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Conference Paper · August 2013

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Spatial and Temporal Analysis of Beach Elevations for Monitoring Coastal Erosion for Sustainable Development: A Case Study of Ola Beach in Cape Coast, Ghana.

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Abstract

Beach profiles are important tools for understanding long-term trends of erosion, accretion and predicting the future evolution of coastal landforms. Beaches are required to be monitored for their sustainable development given their ecological and economic roles in coastal economies. In developing countries, this is particularly important in the context of sea level rise resulting from climate change and poor land use in coastal areas. This paper presents a simple and cost-effective educational tool for coastal erosion monitoring. Employing the Emery technique as the assessment tool, data was collected on a fortnight basis from January- March, 2012 at low tides at the Ola Beach in Cape Coast, Ghana. Mean elevations of the beaches relative to the shoreline were determined as the primary mode of analysis based on four 100 m transects of 20 m intervals laid perpendicular to the shoreline. One way Analysis of Variance (ANOVA) test was used to assess variations in mean beach elevations. The results of a one way ANOVA (p-values of 0.257 and 0.112 for spatial and temporal profiles respectively) suggest that each of the four profiles did not experience any significant changes in elevation over the six survey period. Even though there were no significant differences ($p>0.05$) in mean elevation for both spatial and temporal profiles during the survey period, the data generally suggests that the active shoreface was prone to erosion. It is therefore recommended that for this particular beach, protection measures have to be considered for the adjoining dunes in order to avert possible future catastrophic impacts of coastal erosion. On the basis of the findings, it is possible that beach profiles provide important shoreline position data for geometric evaluation of beaches over time.

Key words: Beach erosion monitoring, Emery technique, Sustainable development, Ghana

Introduction

Beaches are gently-sloping land along the edge of a sea or other large body of water and made up of unconsolidated materials mainly sand, gravel, pebbles, cobbles, rock or shells (Morang, *et al.*, 2002). Beaches are important for a number of reasons. They protect the surrounding landscape from erosion by forming an active interface between land and sea where sediments (sand and other particles) are in constant motion due to wind, tides, relative sea levels, storms and anthropogenic activities as reported by Woods Hole Oceanographic Institute(WHOI, 2001). They also support marine life and biodiversity such as the provision of nesting sites for sea turtles. Economically, sandy beaches are important for local eco-tourism activities (Diop*et* *al*., 2011). However, degradation of beaches has been a matter of global concern in recent years (Ramsay and Cooper, 2002; Payet *et al*., 2009). According to Anthony (2005), 70 % of the world's beaches are experiencing coastline retreat as a result of coastal erosion.

The economic and social impacts of coastal erosion can be very severe and may even compromise the sustainable development of communities located along the coast. Coastal erosion renders properties located along the coastlinesusceptible to destruction or loss in terms of economic value. Beaches, as habitats are lost and the resource base of tourism is lost as well, placing severe pressure on livelihoods built around tourism. The high cost of coastal protection programmes also mean that significant resouces will have to be shifted from other priority areas such as agriculture and energy leading to a possible slump in key areas of the economy. Ultimately the economic base of eroded areas will be affected and sustainable development of such areas will be severely restricted. Stress related illnesses may also become pervasive as property owners lose their assets and income earners lose their primary livelihoods (Johnson, 2014) Increasing human population in coastal areas has contributed to pronounced morphological and scenic changes, particularly, at the beaches. However, the impacts of natural phenomena including climate change cannot be excluded (Anonymous, 2002; IPCC, 2007).In West Africa, degradation due to human impacts has been very significant partly due to demand-driven quest for beach sand that has led to its extraction on a commercial scale for building and other construction purposes (Diop *et al*., 2011). In Ghana, these changes have physically manifested as coastal erosion, flooding, salt water intrusion, mangrove degradation and related socio-economic problems (EPA, 2009). Armah (1991) confirmed that coastal erosion, flooding and shoreline retrogression are problems confronting the Ghanaian coast. With one-third of the Ghanaian population living within 3 km of the coast, the situation requires some urgent attention and intervention. This is because substantial amount of investments in basic infrastructure including roads, fish landing sites, hotels and other residential housing facilities in coastal areas require protection from coastal erosion (Nail *et al*., 1993; Armah and Amlalo, 1998; EPA, 2009). The lateral changes in the coastline position in the country has not only resulted in coastal erosion, but has also destroyed the coastal environment, affected the socio-economic life ofthe local population, threatened cultural heritage and hindered coastal tourism development (Appeaning-Addo, 2009).

Pilkey (2013) observed that under normal circumstances, beach materials accumulate during periods of accretion or are relocated during periods of erosion. According to Marchand (2010), changes in the topography of beaches as a result of coastal erosion, only becomes a problem when there is no room to accommodate the change. However, the most significant changes of beaches occur seasonally following storms but can recover quickly thereafter (WHOI, 2001). In general, changes in beach configuration are related to the onshore-offshore transport of sedimentary materials by waves. This movement of sand reflects in the beach morphology by the construction and destruction of the berm growth and migration of near shore sand bars.

Beach profiling is one way to obtain information about changes taking place along the shoreline and how quickly coastal landforms transform with a fair degree of accuracy and precision (WHOI, 2001). Nail *et al*. (1993) opined that the method could be used as a first step to monitoring coastal erosion prior to the design of appropriate intervention and mitigation measures. Beach profiling coupled with shoreline position data could provide baseline scientific information that could be used for the geometric evaluation of coastal areas. It is an important tool for understanding long-term trends of erosion, accretion and predicting the future evolution of coastal landforms.

