Sediments Composition and Morphology of the Fosu Lagoon Barrier Beach, Bakaano, Cape Coast, Ghana

Ishmael Yaw Dadson[1*]
Peace Semabia Panou[1]
Kofi Adu-Boahen[1]

Abstract

This research examined the Fosu Lagoon Barrier Beach sediment composition at Bakaano in the Cape Coast Metropolis. The researchers focused on the physical attributes of the Fosu Lagoon Barrier Beach at Bakaano in Cape Coast and analysed its sediment composition. The paper analysed twelve (12) samples or specimens of soils/sediments at the laboratory to determine the sediment composition of the barrier beach. The physical dimensions of the barrier beach were measured in the field with a tape measure and a Global Positioning System (GPS). The study established that the Fosu Lagoon Barrier Beach is approximately 130m long and 58m wide. It is shallow in height, about 10m above sea level and composed mainly of coarse sand particles. The granulated sand composition has made this barrier beach fragile. Aside from wave action, human-induced factors were prominent in the catchment area, such as sand mining and artificial breaching of the barrier, accounting for the temporal changes in its physical characteristics. The paper recommends that the Cape Coast Metropolitan Assembly should play a critical role in protecting and maintaining the feature by regulating threatening human activities carried out on it.

Keywords: Sediments composition, Barrier beach, Bakaano, Cape Coast, Coarse sand

[1]Department of Geography Education, University of Education, Winneba, Central Region, Ghana

*Corresponding author's email: iydadson@uew.edu.gh

Received on January 5th, 2023/Accepted on July 13th, 2023

Ghana Journal of Geography Vol. 16 (1), 2024 pages 91-127

Doi: https://dx.doi.org/10.4314/gjg.v16i1.4

Introduction

Beaches are one of the dynamic features along the coast. They are built by sedimentation and other actions of waves, such as accretion and erosion. Beach sediments are solid materials moved and deposited at a specific location (Engelstad et al., 2019). The accumulation of sediments and other beach processes led to the formation of some coastal features, including barrier beaches. A barrier island or beach is an unconsolidated elongated body of commonly sandy (or gravelly) deposits lying above high tide and separated from the mainland by a lagoon or a marsh (Zhang, 2016; Komar, 1998). Bay barriers lie parallel to the land and are connected to the mainland at both ends (Defne et al., 2019). One of the major features of a barrier beach is its morphology. Beach morphology is the physical dimensions of the beach, including its height and other form dimensions. Barrier islands are affected by sedimentation, leading to morphological changes. These morphological changes manifest in the barrier beach's height, length, breadth and other form dimensions (Engelstad et al., 2019). According to Daniels (1999), barrier beaches measure approximately 200m in width with a single ridge or line of low dunes. Barrier beaches or islands are typical along the coast of Ghana, from the Keta barrier in the east to the Dixcove in the west (Nielsen et al., 2007). The Fosu Lagoon Barrier Beach at Bakaano, Cape Coast, is found along the central coastline of Ghana. Like any other barrier, it is essential to the community and the ecology. This slight stretch of land is always occupied by people who engage in activities such as sand mining, football, recreation and tourism, research, and landing beaches for fishermen. During the famous Bakatue festival, the chiefs, elders and the people of the Cape Coast Metropolis stand on this stretch of land to perform rituals to resume fishing activities in the lagoon for another year.

Notwithstanding, this barrier beach, like other barrier beaches in the world, is confronted with frequent over washing, topping and rollback; in the case of each of these happenings, the barrier beach loses its capacity to function as expected. Barrier breaching most often causes the merging of the sea and the lagoon for days, creating inconveniences for the users of that part of the beach—the uncertainty of the usage of the beach regarding storm surges. However, the poor level of indigenous knowledge of the users in averting these natural happenings to reduce their impact on lives and property puts the lives of the users of the facility and properties at risk. Whenever the equilibrium of the barrier is affected, it becomes difficult to use. This hinders all activities on this stretch of the land until the land rebuilds itself. The frequent removal of sediments from this part of the beach makes it unstable.

This instability is reflected in the dynamics of the beach morphology, which is shape and form. These changes are primarily episodic due to the ability of the beach to replenish itself through sedimentation and other wave processes such as erosion and accretion. It is, therefore, essential to analyse the dynamics of this coastal landform in terms of its sedimentation regime and morphological dynamics. It is worthy of note that some scholarly works (Dadson et al., 2016; Davies-Vollum, Zhang & Agyekumhene, 2019; Gerivani, Stephenson, & Afarin, 2020) have been done in this area in the Ghanaian context and other parts of the world. The earlier scholars have focused on beach sedimentation, particle size analysis of beach sediment, coastline analysis and erosion rate, shoreline dynamics of the coast, and development of coastal beach stabilisation. Others (Adu-Boahen & Boateng, 2021; Okyere, Adu-Boahen et al., 2023; Adu-Boahen et al., 2023) also studied the physicochemical analysis or composition of lagoons and ways of reducing storm impacts on coastal lands and making coastal environments safe for habitation. Even though the above studies were geared towards creating awareness of these phenomena in the coastal environment aimed at protecting lives and properties, much effort has not been made to study specific coastal landforms such as the barrier beach. Studying these landforms is equally important as studying the processes that affect them. Thus, getting to know more about the state of some of these landforms, such as barrier beaches, will not only offer us knowledge about what they are but also develop a sense of appreciation. They also arouse the quest to protect them and make them more resilient to function efficiently. Therefore, there is a need to fill the literature gap concerning the subject matter. This study will explore how barrier beaches respond to conditions around them and how these responses influence the beach's state, functionalities and ecological life. This will add to existing knowledge and create a sense of responsibility towards their maintenance. Critical to the need to investigate barrier beach morphodynamics is the ultimate objective for practitioners to make sustainable long-term decisions on managing these systems. Thus, this study was carried out to (1) investigate the physical dimension of the Fosu lagoon barrier beach at Bakaano in Cape Coast, (2) analyse the sediment composition and morphology, and (3) explore the factors responsible for the sediment regime of the Fosu lagoon barrier beach.

Theoretical Perspective

The theory that underpins this study is Waugh's model on factors that control beach processes and the coastal environment. In the model, Waugh (1995) identified four elements, namely marine, terrestrial, atmospheric and anthropogenic, as factors that influence the coastal environment. The terrestrial process controls the coast; therefore, the beach is related to the parent materials that produce sediments. It includes the kind of weathering process that makes them and the nature of the slope on which they are deposited. More so, waves from the marine environment work on the sediments produced to determine the grain sizes of the residues from the beach. Human activities and rising sea levels from climate change may all impact the coastal environment. In a similar vein, Komar (1998) found three significant elements that influence the average particle size of beach sediments. They are the provenance of the debris, the degree of tidal energy, and the prevailing offshore gradient on which the beach is developed. He asserts that particles of beach sediment vary from more than a meter for boulders to less than 0.1mm for fine sand grains. Concerning the study area, these factors are operational in the dynamics of the coastal environment and the barrier morphology. Marine processes, in the form of wave action, terrestrial operations in the form of sediments regime, anthropogenic activities such as sand mining and human trampling, and climatic influence from precipitation and seasonal changes, come together to modify the morphology of the Fosu Lagoon barrier beach.

