UNIVERSITY OF CAPE COAST

LITHOLOGICAL RESPONSES TO SEA EROSION ALONG THE COASLINE FROM GOLD HILL (KOMENDA) TO AMISSANO (SALTPOND)

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BY

MABEL ANIM

Thesis submitted to the Department of Geography and Regional Planning of the Faculty of Social Sciences, University of Cape Coast, in partial fulfilment of the requirements for award of Master of Philosophy Degree in Geography

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: .... Date: ....

Name: Mabel Anim

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature: .... Date: ....

Name: Prof L. A. Dei

Co-supervisor's Signature: .... Date: ....

Name: Dr. B. K. Nyarko

ABSTRACT

Sea erosion, attributed to sea level rise and human activity, has become a threatening phenomenon confronting many coastal settlements worldwide.It has caused destruction to many coastal resources. Measures employed to mitigate sea erosion have been to build defence walls, groynes and revetment. However, these structures only dissipate the wave energy and cause further erosion on the coastline.

The eastern shoreline of Ghana is the most vulnerable as a result of the increase in fetch distance eastwards and other offshore factors. However, other portions of the country's coastline are experiencing high erosion activity. There is therefore the need to understand lithological responses to sea erosion to inform policy makers about the processes of sea erosion.

The study assessed the extent of sea erosion along the coast of Komenda to Saltpond in the Central Region of Ghana. Sampled beaches were observed for sea erosion activities. In addition, particle size analysis was done by means of the Trask's Sorting Index and the Cailleaux Roundness and Flatness indices on sand and pebble samples from selected localities. The analysis revealed that particle size reduced while erosion increased with increased fetch distance. A field measurement conducted on cliff profiles resulted in an estimated annual rate of erosion to be 4 cm-8 cm. As a consequence, the coastline of the study area, especially the sandy coastline, is expected to lie from 10 m to 15 m inland from the current shoreline, by the year 2100.

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DEDICATION

I dedicate this work to my husband and my beloved son, Jojo Baah Entsie.

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LIST OF ACRONYMS

a.s.l	Above Sea Level
DTS	Digital Topographic Sheet
EEZ	Exclusive Economic Zone
EPA	Environmental Protection Agency
GGS	Ghana Geological Survey
GCGS	Gold Coast Geological Survey
ICZM	Intercoastal Zone Management
IPCC	Intergovernmental Panel on Climate Change
md	Median Diameter
M/DCEs	Municipal/District Chief Executives
SLR	Sea Level Rise
So	Sorting Coefficient
UCC	University of Cape Coast
WRI	World Resource Institute

CHAPTER ONE

INTRODUCTION

Background to the study

In the 2009 report by the Intergovernmental Panel on Climate Change (IPCC), climate change and current trends in global temperatures indicate a continuous increase in global sea levels (IPCC, 2009). This has raised concerns among coastal researchers about current and predicted Sea Level Rise (SLR). These concerns have come about as a result of the effects SLR will have on adjacent coastal lowlands. SLR may result in two major changes namely; landward displacement of the land-water interface and inland inundation of coastal lands (erosion and submergence) and underground water changes, resulting from salt water intrusion of coastal aquifers (Leatherman et al., 1983). This study focused on the former (erosion and submergence) taking into consideration the lithological responses to erosion leaving the latter response (underground water changes) for future research. Lithology, in the context of this study, refers to the rock and its constituent minerals.

Coastal zones are dynamic environments characterised by distinct geomorphic processes and coastline configuration (Hinrichsen, 1998). Lithological responses to sea erosion could be manifested in particle size, roundness, spherecity, flatness and asymmetry (Cailleaux, & Tricart, cited in Dei, 1972). Particle movement begins when the drag of the moving fluid overcomes the gravitational and cohesive force of the particle. Particle movement exists in littoral drift along beaches and it is intensified when sea level rises. The rise in sea level facilitates the movement of particles in the sense that the increased volume of water is able to overcome the cohesive and gravitational force of the particles as in fluid dynamics (Krumbein & Sloss, 1963). This implies that smaller particles are set into motion more than larger ones because they offer less resistance to the force of the waves.

The constant battering of waves against rock outcrops through hydraulic action disintegrates rocks and further generates sediments on the beach. Erosion through abrasion process causes further breakdown which reduces the size of brecciated particles to rounded particles (Davidson-Arnott, 2010). Pebble roundness and rate of reduction in size depends partly on the strength of the waves and the type of rock. Therefore, the intensity of erosion could be established by measuring the morphology of particles such as roundness and flatness. Thus, the higher the roundness and flatness indices, the greater the intensity of erosion (Cailleux & Tricart, cited in Dei, 1972).

Sea erosion has been one of the coastal problems worldwide alongside problems of coastal floods, beach pollution, and destruction of biodiversity (Viles & Spencer, 1995; Hinrichsen, 1998). It has been estimated that about 70% of the world's coastline experiences coastal erosion (Bird, 1996). Despite all these problems, a greater percentage of the world's population live within a kilometre of the coast and this population is expected to grow to about 75% during the next three decades (Hinrichsen, 1995; Goldberg cited in Viles & Spencer, 1995).

The attraction of settlement and other human activities at the coast is as a result of its beauty, mild climate, presence of suitable low-lying flat agricultural land, the use of the sea as a means of communication, resources and rich ecological systems that makes life easier for man, plants and animals (Chambers, 1991; Rozengurt & Haydock, 1991; Viles & Spencer, 1995; EPA, 2005). These advantages have resulted in a high coastal population and has accounted for the overcrowding and over exploitation, putting pressure on coastal resources (Viles & Spencer, 1995; Hinrichsen, 1998). With about 60% of the population living in the coastal zone, most part of the world's coastline suffer from severe development pressure and little attention is paid to such problem (WRI, 1995). The management of coastal facilities in a sustainable way, whilst ensuring the health of coastal ecosystems has become a challenge due to increasing temperatures, rising sea levels, storminess and sea erosion.

There have been instances where coastal hazards, especially sea erosion, have affected both natural resources and human activities along the coast, threatening the homes and livelihoods of thousands of people (EPA & World Bank, 1994; Viles & Spencer, 1995; Hinrichsen, 1998). This has been a major problem confronting many nations because combating sea erosion however, comes with high cost (Miller et al., 2007: http://www.irinnews.org/Report). In sub-Saharan Africa, sea erosion is referred to as one of the predominant problems of the region and for that matter the whole world. People living along the coast always have to deal with the two notable problems of sea erosion and coastal flooding (Viles & Spencer, 1995).

Regarding sea erosion and its future threats, climate change is considered as one of the potential causative factors (Barth & Titus, 1984; Waugh, 1995; WRI, 1995; Hinrichsen, 1998). For instance, ice sheet retreat at the end of the Pleistocene period (after the Quaternary Ice Age) and increases in global mean temperatures led to the rise in global mean sea levels. The implication is a continuous greater recession of shorelines in the future (Waugh, 1995; Viles & Spencer, 1995; IPCC, 2007; IPCC, 2009).

According to European Union Report (2004), sea erosion has been a major problem confronting Europe’s coastline. Sea erosion is threatening natural habitats, biodiversity and natural sea defences such as dunes as well as human safety, housing and infrastructure (collapse of houses and roads) and economic activities (www.ec.europa.eu/environment/iczm).

In North America, sea erosion is threatening the city of Richmond and Vancouver International Airport. These two places are being washed out as a result of rising sea levels, flooding and more frequent storm patterns (CanWest News Service and Vancouver Sun, 2008 - www.canada.com/vancouversun).

There is massive sea erosion going on in Chennai, India, and this has caused buildings to sink into the sea. An example is the sinking of the Church of Jesus Christ’s building which is situated on the Marina Beach, about 333 metres (1000 feet) away from the sea. Within a period of 14 years, sea erosion has washed away the 333 metres stretch of land and the church building is on the verge of drowning (www.thaindian.com/newsportal/india).

In Africa, for instance in Togo, some parts of coastal roads had to be reconstructed inland (EPA & World Bank, 1994). Thousands of people have been affected by sea erosion in eastern Cotonou, Benin, Nigeria, and Senegal and in other countries where the sea occasionally washed away parts of the coast alongside buildings. The rate of coastal erosion is regional varying among countries and within countries (EPA, 2005). This may depend on factors such as rock type, nature of coast, offshore factors among others (Hinrichsen, 1998; WRI, 1995; EPA, 2005).

Ghana is no exception from nations facing the problem of sea erosion. The shoreline of Ghana displays the effects of erosion (Dei, 1975; EPA & World Bank, 1994; Appeaning-Addo, Walkden, and Mills, 2008). Areas such as Keta, Ada, Accra, Takoradi and Cape Coast are considered as the most erosion prone areas (EPA & World Bank, 1996; EPA, 2005). This is mostly attributed to the increase in fetch distance eastwards. Also human activities along the coast and offshore factors such as the building of the Akosombo dam, harbours, and breakwaters have reduced sediment delivery eastwards (Dei, 1975; EPA & World Bank, 1994; Saha, 2003).

Hot spot areas in Ghana could be located at Keta coast from Dzelukofe to Blekuso; Accra from Osu to Kpeshie lagoon; Nkontompo beach, between Sekondi and New Takoradi; Ada-Foah beach, from the Volta estuary to Otrokpe and in Cape Coast (EPA, 2004).

Evidences of sea erosion as a result of SLR were confirmed in a reconnaissance survey conducted in 2008 along the coastline of the study area. Concrete structures were found some metres into the sea at Anomabo, Biriwanand Cape Coast. There were other erosion features at Saltpond, Akong, Moree, Iture, Komenda and Abandze.

Ghana is among countries attempting coastal reclamation projects (EPA & World Bank, 1996). The erosion prone Keta/Ada areas are currently the only places where massive protection programmes are going on with few isolated places undertaking localised mitigation measures by building revetments and groynes (EPA & World Bank, 1996; www.ghanadistricts.com/news). Examples of man-made structures like breakwaters could be found at Princess Town, Ajua, Nkontompo, Essipong, James Town beach, Tema and Prampram (EPA, 2004). Some of these are also found in the study area at Kormantse, Anomabo, Abandze, and Duakor (near the University of Cape Coast).

Statement of the problem

Studies have shown increases in global mean temperatures since the mid 20^{th} century (IPCC, 2007). This is likely to increase due to the observed increase in anthropogenic greenhouse gas concentrations. According to the IPCC report for 2009, global mean temperatures have risen and continue to rise through the 21^{st} century (IPCC, 2009). This has led to SLR and hence increased the rate of erosion along adjacent coastal lands.

SLR causes erosion and inundation of shorelines which poses threats to coastal communities, resources and biological processes along the coast (Saha, 2003; EPA, 2004). The usual mitigation measures were to construct structures, as part of policy implementation, which dissipate the wave energy and in so doing these structures weaken and cause further erosion on the beach (Armah & Amlalo, 1998; Saha, 2003). SLR is considered the major cause of sea erosion and future predictions portray serious consequences on coastal lands (IPCC, 2009). Efforts made to curtail the problem are often towards the anthropogenic causes as the natural causes are beyond human control.

Despite all the coastal problems, settlements including ports and harbours and resorts have continued to grow along the coast. Climate change with its associated sea erosion continues to threaten populations and resources along the coast (WRI, 1995; Hinrichsen, 1998). As sea levels continue to rise, accretion becomes difficult with increasing erosion activities. Thus, coastal management has become an important issue (EPA, 2004).

A survey conducted along the study area between Saltpond and Komenda showed ongoing erosion processes with different lithology making up the coastal rock outcrop (Hughes & Farrant, 1963; Dei, 1975; Field observation, 2008-2011). It has also been observed that some areas respond differently to erosion. The study was to examine how the various lithological makeup of the coastline responds to sea erosion.

Research questions

Recent studies have all shown that global mean temperatures have risen drastically over the past century, increases in air temperature between 0.3ºC and 0.6°C since the late 19th century. The introduction of the Intercoastal Zone Management (ICZM) along with its measures is to sustain coastal resources and the coastline. However it seems these laudable objectives of the ICZM have not been met as sea erosion continues to increase along the coast between Komenda and Saltpond and for that matter Ghana as a whole (EPA, 2004). This has raised concerns such as:

1. What is the relationship between SLR and rate of erosion?
2. To what extent does particle size influence the intensity of erosion?
3. What is the relationship between fetch distance and erosion?
4. How does lithology influence erosion?

Objectives of the study

The general objective of the study was to investigate into the lithological responses to sea erosion. The specific objectives were to:

1. Investigate the relationship between lithology and intensity of erosion;
2. Examine the relationship between particle size and intensity of erosion;
3. Establish the relationship between fetch distance and erosion;
4. To estimate the future shoreline of the study area.

Significance of the study

Some natural processes often pose hazard to human occupation and utilisation of the coastal zone through wave action, flooding, storm surges and coastal erosion (Hinrichsen, 1998; Davidson-Arnott, 2010). Because of these threats to human life and activities, there is the need to improve our understanding of the processes operating in the coastal zone so that we can minimise their effects, and use this knowledge in the development of a comprehensive coastal zone management planning.

The study would, therefore, inform policy makers and managers on the responses of shoreline to sea erosion and to provide the basis for coastal zone policy formulation. This will help promote the development of sustainable management practices in coastal regions and sustain coastal resources. This is because the study will highlight on both the processes and rate of erosion caused by both natural and anthropogenic factors and the response of lithology to erosion.

Few studies have been conducted on sea erosion in Ghana and these are mostly concentrated at the eastern shores of the country (Keta and Ada).The study would also contribute to existing knowledge on sea erosion and coastal resources from Komenda to Saltpond and Ghana as a whole. It will also provide the basis for further investigation along the coast from Komenda to Saltpond and to add to existing data on erosion at the central coast of Ghana.

This study was also undertaken to help direct attention towards erosion at the central and western shores of the country. This is because although natural factors such as SLR dominate the causes that lead to sea erosion, differences in lithology and the activities carried out at the coast promote sea erosion while little or no attention is paid to these factors. However, if not checked, the phenomenon may gradually become threatening as in the eastern coast of the country.

Organisation of the study

The study consists of five chapters, each chapter beginning with an introduction. The first chapter comprised the background to the study, statement of the problem, objectives, research questions and significance of the study.

The second chapter dealt with the profile of the study area and the review of relevant and related literature. The chapter dwelled on the size and location, erosion and erosion features, drainage, lithology, vegetation and population and human activities found in the area. Also both empirical and theoretical works that relate to the study were reviewed to adopt approaches that will help model the phenomenon of sea erosion and other geomorphic processes in predicted scenarios.

The third chapter covered the methodological issues including the study design, type of study, research design, data types and sources, accessible unit of analysis, sampling techniques/procedures and data collection method/instrument.

The fourth chapter was on the presentation and analysis of data collected and comparison of findings from the field and that of the literature and the objectives. It also answered the concerns raised from the study.

Lastly, the fifth chapter presented the summary, conclusion and recommendations based on the findings from the study.

CHAPTER TWO

LITERATURE REVIEW

Introduction

Coastal erosion, whether it is caused by natural or anthropogenic factors, is known to be one of the most devastating environmental problems of coastal zones worldwide and it has serious implications on national economies. Natural causes include climate change, i.e. increased concentrations of greenhouse gases, leading to changes in meteorological conditions; winds, precipitation, atmospheric pressure, temperature and increasing global sea level (Barth & Titus, 1984; Bird, 1985; Viles & Spencer, 1995; IPCC, 2007; Davidson-Arnott, 2010;). Anthropogenic causes include damming and unsustainable use of resources along the coast such as bush burning, sand mining, deforestation and other agricultural practices as well as construction of artificial features (Saha, 2003).