The primary objective of this study was to assess the feasibility of using beach profiling as a tool for coastal erosion monitoring in Ghana using the Emery technique. To achieve this goal, beach profiles were constructed and the elevations measured and the volume of sediment deposition and loss at the beach estimated.

The outcome of this study is intended to promote the application and further development of the Emery technique for monitoring coastal erosion along the West African coast relatively quickly and at fairly lower costs. It is also meant to serve as an educational tool for first and second cycle institutions to promote scientific awareness and understanding of the coastal environment. The data can form a basis for validating other data sets including remotely acquired data to aid proactive measures aimed at conserving beaches.

Materials and Methods

Study Area

The Ola beach in the Cape Coast Metropolis of Ghana is a stretch of sandy beach approximately 2 km along the Gulf of Guinea (Figure 1). The area experiences a diurnal tidal effect with a mean tidal period of approximately 12 hours 28 minutes. The study was conducted over a 100m stretch of beach because it provides ample distance information to describe the issue of coastal erosion devoid of redundant data. The study could not go beyond this stretch of space also because of time and resource constraints.

Figure 1: Photograph of the study area (Ola Beach)

The rationale for selecting the site for the study was because the location is very close to a major regional asset notably the trans-West African highway (see Figure 2). The beach occurs within the vicinity of residences and a cluster of social amenities including basic and senior high schools, the University of Cape Coast and the Cape Coast district hospital. Besides, the location provides important livelihood conditions in its use for recreation and tourism as well as serves as important fish landing site for beach seine fishermen within the local community.

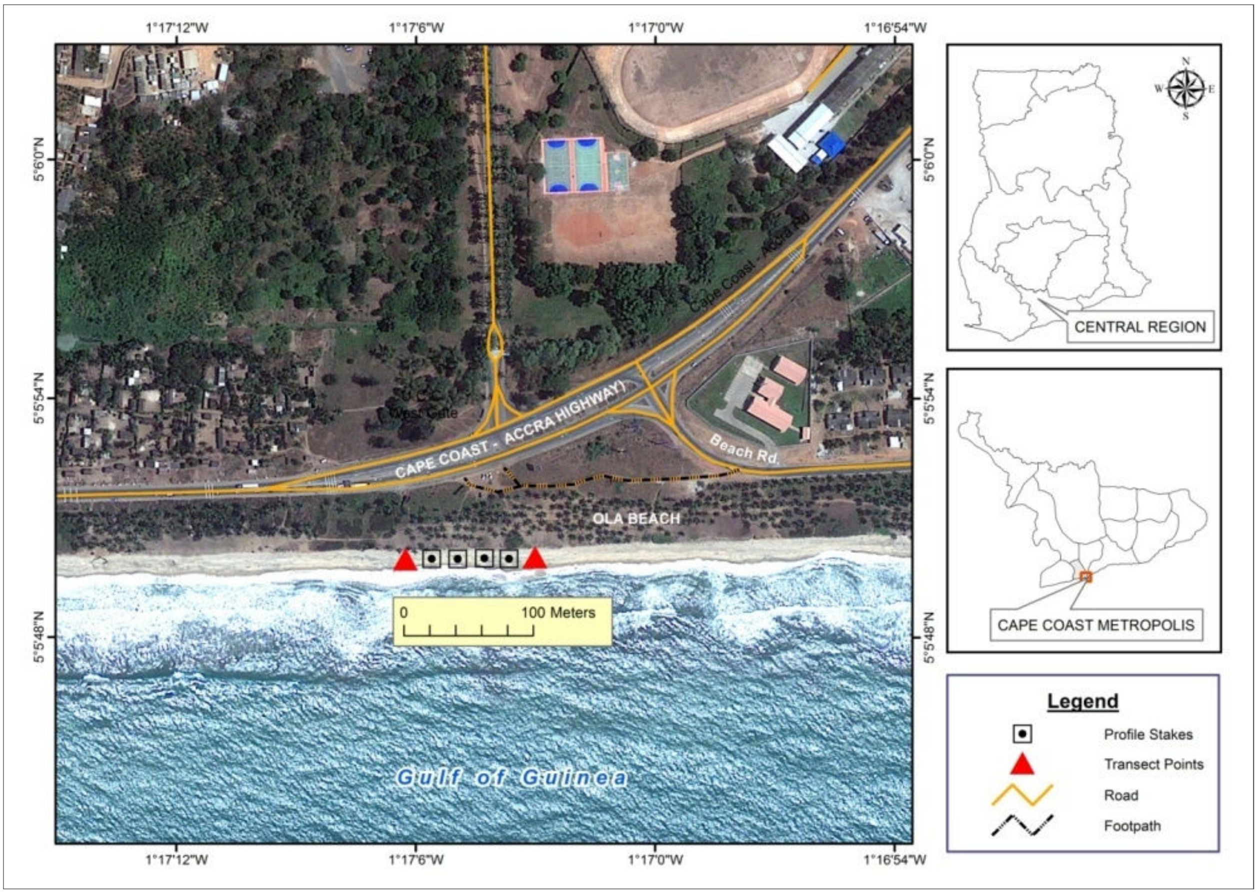

Figure 2: Map of the study area showing the sampling stations

Data Collection

Data was collected through the application of the Emery technique (Emery, 1961). The Emery technique (Figure 3) is a simple method for beach profiling based on the use of two graduated rods. The two wooden rods measuring 4 cm x 2 cm x 200 cm in dimension were aligned and reading of the intersection with the horizon allowed for the determination of differences in level along each profile (Rumpp and Rumpp, 1999).Beach surveys were carried out fortnightly for three months (January to March, 2012) at low tides in order to obtain maximum profile distance. The average intertidal distance of the study area during the study period was measured to be 5.1 m. Since Beach profile is a topographic transect measured perpendicular to the shoreline (WHOI 2001), four 100 m transects were placed perpendicular to the shore at 20 m intervals to cover an area of 600 m^2. A hand held GPS was used to determine the coordinates of the sampling stations (Profiles 1 to 4). The designated stations were marked with a 5 x 5 cm^2 and 150 cm long wooden profile stakes.