Description of the Study Area

Ghana's coastline of over 550km stretch is divided into three zones based on geomorphologic characteristics—the eastern, central and western (Boateng, 2012). The Fosu Lagoon Barrier Beach is on the central coastline, specifically the Cape Coast Metropolis. This coastline represents a medium-energy environment (Boateng, 2012). It is an embayed coast of rocky headlands, sand bars and spits, enclosing coastal lagoons. The area around the Fosu Lagoon barrier is characterised by sandy shorelines, with some rocky outcrops on both the eastern side of the Cape Coast Castle and the west around the Sweet River estuary. It is generally described as low-lying with mainly sandy characteristics, enclosed by the Fosu lagoon. A study by Dadson et al. (2018) summarises the area's geomorphology as follows "areas extending westwards to the beach around the Cape Coast Regional Office are rocky. After the rocky beach around the Cape Coast Regional Office, the sandy beach continues westwards around the Cape Coast Castle, beyond which the sandy beach becomes more prominent. Thus, from the Cape Coast Castle, the sandy beach stretches westwards across the Kakum or Sweet River estuary to the Elmina Castle area, where a rocky beach is found. The rocky beach found around the river Kakum estuary has been named by Dei (1975) as coffee rocks for exhibiting the colour of coffee" (Dadson et al., 2018 p. 9).

The study was conducted on the Fosu Lagoon barrier beach located between the Fosu Lagoon and the adjoining sea at Bakaano in Cape Coast, Fig 1. The Cape Coast Metropolis in the Central Region of Ghana lies between latitudes 5°6'19.26N and 1°14'47.76"W. It is bounded on the east by Abura Asebu Kwamankese District, on the west by Komenda Edina Eguafo Abrem (KEEA) District, on the south by the Gulf of Guinea, and the north by Twifo Heman Lower Denkyira District. The metropolis has a total land area of around 122 square kilometres and is the country's smallest metropolis (ghanadistricts.gov.gh).

The vegetation is primarily secondary forest, with thickets and shrubs reaching an average height of 4.5m. There is a 13-kilometre-long coastline. Temperatures fluctuate between 24°C and 32°C, with humidity levels ranging from 60% to 80%. There are two rainfall seasons, with peaks in June and October. The annual precipitation ranges from 90 to 110 mm along the coast and 110 to 160 mm inland. From November to February, there are dry periods (GMet, 2020). The area is mainly hilly, with valleys between the hills, and the maximum height is around 60m above sea level. The area's main streams or rivers are Siwere and Kakum, which drain into the lagoons of Fosu and Abakam, respectively. Some flood-prone zones within the study area are located below 60 meters above sea level.

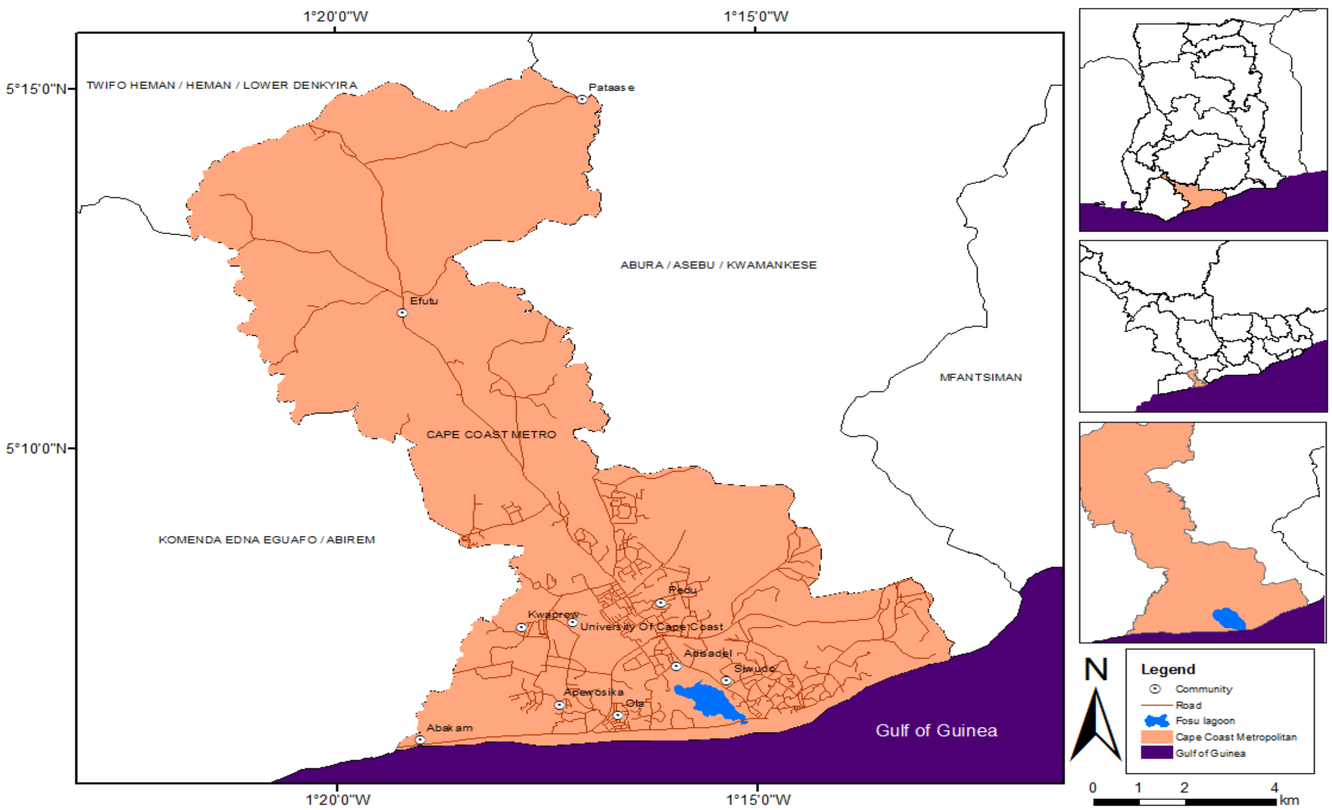

Fig 1: Map of the Study Area in Regional and National Context

Source: Authors construct

Materials and Methods

The research entails onsite fieldwork. The data gathered included a collection of 12 sediment samples for laboratory analysis. There were also measurements of the various dimensions of the barrier beach to gain a deeper understanding of its behaviour. The fieldwork and data collection procedures are discussed in detail in the ensuing paragraphs.

Determining the Size of the Barrier Beach at Bakaano

The total length and width of the beach were measured using a standard tape measure (How Jin Aik et al., 2021). The researchers measured the distance of the barrier beach from the seaward section to the berm and from the berm to the lagoonward side aimed at determining the broadest and narrowest part of the barrier beach. The width measurement was also taken from the sea's shoreline to the lagoonal shore. Measurements were taken from three different portions, the two ends and the middle section, to determine the broadest and narrowest part of the barrier. The measurements were taken in the wet season and repeated in the dry season. The various measurements helped to select the average size of the barrier beach. Apart from the challenge of finding a digital instrument to measure, the manual method was to help compare the result with the already digitalised measurement of the beach. A global Positioning System (GPS) (the Garmin GPSMAP 66th, in terms of accuracy and reliability) was also employed to measure the elevation of the barrier beach.

Sedimentation Analysis of Barrier Beach

Sediment samples were collected for laboratory investigation to determine the sedimentation processes on the beach. Twelve (12) sediment samples were taken from the seaward and lagoon side. Six samples were collected from each side of the beach, respectively, as shown in Figure 2.