Climate change resulting from increased concentrations of greenhouse gases such as carbon dioxide and other trace gases would affect the hydrological process, which has a direct impact on water and coastal erosion (Waugh, 1995). Climate change would affect precipitation such that regions with increased precipitation would experience increased runoff and river sediment load transport and vice versa (Davidson-Arnott, 2010). Therefore, a change in the world's weather pattern will result in the variability of water discharge and sediment supply to the coastal zone. Droughts will result in the reduction of sediment supply to the coastal zone through rivers. Information on changes on meteorological conditions, especially rainfall, winds and temperature is used to assess climate variability and its effect on the coastal zone (Henrichsen, 1998).

In this chapter both empirical and theoretical works of other researchers and writers that were related to the study were reviewed. This exposed the researcher to already existing knowledge on the subject matter. Empirically, it enabled the researcher to delve more into the nature of coast, geology, sub-aerial processes and anthropogenic factors that account for the rate of responses of shorelines to SLR. Some of these factors as well as the theoretical frameworks adopted for the study were reviewed.

The world’s coastline

There are variations in the length of the world’s coastline depending on the methods used. It is estimated to be about half a million kilometres. However, when all the intricacies of indented bays and promontories and offshore islands are included, the total length will be about a million kilometres (Bird & Schwartz, 1985).

It is made up of different types of coast and geological forms. There are volcanic coasts characterised by volcanic activities such as most of the coastlines of the Pacific Ocean islands. These include the coastlines of Fiji, Hawaii and Maui, New Caledonia, Papua New Guinea, Tahiti, Solomon Island and Vanuatu. Other volcanic coastlines include those found in Iceland. There are other parts of the world's coastline also made up of rocky with intervening sandy coastlines. About 20% of the world's coast is sandy and 70% of the sandy coastlines have been retreating (Bird, 1985; 1993)

The Ghanaian coastline and coastal plain

The Ghanaian coastline has a total length of about 539 kilometres (Dei, 1975). Out of this, about 253 kilometres is made up of sandy beaches, forming about 47%. The rest are rocky beaches with alternating sandy beaches in bays (286 km) making up 53% of the entire coastline (Dei, 1975). Sandy cliffs in bays occur in several places and the occurrence of beach rock at 45 metres offshore at certain places such as lower Prampram and Takoradi indicate coastal retreat. In areas where the beach is made up of poorly unconsolidated beach sand or deeply weathered sedimentary or igneous rocks sea cliffs have retreated significantly (Dei, 1975; Field observation, 2008-2011). This is particularly true in areas of sandy beaches such as Saltpond where sandy cliffs have retreated significantly (Field observation, 2008-2011). Such areas show intensive erosion processes even without human activities. This implies that erosion could intensify on sandy coasts and in areas where massive weathering processes operate. There has not been much significant change (erosion, submergence or emergence) along the rocky sections consisting of consolidated, durable rocks since the existing "stillstand". This is due to insufficient geologic time involved i.e. 4000 million years (Dei, 1975).

Studies on the Ghanaian coastline describe how shale of the “Accraian” (Devonian Sandstone) gives rise to sandy bays whilst the massive sandstone of the same formation form promontories of about 12 metres high (McCallien,1962 cited in Dei,1975). These headlands were characterised by steep cliff surfaces and rock boulders at the base.

The Ghanaian coastal plane is underlain by ancient rocks of the Precambrian and the Palaeozoic eras. These include the *Dahomean* (schist and lavas) and the Togo-Akwapim quartzites (GGS Annual Report, 1954-55 cited in Dei, 1975). Most of these were folded, strongly jointed and faulted. There were isolated outcrops of Devonian sandstones around Accra and between Cape Coast and Takoradi. Such sandstones are known locally as *Sekondian* in Cape Coast and Takoradi (Dei, 1975). The *Sekondian* rocks are heterogeneous ranging from shales to the conglomerates of the Sekondi sandstone with few unconsolidated Jurassic conglomerates in Saltpond. Intrusion of granite and pegmatite were common in the Precambrian and Palaeozoic rocks along certain shorelines, for instance, around Dixcove, Saltpond, Apam and Cape Coast.

Central Region coastline and coastal plain

The central region of Ghana’s coast is washed by the Atlantic Ocean and has about 168 km stretch of coastline (DTS, 1996, 2006; www.ghanadistricts.com). The coast shares similar characteristics with the general coastline of the country. It was mostly made up of rocky outcrop beaches with intervening sandy beaches (Dei, 1975). There were few areas without rock outcrop such as from Kormantse through Saltpond up to the *Amissano* estuary and beyond. The area was underlain by ancient rocks of the Precambrian and Palaeozoic with Devonian sandstones forming isolated outcrops between Cape Coast and Takoradi (Dei, 1975; Bird & Schwartz, 1985).

Ghanaian coastal zone

The definition for coastal zone varies depending on the policies for its management. According to Davidson-Arnott (2010), it is a broad term for the area influenced by the proximity to the coast. The onshore and the offshore limits are deliberately defined with no specific boundary. The boundaries are based on the policy and the definition. The limit on land may be some few metres inland in areas where the topography is high or several metres where the land is generally low. The offshore limit may be at the edge of the continental shelf or the Exclusive Economic Zone (EEZ).

Gattusso and Smith (2007) define the coastal zone to include the coastal ocean as well as the portion of the land adjacent to the coast that influences coastal waters. The coastal ocean is the portion of the ocean where physical, biological and biogeochemical processes directly affect the land. It is either defined as the part of the ocean covering the continental shelf or the continental margins (Davidson-Arnott (2010).

The coastal zone could also be defined as the area between the 30 metres contour landward and seaward up to the 100 fathom mark from the coastline. The coastline is the interface of land and water. It is the line reached by waves normally at the foot of cliff or cliff line (EPA & World Bank, 1994; EPA, 2005). However, for the purposes of management and as a proxy for watershed boundaries that might influence coastal areas, a management zone includes all areas that fall within the 75 metres contour line (EPA & World Bank, 1994). By means of this physical boundary, 21 coastal districts have been identified in the Western, Central, Greater Accra and Volta regions of Ghana with some portions of their territories within the 30 metres contour experiencing severe sea erosion (EPA & World Bank, 1994; EPA, 2005; Appeaning et al., 2008). The zone provides valuable opportunities for development of the nation. These include fisheries, tourism, recreation, ports and harbour facilities (Viles & Spencer, 1995).

The coastal zone of Ghana has undergone vast changes. Both natural and anthropogenic factors accounted for these changes (EPA & World Bank, 1996). The zone is drained by rivers and also endowed with other natural resources which are of importance to the different sectors of the economy. While other activities such as agriculture, salt production, oil and gas exploration, sand mining, recreational and industrial developments are carried out in the zone, fishing forms the major primary activity of the zone (EPA & World Bank, 1994).

Significance of the coastal zone

Historically, the coastal zone has been a major focus for the development of human society (Viles & Spencer, 1995). The use of the sea for transport and trade and availability of abundant food from highly productive coastal waters encouraged settlement (Day et al., 1993; Davidson-Arnott, 2010). Many coastal towns and cities have a culture and way of life way back over centuries. The coastal zones continue to be areas of rich potentials for our modern society. The productivity of coastal lagoons, tidal inlets, salt marshes and estuaries found in the zone have an important role to play in food production through maintenance of fisheries and aquaculture and in safeguarding nature and biodiversity (Tsyban et al., 1990).

However, the role of the coastal zones is much broader and more diverse. Coastal zones in general serve functions related to job creation, economic growth and quality of life and agricultural production in coastal plains. This is by means of using coastal water resources such as lagoons, aquifers and desalinization of sea water for fishing and irrigation purposes, promotion of tourism to offer employment and income to the working population. Its pleasing landscapes have aesthetics values (Tsyban, et al., 1990).

Coastal zone are used for energy production including both traditional sources like oil and gas, and renewable ones based on wind and waves. It enhances mobility and commerce through the construction of ports, harbours and coastal transport routes which are key elements in global transport links. Coastal zones serve as buffer zones and are responsible for the absorption and breakdown of pollutants. Coastal areas and their natural resources (marine and terrestrial) have a strategic role to play in meeting the needs and aspirations of current and future coastal populations (Tsyban, et al., 1990).

The environmental importance of the coast and its adjacent areas on and off shore is an important part of a local ecosystem as the mixture of fresh water and salt water in estuaries provides many nutrients for marine life. Salt marshes and beaches also support a diversity of plants, animals, and insects crucial to the food chain. The high level of biodiversity creates a high level of biological activity, which has attracted human activity for thousands of years (Warrick & Oerlemans, 1990).

An increasing part of the global population inhabits coastal regions. Many of the world's major cities have been built on or near good harbours and have port facilities (Tsyban, et al., 1990; Hinrichsen, 1995). Coasts, especially those with beaches and warm water are an important draw for tourists.

The study area

This study investigates the lithological response to sea erosion along the coast between Komenda and Saltpond in the Central Region of Ghana which is on the Gulf of Guinea. The shoreline considered is about 68 km long [Digital Topographic Sheet (DTS), 1996]. The climatic condition that prevails along this coast is of the equatorial type, characterised by wet and dry seasons, and the wind is a southwest monsoon.

According to the views sought from natives living along the coast and field observation, the local sea level is rising and this is in conformity with the global trend at a historic rate of approximately 2 millimetres a year. This is expected to increase, potentially up to about 6 millimetres a year (IPCC, 2007; Appeaning et al., 2008). There was no evidence upon which to base estimates of the influence of climatic change (climatic conditions) on future wave conditions, so for the purposes of this study climatic factors will be held constant. Management of this coast has been undermined by a scarcity of geospatial data and great inconsistency in reported rates of shoreline change, which vary between two metres and eight metres a year (Ly, 1980; Mensah, 1997).

Sea erosion, to some extent, has affected the social and economic life of the resident population, threatened cultural heritage and hindered coastal tourism development. According to Campbell (2006), quite a number of coastal inhabitants have lost their homes to coastal erosion within a 26 year period along some coastal areas in Ghana. This is expected to increase as the shoreline retreats through more and highly developed areas along the coast. Plates 1 and 2 in the Appendix illustrate a typically hazardous situation in the study area, with buildings situated on top of eroding soft cliffs. Some of the residents have relocated their homes and others are yet to do so due to the advancing sea.

The study area comprises the coast of Komenda to Saltpond (particularly the coastline but for the consideration of rivers, stream and lagoons, the coastal zone was also consideration). The area comprises the coastlines of four districts namely Komenda-Edina- Eguafo-Abirem, Cape Coast, Abura Aseibu Kwaman and Mfantsiman West with a total coastline of about 68 kilometres (DTS, 1996; www.ghanadistricts.com). There were about nineteen (19) towns and villages found in the area. Among the towns found in the area were Komenda, Elmina, Cape Coast, Agyaa, Abandze, and Saltpond. Fifteen (15) towns were observed for lithological responses to erosion activities. These towns were Amissano, Biriwa, Cape Coast, Komenda, Iture, Brenu Akyinu, Akong (Queen Ann's Point), Moree, Kormantse, Abandze, Saltpond, Agyaa no 1, Agyaa no 2, Elmina and Anomabo. These towns were selected because of their proximity to the sea, their location on the coastline and the evidences of erosion activities. Towns that were not found on the coastline were not selected for the reason being that they are not directly influenced by the sea and therefore do not experience sea erosion (Field observation, 2008- 2011).

Geology and topography

The major rock types were igneous and sedimentary. These were of the Devonian type belonging to the Precambrian and Palaeozoic eras (Hughes & Farrant, 1963; Dei, 1975; Bird & Schwartz, 1985) The area was divided into three (3) geological zones based on the lithological features on the beach: zones A, B and C.

Zone A starts from the beach at Komenda (the Gold Hill where the Training College is situated) to the west of Fosu lagoon. This was made up of the feldspathic Elmina and Takoradi/Sekondi sandstones which contained amorphous hydrous ferric oxides, indicating that they were iron bearing rocks, thus its brownish-red colour. According to Dei (1975), the rocks are friable, massive and bedded with shaly sandstone at the base with exposed surfaces limonitised. The limonitisation of the rock surfaces especially at Komenda (Gold Hill) has rendered the rocks quite resistant to erosion and has been quite stable. Some erosion features could be identified in this area. There was a major cave of about three metres high and two other smaller ones at the beach of the Komenda

Training College. Undercutting due to wave action has caused the roofs of most of these caves to collapse leaving behind stacks and stumps with limonitised surfaces. Concentric ferruginous bandings were commonly seen on the limonitised surfaces (Crow, 1952 cited in Dei 1975; Field observation, 2008-2011). Dips ranged between about 22°-30° forming gentle slopes towards the sea. There were circular holes and polygonal patterns and long channels on the rocky outcrops particularly at Komenda, Elmina and Iture. There were also found abrasion platforms or benches of about zero to three metres (Hughes & Farrant, 1963; Dei 1975; Field Observation 2008-2011). Plate 6 shows circular holes, polygonal patterns and long channels on the feldspathic sandstone outcrops found at Komenda, Elmina and Iture. It is believed that sea urchins were responsible for the conspicuous holes created. Sea erosion has been active along joints forming the rectilinear channels and there were surface depositions of calcite which were greyish-white in colour. These structures were also seen on the steeply-dipping garnetiferous biotite schists with minor fold nearly parallel to the dips at Anomabo (Hughes & Farrant, 1963; Dei, 1975; Field Observation, 2008-2011).

Zone B is from east of the Fosu lagoon to Abandze. This zone was made up of igneous rocks consisting of granites, pegmatite, schist and granodiorite of the Lower and Upper Birimian type. There was a cave of about 2 m high well developed in the pegmatite at Akong. Close by the cave, a notch was being developed by means of undercutting through the schist and the overlying pegmatite. The collapse of caves was common in this area littering the entire beach with pebbles of all sizes. These pebbles have been subjected to some amount of erosion thus reducing the brecciated surfaces to rounded and semi-rounded surfaces. There were also circular holes similar to those in zone A on the weathered granites at Anomabo. There were abrasion platforms of about 0-12 m high. Most of the rocks here were strongly jointed in a way and had facilitated erosion (Hughes & Farrant, 1963; Dei, 1975; Field Observation, 2008-2011).

Zone C is the area from Kormantse to Amissano and this was underlain by Lower Birrimian rocks of schist, pegmatite, Amissian conglomerates of shale and sandstone. There were no rocky outcrops seen on the beach in this zone. The beach was mainly sandy with active and varying erosion activity. For this reason there were lots of revetments and other concrete structures constructed to check erosion activities. Lagoons were found almost throughout the entire study area with their outlets closed with sand for most of the year. These outlets were excavated during high tides in the raining season when the lagoons experience increased volumes of water (Field Observation, 2008-2011).

The general topography of the area was of moderate relief. There were remains of erosion surfaces of lateritic cappings which were generally low in height (about 40 m -60 m a.s.l). Some of these occurred close to the sea at many places such as Saltpond, Kormantse, Abandze and Moree (GCGS Annual Report, 1938-39 cited in Dei, 1975; Field observation, 2008-2011). Some of these are considered to be erosional surfaces of Mio-Pliocene origin (Dei, 1975). Below the lateritic surfaces were *buttes temoins* of about 15-30 m high representing degraded laterite surface (Dei, 1975).

