



Assessment of short-term beach sediment change in the Volta Delta coast in Ghana using data from Unmanned Aerial Vehicles (Drone)

Philip-Neri Jayson-Quashigah^a, Kwasi Appeaning Addo^{b,*}, Barnabas Amisigo^c, George Wiafe^a

^a Department Marine and Fisheries Sciences, University of Ghana, Legon, Ghana

^b Institute for Environment and Sanitation Studies, University of Ghana, Legon, Ghana

^c CSIR-Water Research Institute, Accra, Ghana

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ABSTRACT

Reduced sediment in delta beach systems affects delta coast topography and influence delta beach evolution. It opens the deltaic environment up to severe ocean waves and tide attack, which threatens vulnerable coastal communities and increases the risk of the inhabitants. Changes in the beach sediment systems vary from few meters to several kilometres and from hours/days (short term) to decades (long term). Various methods have been developed to analyse changes in beach sediments. This study used Unmanned Aerial Vehicle (UAV or Drone) approach to assess short-term sediment dynamics (from April 2017 to April 2018) in three vulnerable beach systems at Old Ningo (west), Fuveme (central) and Keta (east) communities within the Volta Delta coast in Ghana. High-resolution Digital Elevation Models (DEMs) were developed from the drone images captured, which enabled perpendicular profiles to be generated. Sampled sediments were analysed to determine variation in sizes along the coast. Analysis of the profiles revealed that for the period between April 2017 and April 2018, the beach system at Ningo recorded a net loss of about 8,850 m³ volume of sediment; at Fuveme the beach system gained about 12,700 m³ net volume of sediment; in Keta the beach system also gained about 12,100 m³ net volume of sediment. Sediment size analysis revealed that the western section has a relatively finer grain size compared to the east. The coast experienced lower waves between January and February and higher waves between July and August. The pattern of change in the sediment dynamics follows the changing trend in the wave height observed in the region. This indicates that wave dynamics is a major driver of short term sediment change in the Volta delta beach systems. Increased wave intensity as a result of climate change will have a significant impact on the delta beach systems, which will increase erosion and flooding incidence.

1. Introduction

Delta sandy beaches are sensitive to erosional and depositional processes and always changing (Bird, 2008; Kaliraj et al., 2017). The changes are in response to stressors such as waves, tides and human impacts (Appeaning Addo et al., 2018b) m. They occur at a timescale of days (short term) to decades (long term) and at varying spatial scales (Taaouati et al., 2011). Understanding the short to medium term changing trend is critical for developing models that can simulate and predict the dynamics in coastal environments (Mancini et al., 2013; Yoo and Oh, 2016). Such information is also vital for coastal zone engineers and managers as well as scientists for efficient decision-making and for the design and implementation of appropriate engineering interventions (Stive et al., 2002).

Conventional data collection methods that have varying levels of

resolution have been adopted to monitor beach morphological changes over the years (Casella et al., 2016; Long et al., 2016; Turner et al., 2016). They include the use of Global Positioning System (GPS), aerial photographs, satellite imageries and airborne light detection and ranging technology (LIDAR). Systematically operating these conventional methods have challenges, which include requiring large efforts, relatively high cost, low temporal and spatial resolution of data collection (Klemas, 2015). Although the use of GPS for beach monitoring gives accurate information, it is expensive (Leatherman et al., 2005). Aerial photographs have the ability for stereo pair mapping and provide good spatial coverage (Lane et al., 2002). However the process of acquiring the near-vertical photographs and the laborious field preparation can be expensive (Darwin et al., 2013; Whitehead and Hugenholtz, 2014) (Whitehead et al., 2014; Darwin et al., 2013). Satellite imagery approach covers a large area and provides detailed spectral information

* Corresponding author.

E-mail address: kappeaningaddo@ug.edu.gh (K. Appeaning Addo).

(Boak and Turner, 2005). They are affected by cloud coverage, dust during image acquisition, pixel resolution and operational cost (Darwin et al., 2013; Whitehead et al., 2014). Although LIDAR approach produces extremely dense and accurate elevation measurements (Stockdon et al., 2002), it is limited in its temporal and spatial availability because of cost (Boak and Turner, 2005).

These challenges hinder developing systematic monitoring regime for delta beach systems, especially in developing countries (Appeaning Addo et al., 2018a). To overcome these challenges, beach profiling and 2D shoreline analysis are used for beach morphological and sediment volume analyses. However, they do not fully explain the beach volume dynamics (Yoo and Oh, 2016). These approaches generally overlook morphological changes between transects along the shoreline due to the low spatial resolution and may underestimate the volume changes (Eelsalu et al., 2015). Alternative approaches such as the Unmanned Aerial Vehicles (UAV or drone) technique are now being used for beach system monitoring (Appeaning Addo et al., 2018b). This approach is inexpensive, accurate and provide high-resolution (temporal and spatial) images for digital elevation models (DEMs) generation (Appeaning Addo et al., 2018a; Voudoukas et al., 2011). Datasets produced by drone have high resolution (< 10 cm) (Harwin and Lucieer, 2012) and supports the development of high-resolution digital elevation models (DEMs) for detailed change analysis (Hugenholtz et al., 2013). Several studies, such as Appeaning Addo et al. (2018a); Casella et al. (2014); Delacourt et al. (2009); Klemas (2015); Mancini et al. (2013), have applied the drone technology in coastal environmental monitoring and achieved reliable results.

This study uses the drone approach to determine short-term sediment change dynamics in three vulnerable coastal communities in the Volta delta in Ghana. The Volta delta, which forms part of the eastern coast of Ghana, has been identified as a hotspot for erosion. The region is located within the Bight of Benin, which has received appreciable attention in terms of research (Anthony et al., 2016; Anthony, 2015; Blivi et al., 2002). Various studies have confirmed a persistent erosion trend within the Volta Delta (Appeaning Addo, 2016; Boateng, 2012; Jayson-Quashigah et al., 2013; Ly, 1980). Reported rates of shoreline erosion for this region ranges between 2.7 m/year to 8 m/year with some locations experiencing as 17 m/year between 1984 and 2011 (Angnuureng et al., 2013). These rates are considered relatively high resulting in the destruction of infrastructure and livelihoods along this coast. For example, it is estimated that over 70% of the original Keta Township is now under the sea (Fiadzibey, 2005). These studies, however, have mostly relied on lower resolution data to assess the erosion trends, which compromises the results. This study relies on high-resolution data from drone surveys to estimate beach volume and shoreline change within the Volta Delta.

2. Study sites

The three study sites are located along the Volta Delta coast in Ghana (Fig. 1). The Volta delta has been defined to include all areas within the lower Volta basin lying below the 5m contour. It is located within latitudes $5^{\circ}25'$ and $6^{\circ}20'$ North and longitude $0^{\circ}40'$ and $1^{\circ}10'$ East (Appeaning Addo et al., 2018a,b). Morphologically, the delta is characterised by relatively steep and narrow sandy beaches with the upper beach face being approximately 1:3 and the lower beach ranging between 1:10 to 1:15 (Anthony, 2015; Roest, 2018). These profiles vary across the delta, influenced by sediment characteristics such as size, shape and weight, and the incoming waves. According to Anthony (2015), the massive spit characterising the delta occurred recently (post-mid-Holocene) in response to a westward shift in the river mouth and increased sequestering of sand by the Volta through enhanced wave refraction in the area south of Keta. The continental shelf here is narrow extending for about 15–33 km in width.

Geologically, the area is within the Keta Basin, comprising late quaternary rocks and unconsolidated sediments of clay, loose sand and

gravel deposits (Appeaning Addo et al., 2018a,b; Jayson-Quashigah et al., 2013). The 20m top layer is made up of 7m fine sand underlain by clay and weathered shale (Herrmann and Bucksch, 1989).

Waves reaching this coast consists of swell waves from south-south-west (S-SW) direction. The average significant wave height is about 1.4m (Nairn and Dibajnia, 2004) while the annual maximum reaches 2.5 – 3m with periods between 6 and 16s (Nairn and Dibajnia, 2004; Roest, 2018). Seasonal variations occur, with the highest waves arriving between July to August, while the lowest waves occur around January and February (Roest, 2018). There is little variation in the direction of waves approaching this coast and accounts for some of the highest rates of unidirectional longshore sand drift in the world with reported rates between 0.3 and 1.5 million m^3/year at most points (Almar et al., 2015; Laïbi et al., 2014; Nairn and Dibajnia, 2004). The tidal regime is semi-diurnal with a range of about 1 m and a spring tide average of 1.5m (Nairn and Dibajnia, 2004).