As shown in Figure 3, the apparatus comprises two stakes connected by a rope of known length. The 2m length sets the measurement interval for individual data points along the profile. Each stake has a metric-measurement scale which runs from 0 at the top, down to the bottom of the stake.

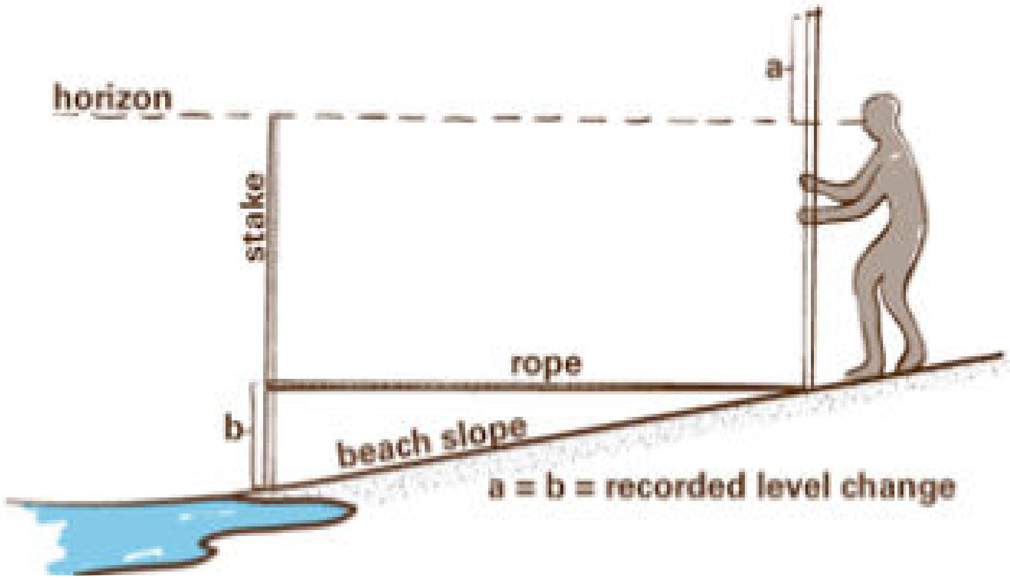

Figure 3: Illustration of the Emery rod technique (Source: Florida Center for Instructional Technology, 2005).

If the beach is sloping downward toward the sea, the horizon is sighted though the hole in the landward rod to coincide with a value on the seaward rod (Figure 3). The distance (a) from the top of the landward rod to the sightline is determined. If the beach is locally sloping upward in the offshore direction, then (a) is measured on the seaward rod and the sighting is with the horizon over the top of the landward rod. In either case, the measured distance (a) is equal to the distance (b) that the beach has either dropped or risen within the horizontal distance between the rods (the rope length).

Data Analysis

Beach profiles were determined by the cumulative vertical elevations (y-axis) plotted as a function of the cumulative horizontal positions (x-axis). The cumulative change in elevation was determined by the summation of the cumulative changes in elevation for the various profiles that were established. The volume of sediment removed or deposited was estimated as the product of the vertical elevations (in metres) and their respective corresponding horizontal distances for each profile. The rate of erosion or accretion was also estimated over the study period. A one-way analysis of variance (ANOVA) and Tukey Post Hoc tests were used to determine the significant differences in mean elevations at 0.05 significance level. The angle of shoreface depression was determined using trigonometric functions based on estimated mean heights of the shoreface elevation/depression and the transect distance used.

Results and Discussion

Spatial Variation in Beach Elevations

The Cape Coast beach was observed to comprise of two main profiles namely low energy accretional profiles and high energy erosional profiles. The vertical elevation of the profiles of all the surveys did not exceed 750 cm below the position of the profile stakes.

The data shows spatial variations in beach elevations among the four profiles (Figure 4). The estimated mean shoreface elevations for profile stake 1 through 4 ranged from 29.1 cm to 31.5cm every two meter distance representing shoreface angle of depression of between 8.4^{o} to 9.1^{o}over the study period. Profile stake 4 registered the highest mean shoreface elevation of 31.5 ± 1.6 cm (SE) whilst the lowest mean value of 29.1 ± 1.0 cm (SE) was recorded at profile stake 2 (see appendix 1). This confirms high shoreface dynamics as shown for all the six surveys, an indication of sediment accumulation from the beach face towards the backshore during periods of accretion and sediment removal during periods of erosion. From this observed trends, it could deduced that the shoreline elevations exhibit low energy accretional profiles while and complimented by high energy erosional profiles at certain locations on the beach similar to findings by Saravanan and Chandrasekars (2010).

The result of the one way ANOVA (p-value of0.257) indicated no significant differences in mean elevation for the profiles for the study period. Post Hoc tests performed failed to establish any pair-wise significant differences in elevation for the different profiles across the survey period.