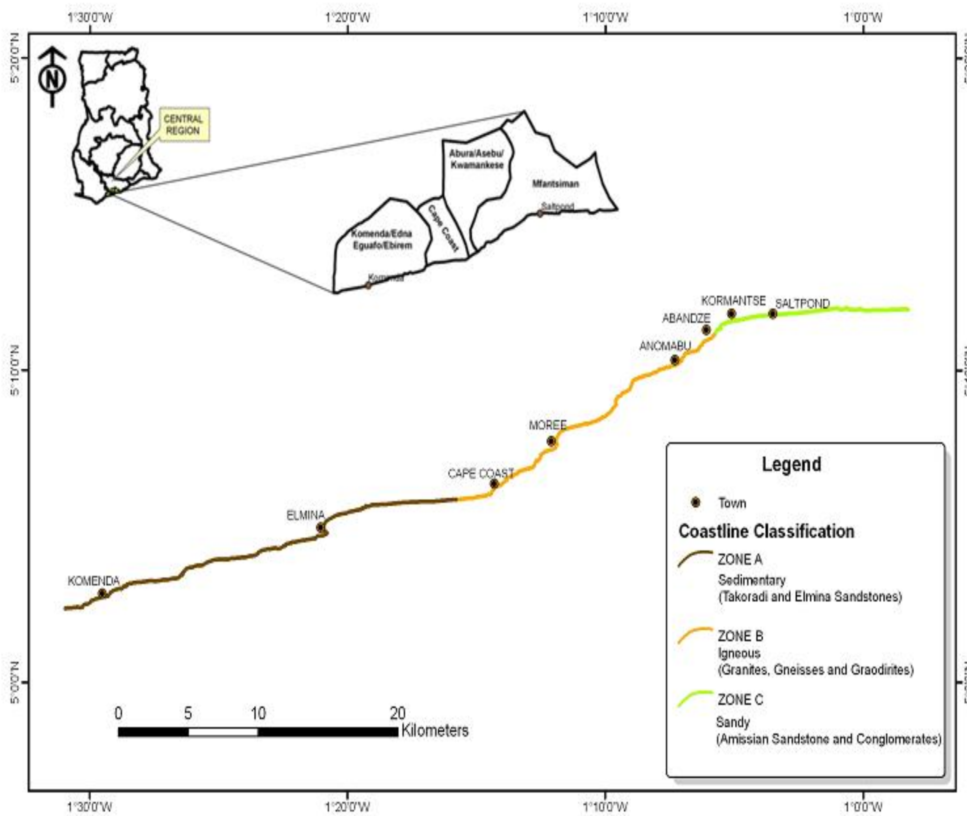

Figure 1: Lithological zones of the study area.

Source: Hughes & Farrant, 1963.

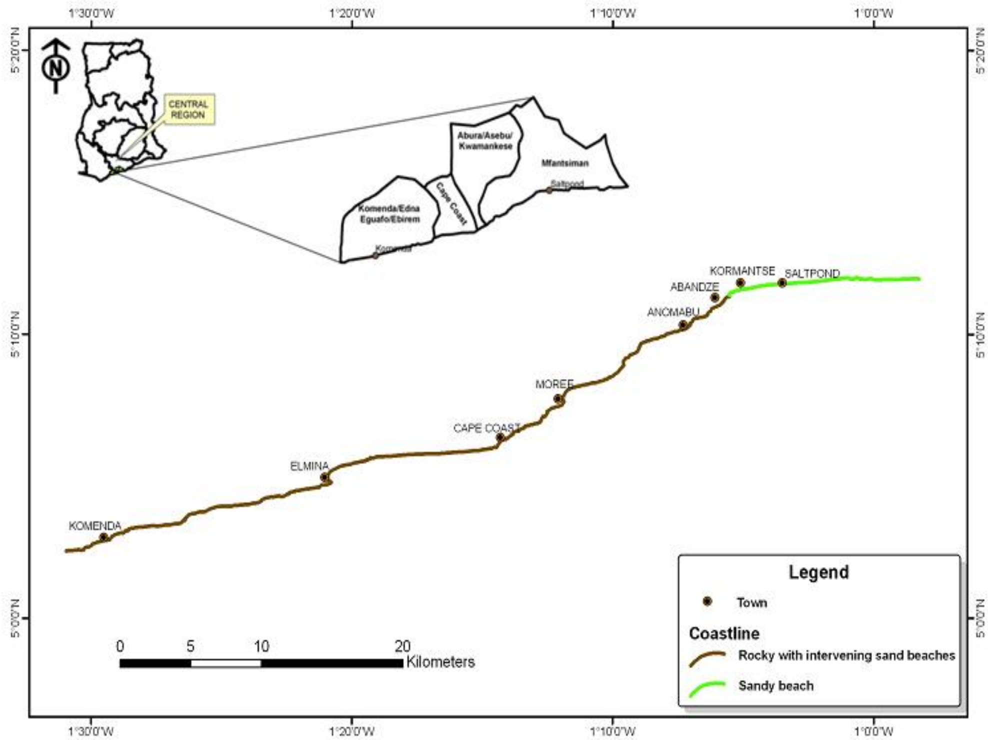

Figure 2: Coastline and nature of beach.

Source: Hughes & Farrant, 1963.

Drainage

The area was drained by rivers and small streams forming lagoons and estuaries. There were rivers such as the Abonka at Komenda, Barabui at Brenu Akyinu, Benya at Elmina, Kakum at Iture, Amissa (Ochi) at Amissano and other smaller streams locally known as *oworaba.* There were thirteen (13) lagoons and estuaries found in the entire study area. The mouths of the estuaries were filled with beach sand most of the time and were removed during the raining seasons when there was high tide and there were enough volumes of water in these water bodies. These spots were sometimes excavated by artificial means (excavation by natives) when it resulted in flooding in the nearby towns. As a result, these spots do not undergo any form of permanent accretion (EPA, 2004; DTS, 1996; Field Observation, 2008-2011).

Table 1 shows some of the lagoons and estuaries in the study area, their major river, tributaries and their location.

Table 1: Rivers, lagoons and estuaries in the study area

Main River	Tributary	Lagoon/Estuary	Location	Town(s)
Abonka	Tawin, Ohua	Susu	Between Dutch Komenda And British Komenda	
Barabui	Asenkye Essuanku, Obuahu	Brenu	Brenu Akyinu	Brenu Akyinu
Benya	Anwin, Baka	Benya	Elmina	Elmina
Kakum	Nkontro Saruwi,		Iture	Iture
Small streams		Fosu	Bakaano	Cape Coast
Woraba		Etsi	Abandze	Abandze
Nkasako		Etufa	Saltpond	Saltpond
Amissa		Amissano	Amissano, Hini	Amissano, Hini, Suprodu

Source: Field Observation, 2008-2011

Climate, soil and vegetation

The area is located in the coastal zone of Ghana. The area experience high temperatures almost all year round. The hottest months are February and March, just before the main rainy season, while the coldest months are July and August. Annual temperature range was between 23°C and 30°C with high humidity of 80% - 95% (Dei, 1975). Although the area experiences high temperatures coupled with high humidity which could have promoted the incidence of high rainfall, there was rainfall anomalies with reduced rainfall values between 700-1000 millimetres annually. This was because the south west monsoon winds, which is laden with moisture, blows almost parallel to the coast. Also there are no mountains to force these moist winds up to form rains. It is also believed that the upwelling of the cold Benguela current which washes along this coast brings in foggy conditions instead of rain. The invariability in climate in the area was influenced more by rainfall than temperature (Dei, 1975).

The dominant soils were lateritic in nature and were derived mainly from the weathered granite and schist. Sandy deposits occurred in the valleys and swampy areas extensively (Field Observation, 2008-2011). The vegetation was influenced by the pattern of rainfall in the area. It was mainly dense shrub giving way to coastal savannah grassland where drainage was poor with few scattered trees. The vegetation in marshy areas was mainly mangroves. These occurred in sheltered areas such as behind bars, lagoons, estuaries and at the back beaches occasionally reached by high tides (EPA & World Bank, 1996)

The original dense vegetation has been displaced, as a result of clearing for farming, charcoal burning, bush fires and other human activities (Dei, 1975). Presently, trees were less dense in the area compared with the interior forest areas, except the occasional acacia plantations and bamboo shrubs found in a few sanctuaries not yet completely deforested (Field observation, 2008-2011).

Population and economic activities

The coastline (coastal zone) of the study area has been among areas of settlement in Ghana, especially by the Fante ethnic group. For instance, 65% of the total land area of Ghana forms the coastal zone and it is home to about 25% of the population in Ghana (EPA, 2004). The area has witnessed increasing economic activity and human impact in recent years. These activities include farming, fishing, charcoal burning, salt mining and other industrial activities and newer sources of economic development such as historical and ecological tourism (White et al., 2008). It is also a coastal zone which has received a disproportionate amount of population redistribution and economic development in Ghana (EPA, 1996).

There has been a growth in the tourism industry in this area and this has made it relevant to have a critical study of the coastline. This is because just as tourism creates job opportunities and promotes development on one hand, it also places development pressure on the narrow strip of land besides the sea including the beach on the other hand. These facts reflected the significance of the study.

Although the study tends to look at the natural factors affecting erosion, the anthropogenic factors were not entirely ignored (White et al., 2008).

Definition of erosion

Erosion is commonly defined as the removal of loose materials or soil in many disciplines. The Encarta World English Dictionary (1999) defines erosion (as in Geology, because it is also applied in medicine and dentistry) as the gradual wearing away of rocks or soil by physical breakdown, chemical solution and transportation of materials as caused by water, wind or ice. The process of erosion is also defined as the disintegration of rocks which lie exposed to agents such as running water, wind and ice (Small, 1978) Erosion could also be defined as the removal of solids (weathered materials) in the natural environment. It usually occurs due to transportation by wind, water, or ice; by down-slope creep of soil and other material under the force of gravity or by living organisms, such as burrowing animals, in the case of bio-erosion (Small, 1978).

It could be deduced from the above definitions that the first step in erosion is weathering (detachment) as it goes through the process of transportation and ends with deposition. Therefore, erosion involves detachment, transportation and deposition (Saha, 2003). The difference between weathering and erosion lies in the movement of the regolith. Although the two processes may occur concurrently, erosion involves movement of loose particles or materials while weathering is the breakdown of rock in situ (Small, 1978; Waugh, 1995).

Based on the sources of energy or the agents, erosion could be classified as wind, glacier, river, or sea erosion. The type of erosion operative in an area is spatio-temporal in nature (Saha, 2003; Small, 1978). Specific areas with different climatic conditions experience different types of erosion that corresponds to the climatic conditions pertaining in the area. For this matter glacial erosion cannot be experienced in humid tropical areas just as wind erosion is not common in forested humid tropical and temperate zones. Some definitions of erosion sometimes include the movement of regolith downslope under the influence of gravity (Waugh, 1995).

Sea erosion

This study focuses on sea erosion which could be defined as the constant battering of the sea (wave action), primarily by the processes of hydraulic action, corrasion, attrition, and corrosion (Davidson-Arnott, 2010). Clark (1996) defines sea erosion as the landward displacement of the shoreline caused by the action of the sea. The phenomenon which acts on all kinds of beaches, both rocky and sandy beaches, exposed and sheltered coasts, primarily occurs through the action of currents and waves. Current and wave actions are sometimes influenced by sea levels or tidal changes. Sea erosion occurs when wind, waves and longshore currents move sand from the shore and deposits it elsewhere. The sand can be moved to another beach, to the deeper ocean bottom, into an ocean trench or onto the landside of a dune. The removal of sand from the beach system results in changes in beach shape and structure (Barth & Titus, 1984; Bird, 1985). These changes could result from cimatogenic movements (isostatic recovery) by means of uplift and subsidence of the coast, or by eustatic changes (changes in the percentage of ice-covered surfaces on the earth as a result of changes in global mean temperatures) which causes the emergence and submergence of the coast by means of increasing or decreasing sea levels (Waugh, 1995).

Factors affecting sea erosion

Sea erosion is influenced by both natural and anthropogenic factors (Barth & Titus, 1984). The natural factors include increases in sea levels as the fundamental cause which influences the other local factors such as action of the waves, tides, currents and winds. The anthropogenic causes are mainly sand mining, offshore dredging, removal of coastal vegetation and offshore causes such as building of dams upstream (Saha, 2003). There are evidences of both natural (increase in sea levels) and human induced factors (sand mining, deforestation etc) which contribute to sea erosion along many coastlines.

A world-wide SLR is a phenomenon that contributes to sea erosion. The forecast for the global SLR for the next century varies considerably. However, the IPCC (2009) estimated an increase of 0.2 metres and 0.5 metres at the middle and end of the 21st century, respectively. An increasing sea level will cause a coastline setback, which is approximately equal to the ratio of SLR and the slope of the active coastal profile, when considering equilibrium profiles (Bird, 1993). Littoral coasts consisting of fine sediments will be exposed to higher setbacks than coasts consisting of coarser sediments. This is because the finer sediments are easily transported even by weaker currents compared to the coarse grained sediments.

Subsidence lowers the surface of a specific region. Subsidence is a local or regional phenomenon in contrast to the sea level rise, which is global. Subsidence can be caused by many different phenomena, natural as well as human. Natural causes can be the settling of sediments, tectonic activity and different kinds of rebound processes, whereas human causes can be the extraction of groundwater, oil or gas in the coastal area (Wigley, 1995). Subsidence acts in the same way as SLR in relation to sea erosion apart from the fact that SLR will always be a global and gradual process, whereas subsidence may occur rapidly depending on the cause of the subsidence.

Processes involved in sea erosion

The processes involved in sea erosion are hydraulic, corrosion, attrition, and abrasion (Small, 1978; Waugh, 1995). Most erosion takes place around high tide and will be carried out in one of these ways. The first is hydraulic erosion which has an effect of a small explosive charge. The sudden impact of a wave on to the cliff face forces air into any cracks that they might be or along the bedding planes, compressing the air briefly then releasing the pressure. The changes in pressure causes the cracks to widen and go further into the cliff, materials break away and are washed out of the cliff by following waves (Small, 1978)

The material washed away becomes means for further erosion. The debris is washed against the base of the cliff in a process known as abrasion and acts in a scraping or grinding motion (Small, 1978). In this process, not only does erosion take place at the foot of the cliff but the sediment itself is worn down and rounded in a process known as attrition. The last type of erosion is a chemical process, particularly in limestone and chalk cliffs where chemicals within the sea water attack the rocks eroding the weaker sections and gradually causing the cliff to collapse (Small, 1978).

Coastal lands may experience long-term erosion under certain conditions. For instance, if sea level is rising, the beach may eventually migrate landward or drown. This causes coastal land behind the beach to erode. Also, if the amount of sand from the seaward side is reduced, a beach will erode the land behind it to maintain a constant sand supply. This also contributes to coastal erosion (Baldwin, et al., 1996). Beaches on eroding coasts undergo seasonal profile adjustments, but they slowly shift their position landward as the land erodes. Hardening a shoreline can interfere with necessary profile adjustments because the dune can no longer share its sand with the beach. As a retreating beach encounters a seawall or revetment it can no longer draw upon a landward sand supply and it begins to erode (Baldwin, et al., 1996).

