the Keta Sea Defence Project is

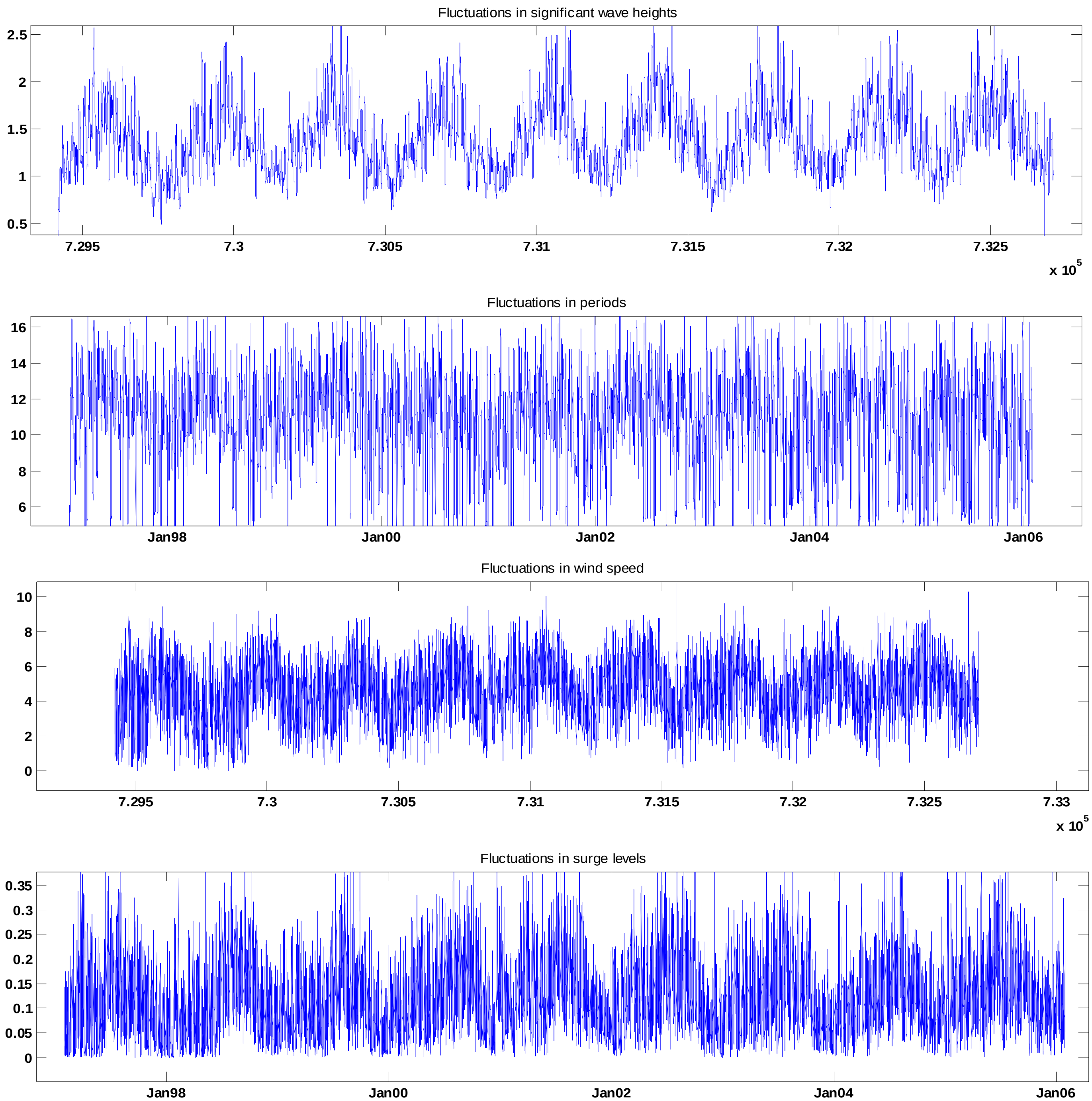

Figure11. The parameter variation of wave heights, periods, wind speed and surge levels along the coastline between 1997 and 2006.

the major cause of increased erosion rates in the study area. This is a signal that the shore-hardening technique, by using the groynes is not the best method of shore protection at Keta. The groynes trapping sediment to build the beach at Keta have starved the shoreline between Kedzi and Hlorve of the needed volume of sediment to maintain