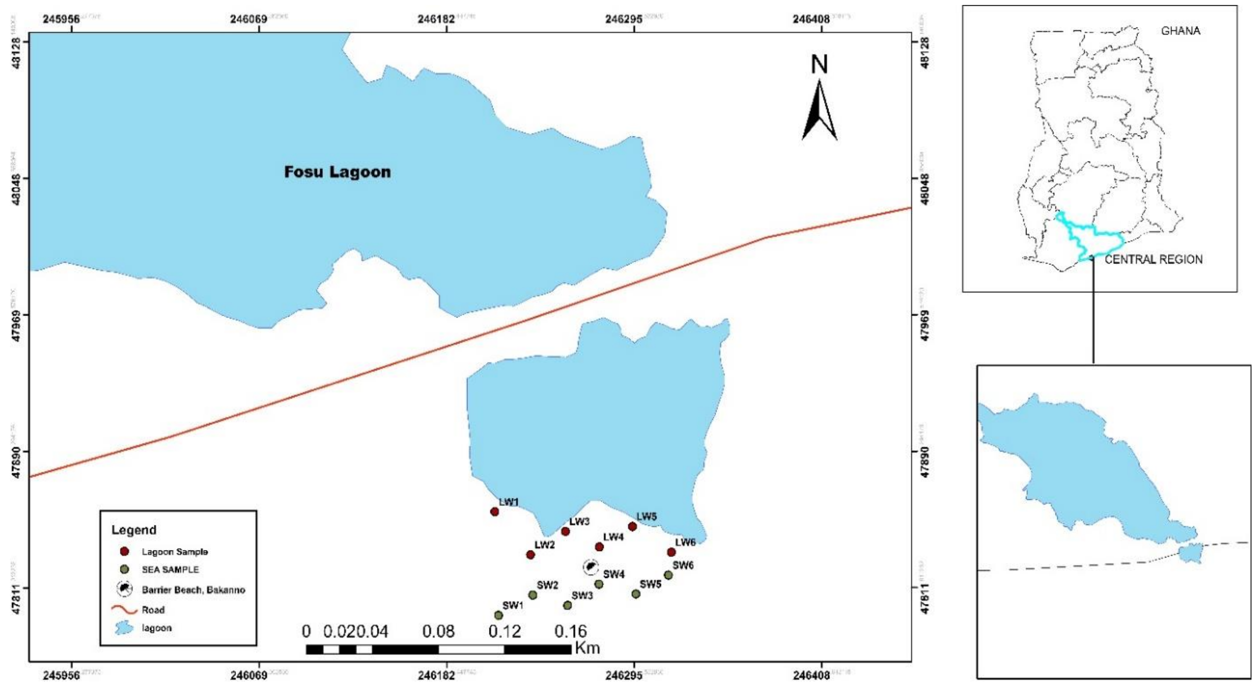

Fig 2: Sediment Sampling Points
Source: Fieldwork, (2020)

The analysis of the sediments was based on the classification by (Wentworth, 1922 Komar, 1998; Masselink et al., 2011), which opines that sand ranges from 0.0625 to 2mm in diameter according to the sediment or particle size classification by diameter (coarse sand is less than 2mm, but greater than 0.2mm). Conversely, fine sand is defined as particles with diameters ranging from 0.2mm to 0.02mm. Silt has a diameter of 0.02mm to 0.002mm, while clay has a diameter of less than 0.002mm. Based on the above criteria and in line with the details in Tables 3 and 4, one can conclude that sand is the barrier's main composition because all the sand values are of high percentages. Waugh (1995) explains that sandy beaches or beaches composed of sand are low in height and have a gentle slope. Given this, when sand is wet, it becomes compact and restricts percolation due to its smooth surface. Hence, the backwash rate on such beaches is high, leading to a high erosion rate. The sediments were collected in an array form. Sw1 was collected from the nearshore position. Sw2 sample was taken from the upper beach directly above Sw1 at 15cm intervals. The procedure was repeated for the remaining selected points along the beach. The same approach was used to sample the rest of the sediments. Sample LW1 was taken from the near shore of the lagoon, while LW2 was collected at the upper beach directly above LW1 in that manner until the end of the barrier.

Sampling Protocols and Analysis

The research followed Musselman's (2012) protocols on sediment sampling spots of water at least 15-20 cm with a depth of (6-8 inches). The reason was to include both recent and relatively older deposits, that is, to cater for both surface and sub-surface sediment regimes. Wooden callipers were graduated and erected at each barrier point where the sediments were to be collected. The mass of sediment samples collected from the various sampling sites is shown in Table 1 in the form of deposits contained and after the materials were sieved. Each sediment sample was kept in an airtight poly bag and labelled respectfully. The sieve size used was less than or equal to 2mm.

Table 1: Mass of Sediment Samples for Analysis

Sampling Location	Mass of Sample	≤2mm Sieving
SW1	511.06	26. 4096
SW2	643.06	6.618
SW3	501. 97	3.2879
SW4	681.99	4.7664
SW5	668.71	20.2469
SW6	601.39	4.2624
LW1	719.97	28.9468
LW2	894.43	4.7097
LW3	740.21	6.3966
LW4	696.85	9.7328
LW5	828.26	34.1478
LW6	683.59	8.6948

Source: Fieldwork, (2020)

The sediments were taken to the Soil Science Laboratory at the University of Cape Coast for analysis. The sediment samples were washed and oven-dried at the laboratory for three days. It was removed from the oven and weighed. After finding the total weight of each sediment sample, a sieve size was less than or equal to 2mm in determining the dimensions of the particles of each sediment sample. The sieved sediments were reweighed to determine the percentage of the particle sizes of the deposits. Each of the sediment samples was treated separately. Following Rowell's (1994) standardised laboratory analysis, the samples were placed back into a sedimentation tank. The sample container was filled with water to a meaningful level by following the protocol. A hydrogen peroxide solution was added to the suspension to destroy organic content further and freely suspend the individual particles. A few hours later, the first suspension sample was drawn from each sedimentation tank using a beret. Each sample drawn was emptied into a beaker. The following sample was drawn after eight hours and the last after four hours. All the pieces were placed in an oven to evaporate the moisture. The residues left in the beakers were each weighed, while the percentages of the sediments' silt, sand and clay composition were calculated and recorded.

The percentages of clay, silt and sand were determined using the mathematical model expressed below, as proposed by Rowell (1994). The ratio of each class of sediment is described as follows:

$$\text{Percentage of Sand} = \sqrt{\frac{\text{mass of sand X 100}}{\text{mass of sampled sediment}}}$$

$$\text{Percentage of Clay} = \sqrt{\frac{\text{mass of clay X 100}}{\text{mass of sampled sediment}}}$$

$$\text{Percentage of Silt} = \sqrt{\frac{\text{mass of silt X 100}}{\text{mass of sampled sediment}}}$$

Results and Discussion

Morphological Dimensions and Characteristics of the Barrier Beach at Bakaano

The result from Table 2 indicates that the Fosu Lagoon barrier beach has an average height of 14m above sea level. It is approximately 130m in length and 58m in width, with ends measuring 58m and 64m, while the middle part measures 52m. Thus, the barrier is broad at the ends but narrows in the middle. The barrier beach is narrow in the middle, probably because of the intense nature of the waves at that part of the beach, as suggested by (Komar & Holma, 1986). According to Komar and Holma (1986), beach erosion is intermittent, with major coastline recessions prevailing amid heavy storms. During the dry season, the barrier was roughly (32m) closer to the sea than to the lagoon, signifying severe storm surges during the rainy season. The barrier beach was closer to the lagoon than the sea during the wet season (approximately 28m).