Sea erosion in Ghana and responses

Many settlements along the Ghanaian coastline have been submerged due to increasing sea levels in the past few decades. Areas that are mostly prone to sea erosion are concentrated at the eastern coastline of the country. Examples of such areas include Keta, Amedzopfe, Dzelukofe, Blekusu, Ada Foa all in the Volta region. Other areas include La, Osu and Kpeshie beaches in Accra, at Nkontompo, between Sekondi and new Takoradi, in Cape Coast areas and Axim shoreline (EPA, 1996). On the average, the annual rate of erosion is 1-2 metres (Appeaning, et al., 2008).

An attempt on coastal reclamation projects both large and small scales are ongoing in some erosion prone areas in Ghana (EPA & World Bank, 1996). The erosion prone Keta/Ada areas are currently the only places where massive protection programmes are going on with few isolated places undertaking localised mitigation measures by building stone revetments and groynes (EPA & World Bank, 1996). Examples of man-made structures like breakwaters could be found at Princess Town, Ajua, Nkontompo, Essipong, James Town beach, Tema and Prampram (EPA, 2004).

Some major coastal features

Physical features along the coast may be grouped into two: features that are developed as a result of erosion (erosion features) and those developed as a result of deposition (depositional features). Although increasing sea levels are mainly known for their erosive effects, sea erosion and deposition are phenomena that could be said to occur concurrently. For the purpose of this research work, both phenomena were investigated as to where they occur and are common and which one dominates (Dei, 2008).

Erosion features

Cliff

Cliff is a common feature along the coast. It is a break in slope of the mainland at the coast (sea cliff). This is caused by erosion of the foreland to a relatively lower level, leaving a cliff face behind (Dei, 2008). The feature can also be found on the shores of rivers, lakes, estuaries, lagoons and other water bodies.

Wave-cut platform and notch

A notch may develop along a line of weakness at the cliff face or at the base of the cliff which has been subjected to prolonged wave action. This may result when wave energy is at its maximum and a high steep wave breaks at the foot of a cliff. The undercutting of the cliff will result in the formation of a wave-cut notch (Waugh, 1995; Dei, 2008; Davidson-Arnott, 2010).

When undercutting is prolonged it causes increased stress and tension in the cliff until eventually it collapses. A repetition of this will cause the cliff to retreat leaving a gently sloping platform at its base known as wave-cut platform (Dei, 2008). This feature cuts across all rocks regardless of their type and structure (Waugh, 1995; Dei, 2008; Davidson-Arnott, 2010). The widening of the platform allows waves to travel over wider area of beach. This dissipates the energy of the wave, reduce erosion and hence reduce the extension of the platform. Thus the width of the platform is normally less than half a kilometre (Waugh, 1995; Davidson-Arnott, 2010).

Cave, geo, blowhole and arch

Further erosion of the notch will enlarge it to form a cave (Dei, 2008). The roof of the cave is sometimes eroded, reaching the surface some distance inland as a vertical pit. This is known as blowhole or gloup. Two caves found on either sides of a headland or promontory may erode back-to-back and break through to form a natural arch. Sometimes the sea cuts inland along a joint to form a narrow, steep-sided inlet called a geo (Dei, 2008; Davidson-Arnott, 2010).

Stack

The next stage is the collapse of the arc leaving a seaward section standing as a stack. Some of these stacks are covered by the sea to form stamps which pose danger for canoes, boats and other oceans vessels that sail close to the coast (Dei, 2008). Other erosion features include wave-cut platforms and benches which also result from the action of waves. According to Dei (2008) these features are developing on the coastline of Ghana and they are of the Recent type. However, they are found in some specific areas along the coast of Ghana. They are about 0 - 2 metres a.s.l. Those above a metre are believed to have been cut by higher sea stands in the past although recent sea action may have contributed (Small, 1978; Dei, 2008).

Headlands and bays

In areas where the coast is underlain by alternating soft and hard rocks, the softer rocks are eroded to form bays or inlets, leaving the hard rock standing out to form promontories or headlands. Initially, the less resistant rock experiences most erosion and develops into bays, leaving the more resistant outcrop as headland (Waugh, 1995). Later the headland receives the highest wave energy and so become more vulnerable to erosion than the sheltered bays. The bay then receives low energy waves and allows sediments to accumulate and help protect that part of the coastline. These features have greater influence on littoral drift (Dei, 2008).

Depositional features

Beach

It is the accumulation of materials or sediment on the shore**.** The shore is the area between low water mark and the base of the cliff. It could also be referred to as the gently sloping shore of a body of water which is washed by waves or tides (Bates, & Jackson, 1984; Dei, 2008). The beach can be rocky, sandy or both. The sediments or material making up the beach may consist of boulders, pebbles, cobbles, coarse sand fine sand and silt. A beach could also be a geological landform along the shoreline of a body of water. The particles of which the beach is composed can sometimes have biological origins, such as shell fragments or coralline algae fragments (Dei, 2008, Davidson-Arnott, 2010).

Although the shore is most commonly associated with the word "beach", beaches are not only found by the sea or ocean. Beaches also occur inland at the margins of the land along lakes and rivers where sediments are reworked or deposited (Davidson-Arnott, 2010). There are several conspicuous parts to a beach, all of which relate to the processes that form and shape it. The part mostly above water (depending upon tide), and more or less actively influenced by the waves at some point in the tide, is termed the beach berm. The berm is the deposit of material comprising the active shoreline (Davidson-Arnott, 2010). The berm has a crest forming the upper part and a face which is the slope leading down towards the water from the crest. At the very bottom of the face, there may be a trough, and further seaward one or more longshore bars; slightly raised, underwater embankments formed where the waves first start to break.

The sand deposit may extend well inland from the berm crest, where there may be evidence of one or more older crests (the storm beach) resulting from very large storm waves and beyond the influence of the normal waves. At some point the influence of the waves on the material comprising the beach stops, and if the particles are small enough winds shape the feature. Where wind is the force distributing the grains inland, the deposit behind the beach becomes a dune (Baldwin et al., 1996).

These geomorphic features make up the beach profile. The beach profile changes seasonally due to the change in wave energy experienced during high and low tides. The beach profile is higher during the dry season when there is low tide and where there is little or no rainfall and run-offs to cause slumping and erosion of cliff face (Baldwin et al., 1996). This leads to gentle wave action during low tide period. The lower energy waves deposit sediment on the beach berm and dune, adding to the beach profile. Conversely, the beach profile is lower in the rainy seasons due to the increased wave energy associated with storms. Higher energy waves erode sediment from the beach berm and dune, and deposit it offshore in deep ocean trenches (Davidson-Arnott, 2010). The removal of sediment from the beach berm and dune decreases the beach profile. However these sediments are deposited offshore at the farther end of the littoral zone.

The line between beach and dune is difficult to define in the field. Over any significant period of time, sand is always being exchanged between them. The drift line (the highest point of material deposited by waves) is one potential demarcation. This would be the point at which significant wind movement of sand could occur, since the normal waves do not wet the sand beyond this area (Small, 1978). However, the drift line is likely to move inland under the influence of storm waves.

Beaches are deposition landforms, and are the result of wave action by which waves or currents move sand or other loose materials of which the beach is made as these particles are held in suspension. Alternatively, sediments may be moved by saltation. Beach materials may also come from erosion of rocks offshore, as well as from headland erosion and slumping producing deposits of talus or scree. Some beaches have very fine and whitish sand and this comes from the erosion of quartz along rocky coasts or offshore on the seafloor. A coral reef offshore may also be a significant source of beach sediments (Small, 1978). Therefore, beach sediments are dependent on the bed rock offshore or onshore.

The shape of a beach depends on whether or not the waves are constructive or destructive, and whether the materials are of fine or coarse sediments (Crowley, 2006). Constructive waves move material up the beach to accumulate while destructive waves move the material down the beach causing erosion. On sandy beaches, the backwash of the waves removes material forming a gently sloping beach. On shingle beaches the swash is dissipated because the large particle size allows percolation, so the backwash is not very powerful, and the beach remains steep (Crowley, 2006).

Beaches as recreation centres

Many beaches are very popular on warm sunny days. In more than thirty countries in Europe, South Africa, Canada, South America and the Caribbean, the best recreational beaches are awarded Blue Flag status, based on such criteria as water quality and safety provision (Oude et al., 1993; Davidson-Arnott, 2010). Although beaches at the study area were not graded among the Blue Flag status beaches, there was some amount of tourism activities being carried out. Therefore, subsequent loss of beach sediments through sea erosion can have a severe effect on tourism revenues.

Due to intense use by the expanding human population, most beaches are either lost due to human impact on the beaches which leads to increased erosion activities. Others are degraded often serving as dumping grounds for waste and litter, necessitating the use of beach cleaners and other cleanup projects. More significantly, many beaches are a discharge zone for untreated sewage in most underdeveloped countries, even in developed countries beach closure is an occasional circumstance due to sanitary sewer overflow. In these cases of marine discharge, waterborne disease from faecal pathogens and contamination of certain marine species is a frequent outcome (Tsyban, et al., 1990).

Mudflat

Mudflats (also known as tidal flats) are coastal wetlands that form when mud is deposited by tides or rivers. They are found in sheltered areas such as lagoons and estuaries. They may be viewed geologically as exposed layers of bay mud resulting from deposition of estuarine silts, clays and other sediments. Most of the sediment within a mudflat is also within the intertidal zone, and thus the flat is submerged and exposed approximately twice daily (Oude, et al., 1993).

Mudflats are typically important regions for wildlife, supporting a large population, although levels of biodiversity are not particularly high. They are often of particular importance to migratory birds. The maintenance of mudflats is important in preventing coastal erosion. However, mudflats worldwide are under threat from predicted SLR, coastal land reclamation for development, dredging due to shipping purposes, and chemical pollution.

Features produced by other processes

Estuary

An estuary is a semi-enclosed coastal body of water with one or more rivers or streams flowing into it, and with a free connection to the open sea (Baldwin et al., 1996). Estuaries are thus subject to both marine influences, such as tides, waves, and the influx of saline water; and river influences, such as flows of fresh water and sediment. As a result, they may contain many biological niches within a small area, and so are associated with high biodiversity.

Estuaries are typically the tidal mouths of rivers and they are often characterized by sedimentation or silt carried in from terrestrial runoff and, frequently, from offshore. They are made up of brackish water. Due to their suitability to human settlement, estuaries typically have a heavy human presence and most cities in the world are located on estuaries. Estuaries are marine environments with varying pH, salinity and water levels, depending on the river that feeds the estuary and the ocean from which it derives its salinity. This is because oceans and seas have different salinity levels depending on the environment they are situated in. Landlocked seas, sea located in desert areas and seas that have few rivers draining into them are highly saline and these tend to have effect on the salinity of estuaries around them (Tsyban, et al., 1990).

Estuaries provide habitats for a large number of organisms and support very high productivity. Estuaries provide habitats for many fish nurseries, depending upon their locations in the world, such as salmon and sea trout. Also, migratory birds' populations, such as the black-tailed godwit, sea herons and cranes make essential use of estuaries.

Two of the main challenges of estuarine life are the variability in salinity and sedimentation. Many species of fish and amphibians have various methods to control or conform to the shifts in salt concentrations. Many animals also burrow to avoid predation and to live in the more stable sediment environment. However, large numbers of bacteria are found within the sediment which has a very high oxygen demand. This reduces the levels of oxygen within the sediment often resulting in partially anoxic conditions, which can be further exacerbated by limited water flux (Day, et al., 1993). Sea weeds such as plankton are key primary producers in estuaries. They move with the water bodies and can be flushed in and out with the tides. Their productivity is largely dependent upon the turbidity of the water.

Lagoon

A lagoon is a body of comparatively shallow salt or brackish water separated from the deeper sea by a shallow or exposed sandbank or sand bar, coral reef, or similar feature. Thus, the enclosed body of water behind a barrier reef or barrier islands or enclosed by an atoll reef is called a lagoon (Dei, 2008).

A delta is a landform that is created at the mouth of a river where the river flows into an ocean, sea, estuary, lake, reservoir, flat, arid land or another river. Deltas are formed from the deposition of the sediment carried by the river as the flow leaves the mouth of the river. These sediments are deposited by a relatively weak current and over long periods of time this deposition builds the characteristic geographic pattern of a river delta (Dei, 2008).

Longshore drift

Longshore drift is conceptualized as a “river of sand” flowing uniformly along the shore. The coastline can be divided into littoral cells of varying length (Carter, 1998). Longshore drift is a nearshore current created by oblique wave angle which is capable of moving large quantities of material in a down-drift direction. The direction is mainly determined by the prevailing wind and the fetch distance.

Littoral cells have been defined as areas of the coast where no inflow or outflow of sediment occurs (Smith & Sayao, 1989). Little interaction usually occurs between cells and coastal processes may be quite different between adjacent longshore cells. Cell boundaries may be well-defined or ephemeral. Well-defined boundaries tend to be coastal structures or morphological features such as headlands, shoals, river mouths, or inlets which exercise major control on the wave refraction pattern and/or inhibit longshore sediment transport. Ephemeral or transitory boundaries are much harder to locate because they are caused by cyclic changes in net drift direction generated by variability in the incident wave climate (Carter, 1998).

Each combination of deepwater wave height, wave period, and approach direction causes a unique cell structure. As the waves change, the cell boundaries move, enabling sediment to be passed alongshore. This concept helps explain why even subtle meteorological variations may affect net drift (Stapor & May, 1983; Stauble & Da Costa, 1987). The predominant drift direction in the study area is west-east along most parts of the coastline due to prevailing winds blowing along the coast. There are, however, local variations in this pattern due to local morphologic controls. Investigators are discovering localized circulation cells on all coasts. Temporal variation also occurs, with changes in meteorology or current circulation patterns (Inman & Frautschy, 1966; Kadib, 1989).

Sediment budget

Sediment Budget could be used to assess shoreline change and it involves the evaluation of the sediment mass balance, or sediment budget, for a given portion of the coast (Komar, 1996). Using this method, the gains (accumulation) and losses (erosion) of sediment to a portion of the shore, often referred to as a control volume, are quantified and evaluated based on estimates of beach volume change (Gornitz, 1991; Thieler & Hammar-Klose, 1999). Changes in the volume of sand for a particular setting can be identified and evaluated with respect to adjacent portions of the shore and to changes in shoreline position over time.

One challenge related to this method is obtaining precise measurements that minimize error since small vertical changes over these relatively low gradient shoreline areas can result in large volumes of material (Thieler & Hammar-Klose, 1999). To apply this approach, accurate measurements of coastal landforms, such as beach profiles, dunes, or cliff positions, are needed. Collection of such data, especially those on the underwater portions of the beach profile, is difficult. In addition, high density measurements are needed to evaluate changes from one section of the beach to the next. While the results can be useful to understand where sediment volume changes occur, the lack of quality data and the expense of collecting the data limit the application of this method in many areas (Thieler & Hammer-Klose, 1999).