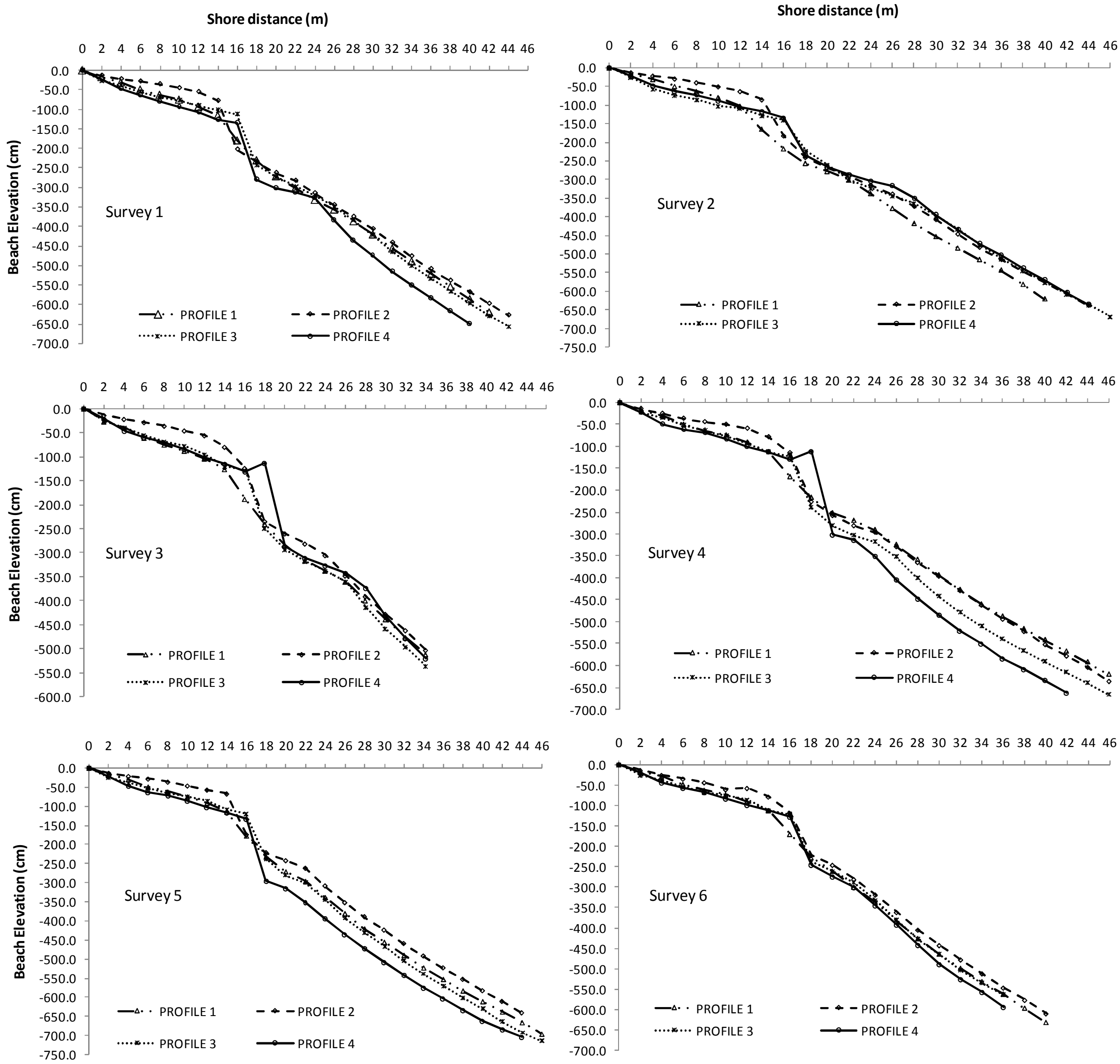

Figure 4: Spatial variations in beach elevation of the six surveys

Temporal Variation in Beach Elevations

Results from the six surveys showed marginal variations in beach elevation for each profile (Figure 5). Temporally, these variations were noticeable ranging from a mean value of 29.5 – 31.6 cm every two meters (see appendix 2A). These represent shoreface depression angles ranging between 8.3^o and 9.1^o. The highest mean beach elevation (31.6 ± 1.1 cm SE every 2 meters) occurred during survey 6. The lowest elevation of 27.0 ± 2.0 cm SE for every two meters was recorded during survey 4. Although the data point to a cyclical dynamics of erosion followed by accretion over the study period, temporal changes in mean elevation generally suggest that the shoreface is prone to erosion. This is because the various berm shapes were indication of low energy accretional profiles confirming the constant movement of sediments on the beach (Holman, 1986; Tinnin and Williams, 2005). The results of a one way ANOVA (p-value of 0.112) suggest that each of the four profiles did not experience any significant changes in elevation over the six survey period. Post Hoc tests also showed no significant differences in elevations for paired surveys.