Table 2: Morphological Dimensions of the Barrier Beach

Parameter	Unit (m)
Height	14
Length	130
Width	58
Outer end	58
Inner end	64
Middle part	52

Source: Fieldwork, (2020)

This implies that the barrier moves seaward or shifts towards the sea during the dry season. This is consistent with the findings of (De Santis, Caldara, & Pennetta, 2020), who claim that barriers form in a seaward orientation and that the barrier succession is typically thick (10–20 m). It lies on offshore deposits, usually produced from fine-grained sands and silt. This is due to the high accretion rate through the slow pace at which the waves erode the sediment brought to the coast to build up. The reverse is valid for the wet season. Thus, in the wet season, the barrier performs a landward movement or shifts towards the lagoon due to the substantial nature of the waves that push the sediments further landward. This is due to the intense erosion in the wet season, resulting in the removal of materials from the seaward side and increasing deposition at the lagoonward side. Judging from the above, it is evident that climate (rainfall and temperature) dramatically influences the coast and, for that matter, the barrier beach due to destructive waves in the wet season. According to Brandão et al. (2022), global climate change affects beach sand through changes in conditions like water temperature, sea level, precipitation, and waves. According to Smoot (2009), climatic parameters such as rainfall or temperature are directly related to sedimentary features on the beach. Climate change is likely to bring heavier rain to some coastal areas, which would also increase runoff and flooding, thereby changing the balance in the coastal system. According to the International Bank for Reconstruction and Development and World Bank (2020), climate change will change the amount of sediment delivered to coastal areas and accelerate erosion. When this occurs, wetlands do not receive enough deposits to keep up with rising seas and may no longer function as natural buffers to flooding. In comparison, during the dry season, the waves become more constructive. In other words, during the wet season, the velocity of circulation near the sea surface increases (Laxague & Zappa, 2020).

Analysis of Beach Sediment Profile

Table 3 summarises the result of the sediments that form the barrier beach. This result was derived from the laboratory analysis conducted on the specimen. As used in Tables 3-8, the abbreviation SW and LW represent Seaward (SW) and Lagoonward (LW) locations, respectively. SW1, SW3, and SW5 were areas closer to the seashore (Seaward), while LW1, LW3, and LW5 were locations more relative to the lagoon's coast (Lagoonward).

Table 3: Particle Size Analysis of Beach Sediment

Sample	%Gravel	% Clay	% Silt	% Sand	Total
SW1	0	0.51	0.22	99.27	100
SW2	0	0.55	0.29	99.16	100
SW3	0	0.41	0.25	99.34	100
SW4	0	0.44	0.22	99.34	100
SW5	0	0.52	0.13	99.35	100
SW6	0	0.66	0.28	99.06	100
LW1	0	0.18	0.23	99.59	100
LW2	0	0.31	0.39	99.3	100
LW3	0	0.47	0.3	99.23	100
LW4	0	1.32	0.27	98.41	100
LW5	0	0.03	0.37	99.6	100
LW6	0	0.49	0.78	98.73	100

Source: Fieldwork, (2020)

As shown in Table 3, the composition of sand dominated the barrier beach, accounting for ninety-nine point two (99.2) per cent of the sediments. The clay content in the deposit recorded 0.5 per cent, whilst silt was the least represented, registering 0.3 per cent of the deposition. The researchers tried to compare the nearshore and upper beach sediments to determine how much the waves have influenced the residues at these locations. Table 4 outlines detailed information on nearshore sedimentation analysis.

Table 4: Nearshore Sedimentation Analysis

Location	% of clay	% of silt	% of sand	Total
SW1	0.51	0.22	99.27	100
SW3	0.41	0.25	99.34	100
SW5	0.52	0.11	99.37	100
LW1	0.18	0.23	99.59	100
LW3	0.43	0.3	99.27	100
LW5	0.03	0.37	99.6	100

Source: Fieldwork, (2020)

It means these locations have insignificant amounts of clay and silt, with sand being the most abundant. On the other hand, the L1, L3, and L5 values depicted in Table 4 also show high percentage values of sand. These specimens were taken from locations close to the lagoon shore. Considering normal conditions, that region would have been inhabited by a considerable amount of silt, mud, and clay. The presence of sea sand deposited close to the lagoon instead of more silt or clay raises the question about their availability at that location. According to Wentworth's (1922) sediment deposition system, coarse particles are deposited first, and silt and smaller particles are deposited deeper inland by sea waves. The values shown in Table 3 are a deviation from the normal. Sand, instead of silt and clay, occupies the lagoonward shore. This prevailing condition could be an indication that the waves are powerful, resulting in a robust littoral drift, or it might be that there has been a landward transgression of the barrier. This causes the sand to be deposited over the lagoon, as explained by Komar (1998: p.33). Again, it could further indicate that the shoreline has moved landward in response to sea level rise.

A critical look at the percentage values of clay at the sea shore and the lagoon shore shows that more clay is close to the sea shore than the lagoon shore. According to Waugh (1995), in a situation where the beach slope is relatively gentle, the percolation rate is high, which allows sediments to be broken in situ. This explains why there is probably more clay on the seaward side of the lagoon than on the lagoons. The sea is the primary medium by which waves supply sediments to the coast. No visible streams or rivers flow along this part of the beach to deposit mud and silt. That might have accounted for the area's low percentage of clay and silt (Huntley, 2023). However, the little traces of mud are deposited landward at the end of the barrier close to the lagoon.

Analysis of Upper Beach Sedimentation

These sediments were collected at the upper beach face directly above SW1, SW3, SW5, LW1, LW3, and LW5 at sea and landward sides. The percentages of clay, silt and sand are provided in Table 5.

Table 5: Percentages of Various Sediments in Sample

Location	% of silt	% of clay	% of sand	Total
SW2	0.29	0.55	99.17	100
SW4	0.22	0.44	99.34	100
SW6	0.28	0.66	99.06	100
LW2	0.39	0.31	99.6	100
LW4	0.39	1.31	99.3	100
LW6	0.78	0.49	98.73	100

Source: Fieldwork (2020)

A thorough examination of the sediment composition of the seaward's upper beach face and the beach's lagoonward half demonstrates that the barrier is primarily made of sand, with more sand depositing on the landward side of the barrier beach than on the seaward side. Based on the above criteria and in line with details provided in Tables 3 and 4, one can conclude that sand is the barrier's main composition because all the sand values have high percentage values. Waugh (1995) explains that sandy beaches or beaches composed of sand are low in height and have a gentle slope. Given this, when sand is wet, it becomes compact and restricts percolation due to its smooth surface. Hence, the backwash rate on such beaches is high, leading to a high erosion rate. This phenomenon explains why the Fosu Lagoon barrier beach has a low and gentle gradient. The intense nature of waves enabled longshore sediment drifts to be deposited at the back of the barrier close to the lagoon, which was also prevalent.

Consequently, the stronger the waves, the further they can push sediments inland. This means that the ability of deposits to be transported far from their source depends on how strong the wave's energy is. It depends on the nature of the offshore slope upon which the beach is found and the height above sea level (Komar, 1998).

Table 6: Particle Analysis of Sediments

Sample ID	Textural class	% of coarse sand	% of fine sand	Total
SW1 `	Sand	96.18	3.82	100
SW2	Sand	96.16	3.84	100
SW3	Sand	94.8	5.2	100
SW4	Sand	96.47	3.53	100
SW5	Sand	97.78	2.22	100
SW6	Sand	94.87	5.13	100
LW1	Sand	98.11	1.89	100
LW2	Sand	99.05	0.95	100
LW3	Sand	99.03	0.97	100
LW4	Sand	98.74	1.26	100
LW5	Sand	99.69	0.31	100
LW6	Sand	99.48	0.52	100

Source: Fieldwork (2020)

Particle Size Analysis of Sediment of the Fosu Lagoon Barrier Beach at Cape Coast

Aside from the sediment composition, the study progressed to analyse the grain size of the sediments that form the Bakaano barrier beach. This helped to give a clearer picture of the situation in the study area for accurate conclusions to be drawn and appropriate intervention given. Below are the percentages of particles of the Bakaano barrier beach sediment. The particle size of deposits that make up a barrier in a particular coastal environment emphasises the energy level of the waves along that part of the beach (Komar, 1998). The particle size analysis result in Table 6 indicates the textural group of the sediments that form the barrier beach. The result shows that the barrier beach is composed mainly of course sand. This is because coarse sand's percentage values are above 90%. Again, the result indicates how strong the waves are along that stretch of land, as confirmed by the particle size analysis and based on the law of selective deposition. The simple rule is, therefore. Generally, a more significant proportion of finer grains may be pushed higher up the beach by waves, while coarse grains are deposited closer to the water (Masselink et al., 2011; Komar, 1998, 1977). This implies that in the analysis of grains to determine the erosion rate, the tendency is that larger particles of sediments are deposited closer to the shore, but as distance increases from the shore inland, the particles get smaller and smaller or finer. This assertion is based on the law of selective deposition and suggests that the parent rocks, which produced the sediments, are complex. Coarser sand materials are usually constructed from hard rocks when they weather (Komar, 1998). The study went further to compare the near shore results of grain size of sediment of the barrier as shown in Table 6. Both the barrier's seaward and lagoon ward positions were considered, and the values are expressed in percentages.