Climate change and sea level rise

Sea level is rising worldwide and it is caused by both natural and human factors. Most research indicates that sea level is rising by approximately 6 millimetres a year (Warrick & Oerlemans, 1990). Although annual rate of 6 millimetres seems to be a relatively small amount of change, a small increase in sea level can have devastating effects. Other factors such as glacial isostatic adjustment are causing coastal lands to sink, increasing the rate of SLR for those areas. Since more than 75% of the human population live within about 60 kilometres of the coast it is important that the effects of any change in sea level rise are studied (Hinrichsen, 1995; Goldberg, 1994 cited in Viles and Spencer, 1995; Michener et al., 1997). There is no physical capability of humans to prevent long term SLR. Humans can only cope with the phenomenon and the key to coping with sea level rise is education of the effects and accurate assessments of hazards for given points in time. In this way, humans can act decisively and appropriately to minimize loss of life, and economic and ecological impacts (Aubrey et al., 1993).

Global sea level can change due to expansion or shrinking of ocean water due to changes in climate and periods of worldwide glacial advance and retreat (Davis, 1997). Human impact has no control over changing the volume of the ocean basins. However, the greenhouse effect can cause the ocean to gather thermal inertia that will heat the continents and slowly melt the polar ice caps, increasing sea level worldwide (Michener et al., 1997).

The effects of sea level rise will be spatially non-uniform since glacial isostatic adjustment will cause some areas to uplift and others to subside (Gornitz, 1991). Furthermore, the characteristics of a given coastline are controlled by many different variables, including interactions between lithology, geomorphology, wave climate, currents and storm frequencies.

The IPCC reports that a centimetre rise in sea level erodes beaches about a metre horizontally. This becomes a large issue for developed beaches that are less than 5 metres from the ocean (IPCC, 2000). In addition, rising sea level would create larger storm surges that would quicken the rate of beach erosion; an intense storm can erode enough shore to change its entire profile in one year (Dubois, 1990). Dubois' research has shown that observed values of beach erosion were two to three times greater than the erosion predicted for that year. Dubois suggests that Bruun's theory and rising sea level may be the primary force responsible for observed erosion rates. Bruun's rule states that a typical concave-upward beach profile erodes sand from the beach face and deposits it offshore to maintain constant water depth (Bruun, 1962). Bruun's rule can be applied to correlate SLR with eroding beaches which is effective on sandy beaches.

With present rates of sea level rise, 70% of the world's sandy beaches are eroding and retreating (Bird, 1985; 1993). If the rate of sea level rise continues to increase, the loss of beach to coastal erosion will increase. Rising sea level would allow saltwater to penetrate farther inland and upstream (IPCC, 2000; Aubrey et al., 1993). Higher salinity impairs both surface and groundwater supplies. This effect would impair water supplies, ecosystems, and coastal farmland. Saltwater intrusion would also harm some aquatic plants and animals as well as threaten human water supply (Day et al., 1993). In humid equatorial climates, gradual sea level rise would cause a brackish-water zone to migrate inland (Gornitz, 1991). Salinity has also been found to decrease seed germination in a variety of wetland species and higher salinity may decrease breeding of seed bank species (Baldwin et al., 1996). In addition to damage to ecosystems, SLR promotes saltwater intrusion into coastal aquifers (Day, et al., 1993).

Although the IPCC lists five impacts as the main consequences of SLR there are many others. SLR has a profound effect on the rate of sedimentation for different parts of the coastal slope. Peak rates of sedimentation occur at higher elevations and less sedimentation occurs on the lower elevations. Varying of sedimentation rates will result in changing vegetation zones and succession on marshes (Olff et al., 1997). In addition, storm surges would force large quantities of shoreface sediments through inlets and create tidal deltas on which barriers would later transgress (Dubois, 1990).

Grade scales

A grade scale is an arbitrary division of a continuous scale of sizes such that each scale unit or grade serves as a convenient class interval for expressing the results of analysis (Krumbein & Sloss, 1963). Two grade scales were reviewed in this study. These were the Wentworth and the Atterberg's grade scales.

The Wentworth grade scale is a geometric grade scale with a constant ratio of half (½) between the classes. Each size grade differs from each other by the constant ratio ½. This gives equal significance to size ratios whether in gravel, sand, silt or clay. The table below shows the limiting diameter and the various description of the Wentworth grade scale (Krumbein & Sloss, 1963).

Table 2: Wentworth's Grade Scale

Grade limits (diameter in mm)	Name
Above 256	Boulder
256-128	Large Cobbles
128-64	Small Cobbles
64-32	Very Large Pebbles
32-16	Large Pebbles
16-8	Medium Pebbles
8-4	Small Pebbles
4-2	Granule
2-1	Very Coarse Sand
1-1/2	Coarse Sand
1/2-1/4	Medium Sand
1/4-1/8	Fine Sand
1/8-1/16	Very Fine Sand
1/16-1/32	Coarse Silt
1/32-1/64	Medium Silt
1/64-1/128	Fine Silt
1/128-1/256	Very Fine Silt
1/256-1/512	Coarse Clay
1/512-1/1024	Medium Clay
1/1024-1/2048	Fine Clay

(Adopted from Krumbein & Sloss, 1963)

Both Atterberg and Wentworth grade scales sought the fundamental physical properties of sediments and provided a means of standardising terminology. However, Atterberg's class interval was based on a unit value of 2 millimetres and involved a fixed ratio of 10 for each successive grade, yielding a limiting diameter of 0.002, 0.02, 0.2, 2.0, 20, and 200 millimetres. Table 3 shows the various classes of grain sizes in Atterberg's grade scale.

Table 3: Atterberg's Grade Scale

Grade limits(diameter in mm)	Name (description)
200-2000	Blocks/Boulders
20-200	Cobbles
2.0-20	Pebbles
0.2-2.0	Coarse Sand
0.02-0.2	Fine Sand
0.002-0.02	Silt
Less than 0.002	Clay

(Adopted from Krumbein & Sloss, 1963)

In this study the Atterberg's grade scale is preferred to the Wentworth grade scale because it deals with a range of size in each class making it simple and concise in nature. The nature of the Wentworth scale makes is quite cumbersome. Also sand samples collected does not comprise silt and clay, thus making it quite appropriate in applying the Atterberg's grade scale. Therefore the Atterberg's grade scale was used to define the beach sediments.

CHAPTER THREE

MATERIALS AND METHODS

Introduction

This chapter discusses methods and procedures that were used to collect data from the field to come out with findings from the study. These were on the type of study, type of data, the sampling technique and sources of data. It also included measures taken to avoid accidents on the field.

Research design

The study involved a pre-field and actual field survey to make measurements during low tide. The entire coastline of the study area was traversed on foot at different times between the years 2008 to 2011 and various locations were revisited many times. Much of the field work was dedicated to detailed note-taking and sketches in order to add up to laboratory analysis, taking of photographs, measurement of cliff profiles and collection of sand and pebble samples.

Type of study

The study was quantitative in nature which sought to study relationships, causes and effects of coastal erosion. It employed objective measurement and statistical analysis of numeric data to understand and explain the phenomenon of sea erosion (Ary, Jacobs & Razavieh, 2002; Sarantakos, 1998). It was also a case study which employed empirical enquiry into contemporary phenomenon of erosion in its natural environment (Sarantakos, 1998).

Types and sources of data

A survey was conducted to collect data through observation of erosion features and processes along the coast. The whole study area was observed and traversed on foot from Komenda to Saltpond, beginning on October 2008 to April, 2011. Measurement conducted on cliff profiles, sand grains and pebbles were used as primary data to generate flatness and roundness indices and the sorting coefficient.

In addition, a content analysis was done using data from institutions such as the Ghana Survey Department, Ghana Geological Survey Department, Photogrammetry and Remote Sensing and GIS centres at UCC and University of Ghana, Legon and various institutional libraries. The data from the Ghana Survey Department were 2006 digital images of the coastal stretch and topographic maps showing relief, drainage, population and settlement and the entire coastline of the country out of which was extracted the coastline of the study area. The topographic map was Geo-referenced which gave the exact position of town, rivers, lagoons and other coastal resources such as beaches and estuaries. A geological map at a scale of 1:50000 and a Bulletin from the Geology Department were used to identify the rock type in the study area. It was found out from these two maps that rocks in the study area were made up of the Pre-Cambrian, Upper Jurassic and the Recent formations (Hughes & Farrant, 1963). These maps also provided information on mineral components and some characteristic nature of the rocks such as dipping, jointing and faulting. The Cape Coast granites were mainly made up of schist with pegmatite intrusions. It was also highly faulted and jointed. The Recent and Jurassic formations were found at Kormantse and Saltpond which were made up of sand, silt, Amissian pebbly shale and sandstone (Dei, 1975; Hughes & Farrant, 1963).

Information on sea erosion could not be extracted from maps and other secondary sources such as the extent of beach land to which coconut trees covered in the past years, how many have been eroded or uprooted by the action of the sea, and the amount of revetments and groynes that have been buried or eroded along the beach. Therefore, the views of people living along the coast on sea erosion and coastal resources were sought to make up for the gaps in the existing data.

Sampling procedure

The study area was divided into three sub-zones based on well known characteristics such as lithology (Ary, et al., 2002; Fisher, 2007). Initially, points were randomly located on an area map (location map) for the collection of samples and these points were located on the ground by means of the Global Positioning System (GPS). It was later realised that some of the selected points fell on rocky beaches that were not accessible or where sand samples could not be collected. Therefore, purposive sampling was used to select the spots based on number of the resources present, accessibility, and evidence of erosion alongside the location map.

It was intended that each sample will be collected from each locality selected. This idea was later abandoned based on field observation which indicated variations in rates of erosion, processes involved in erosion and sand texture even within the same locality. Two or more samples were collected from each location. Purposive sampling was used in collecting pebbles from rocky beaches. This was because rounded pebbles were not present at all rocky beaches. These were found at Elmina, west of Abandze headland and Cape Coast (at Amoakofua). Some locations were entirely devoid of pebbles and only sand samples were collected for analysis. In all ninety pebbles were collected from three locations.

Sample size

In this study, pebbles of different rocks and sizes were collected from different locations in the study area. The predominant rocks (pebbles) collected were the Lower Birimian schist from Cape Coast, Abandze quartzite and Elmina sandstone**.** The pebbles were collected from three major locations with different rock types. Thirty (30) pebbles from the same rock type were collected from each location. In all ninety (90) pebbles were collected from these locations and measured. In addition thirty (30) sand samples from sixteen locations were collected for sand analysis.

Data collection method and instrument

This involved a field work on observation and measurement of cliff profiles and laboratory analysis on sand and pebble samples.

Fieldwork

Earlier observation was carried out along the coasts of Saltpond (from the Amissano Estuary) through to the beach at Komenda. The beaches of these areas showed an appreciable evidence of sea erosion, cliff retreat and new levels of the sea. For instance, at Saltpond, there were retreats of sandy cliff surfaces. There were also remains of concrete structures found few metres into the sea at Anomabo and Cape Coast. The structures indicated an earlier port activity some decades ago. There were wooden pillars and stone revetments to check erosion at the beach resorts near Saltpond, Abandze, Anomabo and Brenu Akyinu. Some of these structures have been removed by the sea. The beaches at Komenda Training College (Gold Hill) and Akong (Queen Anne's Point) showed erosion features such as cave, stack, geo and retreated cliff surfaces.

The entire shoreline of the study area was traversed on foot at different times from 18th October 2008 to May 2011. Specific areas that shows active erosive processes were revisited many times during high and low tides. The sea in a way dictated the pace of the whole work due to rising and falling tides. For instance, due to the usually high tides and strong waves during June to August, much of the fieldwork (observation, collection of sand, pebbles and cliff measurements) was suspended for a while to avoid accidents since collection of data was done on forebeach which was entirely covered during high tides. Much of the field work was devoted to observation, note taking, making of sketches, measurements of cliff profiles, height of benches, taking photographs and collection of sand and pebble samples.

A survey was conducted along the coastal zone to identify resources and to gather information within the zone. This was followed by identification of erosion features and hot spots along the coastline. These hot spots were shown in photographs in the Appendix. Sand samples were collected on Recent beaches. Pebbles were collected on rocky beaches at the nearshore waters at low tide to avoid accidents. The collection was done along the coastal stretch from Komenda to Saltpond. This was done in accordance with the increases in fetch distance eastwards and to verify its effect on erosion.

Sand and pebble samples were labelled based on the towns, location and date of collection. For instance, pebble or sand sample collected at Cape Coast had the following labelling: cc/o/20/01/10. This bears the name of the town, specific spot in the selected town (beach), day, month and year. Thus the above labelling means Cape Coast, at Ola beach on the 20th day of January, 2010. 100 grams of sand samples were collected from each spot but only 20 grams was used for laboratory analysis.

Field measurement was done at the beach at Saltpond Redevelopment Institute (SRI) where a dynamic beach profile was observed. The rate of erosion and deposition was recorded at different times using ranging poles within a period of eight months, during high and low tides. This was done to allow for estimation of the future coastline of the study area.

Photographs of erosion processes and features were taken using a digital camera of 10 mega pixels. Other instruments included trowels, soils sampling sacks, gloves, electronic balance, crucibles, crushing spoons and micrometric cible were used on the field and at the laboratory.

Laboratory analysis

Laboratory studies were conducted mainly on sand and pebble samples collected from the field. The sand samples were analysed at the Departments of Soil Science, University of Cape Coast and at the University of Ghana, Legon. Sand samples of about 100 grams were collected from each sampling location on Recent beaches and thoroughly dried in an electronic oven. Grain sizes were determined immediately after drying since beach sand attracts atmospheric moisture which makes it wet after a short while. Only 20 grams out of each of the 100 grams of sand samples was used to determine grain sizes. An electronic balance which weighs up to 500 grams was used to determine the weight. A British-made sieve of the brand Griffin and George was used to determine the grain sizes with the use of crucibles and crushing spoon.

The variables (radius and length, thickness and breadth of the pebbles) in the roundness and flatness indices were extracted by means of measurement using the Micrometric Cible. This was a sheet of paper which has been calibrated by means of concentric rings. The interval between each ring was a millimetre. The whole process of sampling involved mainly the collection of sand and pebbles while observing the influence of lithology on erosion processes in the evolution of coastal landforms that has modified the coastline.

The following mathematical models were used to analyse particle size distribution on the field:

Trask's Sorting Index: *So*= √Q1/Q3

Where *So* is the Sorting Coefficient, *Q1* is the smaller quartile, 25% value, *Q3* is larger quartile 75% value (Krumbien & Sloss, 1963). The sorting coefficient (*So)* applies to silt, clay, gravels and sand. The *So* and the median diameter (md) gives a clue or knowledge about the formation of the clastic sediments. The median diameter gives knowledge about the strength of the current that moved the material to their deposition sites whereas the sorting soefficient (*So*) is an index of a range of conditions present during transportation of the sediments by the fluid (sea water/waves). These may include degree of turbulence, velocity, and distance of transportation. According to Trask (1932), well-sorted marine sediments have *So* values less than 2.5, moderately sorted sediments with a range between 2.5 to 4.0, while a poorly sorted sediments have values larger than 4.0. A *So* value of 1.0 means a perfectly sorted beach. Therefore, the more nearly equal the two quartiles are, the more closely the sorting coefficient approaches 1.0, implying a perfect beach profile which is difficult to achieve (Dei, 1972; Krumbein & Sloss, 1963).