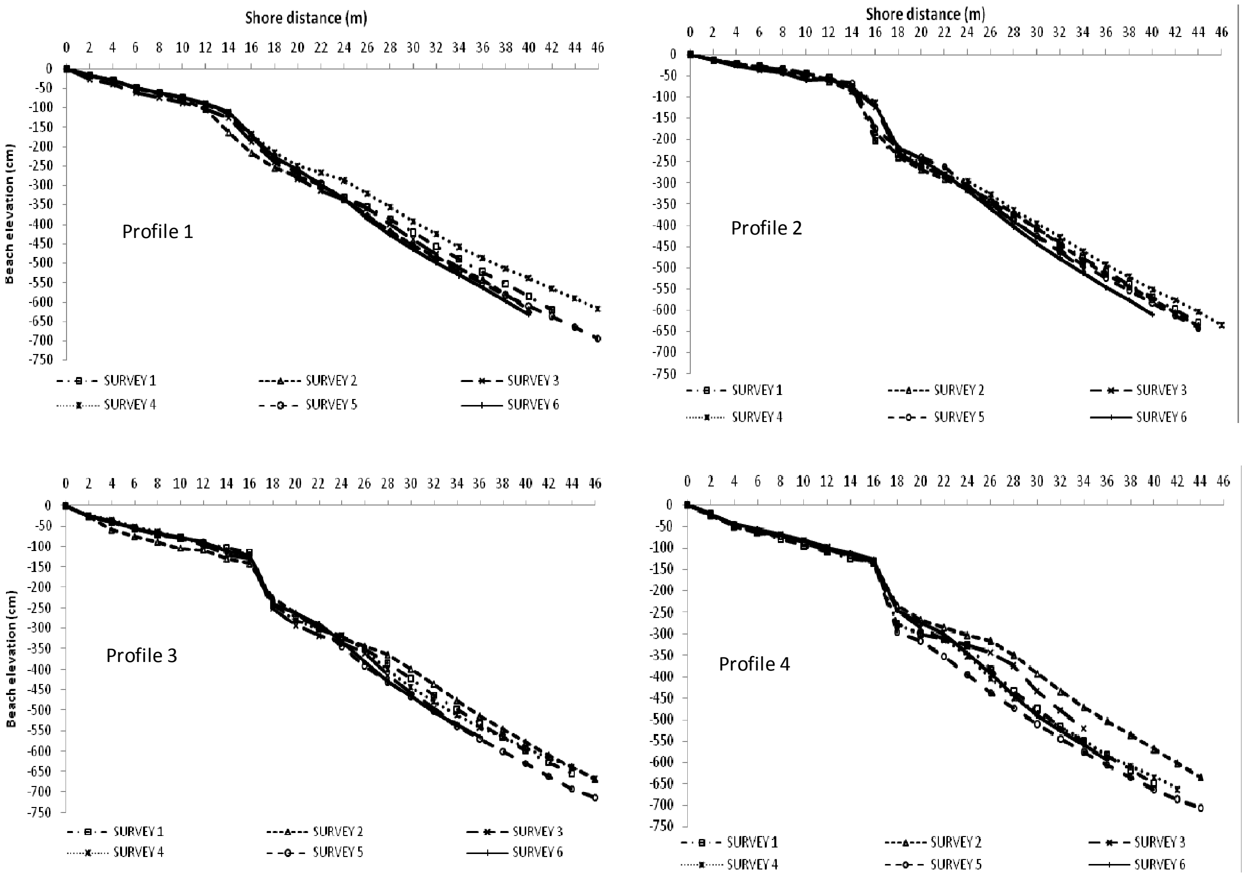

Figure 5: Temporal variation in mean elevations of the four profiles

Volume of Sediment Accretion and Loss

The relatively sharp beach gradient as shown in Figures 4 and 5 with short intertidal distance of a little over 5 m was expected to result in a fairly high rate of erosion as opposed to accretions. However, the cumulative loss in sediment over the study period was 61.6 m^3 representing 0.11% of the total sediment at the study site (Table 1). This is indicative of the occurrence of fairly low amount of erosion.

According to Komar (1998), such an assessment even though may be simple, provides reasonably accurate measurements of beach profiles in terms of the accretion and loss of sediments. It also has the advantages in the use of light, inexpensive equipment, which can be easily carried to distant survey sites, for very rapid surveys.

Table 1: Cumulative changes in sediment accretion and loss

Survey	Sand volume (m^3)	Cumulative change in sediment volume (m^3)	Percentage cumulative change (%)
1	1022.0	0	0
2	1025.2	3.2	0.31
3	824.0	-201.2	-19.63
4	1033.0	209.0	25.36
5	1102.6	69.6	6.74
6	960.4	-142.2	-12.90
Total		**-61.6**	**-0.11**

Conclusions

The data suggests that the Ola beach is prone to erosion because the shoreface was characterized by a generally more active sediment removal than accretion over the study period. The study proposes longer-term and broader spatial monitoring of the beach and advocates for protection of the beach and its adjoining dunes in order to mitigate possible future catastrophic impacts of coastal erosion which could lead to deep escarpments at the studied site. The study confirms that the Emery technique is a valuable tool for geometric evaluation of beaches in Ghana over time.

The technique is a low-cost tool, deplores minimal technology for validating other data sets such as remotely sensed that may be acquired to aid beach development interventions and serve as educational tool for second cycle and tertiary institutions.

Acknowledgement

This study was conducted within the context of the Integrated Coastal Zone Management Programme at the Department of Fisheries and Aquatic Sciences of the University of Cape Coast. The authors are grateful to Ms. Pam Rubinoff of the Sea Grant Programme, Coastal Resources Center (CRC) of the University of Rhode Island, USA for the technical assistance during the inception of the field surveys in Ghana.

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Appendix

Appendix 1: Cumulative total elevation per survey obtained during the study from January through March, 2012

1A: Survey 1

CUMULATIVE DISTANCE (m)	PROFILE 1	PROFILE 2	PROFILE 3	PROFILE 4
0.0	0.0	0.0	0.0	0.0
2.0	-17.0	-13.0	-26.0	-21.5
4.0	-30.5	-22.0	-38.5	-47.5
6.0	-49.0	-28.0	-55.5	-64.0
8.0	-62.5	-35.0	-68.5	-80.5
10.0	-75.0	-45.0	-77.5	-94.0
12.0	-93.0	-55.0	-89.5	-108.0
14.0	-116.0	-77.5	-102.5	-126.0
16.0	-179.5	-202.5	-113.0	-133.5
18.0	-230.5	-233.5	-242.0	-278.0
20.0	-271.5	-262.5	-272.0	-301.0
22.0	-302.0	-282.5	-297.0	-313.0
24.0	-332.0	-314.5	-321.0	-326.0
26.0	-357.0	-345.0	-349.5	-384.0
28.0	-387.0	-375.0	-384.0	-435.0
30.0	-421.0	-406.5	-422.0	-475.0
32.0	-457.0	-441.5	-464.5	-516.0
34.0	-490.0	-476.5	-499.5	-551.0
36.0	-523.0	-509.0	-533.0	-584.0
38.0	-555.0	-539.0	-565.0	-617.0
40.0	-587.0	-569.0	-597.0	-649.0
42.0	-621.0	-598.0	-628.0	
44.0		-628.0	-656.0	