Various estimates have been reported for the pre-dam sediment yield from the Volta River. Tilmans (1993) reported 2.5million m^3/year before the construction of the Dam while Boateng et al. (2012) estimated the pre-dam supply of 71 million m^3/year which was reduced to 7 million m^3/year after the construction of the Dam. Anthony & Blivi (1999) reported 1 million m^3/year . From these estimates, only Boateng et al. (2012) provided a clear methodology for their estimates. Though these estimates cannot be directly confirmed, Nyarko et al. (2016) through sediment dating have confirmed that sedimentation rates at the Volta estuary reduced drastically from $1.08 \text{ gcm}^{-2}\text{y}^{-1}$ before the construction of the Dam to $0.50 \text{ gcm}^{-2}\text{y}^{-1}$ (50% reduction) after the construction.

Presently, the sea level is rising at a rate of about 3.1 mm/yr (Sagoe-Addy and Appeaning Addo, 2013). The sea level is predicted to continue changing in conformity to the global trend (Armah et al., 2005).

The basic winds along the study include the southwest monsoon. It blows from the south-west direction (210° – 240°) from the sea to land at about 45° angle to the coast and it is approximately in the same direction with the waves (Angnuureng et al., 2013). During the Harmattan season (December–February) winds occasionally blow from the northwest. The monthly average wind speed ranges between 1.7 and 2.6 m/s (Angnuureng et al., 2013).

The three sites selected for this study are in three different districts, which are part of the nine administrative districts located wholly or partially in the Volta delta. The coastline of the delta stretches approximately 150 km from Ghana's eastern boundary with Togo to Prampram in the west (Fig. 1). The beaches are sandy and erosional (Appeaning Addo et al., 2018b). This coastal zone has been identified by several studies as a hotspot for coastal erosion (Appeaning Addo, 2016; Appeaning Addo et al., 2018a; Boateng, 2012; Jayson-Quashigah et al., 2013).

Some locations in the past recorded some of the highest rates of coastal erosion in Ghana (up to 8 m/year) (Boateng, 2012; Ly, 1980). This resulted in significant destruction of houses and livelihoods as well as the displacement of households (Appeaning Addo et al., 2018a). It is estimated that over 70% of the original township of Keta (a coastal community in the delta region) has been lost to sea erosion (Akyeampong, 2001; Fiadzibey, 2005). Increased coastal erosion has been attributed to the significantly reduced sediment flow from the Volta river as a result of dam construction on the river in 1964 (Ly, 1980). The annual sediment transport before the dam construction was about 7.5 million m^3/s (Bollen et al., 2011). Since the construction of the dam, there are no peaks inflow discharge and the sediment transport is reduced to only a fraction of the original transport (Bollen et al., 2011). Different types of sea defence structures have been constructed along portions of the coast to manage the impact of coastal erosion. They include the Keta Sea Defence Project (groyne, revetment and nourishment), Dzita-Atorkor sea defence work (revetment) and Ada sea defence project (groynes) as shown in Fig. 1. Though the defence structures have stabilised the shoreline locally, erosion is still ongoing,

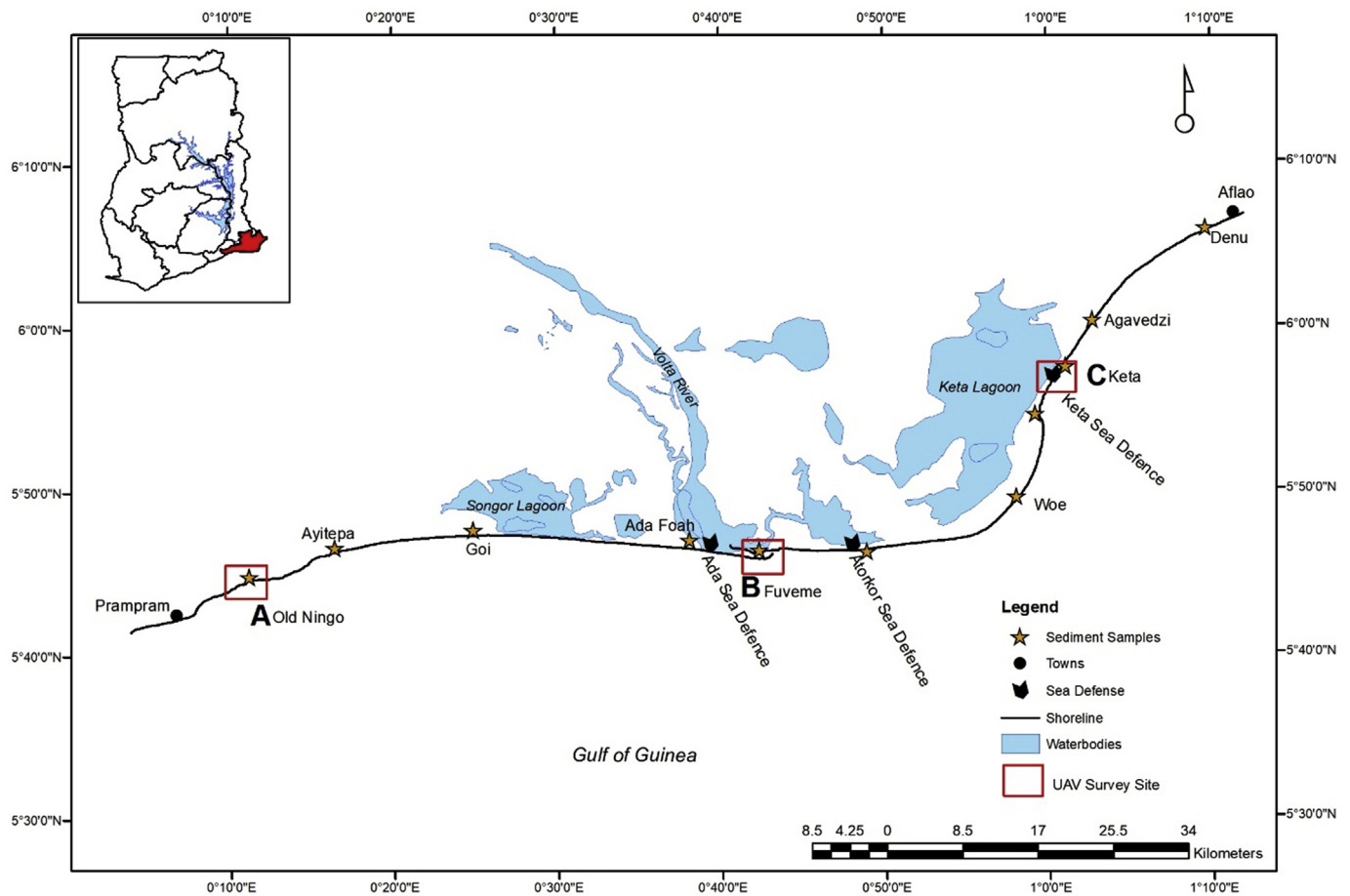


Fig. 1. Map of the Volta Delta showing the three study sites and sediment sample locations.

especially along the up drift side of these structures (Angnuureng et al., 2013; Appeaning Addo, 2016; Jayson-Quashigah et al., 2013). Swell waves approach the coast from the south southeast direction with a wave height of about 1.4 m and a period of about 11 s (Angnuureng et al., 2013). The tidal range is about 1 m and tidal current influence on sediment transport is minimal (Appeaning Addo et al., 2018b; Roest, 2018).

The selection of the three sites was informed by the erosion trends observed from the longer-term shoreline analyses (Boateng, 2012; Wiafe et al., 2013). The sites are, Old Ningo (A), Fuveme (B) and the Keta Sea Defence Site (C) (Fig. 1). Site B and C are located downdrift of the estuary while site A is located up drift.

Site 'A' records historical high rates of erosion (8.7 m/year) according to a study by Boateng (2012) with evidence of destruction of houses and livelihood (see Fig. 3. 21). The closest human intervention is a recent breakwater constructed at Asogli (about 16 km west). Site B recently recorded high rates of erosion and tidal flooding with the destruction of houses and property (Appeaning Addo et al., 2018a). This site is situated between two major sea defence projects namely, the Ada and Atorkor projects (Fig. 3.1). Site C is generally more stable due to the sea defence structure in place but exhibits knock-on effects at the down-drift of the structure (Angnuureng et al., 2013). These selected sites represent three scenarios; a steadily eroding beach (site A), a very dynamic beach (site B) and a relatively stable beach (artificial-site C). Each survey site stretches approximately 2 km alongshore and about 300 m across-shore. However, for analyses purposes, the cross-shore extent was limited to the landward edge of the beach.