The median diameter (md) is a value achieved by tracing the 50% line to the graph and reading its value on the x-axis. It represents the middlemost grain as well as the average grain size. This value implies an equal weight frequency of grains on both sides of the distribution. Two sands may have the same median diameter, yet one sand may have a much wider range than the other. The difference is shown by means of the shape of their respective graphs and their *So* values (Dei, 1972; Krumbein & Sloss, 1963). The degree of sorting (the extent to which grains spread on either side of the average) is a measure of the spread of the distribution. Graphically plotted weighted grain sizes that showed sigmoid curves are characteristic of well-sorted marine and aeolian deposits.

Cailleaux's pebble indices:

Roundness index: $R = (2r/d)\ (1000)$

Where R is the roundness of pebble, *r* is the radius of the smallest curvature of pebbles, *d* is the diameter of the pebble, which is also equivalent to the length, all in millimetres. The average method was used to get the true radius of the pebbles. This was achieved by measuring all the four radii and finding the average i.e. $r = r^1 + r^2 + r^3 + r^4 /4$ (Krumbein & Sloss, 1963).

The whole fraction was multiplied by the 1000 because of the almost insignificant value of the index so that it could be readable. Pebble roundness is related to wear during transport or constant blasting of wet sand at stationary rocks (Dei, 1975). It is thus considered as a measure of the susceptibility of rocks to erosion. However, pebbles of differing mineralogy and physical and chemical properties respond differently to erosion. Therefore, pebbles collected from locations were grouped according to the type of rocks to analyse the effect of erosion on these rock.

Flatness index: F= L+b/2E

Where *F* is the flatness of pebble, *L* is the length, the point at which there is a change in the curvature of the pebble, *b* is the breadth (may be equal to 2r or the diameter) and *E* is the thickness of pebble, all in millimetres. (Krumbein & Sloss, 1963)

Pebble flatness also implies the intensity of erosion on the rock. Just as roundness is influenced by factors such as mineral constituent, physical and chemical properties likewise pebble flatness. Therefore grouping of pebbles during measurement and analysis was done to ascertain accuracy.

The purpose of mechanical analysis was to obtain graphical or a numerical data about the particles sizes in the sediments. The functional aspect of particle shape helps with the interpretation of beach environments. This is made possible by drawing graphs of the various grain sizes on a semi-logarithmic graph (semi-log graph). The semi-logarithmic graph (semi-log graph) is used to plot the weighted sand samples. This type of graph is best used in plotting exponential variables against constant ones. In this analysis, the sieve sizes gave the exponential variables since each successive figure represents half of the preceding one. It also represented the particles' diameter. The semi-log graph or semi-log plot is a way of visualizing data that are changing with an exponential relationship. One axis is plotted on a logarithmic scale. This kind of plot is useful when one of the variables being plotted covers a large range of values and the other has only a restricted range. The advantage being that it can bring out features in the data that would not easily be seen if both variables had been plotted linearly.

Data analysis

Tables, graphs, and charts were used to analyze data. There were tables on pebble morphology, recordings of field measurements on erosion and accumulation of beach sand. Charts in the form of histograms and line graphs were used to show the various particle sizes distribution, flatness and roundness indices and how lithology responded to erosion in each locality by means of the sorting characteristics of beach sand. This gave a clearer picture of the areas with maximum and minimum particle sizes and areas susceptible to sea erosion.

The analyses of sand and pebble samples were done individually according to location after which sampled beaches were grouped according to the lithological zone in which they were found. This brought out the sorting characteristics of the sampled beaches and the type of currents that deposited the beach materials.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

Introduction

A natural coastal system includes experiences of varying sea levels at various locations worldwide. From an erosion perspective, the most important physical effect is a slow, long-term recession of the shoreline due to direct flooding and partly to profile adjustment to the higher sea level. According to Bruun (1962), a 1cm rise in sea level would result in a 1m shoreline retreat. However, the geomorphology, hydrology and the geological make up of the coastline substantially influence the type and quantity of sediment delivered to the beach as well as the frequency of sediment movement which in effect influences erosion (Davidson-Arnott, 2010). Therefore the Bruun's model is only applicable on sandy coastlines. Because the study area comprises both sandy and rocky coastlines, particle size analysis was used to analyse the phenomenon of sea erosion

Graphical presentation of particle size distribution can be done in two ways. One of these could be a block diagram, a histogram, which gives the percentage of grains in the grade sizes present with their median grain sizes of the sediment. Another is a cumulative curve which is prepared by adding the percentages in succeeding grades and drawing a smooth curve through the points.

Histograms present a factual picture of the abundance of grains in each grade size in a readily visualised form. However they give little information on numerical summaries of data. Therefore the corresponding cumulative curves were used in addition to the histograms in determining the particle size distribution and properties.

According to Krumbien and Sloss (1963), one of the methods for the statistical summary of sediments is based on quartiles obtained graphically from the cumulative curve. These quartiles were determined by following the 25%, 50% and 75% lines on the graph (on the y-axis) and to their intersection with the cumulative curve, then the values read on the size scale which lie directly below the intersection (on the x-axis). These values served as variables in the Trasks' Sorting Coefficient and in determining the median diameter. The median diameter (*md*) showed how widely the spread of the grain sizes were and how well sorted the grains were. It also gives information about the strength of the wave that deposited the sediments. This helped to identify stable beaches with less or no erosion activities and unstable beaches.

There were no published data on actual sediment delivery and movement in the study area, so the following discussions were largely based on field observation and also founded on consideration of the overall geologic history as well as current geomorphic and hydrologic characteristics of the coastline. The study based its analysis of data mainly on sand and pebble samples collected from the study area.

Several studies conducted on the morphology of marine particles attest to the fact that they are relevant to the interpretation of past and recent geological forms and processes and on the reconstruction of paleogeographical environments. Earlier researchers such as Wentworth (1922), Cailleaux (1945) cited in Dei 1972, and Dei (1972), among others, confirmed the usefulness of shape parameters in the reconstruction of paleogeographical environments.

The first order of the Cailleaux roundness index was applied in this work because it has been widely accepted and used by many researchers on particle shape analysis and it is also more easily interpreted. The interpretation was based on field observations and on Cailleaux’s two indices of wear and tear namely roundness and flatness and also on Task’s sorting coefficient.

According to Dei (1972), roundness is basically related to wear during transport or to constant wet sand blasting of stationary materials. Therefore, roundness and flatness were considered as a measure of the susceptibility of such materials to erosion.

Particle size analysis of pebbles

Morphology of pebbles

Table 4: Roundness and flatness values of schist

Sample	L	b	r^1	r^2	r^3	r^4	r	E	F=(L+b/2E)	R=[2r/L(1000)]
1.	14	14	4	4	6	8	5.5	8	1.8	785.7
2.	10	12	6	6	3	3	4.5	6	1.8	900.0
3.	30	20	10	10	2	2	6.0	4	2.8	400.0
4.	8	8	4	4	1	1	2.5	8	4.0	625.0
5.	10	10	6	4	4	4	4.5	8	1.3	900.0
6.	10	8	4	4	2	4	3.5	6	1.5	700.0
7.	14	16	8	8	4	4	6.0	8	1.9	857.1
8.	8	8	4	4	1	1	2.5	2	4.0	625.0
9.	10	12	6	6	3	3	4.5	6	1.8	900.0
10.	12	12	6	6	4	4	5.0	8	1.5	833.3
11.	14	8	4	4	5	5	4.5	10	1.1	642.9
12.	16	12	6	6	4	3	4.8	7	2.0	593.8
13.	18	12	6	6	2	2	4.0	4	7.5	444.4
14.	20	16	8	8	4	4	6.0	8	2.3	600.0
15.	8	12	6	6	4	4	5.0	8	1.2	1250.0
16.	14	16	8	8	2	2	5.0	4	3.8	714.3
17.	8	8	4	4	4	2	3.5	6	1.3	875.0
18.	8	8	4	4	2	2	3.0	4	2.0	750.0
19.	10	8	4	4	2	2	3.0	4	2.3	600.0
20.	30	16	8	8	6	6	7.0	12	1.9	466.7
21.	10	12	6	6	1	1	3.5	2	5.5	700.0
22.	20	8	4	4	1	1	2.5	2	7.0	250.0
23.	14	10	6	4	2	2	3.5	4	3.0	500.0
24.	22	8	4	4	2	2	3.0	4	3.8	272.7
25.	18	12	6	6	2	2	4.0	4	3.8	444.4
26.	10	12	6	6	2	2	4.0	4	2.8	800.0
27.	12	10	6	4	2	2	3.5	4	2.8	583.3
28.	10	16	10	6	6	4	6.5	10	1.3	650.0
29.	28	10	6	4	2	2	3.5	4	4.8	250.0
30.	8	10	6	4	2	2	3.5	4	2.3	875.0

Source: Laboratory analysis, 2010

Table 4 shows roundness and flatness values of pebbles collected from Amoakofua in Cape Coast. Flatness values ranged from 1.1 to 7.5. The rocks here were mostly schist and they were platy-like in nature, have basal cleavages and easily break at the joints, thus its high flatness values.

On the other hand, roundness was moderate with most values below 1000. Only few pebbles (0.1 %) have values above 1000. Roundness is short-lived due to the susceptibility of schist to fragmentation after attaining roundness. Most of the pebbles were moderately rounded because they were in the process of being rounded again after undergoing fragmentation. Perhaps the few that exceeded 1000 may have gone through serious abrasion processes in potholes and have achieved high roundness.

Table 5: Percentage representation of roundness and flatness values of schist

Description	Range of values for roundness	Percentage	Range of values for flatness	Percentage
Less	250-500	26.6	1.0-2.0	46.6
Moderately	501-1000	73.3	2.1-5.0	43.3
Highly	above 1000	0.1	5.1-10.0	10.1
Total		**100.0**		**100.0**

Source: Laboratory analysis, 2010.

Table 5 shows the percentage of roundness and flatness of pebbles in each description. From the table, 73.3% of pebbles were moderately rounded with only 0.1% having values exceeding 1000. This implies that the highly metamorphosed schist of Amoakofua in Cape Coast acquires roundness quickly but they are short-lived due to frequent fragmentation of schist because of its fissile nature. The pebbles were undergoing rounding after fragmentation, thus the higher percentage under moderately rounded. Compared to the other two (Elmina sandstone and

Abandze quartzite) it is the most flat pebbles in the study area with values as high as 7.5 (Table 4).

Table 6: Roundness and flatness values of Elmina sandstone

Sample	L	b	r^2	r^2	r^3	r^4	R	E	F=(L+b/2E)	R=[2r/L(1000)]
1.	30	12	6	6	2	4	4.5	6	3.5	300.0
2	30	12	2	4	6	6	4.5	6	3.5	300.0
3	40	8	8	8	2	2	5.0	4	4.8	250.0
4	14	10	6	4	6	4	5.0	10	1.2	714.3
5	10	18	2	2	6	6	4.0	16	0.9	800.0
6	22	22	10	12	6	6	6.0	12	1.9	545.5
7	30	16	6	6	8	8	7.0	12	1.9	466.7
8	10	16	4	6	4	4	4.0	16	0.8	900.0
9	20	16	8	8	6	12	8.5	18	1.0	850.0
10	30	18	10	8	4	8	7.5	12	2.0	500.0
11	28	10	4	6	2	2	3.5	4	4.8	250.0
12	14	12	6	6	2	2	4.0	4	3.0	571.4
13	10	14	4	4	2	4	3.5	8	1.5	700.0
14	50	4	6	8	2	2	4.5	4	6.8	180.0
15	30	14	6	8	6	4	6.0	10	2.2	400.0
16	30	12	6	6	4	4	5.0	8	2.6	333.3
17	28	12	6	6	4	4	5.0	8	2.5	357.1
18	12	16	8	8	2	4	5.5	6	2.3	916.7
19	14	14	6	8	4	4	5.5	8	1.4	785.7
20	20	12	6	6	6	4	5.5	10	1.6	550.0
21	10	12	6	6	4	6	4.3	5	2.2	850.0
22	10	16	4	4	2	2	6.0	8	1.6	600.0
23	8	10	6	4	2	2	3.5	4	2.3	875.0
24	30	12	6	6	10	2	6.0	12	1.8	400.0
25	8	10	4	6	4	4	4.5	8	1.1	1125.0
26	10	10	6	4	6	4	5.0	10	1.0	1000.0
27	20	20	10	10	4	4	7.0	8	2.5	700.0
28	28	20	8	8	10	10	9.0	16	1.5	642.8
29	35	14	8	6	4	2	5.0	6	4.1	285.7
30	30	6	4	6	6	8	6.0	10	1.8	400.0

Source: Laboratory analysis, 2010

Table 6 shows the roundness and flatness values of pebbles from Elmina. Roundness ranged from 180 to 1125. They were moderately rounded with only one value exceeding 1000. Pebbles showed polished brecciated surfaces that indicated that erosion was intensive and ongoing. The lone figure above 1000 may have been picked from an area of increased wave energy resulting from rocky outcrops and in a pothole where pebbles were turned constantly.

Flatness also ranged from 0.8 to 6.8 with only 3.4% having higher values. It was also realised that pebbles with increased roundness had lower flatness value. For instance, samples 14 which had the highest flatness index of 6.8 had the least roundness value of 180. This was followed by sample 3 with a flatness index of 4.8 and roundness index of 250. These were picked from areas with high increased sea energy and erosion activity. Other samples such as 5, 25 and 26 also had low flatness of 0.9, 1.1 and 1.0 with high roundness of 800, 1125 and 1000 respectively. There were few exceptions such as samples 4, 10 and 23 which had relatively high flatness and roundness values and these were influenced by extreme values for length and radius of the pebbles resulting from brecciaing.

Table 7: Percentage representation of roundness and flatness values of sandstone

Description	Range of values for roundness	Percentage	Range of values for flatness	Percentage
Less	180-500	43.3	0.8-2.0	53.3
Moderately	501-1000	53.3	2.1-5.0	43.3
Highly	above 1000	3.4	5.1-10.0	3.4
Total		**100.0**		**100.0**

Source: Laboratory analysis, 2010

It is seen from Table 7 that majority of pebbles fell under moderately rounded forming 53.3% of the entire sample. Only 3.4% had values exceeding 1000. These may have been collected from areas with intense abrasion process such as in potholes where pebbles are turned constantly. The rest (43.3%) had values ranging from 180 to 500 which were less rounded. Although the sample had 43.3% of pebbles that were less rounded, it could be described as moderately rounded because more than half of the sample (53.3%) fell within the range 501-1000. This is because the pebbles were freshly broken, had polished brecciated surfaces and undergoing rounding.