1B: Survey 2

CUMULATIVE DISTANCE (m)	PROFILE 1	PROFILE 2	PROFILE 3	PROFILE 4
0.0	0.0	0.0	0.0	0.0
2.0	-17.0	-13.0	-26.0	-24.0
4.0	-31.0	-22.0	-58.0	-50.0
6.0	-50.0	-30.0	-74.0	-64.0
8.0	-63.5	-40.0	-87.0	-73.0
10.0	-79.5	-51.0	-103.0	-88.0
12.0	-103.5	-64.0	-108.0	-105.0
14.0	-164.5	-86.0	-130.0	-116.5
16.0	-217.5	-183.0	-142.0	-134.5
18.0	-256.5	-241.0	-224.0	-234.5
20.0	-278.5	-269.5	-261.5	-267.5
22.0	-301.5	-292.0	-301.5	-286.5
24.0	-337.5	-315.5	-323.5	-304.0
26.0	-377.5	-339.5	-343.5	-317.0
28.0	-417.5	-372.0	-364.0	-350.0
30.0	-453.0	-408.0	-398.5	-394.0
32.0	-484.0	-447.0	-434.5	-435.0
34.0	-515.0	-482.5	-476.5	-472.0
36.0	-543.0	-515.5	-513.5	-504.0
38.0	-581.5	-545.5	-545.5	-537.0
40.0	-620.5	-575.5	-577.0	-570.0
42.0		-606.5	-607.5	-603.0
43.0		-638.5	-637.5	-635.5
44.0			-668.5	

1C: Survey 3

CUMULATIVE DISTANCE (m)	PROFILE 1	PROFILE 2	PROFILE 3	PROFILE 4
0.0	0.0	0.0	0.0	0.0
2.0	-27.0	-14.0	-26.0	-22.0
4.0	-40.0	-22.0	-39.0	-47.0
6.0	-61.0	-28.5	-56.0	-61.0
8.0	-75.0	-36.0	-69.5	-71.0
10.0	-88.0	-46.0	-78.5	-85.0
12.0	-104.0	-56.0	-96.0	-102.0
14.0	-126.0	-80.0	-120.0	-116.0
16.0	-188.0	-124.0	-130.0	-132.0
18.0	-240.0	-235.0	-250.0	-114.0
20.0	-284.0	-260.5	-293.0	-286.5
22.0	-316.0	-281.5	-319.0	-312.5
24.0	-337.0	-305.5	-337.0	-327.5
26.0	-360.0	-348.0	-360.5	-343.5
28.0	-399.0	-391.0	-414.0	-374.5
30.0	-438.0	-428.0	-458.0	-432.5
32.0	-476.0	-462.0	-496.0	-477.5
34.0	-511.0	-503.0	-536.0	-520.5

1D: Survey 4

CUMULATIVE DISTANCE (m)	PROFILE 1	PROFILE 2	PROFILE 3	PROFILE 4
0.0	0.0	0.0	0.0	0.0
2.0	-17.0	-13.5	-22.0	-21.0
4.0	-30.0	-24.5	-34.0	-49.0
6.0	-49.5	-35.5	-50.5	-60.0
8.0	-62.5	-43.5	-62.5	-69.0
10.0	-74.0	-49.5	-76.5	-83.0
12.0	-90.0	-58.5	-92.0	-99.0
14.0	-112.0	-78.0	-111.0	-113.0
16.0	-169.0	-114.0	-123.0	-129.0
18.0	-216.0	-226.0	-240.0	-111.0
20.0	-251.5	-257.5	-280.0	-301.0
22.0	-268.5	-280.5	-303.0	-313.0
24.0	-289.5	-295.5	-316.0	-351.0
26.0	-323.5	-328.5	-352.0	-405.0
28.0	-357.5	-364.5	-399.0	-448.0
30.0	-392.5	-395.5	-441.0	-485.0
32.0	-426.0	-428.5	-478.0	-520.0
34.0	-459.0	-461.5	-510.0	-549.0
36.0	-487.0	-493.5	-540.0	-585.0
38.0	-515.0	-521.5	-565.0	-609.0
40.0	-540.5	-551.5	-590.0	-634.0
42.0	-566.5	-577.5	-614.0	-662.0
44.0	-591.0	-603.5	-638.0	
46.0	-619.0	-635.5	-666.0	

1E: Survey 5

CUMULATIVE DISTANCE (m)	PROFILE 1	PROFILE 2	PROFILE 3	PROFILE 4
0.0	0.0	0.0	0.0	0.0
2.0	-17.0	-14.0	-26.0	-23.0
4.0	-30.5	-22.0	-38.0	-47.0
6.0	-49.5	-29.0	-54.0	-63.0
8.0	-62.5	-37.0	-67.0	-72.0
10.0	-75.5	-47.0	-76.0	-88.0
12.0	-91.5	-58.0	-87.0	-104.0
14.0	-115.5	-68.0	-110.0	-118.0
16.0	-177.5	-175.0	-121.0	-135.0
18.0	-232.5	-222.0	-238.0	-296.0
20.0	-271.5	-243.0	-281.0	-317.0
22.0	-296.5	-263.0	-300.0	-353.0
24.0	-338.5	-309.0	-344.0	-395.0
26.0	-380.5	-353.0	-392.0	-437.0
28.0	-420.5	-390.0	-430.0	-474.0
30.0	-455.5	-425.0	-467.0	-510.0
32.0	-489.5	-460.0	-504.0	-544.0
34.0	-522.5	-493.0	-539.0	-575.0
36.0	-552.5	-524.0	-570.0	-605.0
38.0	-582.5	-554.0	-601.0	-635.0
40.0	-610.5	-584.0	-631.0	-662.0
42.0	-637.5	-612.0	-663.0	-685.0
44.0	-665.5	-642.0	-693.0	-705.0
46.0	-695.5		-714.0	