3. Methodology

3.1. Data acquisition

Beach surveys (between 4 and 5 surveys) at the three sites were conducted between June 2016 and April 2018 using a DJI Phantom 3 professional drone with a 4k camera (12 megapixels). Ground Control Points (GCPs), consisting of concrete pillars buried to ground level and clearly marked (Fig. 2), were established and coordinated by connecting them to the Ghana Metre grid system. The approach followed similar standards used by the Ghana Survey Department (Ofori-Boadu, 2006). Eight (8) control points were established at sites 'A' and 'B', while site 'C' has 10 control points. More GCPs were established at site 'C' due to the presence of groynes making the terrain more complex (Fig. 3). The number of control points established per site was adequate for the study as a minimum of four symmetrically distributed control points are required in photogrammetric analysis (Miřijovský and Langhammer, 2015; Wolf et al., 2000).

Using a static Differential GPS (D-GPS) method with reference to established Ghana National coordinated pillars, each control point was observed for about 25 min on the average (Fig. 2) in order to reduce the Root Mean Square Error (RMSE). The data recorded was post-processed using standard algorithms in Topcon post-processing software. The resultant RMSE values were less than 0.04 m for both vertical and horizontal accuracies, which increased confidence in the reliability of the data for analysis. Site B and C had an existing pillar with height corrected to sea level while existing pillars at site A had only ellipsoidal heights.

Flight paths were pre-planned using the DroneDeploy web platform (DroneDeploy, n.d.). A height of 150 m was set above ground level to



Fig. 2. Establishment of control points.

allow for wider coverage of the beach while maintaining a considerably high ground sampling distance of 7 cm (0.07m). A frontal overlap of 80% and a side overlap of 70% were defined to improve stereoscopy and 3D reconstruction. The actual field campaigns were designed to coincide with low tides as much as possible using available tide forecast (Tide-Forecast, 2018) and to cover periods of low and high wave heights (April and August). Table 1 shows the surveys for the various sites and their timing. Depending on wind conditions, each flight lasted between 30 min and 1 h. Mobile markers (patterns printed on A0 flexible white materials) were placed on the GCPs before every flight to allow for easy identification during image processing.

4. Data processing

On average, about 400 images were captured during each flight. The images were manually filtered to remove blurred or overexposed shots, as well as images that had the landing gear of the drone showing due to strong winds. This reduced errors in the final point cloud. A '3D' scene reconstruction was performed using 'Structure from Motion' (SfM) and 'Multi-View Stereo' (MVS) algorithms (Smith et al., 2015; Snively, 2011) implemented in 'Agisoft Photoscan' software (Agisoft, 2018). The 'Agisoft Photoscan' software package was selected for this study because it produces more reliable results compared to the other software's (Sona et al., 2014). The SfM analyses include (1) image alignment which involved detection and matching of image features, providing the basic image structure (Mancini et al., 2013), (2) pixel-

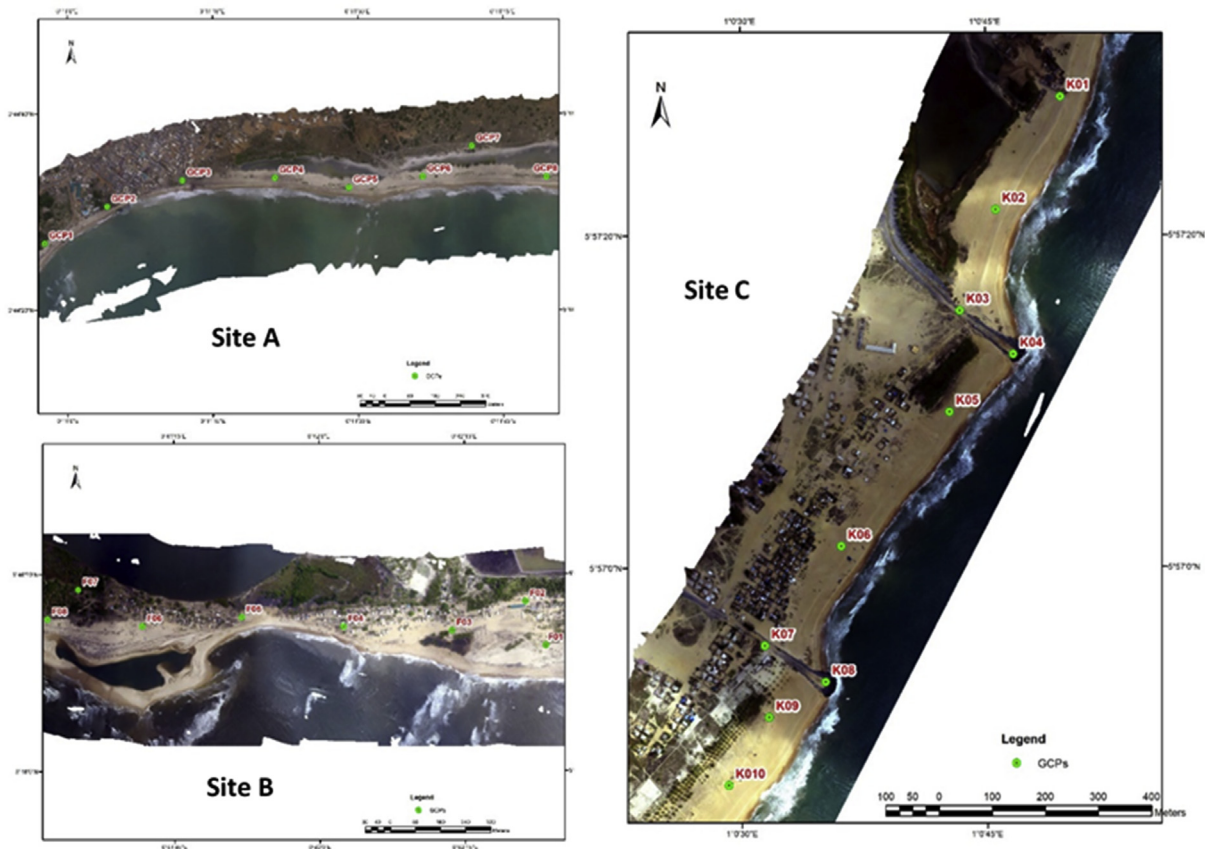


Fig. 3. Distribution of GCPs for the three survey sites.

Table 1
Flight sites, dates and number of flights.

Site	Site Description	Flight Dates	Total Flights
Site 'A'	Old Ningo, no intervention (slow eroding coast)*	12th January 2017 7th April 2017 24th August 2017	4
Site 'B'	Fuveme, Close to the estuary. No interventions (Fast eroding)	12th April 2018 24th June 2016 10th August 2016 6th April 2017 15th August 2017 ⁺ 11th April 2018	5
Site 'C'	Groyne 5 & 6 of the KSDP at Kedzi	23rd June 2016, 5th April 2017, 14th August 2017, April 2018	4

⁺ Half of the images lost due to technical challenges.

*This site was started latter due to initial weather challenges.

based dense stereo reconstruction using the aligned data and the ground control points, and (3) building of orthophotos and DEM. Where artificial objects exist along the beach (including fishing boats and buildings), the DEM was classified to extract the bare ground thereby reducing exaggeration of topographic heights.

5. Geomorphic change detection

A standard 'DEM of Difference' (DoD) approach was adopted for assessing morphological change and beach sediment budget estimation based on Brasington et al. (2003) and Wheaton et al. (2010). The DoD was generated by subtracting an earlier DEM from a newer DEM:

$$\Delta DEM = Z_2 - Z_1 \quad (1)$$

where ΔDEM is the DoD, Z_2 is the recent DEM and Z_1 is the older DEM.

The individual total RMSE from the image processing was used as the uncertainty for each DEM. The total RMSEs for the DEMs were propagated as:

$$\delta u = \sqrt{(\delta z_1^2 + \delta z_2^2)} \quad (2)$$

where δu is the propagated error, δz_1 and δz_2 are the errors from the individual DEMs.

This propagated error was used as a minimum level of detection threshold ($_{\min}LoD$) to distinguish actual surface changes from the inherent noise (Brasington et al., 2003; Wheaton et al., 2010).