Table 8: Roundness and flatness values of quartzite

Sample	L	b	r^1	r^2	r^3	r^4	R	E	F=(L+b/2E)	R=[2r/L (1000)]
1	20	16	4	4	8	6	5.5	16	1.1	550.0
2	20	14	4	6	2	4	4.0	8	2.1	400.0
3	14	16	8	6	8	14	9.0	18	0.8	1285.7
4	30	20	8	10	6	6	7.5	10	2.5	500.0
5	26	20	10	8	8	10	9.0	20	1.2	692.3
6	12	14	8	10	6	6	7.5	16	0.8	1250.0
7	18	16	4	6	4	4	4.5	10	1.7	500.0
8	22	10	8	4	4	6	5.5	12	1.3	500.0
9	30	20	10	12	10	8	10.0	48	0.8	666.7
10	30	20	10	10	8	8	9.0	26	1.6	600.0
11	10	20	10	6	8	10	8.5	18	0.8	1700.0
12	35	22	8	10	12	6	9.0	18	1.6	514.3
13	8	12	6	4	4	4	4.5	8	1.3	1125.0
14	20	14	6	8	4	6	6.0	10	1.7	600.0
15	10	16	8	8	6	6	7.0	16	0.8	1400.0
16	6	18	10	8	10	8	9.0	18	0.7	3000.0
17	16	20	8	12	6	8	8.5	14	1.3	1062.5
18	20	16	2	8	8	8	6.5	10	1.8	650.0
19	12	14	6	8	6	8	7.0	16	0.8	1166.7
20	20	16	6	10	4	6	6.5	10	1.8	650.0
21	30	20	10	10	10	10	10.0	20	1.3	666.7

Table 8 (continued)

Sample	L	b	r^1	r^2	r^3	r^4	r	E	F=(L+b/2E)	R=2r/L(1000)
22	18	10	2	2	8	6	4.5	8	1.8	500.0
23	12	20	10	8	8	6	8.0	14	1.1	1333.3
24	14	14	8	6	4	8	6.0	14	1.1	1214.3
25	14	16	6	8	8	8	7.5	14	1.1	1071.4
26	20	16	8	8	4	4	6.0	8	2.3	600.0
27	14	16	8	8	10	4	7.5	14	1.1	1071.4
28	20	24	14	10	8	10	10.5	18	1.2	1050.0
29	22	14	6	8	3	3	5.0	6	3.0	454.6
30	14	12	6	6	2	4	4.5	6	2.2	642.9

Source: Laboratory analysis, 2010

Table 8 shows the roundness and flatness values of quartzite from Abandze. Flatness values ranged from 0.8 to 3.0. About 16.7% of the pebbles were moderately flat. It indicated that the rocks were the least flat (compared with the other rocks from the other two locations) with 83.3% of the values falling within 0.1-2.0. On the other hand pebble roundness was high with majority of the roundness values exceeding 1000. The range of values of roundness was from 400 to 3000. Forty percent (40%) had achieved roundness values that were above 1000 with only 20% that were less rounded (from 400 to 500). It was also observed that there was no roundness values below 400 and no flatness value above 5.0 because the pebbles were highly rounded. Among the three different types of rocks, the quartzite was the most rounded.

Table 9: Percentage representation of roundness and flatness values of quartzite

Description	Range of values for roundness	Percentage	Range of values for flatness	Percentage
Less	100-500	20.0	0.1-2.0	83.3
Moderately	501-1000	40.0	2.1-5.0	16.7
Highly	above 1000	40.0	5.1-10.0	00.0
Total		**100.0**		**100.0**

Source: Laboratory analysis, 2010

From Table 9, it could be seen that there were no flatness values between 5.1 and 10.0 although roundness increased to 3000. The percentage of pebbles that fell under least flat was 83.3% with only 16.7% being moderately flat. Again the general observation of the inverse relationship between roundness and flatness was manifested in the Abandze quartzite. The quartzite was the most rounded among the three types of rocks with values as high as 3000.

Graphical Presentation of pebble morphology

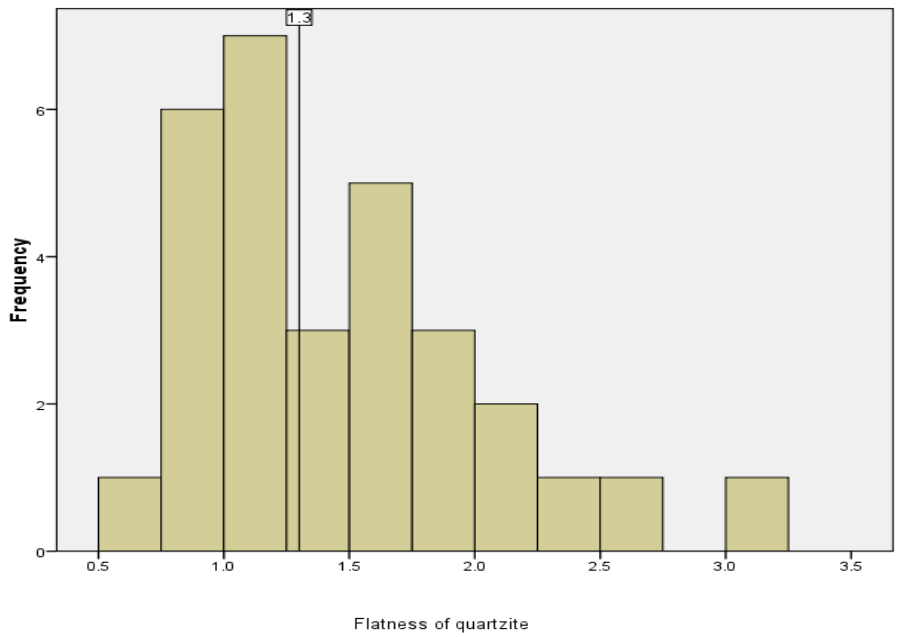

Figure 3: A histogram showing the flatness of Abandze Quartzite

Figure 3 is a histogram showing the flatness of Abandze quartzite. From the graph, majority of the values fell between 1.0 and 1.25. This was followed by values between 0.75 and 0.9 with 1.5-1.75 having the third highest frequency. The frequencies of the high values of flatness (2.5-3.0) were very low (1) indicating that they were highly rounded. It had a median value of 1.3 representing the middlemost figure which was low. This implied that pebbles from this location had generally low flatness values. The figure is a trimodal graph which was an indication of samples collected from a stretch of three different locations namely Abandze west of the headland, Agyaa and between Agyaa and Anomabo.

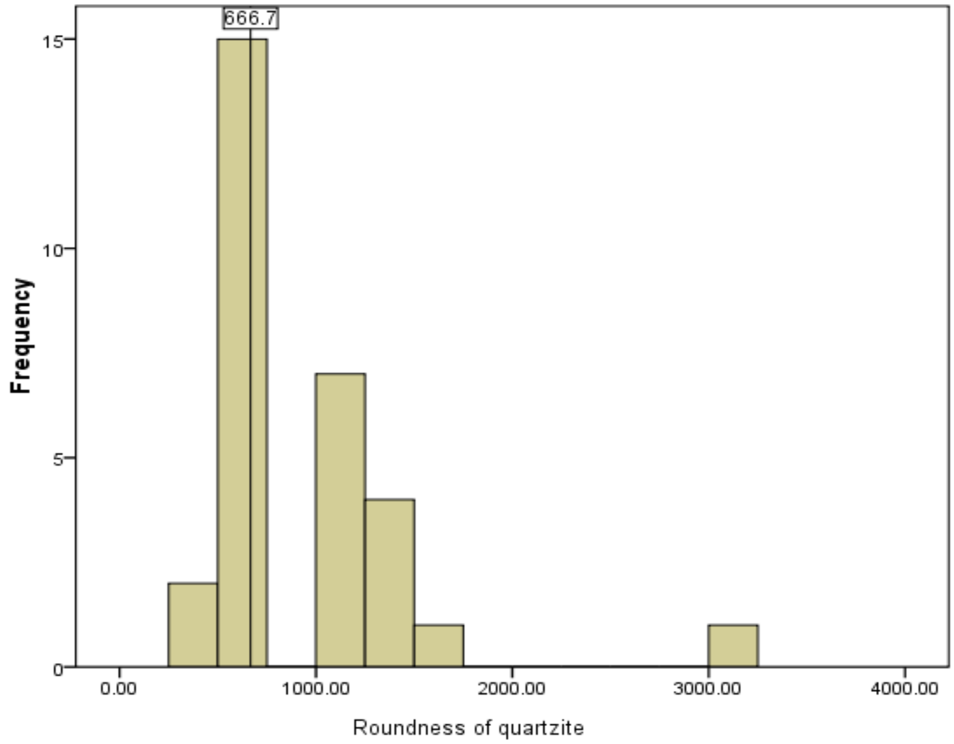

Figure 4: A histogram showing the roundness of Abandze Quartzite

Figure 4 is a histogram showing roundness of Abandze quartzite. It had a median of 666.7. It conform to Figure 3 that the pebbles were collected from three different locations. It was also a trimodal graph showing three different peaks. The implication is that the pebbles were collected from three different environments (Abandze town, west of Abandze headland and the stretch towards Agyaa and Anomabo) with different wave energy and quite different rate of erosion. There was an area with very high sea energy and intense erosion thus resulting from the lone value of 3000. The peak on the left represents pebbles collected from a location towards the west where erosion was relatively minimal;

the middle peak was from a central location, whereas the last peak on the right was towards the east where there was increased wave energy and intense erosion.

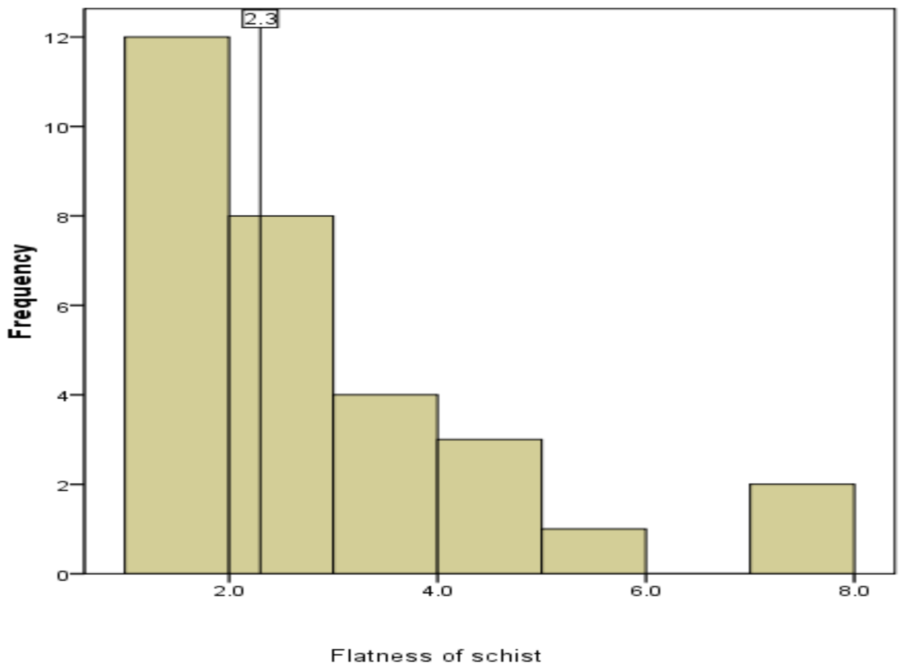

Figure 5: A histogram showing the flatness of schist, Cape Coast

Figure 5 is a bimodal graph of flatness values of pebbles from Amoakofua, Cape Coast. Samples were collected from two different environments, around the eastern side of the Cape Coast castle and at Amoakofua as indicated by the two peaks. The median, which represented the middlemost value, was 2.3 which was quite high. It is shown on the graph that flatness increased eastwards. The second and lone peak represented pebbles collected towards the east (Amoakofua) while the first peak (on the right), represented pebbles collected towards the west. Again, flatness increased towards the east signifying increased wave energy towards the east.

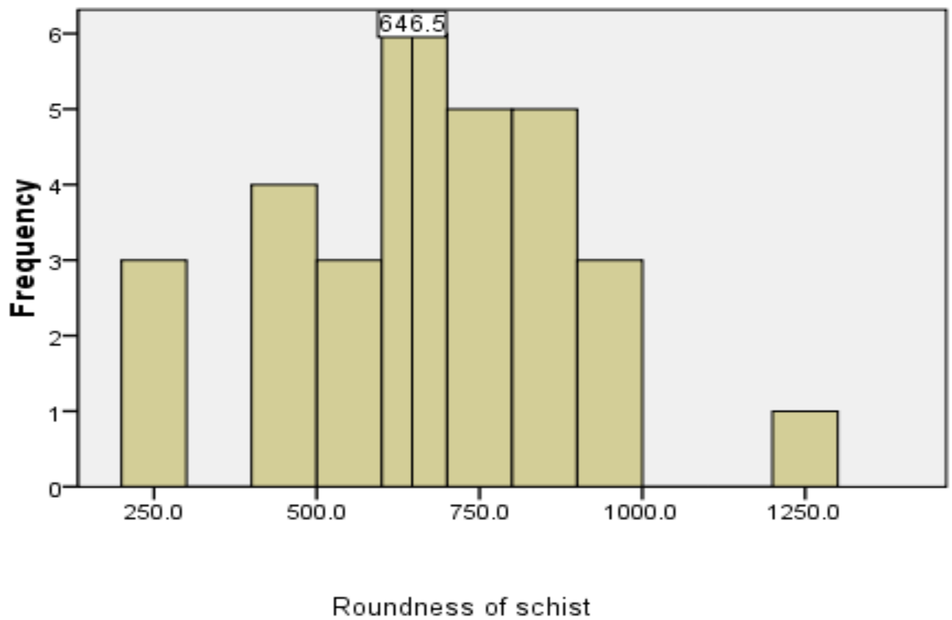

Figure 6: A histogram showing the roundness of schist, Cape Coast

Figure 6 is a trimodal graph showing roundness of schist from Cape Coast with a median value of 646.5. This did not conform to the flatness graph of the same location in Figure 3 which was bimodal. The lone peak with the extreme value represented pebbles that may have come from the same location but different environment with intense abrasion process such as in potholes where pebbles were turned constantly. The peak on the right with the least value represented pebbles collected towards the west, the middle peak showed pebbles picked towards the east and the last peak in the same location but from a pothole. The lone peak with highest value may also represent pebbles that had attained roundness at its apex which will soon undergo fragmentation due to the fissility of schist.

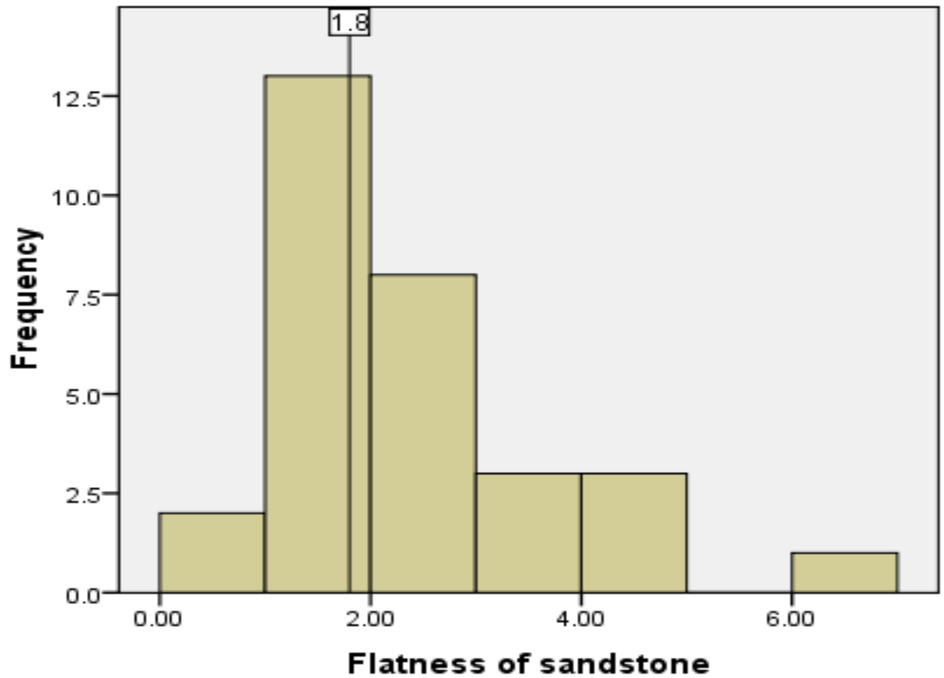

Figure 7: A histogram showing the flatness of Elmina Sandstone

Figure 7 showed that the samples were not from the same location but from two different environments. One location was towards the east while the other was to the west. From the graph, flatness increased towards the west with value as high as 6.8. This was in conformity with the inverse relationship between roundness and flatness as well as the general observation that roundness increased eastwards with increases in fetch distance.