1F: Survey 6

CUMULATIVE DISTANCE (m)	PROFILE 1	PROFILE 2	PROFILE 3	PROFILE 4
0.0	0.0	0.0	0.0	0.0
2.0	-17.0	-14.0	-26.0	-22.0
4.0	-30.0	-26.0	-38.0	-44.0
6.0	-48.5	-35.0	-56.0	-57.0
8.0	-62.5	-44.0	-68.0	-68.0
10.0	-73.5	-61.0	-77.0	-82.5
12.0	-90.5	-58.0	-87.0	-100.0
14.0	-112.5	-79.0	-112.0	-112.0
16.0	-171.0	-119.0	-122.0	-128.0
18.0	-227.5	-222.0	-239.0	-246.5
20.0	-261.5	-246.0	-262.0	-275.5
22.0	-300.5	-281.0	-290.0	-301.5
24.0	-336.5	-318.5	-333.0	-345.5
26.0	-383.5	-361.5	-381.0	-393.5
28.0	-426.5	-404.5	-428.0	-442.5
30.0	-464.5	-442.5	-465.0	-489.5
32.0	-499.5	-477.5	-503.5	-525.5
34.0	-532.0	-511.5	-535.5	-558.5
36.0	-563.0	-546.5	-564.5	-594.5
38.0	-597.5	-576.5		
40.0	-632.5	-609.5		

Appendix 2: Cumulative total elevation per profile stake obtained from January through March, 2012

2A: Profile stake 1

CUMULATIVE DISTANCE (m)	SURVEY 1 (cm)	SURVEY 2 (cm)	SURVEY 3 (cm)	SURVEY 4 (cm)	SURVEY 5 (cm)	SURVEY 6 (cm)
0	0.0	0.0	0.0	0.0	0.0	0.0
2	-17.0	-17.0	-27.0	-17.0	-17.0	-17.0
4	-30.5	-31.0	-40.0	-30.0	-30.5	-30.0
6	-49.0	-50.0	-61.0	-49.5	-49.5	-48.5
8	-62.5	-63.5	-75.0	-62.5	-62.5	-62.5
10	-75.0	-79.5	-88.0	-74.0	-75.5	-73.5
12	-93.0	-103.5	-104.0	-90.0	-91.5	-90.5
14	-116.0	-164.5	-126.0	-112.0	-115.5	-112.5
16	-179.5	-217.5	-188.0	-169.0	-177.5	-171.0
18	-230.5	-256.5	-240.0	-216.0	-232.5	-227.5
20	-271.5	-278.5	-284.0	-251.5	-271.5	-261.5
22	-302.0	-301.5	-316.0	-268.5	-296.5	-300.5
24	-332.0	-337.5	-337.0	-289.5	-338.5	-336.5
26	-357.0	-377.5	-360.0	-323.5	-380.5	-383.5
28	-387.0	-417.5	-399.0	-357.5	-420.5	-426.5
30	-421.0	-453.0	-438.0	-392.5	-455.5	-464.5
32	-457.0	-484.0	-476.0	-426.0	-489.5	-499.5
34	-490.0	-515.0	-511.0	-459.0	-522.5	-532.0
36	-523.0	-543.0		-487.0	-552.5	-563.0
38	-555.0	-581.5		-515.0	-582.5	-597.5
40	-587.0	-620.5		-540.5	-610.5	-632.5
42	-621.0			-566.5	-637.5	
44				-591.0	-665.5	
46				-619.0	-695.5	
Mean Elevation (cm/2m)	**29.6**	**31.0**	**30.1**	**27.0**	**30.7**	**31.6**

2B: Profile stake 2

CUMULATIVE DISTANCE (m)	SURVEY 1 (cm)	SURVEY 2 (cm)	SURVEY 3 (cm)	SURVEY 4 (cm)	SURVEY 5 (cm)	SURVEY 6 (cm)
0	0.0	0.0	0.0	0.0	0.0	0.0
2	-13.0	-13.0	-14.0	-13.5	-14.0	-14.0
4	-22.0	-22.0	-22.0	-24.5	-22.0	-26.0
6	-28.0	-30.0	-28.5	-35.5	-29.0	-35.0
8	-35.0	-40.0	-36.0	-43.5	-37.0	-44.0
10	-45.0	-51.0	-46.0	-49.5	-47.0	-61.0
12	-55.0	-64.0	-56.0	-58.5	-58.0	-58.0
14	-77.5	-86.0	-80.0	-78.0	-68.0	-79.0
16	-202.5	-183.0	-124.0	-114.0	-175.0	-119.0
18	-233.5	-241.0	-235.0	-226.0	-222.0	-222.0
20	-262.5	-269.5	-260.5	-257.5	-243.0	-246.0
22	-282.5	-292.0	-281.5	-280.5	-263.0	-281.0
24	-314.5	-315.5	-305.5	-295.5	-309.0	-318.5
26	-345.0	-339.5	-348.0	-328.5	-353.0	-361.5
28	-375.0	-372.0	-391.0	-364.5	-390.0	-404.5
30	-406.5	-408.0	-428.0	-395.5	-425.0	-442.5
32	-441.5	-447.0	-462.0	-428.5	-460.0	-477.5
34	-476.5	-482.5	-503.0	-461.5	-493.0	-511.5
36	-509.0	-515.5		-493.5	-524.0	-546.5
38	-539.0	-545.5		-521.5	-554.0	-576.5
40	-569.0	-575.5		-551.5	-584.0	-609.5
42	-598.0	-606.5		-577.5	-612.0	
44	-628.0	-638.5		-603.5	-642.0	
46				-635.5		
Mean Elevation (cm/2m)	**28.5**	**29.0**	**29.6**	**27.6**	**29.2**	**30.5**