The result of the sediment (Table 7) specimen taken from the near shores of the lagoon and the sea indicates the presence of coarse sand dominating on both sides of the barrier. It demonstrates that the waves' energy level is high, as the literature has shown.

Table 7: Comparisons of Nearshore Particle Size of Sediments of the Study Areas

Location	Textural class	% of coarse sand	% of fine sand	Total
SW1	Sand	96.18	3.82	100
SW3	Sand	94.8	5.2	100
SW5	Sand	97.78	2.22	100
LW1	Sand	98.11	1.89	100
LW3	Sand	99.03	0.97	100
LW5	Sand	99.69	0.31	100

Source: Fieldwork, (2020)

Therefore, the waves can transport and deposit coarser sand to build up to form the beach. In this circumstance, Waugh (1995) identifies the marine environment as essential for modifying the beach environment. This paper also compared upper beach particles to see whether there would be a variation.

Table 8: Upper Beach Particle Size Analysis of Sediments of the Study Areas

Location	Textural class	% of coarse sand	% of fine sand	Total
SW2	Sand	96.16	3.84	100
SW4	Sand	96.47	3.53	100
SW6	Sand	94.87	5.13	100
LW2	Sand	99.05	0.95	100
LW4	Sand	98.74	1.26	100
LW6	Sand	99.48	0.52	100

Source: Fieldwork, (2020)

The upper beach particle size analysis in Table 8 also recorded coarse sand as the main textural class of sediment found on the beach. From the near shore to the upper coast of the barrier beach's landward and seaward side, it was observed that coarse sand is the main sediment composition that forms the barrier beach at Bakaano (Rieux et al., 2023; Sherwood et al., 2023, Ritchie, et al., 2023). It reflects the nature of factors that come into play to act on the beach. This result confirms Waugh's assertion that a combination of factors comes into play to modify the coast and the beach. Terrestrial factors, marine, climate and humans interact with each other to influence the barrier beach. Thus, waves in the marine environment attack geological rocks through weathering to supply sediment to the coast through deposition to build up the barrier beach. Also, the nature of the geological rocks determines the type, grain size and nature of sediment that will form the barrier (Preston et al., 2018.; Komar, 1998). The laboratory investigation conducted on the sediment specimens to determine the composition and grain sizes of the deposit, including the barrier beach at Bakaano, revealed that coarse sand is the primary material that forms the barrier (Huisman et al., 2016). The percentage of fine sand that forms the barrier is deficient. The laboratory findings in the table indicate that finer sand particles are discovered on the seaward side of the barrier than on the landward sides. This suggests that sand particles deposited landward of the barrier are coarse.

Nevertheless, at site LW6 in Table 8, the condition is different. The values show a low percentage of coarse sand. It is a result of the inability of the sea waves to deposit sand materials close to that part of the lagoon shore. The proportion of material delivered to the barrier by longshore or tidal current flow is determined by particle size and flow speed (Komar, 1998). The sediment assemblages are influenced by wave/tidal action, littoral currents, and the slope's character; thus, the grain size distribution of beach sand is a consequence of the hydrological conditions (Kunert et al., 2010; Komar, 1998). The particle concentrations along beaches result from a complex interplay between the sediment input, the tidal energy threshold, and the offshore gradient on which the beach is established (Martim et al., 2021; Bujan et al., 2019; Ouillon, 2018). The intensity of the wave action in the littoral zone generally re-deposits and sorts materials of all grain sizes (Abdulkarim et al., 2014). Consequently, the character of beach sediment is influenced not only by wave action but also by the number of clastic materials supplied to the beaches (Lapietra et al., 2022, Guerrera et al., 2021; Abdulkarim et al., 2014). Waugh (1995) depicts that other variables influence the beach sediment. Usually, the supply of fine-grained suspended sediment typically decreases on mid-high latitude coasts due to the absence of significant rivers (Short & Neckles, 1999).

The study area also experiences lower weathering rates due to few sea cliffs. These have negatively impacted the amount of sediment supplied to build the barrier. As suggested, the sediment supply rate to the beach is lower than that of the river-fed beach. (Short & Neckles, 1999). Short and Neckles's (1999) assertions go a long way to explain why the Bakaano beach is low and has coarser sand. Thus, a flowing river to the beach is absent due to its latitudinal position. Also, there are a few sea cliffs to be weathered to speed up the rate of sediment supply to the beach. It was also shown that not all barrier components are easily degraded. Specific characteristics are more resilient than others. This may probably be due to the heterogeneous nature of the sediments that built the coast. It may also mean wave activities are more substantial at some parts of the barrier than at other positions. From this study, it was evident that the surface of the barrier is most often eroded. This may be attributed to the frequent overtopping and rollbacks that occur on the barrier, washing away loose sediment from the surface of the barrier. This might explain why the height barrier is mostly low (Smallegan et al., 2016).

The sea is the barrier's leading contributor to sediment accumulation. This is so because no rivers flow into the sea at that part of the coast. Nevertheless, occasionally, the de-silting of the lagoon adds up some quantity of sediments to supplement the one brought in by the sea. The loose, unconsolidated coarse sand that forms the barrier beach accounts mainly for the instability of the barrier. This is because strong waves quickly erode the sediments during overwash conditions; storms and rollbacks make the erosion rate exceed the rate of sediment deposition. Therefore, there is a disequilibrium between the sediment supply and erosion rates. These situations most often result in a deficit, creating an imbalanced condition that affects the profile of the beach.

Factors that Influence Barrier Morphology and Sediment Regime

The natural factors responsible for changing the morphology of the barrier beach have been identified as waves and storm surges. Waves are recognised as one of the paramount agents in the marine environment responsible for shaping the coast and its features. The work of waves cannot be overemphasised due to their role in sediment movement. As can be deduced from the above discussion, the role played by waves is evident. The waves act as agents of both transport and erosion. It also influences the height of the barrier beach. When waves regularly pound a barrier, as is the experience with the Fosu Lagoon Barrier beach, it takes on a low profile. This explains why the barrier is narrow in the middle since that part experiences more wave action. It also explains why the barrier beach is affected by landward and seaward movements. Due to the erosive power of the waves, especially during high tides, little sediment is brought and deposited at the coast to build up. The little deposition made during swash is breached during strong backwash (Chen et al., 2023; Baldlock, 2021). This phenomenon has kept the height of the barrier beach so low (Ions et al., 2021). The closeness of the barrier to the sea or the lagoon indicates the influence of both waves and climate on barrier beaches, as identified by Waugh in his model on the coast. According to Waugh (1995), high temperature during the dry season leads to a high evaporation rate. This causes a reduction in the volume of water (Kraus et al., 2008). When there is a reduced volume of water, the waves also become less active (Ions et al., 2021). Consequently, tides are low during this time, and the activities of waves are also minimal. Sediments deposited at the coast accumulate just above high tides to build up, as indicated in the literature on the activities of waves (Wesselman et al., 2018; Preston et al., 2018).