5.1. Shoreline change analysis

The high water mark (HWL) which has been used by other studies as shoreline proxy (Angnuureng et al., 2013; Appeaning Addo et al., 2008; Jayson-Quashigah et al., 2013) was extracted from the orthophotos by manual digitization. Perpendicular transects were cast at 10m intervals in order to capture as many details as possible of the change. The rates of shoreline change were estimated along each transect using linear regression statistical analyses in AMBUR-R (Jackson et al., 2012). Individual RMSEs from the drone image processing was used to represent the positional accuracy for each shoreline position. The annualised shoreline accuracy (E_x) was estimated to be 0.20 m/year using the formula:

$$E_x = \frac{\sqrt{E_a^2 + E_b^2 + E_c^2 + \dots E_z^2}}{T} \quad (3)$$

Where $E_a, E_b, \dots$, are the individual shoreline positional error and T is the time that has elapsed (Appeaning Addo et al., 2008; Jayson-Quashigah et al., 2013).

5.2. Grain size analysis

Sediment samples were collected from about 11 locations (33 samples) across the study area for grain size analysis (see Fig. 1). This enabled the granulometric characteristics and textural properties of the beaches surveyed to be determined. Sampling was done at the back beach, high water mark and at the low watermark for each site using a hand trowel up to recommended depths of 10–15 cm. The 33 samples were sent to the lab, oven-dried for up to 20min and analysed using sieve analysis (Blott and Pye, 2001; Rashedi and Siad, 2016). The sieves were fixed on a mechanical shaker for about 15min to sort the sediments. The sieve sizes used were 1000, 710, 500, 355, 250 and 63 μ m. Grain size calculations were based on the formulae proposed by Folk and William Ward (1957).

6. Results

The resolution of the DEMs generated were less than 26 cm with vertical accuracies ranging between 0.95 and 20 cm (Higher RMSEs were mostly recorded when weather conditions/illumination was poor resulting in higher errors in point matching) while the orthophotos had a ground resolution of approximately 7 cm. Such high resolution and accuracies increased confidence in the identification of the various beach features including areas of sand mining and the intertidal slope (Fig. 4).

7. Morphological changes at Ningo (site 'A')

The site 'A' beach is relatively narrower covering an area of about

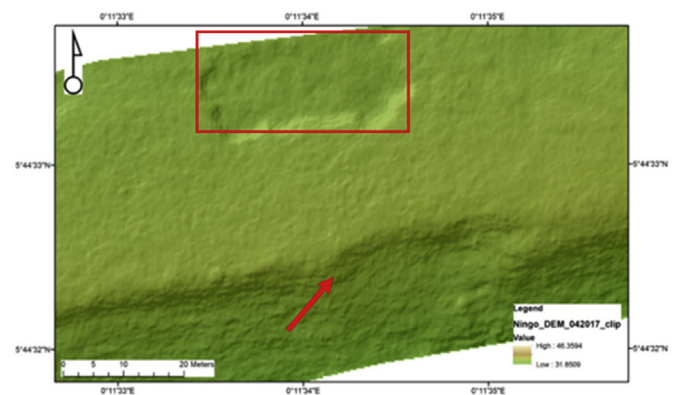


Fig. 4. DEM showing a sand mining site (indicated in a red box) and the intertidal zone (red arrow). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

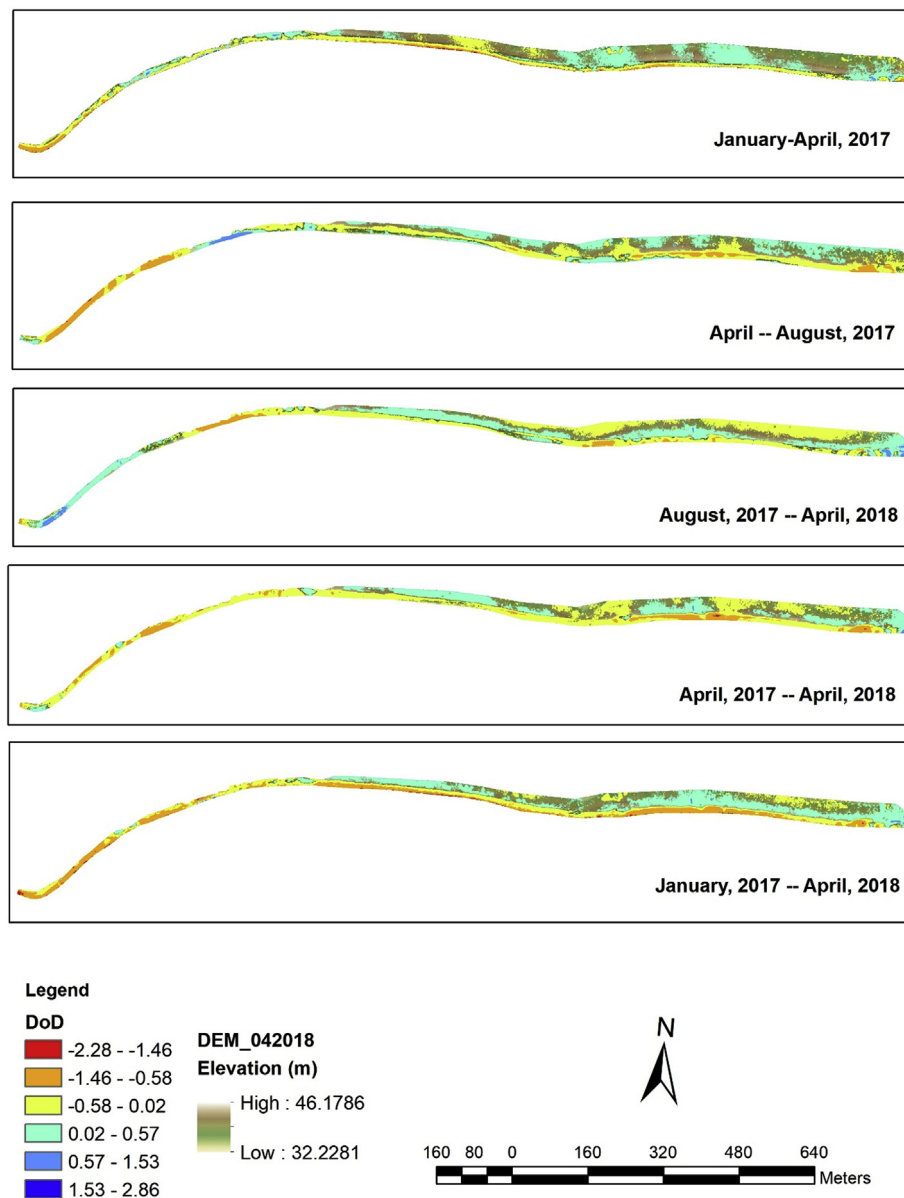


Fig. 5. Spatial representation of erosion and sedimentation at Ningo.

Table 2
Summary of Sediment volume changes at Ningo (January 2017 to April 2018).

	PERIOD				
	Jan-2017 to Apr-2017	Apr-2017 to Aug-2017	Aug-2017 to Apr-2018	Apr-2017 to Apr-2018	Overall
Erosion (Volume-m ³)	-6,676.39 (± 1,033)	-9,479.00 (± 1,317)	-6,515.97 (± 1,202)	-11,198.00 (± 1,666)	-15,571.23 (± 1,478)
Average Depth of Erosion (Height-m)	-0.39 (± 0.06)	-0.39 (± 0.05)	-0.26 (± 0.05)	-0.36 (± 0.05)	-0.59 (± 0.06)
Deposition (Volume-m ³)	2,947.98 (± 1,041)	2,782.66 (± 833)	4,167.48 (± 937)	2,350.48 (± 723)	2,964.16 (± 955)
Average Depth of Deposition (Height-m)	0.17 (± 0.06)	0.18 (± 0.05)	0.21 (± 0.05)	0.17 (± 0.05)	0.17 (± 0.06)
Net Volume Change m ³	-3728.41 (± 1,466)	-6696.34 (± 1,558)	-2,348.48 (± 524)	-8,847.48 (± 1,816)	-12,607.07 (± 1,781)
Sediment Imbalance (%)	-19	-27	-11	-33	-34

60, 226 m². It recorded a net loss of sediment. For the entire period of analysis (January 2017 to April 2018), about 26,612 m² (representing 84% of the beach) experienced erosion (Fig. 5) with a net sediment volume loss of about 12,610 m³ (see Table 2) at a rate of 788 ± 111 m³/month. Pixel-based depths of erosion and deposition range between -2 and 1m (Fig. 7) for this area with areal averages less than 1m (Table 2). From January to April 2017, a net change of

-3,728 m³ was estimated which almost doubled to -6,696 m³ from April to August 2017. The net change reverted to a lower level of -2,348 m³ between August 2017 and April 2018. Sediment imbalance (departure from equilibrium) for the beach was approximately -34%. This indicates a large deficit in the sediment budget for this beach compared to the other sites.