2C: Profile stake 3

CUMULATIVE DISTANCE (m)	SURVEY 1 (cm)	SURVEY 2 (cm)	SURVEY 3 (cm)	SURVEY 4 (cm)	SURVEY 5 (cm)	SURVEY 6 (cm)
0	0.0	0.0	0.0	0.0	0.0	0.0
2	-26.0	-26.0	-26.0	-22.0	-26.0	-26.0
4	-38.5	-58.0	-39.0	-34.0	-38.0	-38.0
6	-55.5	-74.0	-56.0	-50.5	-54.0	-56.0
8	-68.5	-87.0	-69.5	-62.5	-67.0	-68.0
10	-77.5	-103.0	-78.5	-76.5	-76.0	-77.0
12	-89.5	-108.0	-96.0	-92.0	-87.0	-87.0
14	-102.5	-130.0	-120.0	-111.0	-110.0	-112.0
16	-113.0	-142.0	-130.0	-123.0	-121.0	-122.0
18	-242.0	-224.0	-250.0	-240.0	-238.0	-239.0
20	-272.0	-261.5	-293.0	-280.0	-281.0	-262.0
22	-297.0	-301.5	-319.0	-303.0	-300.0	-290.0
24	-321.0	-323.5	-337.0	-316.0	-344.0	-333.0
26	-349.5	-343.5	-360.5	-352.0	-392.0	-381.0
28	-384.0	-364.0	-414.0	-399.0	-430.0	-428.0
30	-422.0	-398.5	-458.0	-441.0	-467.0	-465.0
32	-464.5	-434.5	-496.0	-478.0	-504.0	-503.5
34	-499.5	-476.5	-536.0	-510.0	-539.0	-535.5
36	-533.0	-513.5		-540.0	-570.0	-564.5
38	-565.0	-545.5		-565.0	-601.0	
40	-597.0	-577.0		-590.0	-631.0	
42	-628.0	-607.5		-614.0	-663.0	
44	-656.0	-637.5		-638.0	-693.0	
46		-668.5		-666.0	-714.0	
Mean Elevation (cm/2m)	**29.8**	**29.1**	**31.5**	**29.0**	**31.0**	**31.4**

2D: Profile stake 4

CUMULATIVE DISTANCE (m)	SURVEY 1 (cm)	SURVEY 2 (cm)	SURVEY 3 (cm)	SURVEY 4 (cm)	SURVEY 5 (cm)	SURVEY 6 (cm)
0	0.0	0.0	0.0	0.0	0.0	0.0
2	-21.5	-24.0	-22.0	-21.0	-23.0	-22.0
4	-47.5	-50.0	-47.0	-49.0	-47.0	-44.0
6	-64.0	-64.0	-61.0	-60.0	-63.0	-57.0
8	-80.5	-73.0	-71.0	-69.0	-72.0	-68.0
10	-94.0	-88.0	-85.0	-83.0	-88.0	-82.5
12	-108.0	-105.0	-102.0	-99.0	-104.0	-100.0
14	-126.0	-116.5	-116.0	-113.0	-118.0	-112.0
16	-133.5	-134.5	-132.0	-129.0	-135.0	-128.0
18	-278.0	-234.5	-243.5	-279.0	-296.0	-246.5
20	-301.0	-267.5	-286.5	-301.0	-317.0	-275.5
22	-313.0	-286.5	-312.5	-313.0	-353.0	-301.5
24	-326.0	-304.0	-327.5	-351.0	-395.0	-345.5
26	-384.0	-317.0	-343.5	-405.0	-437.0	-393.5
28	-435.0	-350.0	-374.5	-448.0	-474.0	-442.5
30	-475.0	-394.0	-432.5	-485.0	-510.0	-489.5
32	-516.0	-435.0	-477.5	-520.0	-544.0	-525.5
34	-551.0	-472.0	-520.5	-549.0	-575.0	-558.5
36	-584.0	-504.0		-585.0	-605.0	-594.5
38	-617.0	-537.0		-609.0	-635.0	
40	-649.0	-570.0		-634.0	-662.0	
42		-603.0		-662.0	-685.0	
44		-635.5			-705.0	
Mean Elevation (cm/2m)	**32.5**	**28.9**	**30.6**	**31.5**	**32.0**	**33.0**

Appendix 3: Volume of sand on the beach from January through February, 2012.

	SURVEY 1	**SURVEY 2**	**SURVEY 3**	**SURVEY 4**	**SURVEY 5**	**SURVEY 6**
PROFILE 1	248.4	248.2	200	247.6	278.2	253
PROFILE 2	251.6	255.4	201.2	254.2	256.8	243.8
PROFILE 3	262.4	267.4	214.4	266.4	285.6	225.8
PROFILE 4	259.6	254.2	208.4	264.8	282	237.8
Total	1022.0	1025.2	824	1033	1102.6	960.4