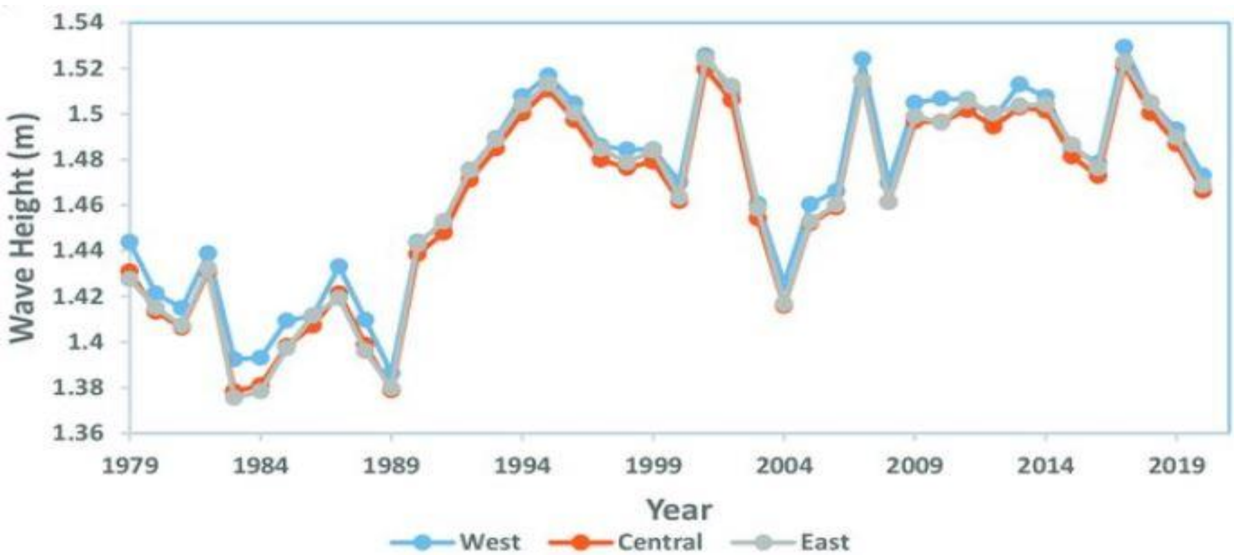

Figure 3: Spatial Distribution of the Annual Wave Power on the Coast of Ghana Estimated as an Average between 1979-2020

Source: Tulashie et al. (2022)

Continuous observation along the study area revealed the wave power. It was realised that the wave power along the coast of Ghana was so powerful to generate power. The winds in the study area were so strong that to shape the barrier beach significantly. A similar observation was made by Tulashie et al. (2022) during their feasibility study of wave power in Ghana, and they concluded that wave energy could be another renewable energy source in Ghana (Figure 3 is an adapted model by Tulashie et al. (2022) to support the observation made by the current researcher concerning the strength of waves. On the other hand, during the wet or rainy season, when more water is received, the volume of water increases. Activities of strong winds propel the sea into storms and strong waves (Komar, 1998). According to Richard (2012), the high energy level of the waves during this time causes the waves to be destructive. When these waves reach the shore, they can push the deposited sediments further inland through frequent rollbacks, overwash and overtopping conditions (Ions, Karunarathna, Reeve & Pender, 2021). This explains the two positions of the barrier in both wet and dry seasons (de Alegria-Arzaburu & Masselink, 2010).

Similarly, the frequency of sediment accumulation on the shore is higher during the rainy season than during the drought seasons, and so is the erosion rate during the wet seasons. The barrier attached itself to the coastline to form a continuous stretch of land. It has the characteristic of a simple over-the-wash-dominated barrier rich in sand, as espoused by (Gares & White 2005; Jermy, 2013) under their barrier beach classification. In terms of alignment, the barrier is swash-aligned. As a result, it has a steep beach face, a distinct crest and a back slope which fronts the Fosu lagoon. The barrier performs a landward movement in terms of migration; it also experiences frequent overtopping, crest cutback, over-washing and breaching, especially during the wet season (Phillips et al., 2020). Due to how the sediments brought offshore are deposited, the barrier is linear or elongated (Komar, 1998).

It was observed that human activities were impinging on the morphology and sediment regime of the barrier beach. One anthropogenic factor the research encountered is artificial barrier breaching. The artificial breaching occurs mainly during the Fetu festival, allowing seawater to enter the lagoon (Figure 4). During the process, the water erodes and widens the small channel within the barrier. As a result, the barrier changes its form from a continuous bar to a spit. It was reported that the Metropolitan Assembly artificially breached the barrier. Barrier breaching, especially from the lagoon side, is one of the causes of the instability of the beach in this area. During the rainy season, sediments are transported downslope by runoff water that drains into the lagoon. The increased volume of water in the lagoon causes the water to spill into the nearby facilities and homes, causing floods. One of the consequences of not manually breaching the lagoon is potential flooding hazards in adjacent low-lying areas and the development of algae blooms and invasive plant species. Another impact of the opening is rapid changes to the location of the barrier breaching (tidal inlet), erosion on the barrier and sedimentation in the lagoon (Davies-Vollum et al., 2019). It was also noted that the barrier beach was breached manually to facilitate the migration of salmon or the threatened steelhead trout. Kraus et al. (2008) are of the view that natural and manual breaching of barrier beach lagoons is a concern for species transiting or inhabiting such freshwater lagoons.

Figure 4: Seawater Flowing into the Fosu Lagoon Through a Channel Created in the Barrier

Source: Fieldwork (2020)

Another observation made was sand mining, as shown in Figure 5. Unregulated mining of large volumes of sand along the beaches is a driver of erosion. The balanced action of depositional and erosional forces usually forms sea beaches. Although this balance is naturally maintained, human interference causes excessive decay and, thus, the retreat of beaches. Sand mining also destabilises the barrier beach. According to Mensah (1997), the volume of sediments that built the barrier is reduced, affecting the beach's stability. Similar observations were made by Davies-Vollum et al. (2019) on the Muni Lagoon in Winneba.

Figure 5: Illegal Sand Mining Activities on the Barrier Beach

Source: Fieldwork (2020)

Sporting activities were recorded along the study area, as shown in Figure 6, and the barrier beach was prepared for sporting action. The use of the beach as the training ground for athletes and footballers has become rampant, and as they train on the barrier, their foot breaks and loosens the sediments, making them unconsolidated. The surge of wind and waves carries the deposit away, causing the barrier to lose soil and reduce height.

Figure 6: Barrier Beach has been used as a Training Ground

Source: Fieldwork, (2020)

The daily fishing activities on the beach cause a lot of people to influx to the beach to engage in many works. Figure 7 shows a boat that has been dragged onto the barrier. Some of these activities include joining in the pulling out of vessels arriving from fishing onto the beach, and buyers of the fish for retailing also move to the beach to buy the fish from the fishermen (Baffour-Awuah, 2014). In the course of these activities, their feet trample over the deposited sediment, and they become unconsolidated. This causes the residues to be prone to erosion, resulting in a change in the form of the beach. The fishermen, after fishing, sit on the barrier to mend their nets and repair their boats. These fishermen leave the canoes and boats on the barrier. As the vessels are moved in and out of the barrier over the deposited dunes, those parts of the barrier lose sand, changing the shape of the barrier.

Figure 7: The Barrier Serves as a Landing site for Fishing Activities

Source: Fieldwork (2020)

Another factor worthy of consideration is the dredging of the lagoon, Figure 8. The sediments are deposited on the barrier beach whenever the lagoon is dredged. Positively, this activity supplies more sediment to the beach, which makes the beach more resilient. However, the deposits are sometimes collected and sent away, resulting in sand loss at the beach. Removal of residue can also affect benthic habitats, and the organisms that live in and on the seabed are directly and immediately impacted by sediment removal and placement. Changes to water depth, sediment composition, and the hydrodynamic conditions at the seafloor can affect habitat quality for benthic organisms, which are significant food resources for shore and waterbirds and other marine species. All these activities contribute to changing the balance in the barrier (USGS, 2021). Reef et al. (2020) also find that the distance between a new breach and its nearest neighbour is more important for its survival than the size of the breach or the degree of saturation of the barrier coast. The finding is consistent with Godson et al. (2022), who avers each of these activities has a unique way of influencing the morphology of the beach. Therefore, anthropogenic and natural factors interplay, resulting in sudden or episodic changes in the morphology of the barrier, including its sediment regime.