Spatially, the highest rates of erosion were recorded at the western

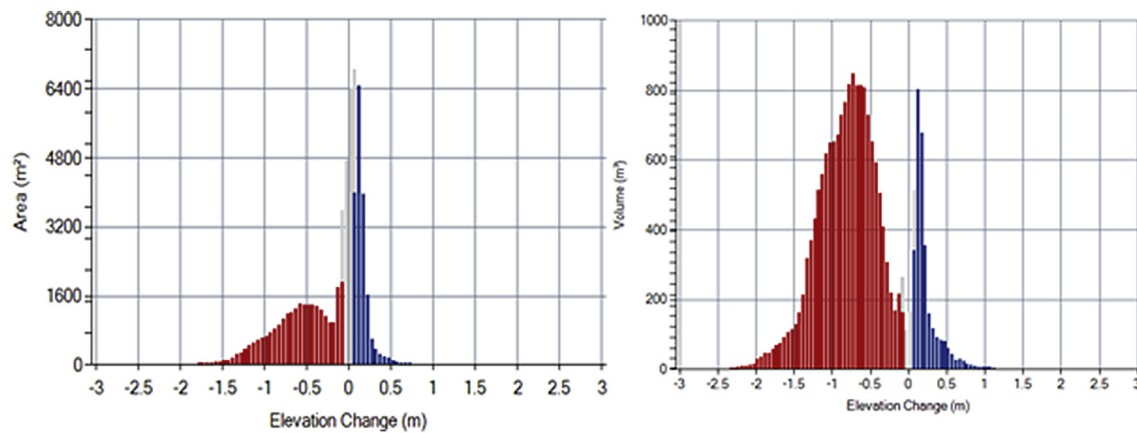


Fig. 6. Pixel-based area of erosion and accretion (left), and sediment volume change (right) at Ningo (January 2017 to April 2018). Red and blue bars indicate erosion and accretion respectively while grey bars show no change. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

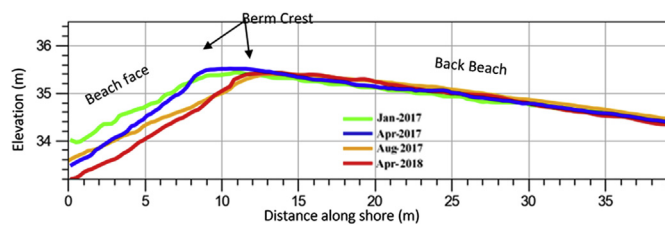


Fig. 7. Beach profiles showing deposition on the back beach and erosion of berm/shoreline.

section of the study area (Fig. 6). Field observations revealed the development of an offshore bar just at the mouth of the estuary, which could be influencing the dynamics observed.

Sediment deposition on this site occurred mainly at the back-beach due to wave overtopping, which is migrating the berm crest landward. Consequently, two of the GCP's, which were planted approximately to the ground level were buried to an estimated depth of about 20 cm during the last field campaign in April 2018. The phenomenon is also evident from the time series plot of beach profile from the eastern section of the beach (Fig. 7). This information is relevant for establishing realistic boundary conditions for beach and dune erosion models (Hancock and Kobayashi, 1994).

Over the period under study, the short-term rate of shoreline erosion was estimated as -3.5 ± 0.2 m/yr (Fig. 8) with maximum erosion being about -9.7 m/yr. The analysis confirms the occurrence of erosion along the coast as identified by Ly (1980). The shoreline moved over 12 m inland along the western section for the 16 months (1.3 years) period studied.

7.1. Morphological changes at Fuveme (Site 'B')

For site 'B', the data spanned over a relatively longer period of 22

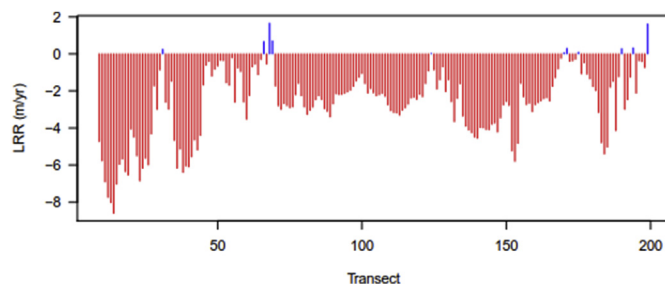


Fig. 8. Shoreline Rate of Change at Ningo (alongshore from west to east).

months (1.8 years). The Fuveme beach was comparatively wider across-shore covering a total area of about 131,721 m². Between June 2016 and April 2018, sediment deposition estimated was 52% (an area of about 64,000 m²) with a net gain of $\sim 5,150$ m³. About 69,200 m³ of sediment was eroded while 74,400 m³ was deposited, representing a surplus of only 2%. Sediment deposit occurred mostly on the eastern section. This relates to the west-east longshore drift direction (Fig. 9). The average depth of erosion was 1.08 m while the average depth of deposition is 1.38 m. Pixel-based elevation changes ranged between -3 and 4.5 m (Fig. 10). From June 2016 to August 2016, erosion was dominant (57%) with a net volume of $\sim 80,500$ m³ removed and $\sim 60,500$ m³ deposited (see Table 3). Between August 2016 and April 2017, there was increased deposition of about $\sim 62,400$ m³. This is mainly due to an influx of sediment to the area evidenced by the development of a swash bar towards the estuary (Fig. 11). From April 2017 to April 2018, sediment deposition again dominated with about 57% of the area experiencing deposition and a net gain of $\sim 12,700$ m³.

This site was particularly highly dynamic showing evidence of high erosion as well as deposition over the period. From June 2016 to April 2018, the shoreline moved over 60 m indicating high erosion along sections on the western side of the coast and accretion on sections on the eastern part of the coast. Coastal erosion has resulted in the destruction of several houses including the only school in the community (Appeaning Addo et al., 2018a,b). One of the GCPs established over 50 m from the shore was lost to erosion in the short term.

Analysis of the profiles generated from the DTM (Fig. 12) reveals high erosion along the coast with over 2 m depth of erosion over the period. It also shows sediment deposition that has accumulated between August 2017 and April 2018.

Lateral shoreline change analysis confirms a relatively high mean erosion of rate of -16 m/year with rates reaching -40.4 m/year (Fig. 13) at the frontage of the Fuveme community, which has led to the destruction of buildings as identified by Appeaning Addo et al. (2018a). Down drift, relatively high accretion rates are observed with mean rate of 17.6 m/year reaching 34.2 m/year.

7.2. Morphological changes at Keta (Site 'C')

For site 'C', the analysis was carried out over the same period (June 2016 and April 2018) as site 'B'. The site also has a wide beach with a total area of about $\sim 106,400$ m². For the entire period, erosion was $\sim 22,200$ m³ (39.5%) while deposition was $\sim 34,000$ m³ with the depth of erosion and deposition being 1.06 m and 1.39 respectively (Table 4). Pixel elevation change values range from -3 to 2 m (Fig. 14). This gives a net gain of $11,801$ m³ of sediment (representing a relatively higher surplus of 11%). Between April 2017 and August 2017, volume erosion