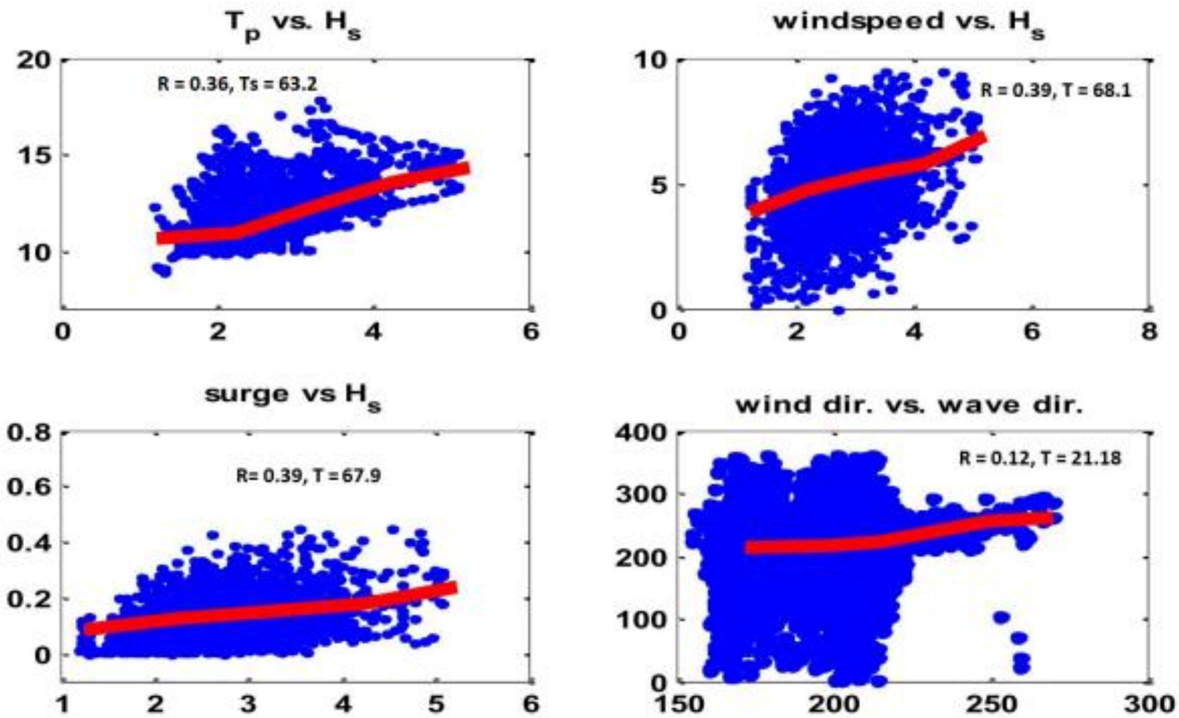

Figure 12. Estimation of the correlation between the wave parameters that were obtained and validated by student test statistic.

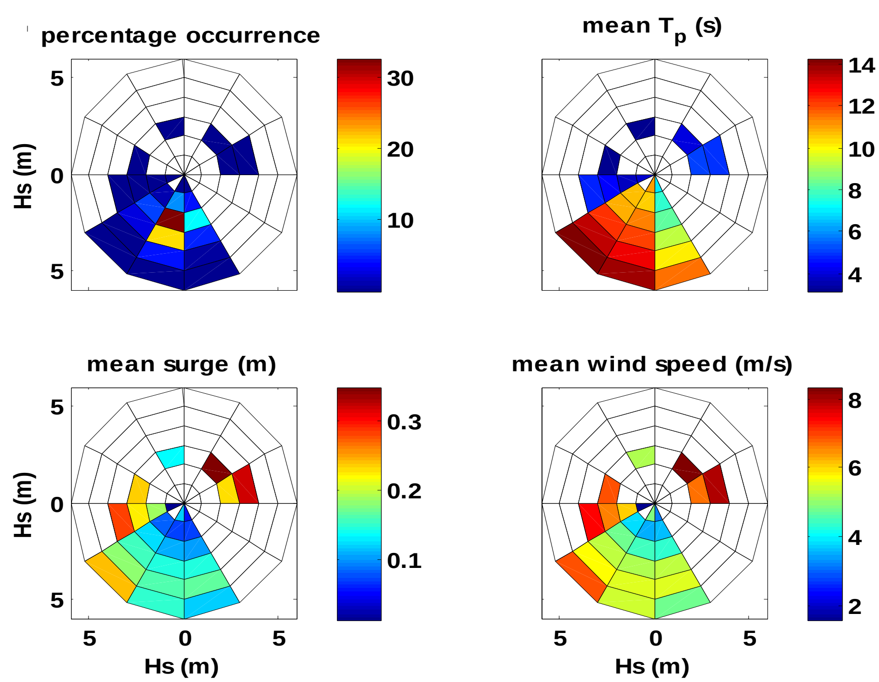

Figure 13. Percentage occurrence of wave.

the beaches. There is a general deficit in the sediment budget of the study area. The relatively low-lying topography of the beach and the unique location of the study area render it highly vulnerable to both sea level rise under climate change and lagoon water rise in the event of high rainfall. Swell waves approaching the coast facilitate generating relatively high energy currents that transport sediment along and across shore. Other factors that contribute to the high rate of erosion include the shoreline orientation. It enables long shore currents to form when the waves break obliquely.

It is recommended that a critical assessment of the coastal erosion situation in the study area should be undertaken to determine a suitable mitigation strategy for the communities. Although the period under study is short and could be influenced by cyclic events, there is the need to embark on a regular monitoring scheme to enable understanding into the changing trend. A subsequent study already started is intended to look at the changes in an intensedspatio-temporal scale. This would specify any unusually large hydrodynamic feature. It is suggested that if halting of building of settlements near the beach, planting of mangroves near the estuary, and halting of sand mining are encouraged, these could also reduce the shoreline erosion.

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