Figure 8: Part of Fosu Lagoon and the Barrier Beach Being Dredged

Source: Field (2020)

Conclusion and Policy Recommendations

The paper assessed the sediment characteristics and morphological dimensions of the Fosu lagoon barrier beach at Bakaano, Cape Coast, through an onsite field study. It was found that the barrier beach is composed mainly of coarse sand with a relatively low height. Wave erosion attacks the barrier from both ends, seaward and lagoonward sides. In addition, terrestrial and human activities complement the wave action to modify the physical characteristics of the barrier beach. As a result, the barrier was found to be highly unstable, especially considering the seasonal dimensions, that is, the wet and dry seasons, thus making it more fragile. Therefore, the researchers recommend that all interested stakeholders, especially the Cape Coast Metropolitan Assembly, play a critical role in protecting and maintaining the feature. This could be possible if measures are put in place to regulate the number of human activities within the catchment area, thereby reducing the number of human footprints that trample on the sand deposits to break the dunes. This will help make the sediment hard, compact, and more resistant. We also recommend detailed geomorphic research along the entire coastline of Ghana to unravel the modifications occurring due to natural and anthropogenic alterations.

References

Abdulkarim, R., Akinnigbagbe, E. A., Imo, D. O., Imhansoloeva, M. T., Aniebone, V. O., Ibitola, M. P., ... & Appia, Y. J. (2014). Grain size analysis of beach sediment along the barrier bar lagoon coastal system, Lagos, Nigeria; its implication on coastal erosion. *Global Journal of Geological Sciences*, *12*, 31-37.

Adu-Boahen, K., Boateng, I, Okyere, E. Y., & Kyeremeh, S. (2023). An assessment of water quality and the locals' perception of coastal lagoon pollution in Ghana: A case study of Chemu lagoon in Tema. *Asian Review of Environmental and Earth Sciences*, *10*(1), 28–39/ https://doi.org/10.20448/arees.v10i1.4440.

Adu-Boahen, K., & Boateng, I. (2021). Mapping seasonal variation in the distribution and concentration of heavy metals using water quality index and geographic information system-based applications. *Journal of Geographical Research* DOI: https://doi.org/10.30564/jgr.v4i2.3100.

Baffour-Awuah, E. (2014). Perceptive views of fishermen on the sustainability of fishing in the Fosu lagoon in Cape Coast, Ghana. *Journal of Economics and Sustainable Development*, *5*(10), 94-103.

Baldlock, T. (2021). Swash zone dynamics. http://www.coastalwiki.org/wiki/sawsh zone dynamics. Accessed 29.06.2023.

Boateng, I. (2012). An application of GIS and coastal geomorphology for large scale assessment of coastal erosion and management: a case study of Ghana, *Journal of Coastal Conservation*, 16 (3)383-397. https://www.jstor.org/stable/23325708.

Brandão J, Weiskerger C, Valério E, Pitkänen T, Meriläinen P, Avolio L, Heaney C.D, & Sadowsky M. J. (2022). Climate change impacts on microbiota in beach sand and water: Looking ahead. *Int J Environ Res Public Health.* 19(3):1444. doi: 10.3390/ijerph19031444. PMID: 35162479; PMCID: PMC8834802.

Bujan, N, Cox, N.R & Masselink, G (2019). From fine sand to boulders: Examining the relationship between beach-face slope and sediment size, *Marine Geology*, 417, 106012, https://doi.org/10.1016/j.margeo.2019.106012.

Chen, W., van der Werf, J. J. & Hulscher, S.J.M.H. (2023). A review of practical models of sand transport in the swash zone, *Earth-Science Reviews*, 238, 104355, https://doi.org/10.1016/j.earscirev.2023.104355.

Dadson, I.Y., Adu-Boahen K., & Nyarko, B. K. (2018). Morphological classification and protection of the central coastline: Implications for coastal erosion management in Ghana. *Socialsci Journal* 22581-6624.

Dadson I.Y., Owusu, B. A. Osman A, (2016). Analysis of shoreline change along Cape Coast-Sekondi Coast, Ghana", *Geography Journal*, vol. 2016, Article ID 1868936, 9 https://doi.org/10.1155/2016/1868936.

Daniels, R.C. (1999). Barrier beaches and Barrier islands. In: Charles W. Finkl, Environmental Geology. Encyclopedia of Earth Science. Springer, Dordrecht. pp 40–44 https://doi.org/10.1007/1-4020-4494-1_27.

Davies-Vollum, K. S., Zhang, Z., & Agyekumhene, A. (2019). Impacts of lagoon opening and implications for coastal management: Case study from Muni-Pomadze lagoon, Ghana. *Journal of Coastal Conservation*, *23*(2), 293-301.

de Alegria-Arzaburu, A.R., & Masselink, G. (2010). Storm response and beach rotation on a gravel beach, Slapton Sands, UK. *Mar. Geol.*, *278*, 77–99.

Defne, Z., Ganju, N.K. & Moriarty, J.M. (2019). Hydrodynamic and morphologic response of a back-barrier estuary to an extratropical storm. *JGR Oceans.* https://doi.org/10.1029/2019JC015238.

Dei, L. A. (1975). Morphology of the rocky shoreline of Ghana. *Bulletin of the Ghana Geographical Association.* 17, 1–30.

De Santis V, Caldara M, Pennetta L. Transgressive architecture of coastal barrier systems in the Ofanto incised valley and its surrounding shelf in response to stepped sea-level rise. *Geosciences*. 2020; 10(12):497. https://doi.org/10.3390/geosciences10120497.

Engelstad, P.S., Falkowski, M., Wolter, P., Poznanovic, A., & Johnson, P. (2019). Estimating canopy fuel attributes from low-density LiDAR. *Fire* 2, *2*, 38. https://doi.org/10.3390/fire2030038.

Ghanadistricts.gov.gh. www.Cape Coast Metropolitan Assembly.

Ghana Meteorological Agency (GMet, 2020). Climatic data. Accra, Ghana

Gares, P. A., & White, S. A. (2005). Volumetric analysis of overwash fans resulting from tropical storms on North Hatteras Island, North Carolina. *Southeastern Geographer, 45(1),* 1-15.

Gerivani, H., Stephenson, W., & Afarin, M. (2020). Sea cliff instability hazard assessment for coastal management in Chabahar, Iran. *Journal of Coastal Conservation*, *24*(1), 1-17.

Guerrera, F, Martín-Martín, M, Tramontana, M., Nimon, B, Essotina Kpémoua, K (2021). Shoreline changes and coastal erosion: The case study of the coast of Togo (Bight of Benin, West Africa Margin). *Geosciences*, *11*, 2–40. https:// doi. org/10. 3390/ geosciences11020040.

Godson, P. S., Chadrasekar, N., Krishnakkumar, S and Thanga Vincent S. G. (2022). Anthropogenic impacts on the benthic habitat morphology: in Ecology and Biodiversity of Benthos pp135-207. ScienceDirect-Elsevier

How Jin Aik, D., Ismail, M.H., Muharam, F. M. & Alias M.A. (2021). Evaluating the impacts of land use/land cover changes across topography against land surface temperature in Cameron highlands. *PLoS One*. 21;16 (5):e0252111. doi: 10.1371/journal.pone.0252111. PMID:34019599; PMCID: PMC8139479.