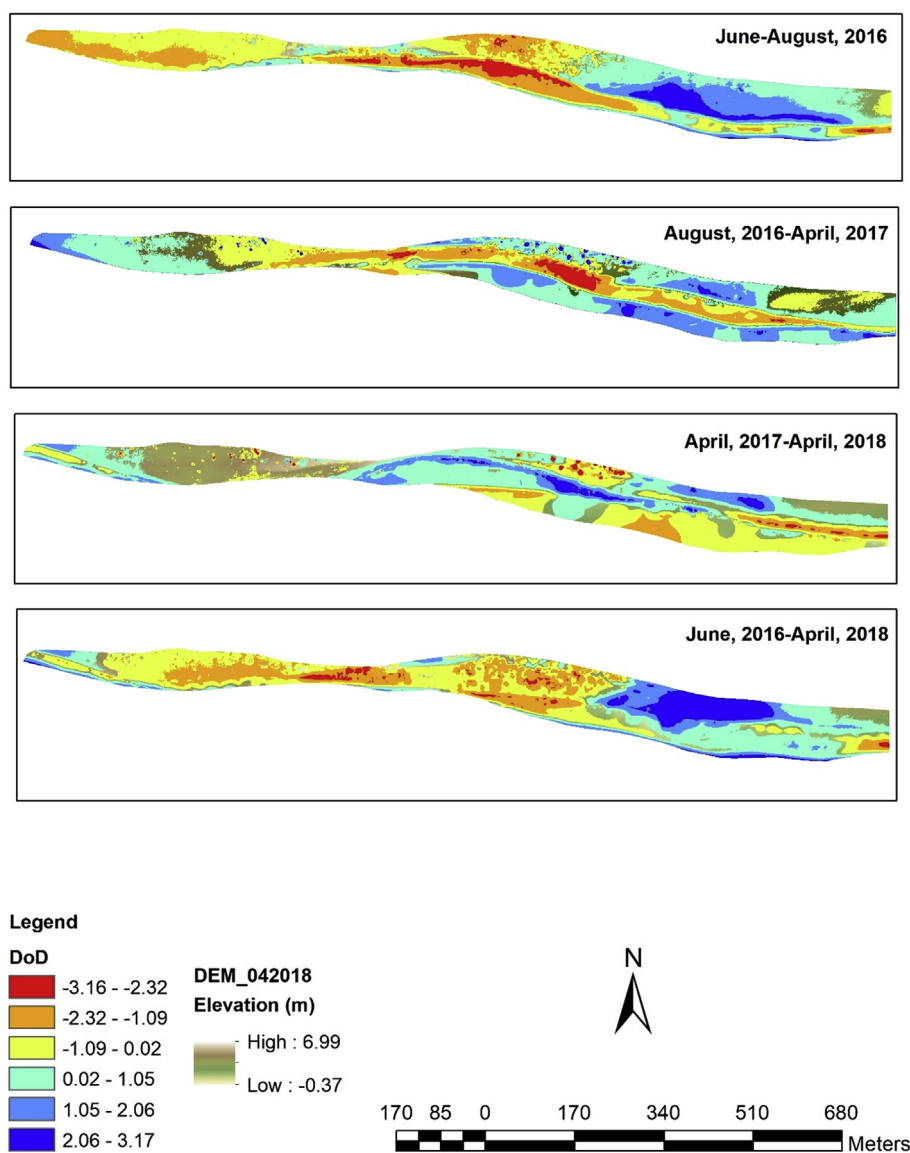


Fig. 9. Spatial distribution of Volume change from DoD (June 2016 to April 2018).

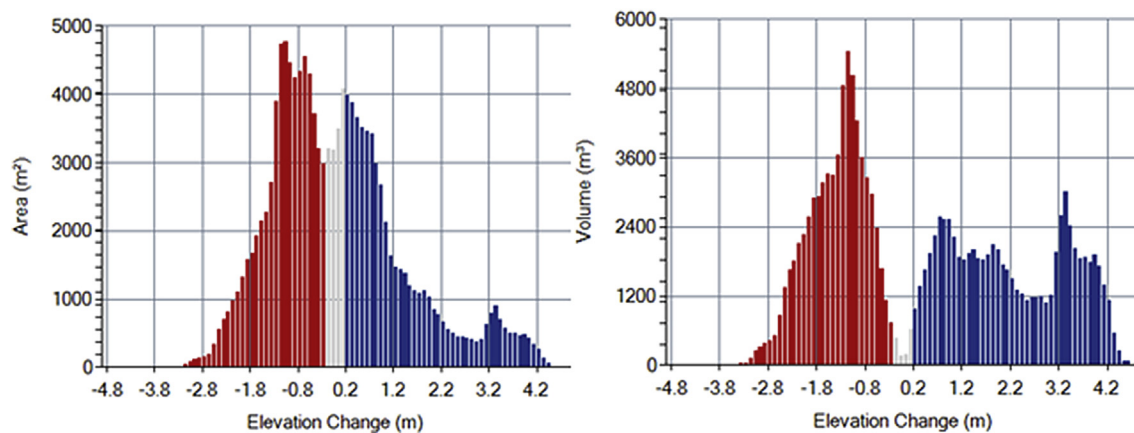


Fig. 10. Area of erosion and accretion (left), and sediment volume change (right) at Fuveme (June 2016 to April 2018). Red and blue bars indicate erosion and accretion respectively while grey bars show no change. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Sediment volume change for Fuveme (June 2016 to April 2018).

	PERIOD			
	Jun-2016 to Aug-2016	Aug-2016 to Apr-2017	Apr-2017 to Apr-2018	Overall
Erosion (Volume-m ³)	−80,455.44 (± 6,874)	−49,481.46 (± 4,253)	−36,309.80 (± 6,385)	−69,188.20 (± 10,020)
Erosion (Height-m)	−1.15 (± 0.10)	−1.06 (± 0.09)	−0.87 (± 0.15)	−1.08 (± 0.16)
Deposition (Volume-m ³)	60,433.50 (± 2,206)	62,379.10 (± 6,319)	48,978.41 (± 8,270)	74,330.18 (± 8,421)
Deposition (Height-m)	1.14 (± 0.10)	0.90 (± 0.09)	0.90 (± 0.15)	1.38 (± 0.16)
Net Volume Change m ³	−20,021.94 (± 8,635)	12,897.64 (± 7,177)	12,668.61 (± 1,449)	5,141.98 (± 3,089)
Percentage imbalance (%)	−7	6	7	2



Fig. 11. Swash bar that developed closed to the estuary (Photo Credit: Author, 6th April 2017).

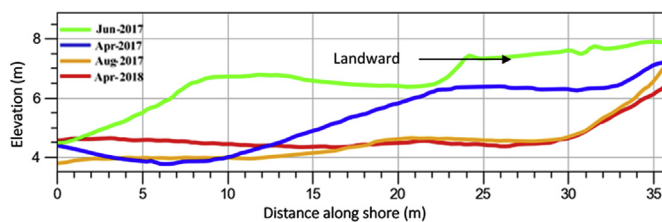


Fig. 12. Beach profiles from the high eroding section of the beach.

and deposition were 13,200 m³ and 34,400 m³ respectively, with a net volume difference of 21,200 m³ (22% gain). From August 2017 to April 2018 there was a net loss of −6,400 m³ (representing a 15% deficit). Spatially, this site exhibits more stable beach with erosion and accretion patterns concentrated around the shoreline (Fig. 15).

It emerged that erosion was severe on the downdrift side of the groynes, which traps sediment, while deposition occurred on the up drift side (Fig. 15). It can also be inferred from the spatial distribution that the threshold used was effective since there was no change on the groynes as expected.

Comparing profiles in-between the groynes (Fig. 16) confirms

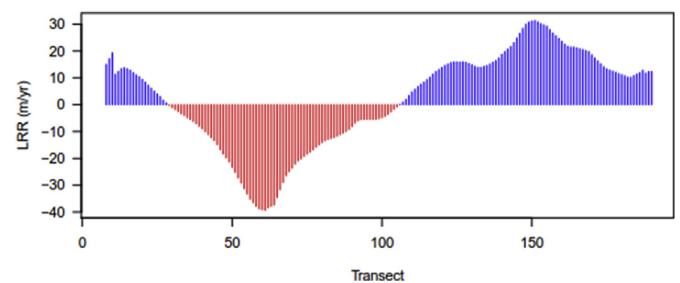


Fig. 13. Shoreline change between June 2016 and April 2018.

sediment trapping on the up drift side of the groynes, which resulted in accretion and erosion downdrift. A cyclical trend was observed in-between the groynes.

Lateral shoreline change analyses (Fig. 17), confirms the observed trends from the volume change dynamics. It was observed that the highest rates of erosion and deposition occurred at the downdrift of the groyne to the east, which is the last groyne of the Keta Sea Defence Project. Mean erosion rate was −2.5 m/year reaching a maximum of

Table 4
Sediment volume change at Keta (June 2016 to April 2018).

	PERIOD				
	Jun-2016 to Apr-2017	Apr-2017 to Aug-2017	Aug-2017 to Apr-2018	Apr-2017 to Apr-2018	Overall
Erosion (Volume-m ³)	−34,891.64 (± 6,702)	−13,199.93 (± 5,232)	−13,699.61 (± 5,450)	−11,188.47 (± 3,888)	−22,222.14 (± 5,564)
Erosion (Height-m)	−1.41 (± 0.27)	−0.72 (± 0.29)	−0.70 (± 0.28)	−0.61 (± 0.21)	−1.05 (± 0.26)
Deposition (Volume-m ³)	36,614.87 (± 11,812)	34,363.94 (± 9,780)	7,323.86 (± 3,238)	23,274.42 (± 6,021)	34,023.14 (± 12,172)
Deposition (Height-m)	0.84 (± 0.27)	1.00 (± 1.00)	0.63 (± 0.28)	0.82 (± 0.21)	0.73 (± 0.26)
Net Volume Change m ³	1,723.22 (± 5,81)	21,164.01 (± 1,092)	−6,375.75 (± 339)	12,085.96 (± 1,167)	11,801.00 (± 3,581)
Percentage imbalance (%)	1	22	−15	18	10

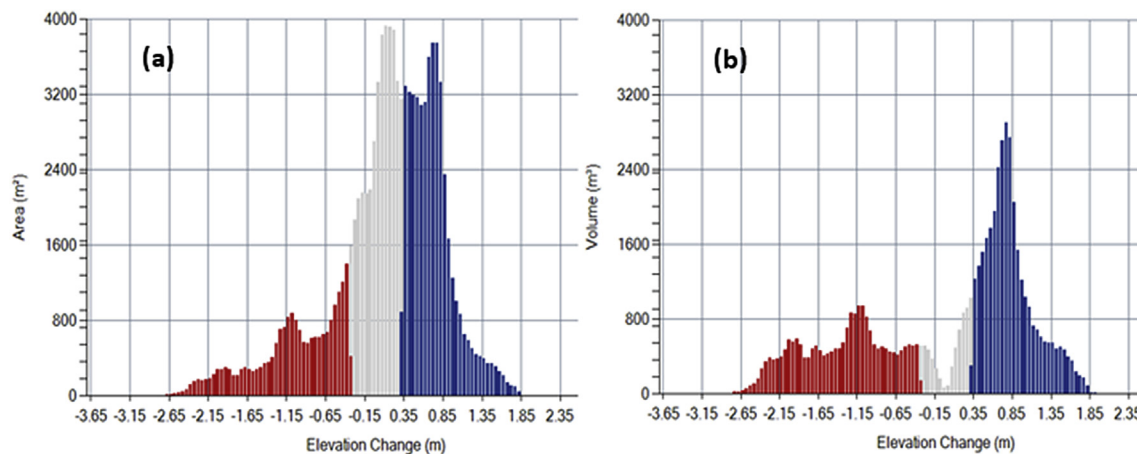


Fig. 14. Sediment Dynamics site 'C' from June 2016 to April 2018: (a) Area change and (b) volume change. Red and blue bars indicate erosion and accretion respectively while grey bows show no change. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

−6 m/year while mean accretion rate was relatively higher, −4 m/year reaching 10 m/year.

7.3. Sediment characteristics

The results of the sediment analysis revealed that the beach system comprises of 100% sand across the study area. The samples fall within medium and coarse sand range with median or D50 values ranging between 482.3 μ m and 920.2 μ m (see Fig. 18). Samples from the western section have fine grain size compared to those from the east (Fig. 20). The values are similar to those reported by Bollen et al. (2011) which ranges between 600 μ m (Ada) and 900 μ m (Keta) with beach face sizes reaching over 800 μ m (Nairn and Dibajnia, 2004).

8. Discussion

8.1. Beach volume and shoreline dynamics

Results for the three sites were compared for the period between April 2017 and April 2018 when data was consistent for all three sites. It emerged that Old Ningo experienced a net loss of about −8,850 m³ with 83% of the beach experiencing erosion. The percentage imbalance for this beach was −33%. The shoreline has also eroded at an average rate of −3.5 m/year. The erosion situation is threatening coastal infrastructure with evidence of destruction of houses (Fig. 19) at the western end of the study area.

Fuveme had a net gain of 12,670 with 57% of the beach experiencing deposition over the one-year period. The area had also experienced high erosion with many houses lost to erosion and people displaced as identified by Appeaning Addo et al. (2018)a,b. The beach started rebuilding by April 2018 (Fig. 20) with over 60m of land regained, while the bar that formed up drift (see Fig. 11) had also decayed. This

presupposes a form of cyclical event ongoing in the area. The area erodes over a period and accretes. The cyclic dynamics suggest adopting a management approach to sustainably manage the system as well as increase the resilience of the inhabitants.

There was a positive 7% departure from equilibrium indicating an almost stable situation. Keta, similar to the situation in Fuveme had a net gain of ~12,100. However, a significant part of the beach is experiencing deposition (68%) with a higher positive departure from the equilibrium of 18%. This indicates more sediment is reaching Keta compared to Old Ningo and Fuveme. The values recorded for Keta were similar to reported infilling volumes during the construction of the sea defence groynes which vary between 5,000 and 25,000 m³ for periods of weeks up to 3 months (Nairn and Dibajnia, 2004). A similar trend was observed for the entire period of data analysed. Ningo had a total net loss of −12,600 m³ corresponding to lateral erosion rate of −3.5 m/year, while Fuveme had a net deposition of 5,150 m³ which corresponds to accretion rate of 17.6 m/year which exceeds erosion rate of −16 m/year. Keta recorded the highest net gain of 11,800 m³ which is confirmed with lateral accretion dominating at a rate of 4 m/year with erosion occurring at a relatively lower rate of −2.5 m/year.

8.2. Factors affecting beach volume dynamics

The west-east littoral drift direction associated with the Volta delta coast influences the trends observed in beach sediment dynamics (Almar et al., 2015; Anthony et al., 2016). Coupled with the associated energetic swell waves and longshore currents, relatively large volumes of sediment are transported downdrift. However, the significant differences in volume across the sites indicate there are local sources contributing to the sediment budget. Ly (1981) examined two main sources of sediment for the eastern coast classified as allochthonous and autochthonous. The allochthonous involved contribution from rivers

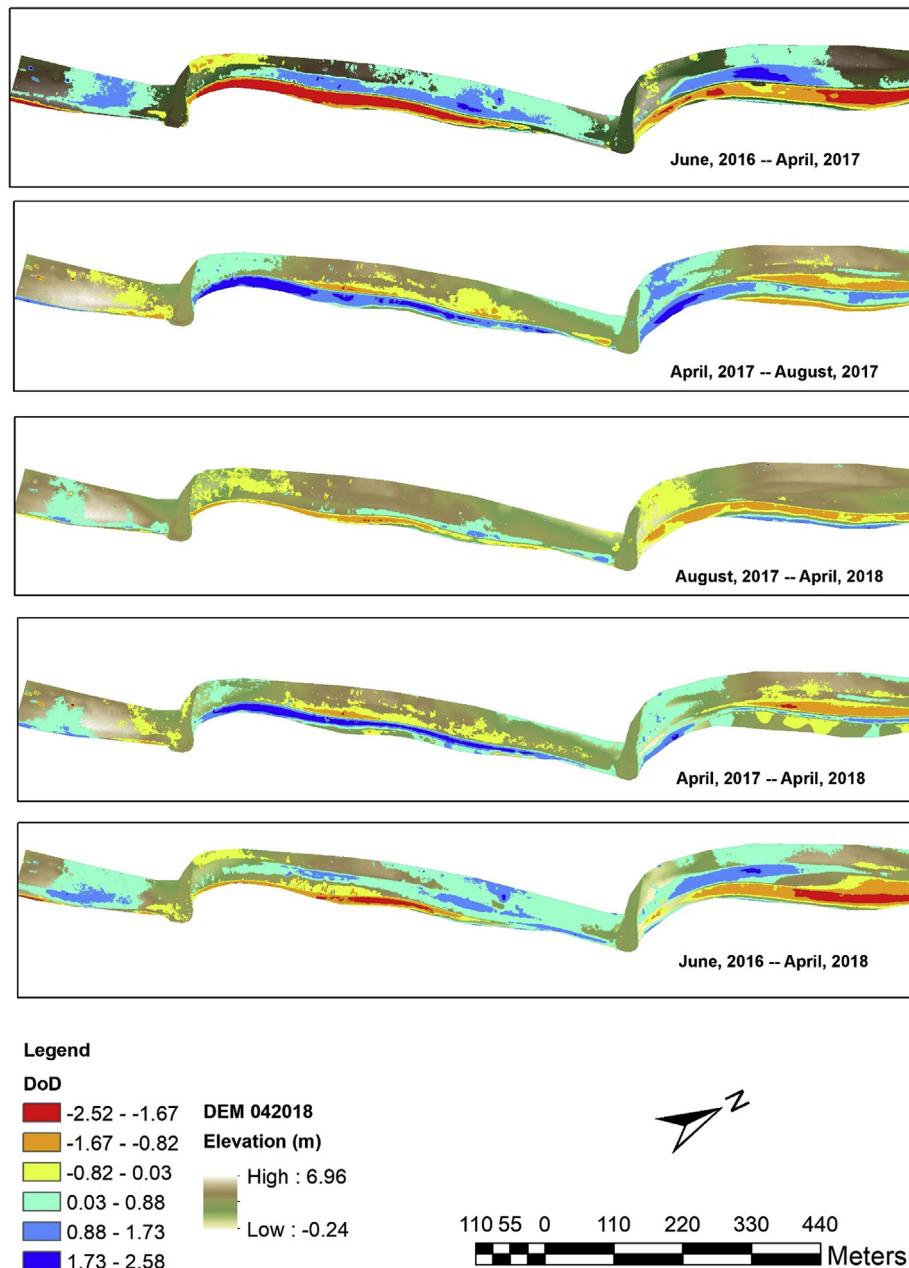


Fig. 15. Spatial distribution of volume change at Keta. The black triangles show the location of the groynes.