Huisman, B.J.A. de Schipper, M.A. & Ruessink, B.G (2016). Sediment sorting at the Sand Motor at storm and annual time scales, *Marine Geology*,381, 209-226,https://doi.org/10.1016/j.margeo.2016.09.005.

Huntley, B.J. (2023). Soil, Water and nutrients. In: Brian John Huntley. Ecology of Angola. Springer, Cham.127-147. https://doi.org/10.1007/978-3-031-18923-4_6.

Ions K, Karunarathna H, Reeve DE, Pender D. (2021). Gravel barrier beach morphodynamic response to extreme conditions. *Journal of Marine Science and Engineering*; 9(2):135. https://doi.org/10.3390/jmse9020135

International Bank for Reconstruction and Development and World Bank (2020). Effects of climate change on coastal erosion and flooding. Technical Report in Benin, Côte d'Ivoire, Mauritania, Senegal, and Togo. Washington, DC, USA.

Jermy, A. (2013). Diffusion barrier segments the stalk. *Nature Reviews Microbiology*, *11*(2), 69-69.

Komar, P. D. (1998). *Beach processes and sedimentation* (2nd edition) Upper Saddle River, New Jersey: Prentice Hall.

Komar, P. D. & Homa R. A. (1986). Coastal processes and the development of shoreline erosion. *Ann Rev. Earth Planet Sci*. 1986. 14:237-65

Kraus, N. C., Patsch, K., & Munger, S. (2008). Barrier beach breaching from the lagoon side, with reference to Northern California. *Shore & Beach, 76, 33-43*

Kunert, C., Harting, J., & Vinogradova, O. I. (2010). Random-roughness hydrodynamic boundary conditions. *Physical review letters*, *105* (1), 016001

Lapietra, I., Lisco, S.N., Milli, S., Rossini, B., & Moretti, M. (2022). Sediment provenance of a carbonate bioclastic pocket beach — Le Dune (Ionian Sea, South Italy), *Journal of Palaeogeography*, 11(2), 238-255, https://doi.org/10.1016/j.jop.2022.03.005.

Lexague, N. J. M. & Zappa, C. J. (2020). The impact of rain on ocean surface waves and currents. *Geophysical Research Letters. Willey*. 47(7):e2020GL087287. DOI: 10.1029 /2020GL 087287

Martim, A.B., Moulton, P. A. H., Graziela, M. S., Keane, R., & Guilherme, B. F. (2021). Surfzone-beach-dune interactions along a variable low wave energy dissipative beach, *Marine Geology*, 435,106438, https://doi.org/10.1016/j.margeo.2021.106438

Masselink, G., Hughes, M., & Knight, J. (2011). *Introduction to coastal processes and geomorphology*. Routledge.

Mensah, J. V. (1997). Causes and effects of coastal sand mining in Ghana. *Singapore Journal of Tropical Geography* 18(1), 69-88.

Musselman, R. (2012). Sampling procedure for lake or stream surface water chemistry. Res. Note RMRS-RN-49. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 11 p

Nielsen, L., Jørgensen, N. O., & Gelting, P. (2007). Mapping of the freshwater lens in a coastal aquifer on the Keta Barrier (Ghana) by transient electromagnetic soundings. *Journal of Applied Geophysics*, *62*(1), 1-15.ttps://doi.org/10.1016/j.jappgeo..002.

Okyere, E. Y., Adu-Boahen, K., Boateng, I., Dadson, I. Y., Boanu, N. Y., & Kyeremeh, S. (2023). Analysis of ecological health status of the Muni Lagoon: Evidence from heavy metal content in its water and fish samples. *Geo: Geography and Environment*, *10*(1). https://doi.org/10.1002/geo2.115

Ouillon, S. (2018). Why and how do we study sediment transport? Focus on coastal zones and ongoing methods. *Water*, *10*(4), 390. https://doi.org/10.3390/w10040390

Phillips, B.T., Brown, J.M., & Plater, A.J. (2020). Modeling impact of intertidal foreshore evolution on gravel barrier erosion and wave runup with Xbeach-X. *J. Mar. Sci. Eng. 8,* 914.

Preston, J., Hurst, M. D., Mudd, S. M., Goodwin, G. C., Newton, A. J., & Dugmore, A. J. (2018). Sediment accumulation in embayments controlled by bathymetric slope and wave energy: Implications for beach formation and persistence. *Earth Surface Processes and Landforms*, *43*(11), 2421-2434.https://doi.org/10.1002/esp.4405.

Reef, K. R., Roos, P. C., Andringa, T. E., Dastgheib, A., & Hulscher, S. J. (2020). The impact of storm-induced breaches on barrier coast systems subject to climate change—a stochastic modelling study. *Journal of Marine Science and Engineering*, *8*(4), 271.https://doi.org/10.3390/jmse8040271

Richard Jr, A. (Ed.). (2012). *Geology of holocene barrier island systems*. Springer Science & Business Media.

Rieux, A., Weill, P., Mouazé, D & Tessier B. (2023). Influence of sediment composition on morphology and internal structure of mixed siliciclastic–bioclastic coastal barriers: Contribution of flume experiments. *Sedimentology 70*. https://doi.org/10.1111/sed.13083

Rowell, D. L. (1994). *Soil science: Methods & applications*. Routledge, 1-15.

Sherwood, C. R., Ritchie, A. C., Over, J. S. R., Kranenburg, C. J., Warrick, J. A., Brown, J. A & Hegermiller, C. A. (2023). Sound-side inundation and seaward erosion of a barrier Island during hurricane landfall. *Journal of Geophysical Research: Earth Surface*, *128*(1), e2022JF006934. https://doi.org/10.1029/2022JF006934

Short, F. T., & Neckles, H. A. (1999). The effects of global climate change on seagrasses. *Aquatic Botany*, *63*(3-4), 169-196.

Smallegan, S. M., Irish, J. L., Van Dongeren, A. R., & Den Bieman, J. P. (2016). Morphological response of a sandy barrier island with a buried seawall during Hurricane Sandy. *Coastal Engineering*, *110*, 102-110.

Smoot, J.P. (2009). Sedimentary indicators of climate change. In: Gornitz, V. (eds) Encyclopedia of paleoclimatology and ancient environments. Encyclopedia of Earth Sciences Series. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-4411-3_210

Tulashie, S.K., Odai R., Dahunsi, A. M & Amenakpor J. (2022). Feasibility study of wave power in Ghana. *International Journal of Sustainable Engineering* 15(1):301-313 DOI: 10.1080/19397038.2022.2145384

U.S. Geological Survey and U. S Fish & Wildlife Service Report (2021). Impacts of sediment removal from and placement in coastal barrier island systems. St. Petersburg, USA. https://www. fws.gov/cbra /documents/ FAQs-USGS-FWS-Coastal-Barrier-Report.pdf

Waugh, D. (1995). *Geography: An integrated approach (2nd ed.)*, Surrey, UK: Thomas Nelson and Sons Ltd.

Wesselman, D., de Winter, R., Engelstad, A., McCall, R., van Dongeren, A., Hoekstra, P.,& van der Vegt, M. (2018). The effect of tides and storms on the sediment transport across a Dutch barrier island. *Earth Surface Processes and Landforms*, *43*(3), 579-592. https://doi.org/10.1002/esp.4235

Wentworth, C. K. (1922). A scale of grade and class terms for clastic sediments. *Journal of Geology*, 30, 377-392.

Zhang, W. (2016). Barrier island. In: Kennish M.J. (eds). Encyclopedia of estuaries. *Encyclopedia of Earth Sciences Series*. Springer, Dordrecht. Retrieved on November 18, 2020 from https://doi.org/10.1007/978-94-017-8801-4_124.