and streams to the coast (Ly, 1981). The study concluded that after the construction of the Akosombo Dam, the Volta River delivers only fine sediment to the coast due to the trapping of coarser sediments from upstream by the Dam. Such fine sediments (less than $150\ \mu\text{m}$) are easily suspended and deposited offshore. They do contribute much to the beach sediment budget. The sediment grain-size analyses from the study reveals that the grain sizes are much larger than those reported for the River. This confirms that contribution from the River may not be much. Ly (1981) reported that the main source of sediment to the beach is the autochthonous, coming from erosion of unconsolidated Quaternary deposits exposed at the shoreline and transported eastwards. This is the most plausible explanation to the dynamics observed. However, the presence of relatively finer sediments at Ningo ($502.3\ \mu\text{m}$) and at Goi (482.3) further west, indicates that the up drift area may not be a major source of coarse sand contribution to the sediment budget close to the estuary at Ada and east of the estuary, which have relatively coarser grain size ($\approx 891\ \mu\text{m}$). Ly (1981) reported

similar trends for the entire coast of Ghana observing finer beach sediment in the west as compared to the east. The fine sediments are easily suspended and sometimes deposited beyond the littoral zone. This confirms observation by Nairn et al. (1998) who reported that the area is prone to huge loss of sediment to the offshore zone.

The shoreline fronting the Volta delta is characterised by migrating sand from small beach cusps to larger (300m long) tongues of sand (Nairn et al., 1998). This phenomenon results in fluctuations in shoreline position up to 50m or more over a period of several weeks (Nairn et al., 1998). During the period of this study, a swash bar measuring over 500m was observed to have been formed by August 2017 close to the estuary (Fuveme). This geomorphic feature decayed completely by April 2018 serving as a local source of sediment for the beach immediate downdrift (see Fig. 22). These dynamics observed at Fuveme supports the view that migration of sand by waves contributes significantly to the sediment budget on the eastern coast of Ghana. Furthermore, sediment analyses for the immediate west of the estuary

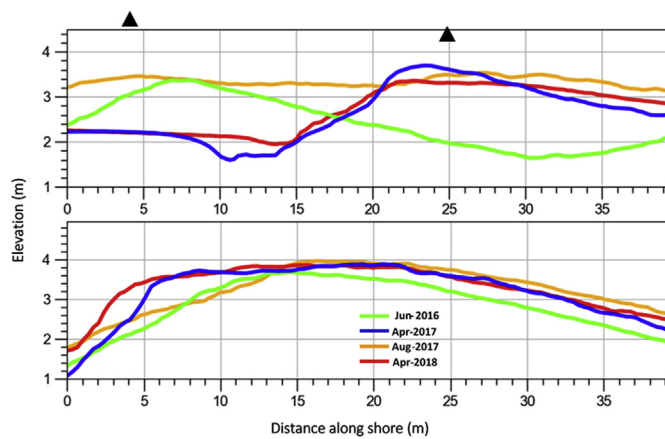


Fig. 16. Beach profile plot for down-drift (top) and up-drift (bottom) of the groynes.

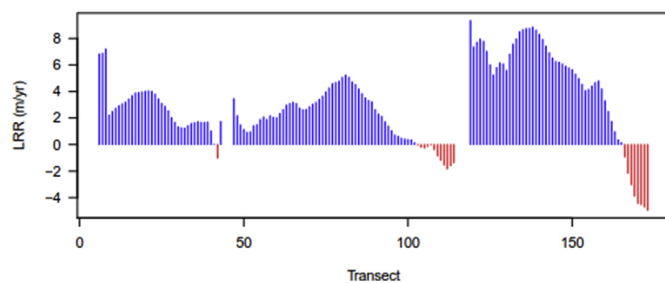


Fig. 17. Shoreline change at Keta between June 2016 and April 2018.

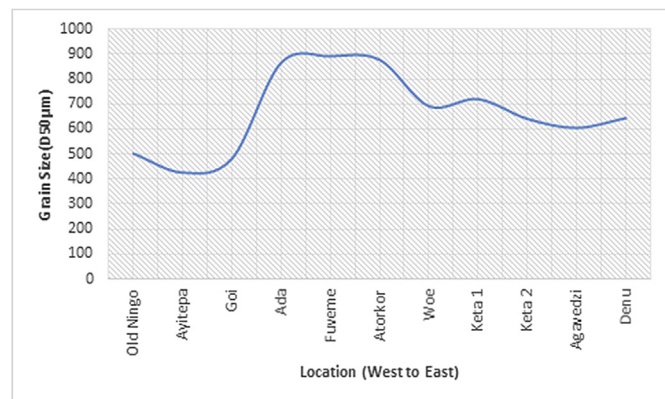


Fig. 18. Grain size distribution across the Study Area.

(Ada) records similar grain size ($920.2\mu\text{m}$) to that of Fuveme which further suggests by-passing of sediment to reach the eastern part of the estuary. The construction of the Ada sea defence could, therefore, be having a significant effect on the sediment budget at Site 'B' which had experienced high erosion in the short term (Appeaning Addo et al., 2018a). The curb the extreme erosion from wave action in this area, management options that reduce the impact of waves such as offshore break waters can be tested for this site. Also integrated management should be adopted to reduce the knock on effects which affecting this site. Additionally, field observations revealed anthropogenic contributions to beach volume erosion, particularly at Old Ningo. Nearshore gravel mining (Fig. 21) goes on along the coast and informal interviews with residents indicate that this activity has increased. Possible management options for this site is to enforce legislations to halt beach sand mining. Furthermore, to augment the sediment deficit, beach nourishment or the Dutch 'sand motor' system can be explored.

The shoreline is more stable in the Keta area because of the defence structure in place. However, high erosion is occurring down-drift of the structure confirms which confirms the 'knock-on effect' of the groynes. Again it recommended future shoreline management along the delta shoreline should be skewed towards soft engineering options as much as possible and should be holistic. The sediment dynamics could be explored further with a longer period and more frequent surveys at the established monitoring sites to fully capture the seasonal effects. Such monitoring efforts have been initiated at one site within the delta with monthly surveys ongoing (Angnuureng et al., 2019).

9. Conclusion

This study demonstrated the utility of UAV surveys in monitoring short-term beach morphological and sediment budget changes. High-resolution DEMs ($< 26\text{ cm}$) with vertical accuracies ranging between 9 and 20 cm were constructed and used for sediment budget analysis. Overall, the Delta beaches are highly dynamic with high rates of erosion and accretion in response to wave regimes and human interventions along the coast. Sediment volume input is higher on the eastern side of the Delta compared to the west due to inputs from local sources. For the comparable period between April 2017 and April 2018, the western part of the estuary experienced a net volume erosion of $-8,847.48 \pm 1,861\text{ m}^3$ while the eastern sites experienced between $5,141.98 \pm 3,089\text{ m}^3$ and $12,085.96 \pm 3,089\text{ m}^3$. For the entire period similar trends were recorded for the three sites with Ningo recording $-12,600\text{ m}^3$ while Fuveme and Keta net deposition of $5,150\text{ m}^3$ and $11,800\text{ m}^3$. The approach used here can be replicated across the Gulf of Guinea to estimate regional sediment dynamics in support of integrated coastal zone management.



Fig. 19. Impacts of erosion at the western section of the study area (a) A beach resort being undermined and (b) houses being destroyed in the background (Photo Credit: Author and Emmanuel Brempong, 12th January 2017).



Fig. 20. Aerial view of a portion of Fuveme Showing the beach being built up. The red line shows the previous shoreline position (August 2017) and the red circle shows where the bar had developed previously while the blue arrow shows the extent of the beach that has been built (Over 80m). (Photo by Authors; April 2018). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)



Fig. 21. Gravel mining from Nearshore at Ningo (a) Heaps of mined gravel along the beach ready for sale (b) gravel being transported via wheelbarrows to a waiting vehicle across the tidal pool in the background.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ocecoaman.2019.104952>.

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