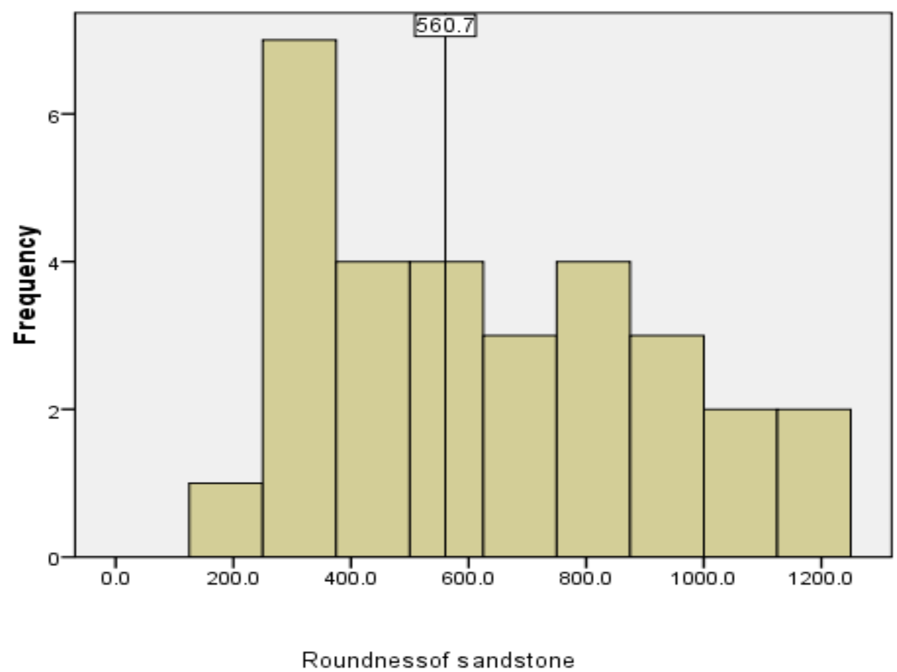

Figure 8: A histogram showing the roundness of Elmina Sandstone

Figure 8 is a bimodal graph with a median value of 660.7. It indicated that samples were collected from two locations. One location was towards the west, Elmina around the castle and the other towards Iture. This graph also confirmed the general pattern of increased erosion eastwards. Here pebbles collected around Elmina (towards the west) were less rounded representing the peak with the low roundness value while those collected in the east (Iture) were more rounded representing the peak with high value (as high as 1200). The high frequency of low roundness implied that the pebbles were freshly broken sandstone which had been worked on as they were transported towards the east (Iture). There was an increased erosion activity at Elmina especially around the castle which continued towards the east.

General observation

Field observations showed that rocks found in sheltered beaches such as estuarine beaches with vegetation cover were brittle, fragile and appeared “decayed” due to the presence of humic acid released by dead plants and animals. Such was the case of the sandstone found at the Kakum river estuary at Iture where most of the rocks appeared decayed and weak. These rocks were predominantly the Elmina sandstone which contained lots of feldspar which cannot withstand this hot humid condition (Dei, 1975).

On the other hand, rocks on rocky coastline devoid of vegetation appeared less fragile and quite resistant to erosion. Therefore, under hot, humid conditions, particles of higher mechanical and chemical resistance such as quartzite and schist, achieved rounded shapes faster than those of less mechanical and chemical resistance. The Cape Coast schist and Abandze quartzite were not found in sheltered areas and were exposed to direct sea action. This partly explained why the quartzite of Abandze and the schist of Cape Coast had higher roundness values but for the schistosity of the Cape Coast schist its roundness was short lived. Quartzite is both chemically and physically more resistant. The rounding of quartzite takes longer time. This rounding may be accelerated through corrosion by calcite which may in turn lead to the pitting of the surface of the rocks (Dei, 1972). The quartzite of Abandze might have undergone such process of corrosion thus it was more rounded and less flat.

The sandstone at Komenda had uniformed hard grains, contained feldspars, and was brownish-pink in colour due to the presence of pink feldspars and dark brown limonitic cement (Crow, 1952 cited in Dei, 1972). However in areas where these rocks appeared limonitised and lithified such as at the Gold Hill-Komenda, they were quite resistant.

Inferring from the above Tables of pebble morphology, it could be deduced that roundness had an indirect relationship with flatness. In general, increases in roundness led to low flatness values. The quartzite of Abandze had high roundness values and low flatness values due to increased fetch distance, increased erosion activity eastwards and accelerated corrosion of quartzite by calcite (Dei, 1972).

Particle size analysis of sand samples

Sand samples were analysed using their weighted grain sizes. The Figures below show the graphical representation of weighted grain sizes of sand samples collected from the study area with their corresponding Sorting Coefficient (So index) and Median Diameters.

Graphical presentation of weighted grain sizes and sorting characteristics of sand samples

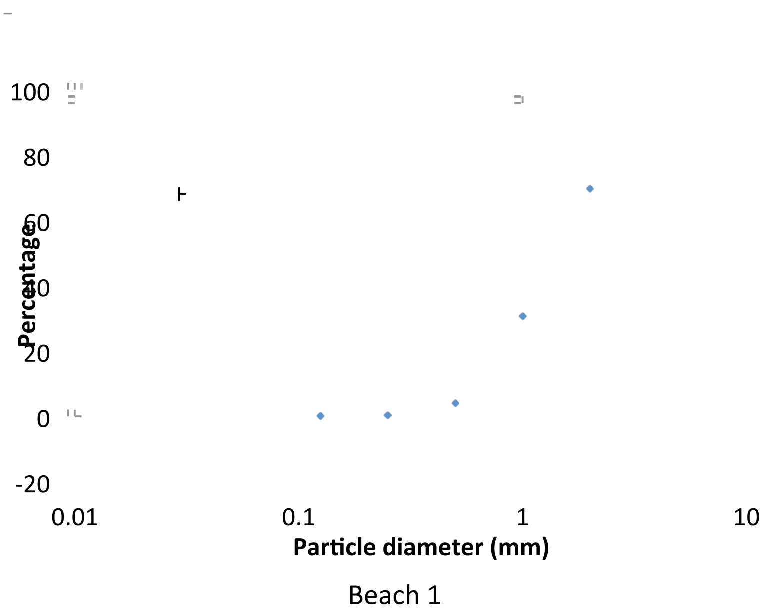

Figure 9: Weighted grain sizes and sorting coefficient of sand samples at Komenda, Gold Hill Backbeach

Figure 9 (Beach 1) is the beach at Komenda Gold Hill where the training college is situated. It has a median diameter (*md*) of 1.6 mm which showed that the particles were large. The *So* value could not be calculated because the sediments were badly sorted and contained lots of shell fragments and extremely large particle which were eliminated because they did not fit in the description of particles in the Grade Scale used. There was little transportation involved due to a short fetch distance resulting from the outcrop of the limonitised hill and the sediments were deposited suddenly. Erosion was quite intense due to increased wave energy resulting from the rocky outcrop.

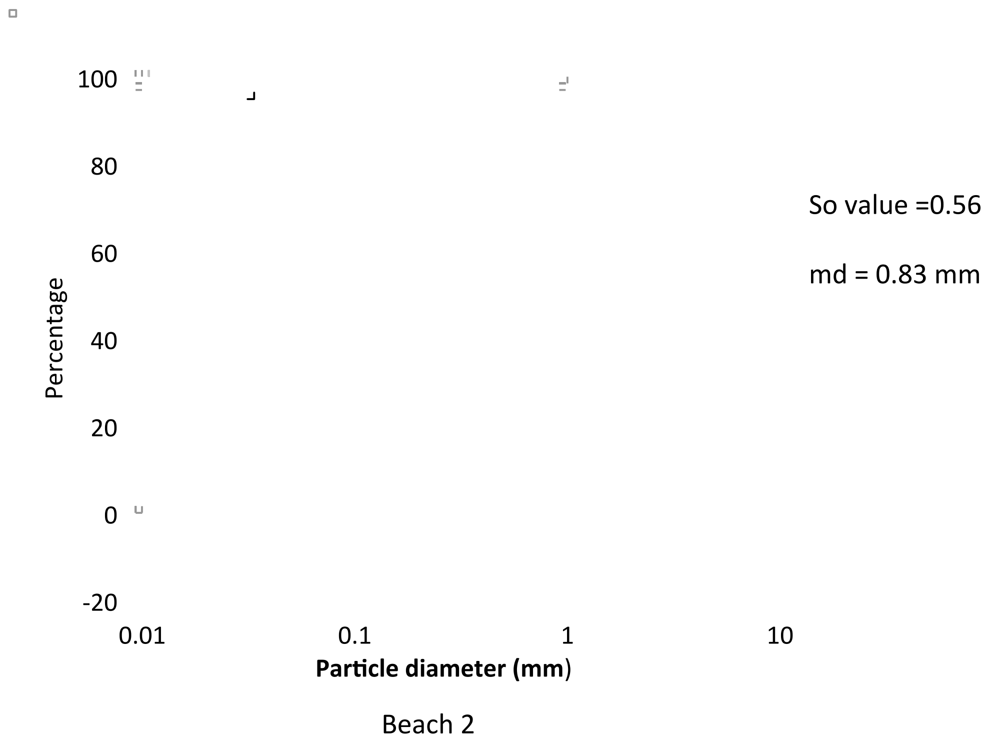

Figure 10: Weighted grain sizes and sorting coefficient of sand samples at Komenda, Gold Hill Forebeach

Beach 2 in Figure 10 is moderately sorted with *So* value of 0.56 and *md* of 0.83 mm. The sample was collected from the forebeach of the beach at Gold Hill, Komenda. It had medium grain size as shown by the asymmetrical curve towards medium grains.

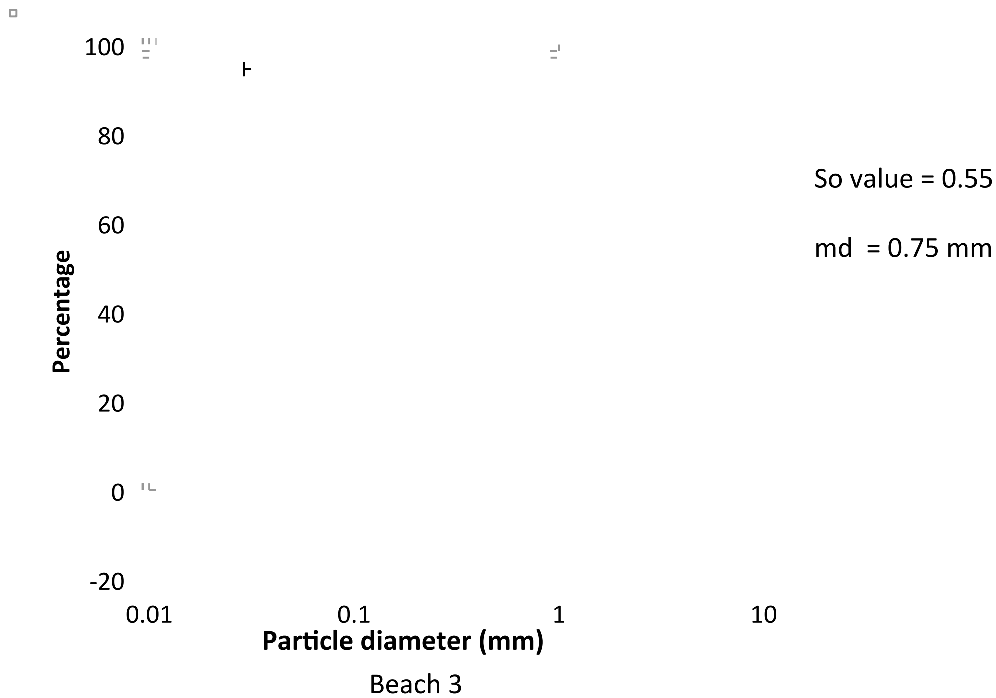

Figure11: Weighted grain sizes and sorting coefficient of sand samples at Komenda, East of Training College

Figure 11 (Beach 3) is the beach at Komenda east of the Training College. It has Sorting Coefficient (*So* value) of 0.55 and a median diameter (*md*) of 0.7 mm. This implied that the sediments were moderately sorted with medium grains. Here the longshore drift had time to draw the sediments in succession according to the particles' diameter but the fetch distance was short. The beach was washed by a weak current due to the cove in which the beach was found and this current was not able to move the larger particles that had been deposited at the backbeach of the beach at Gold Hill. Erosion on the beach was minimal and limited to the sandy cliff face.

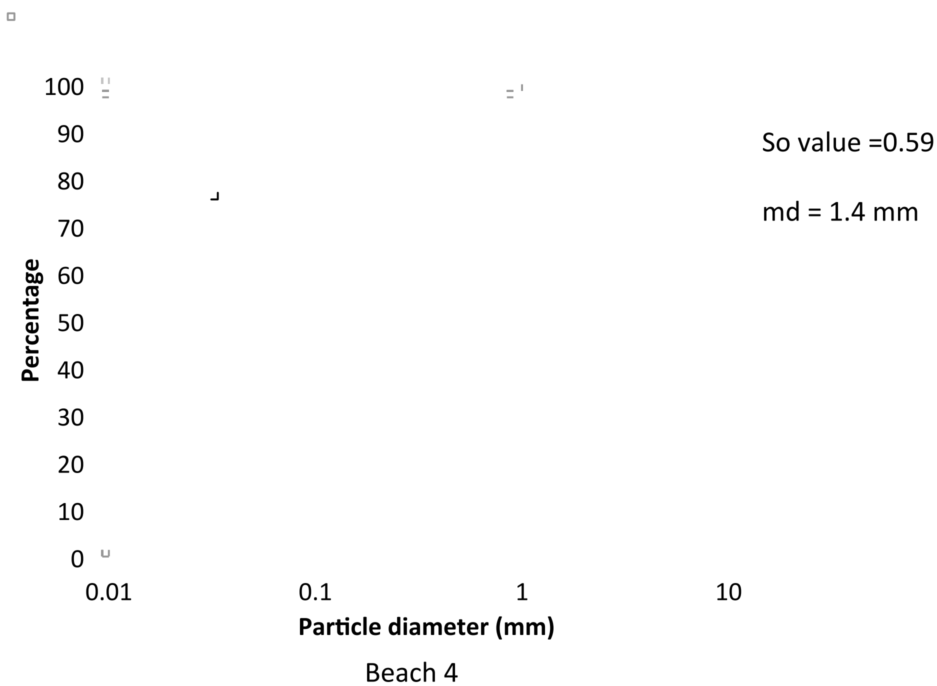

Figure 12: Weighted grain sizes and sorting coefficient of sand samples at Brenu Akyinu 1

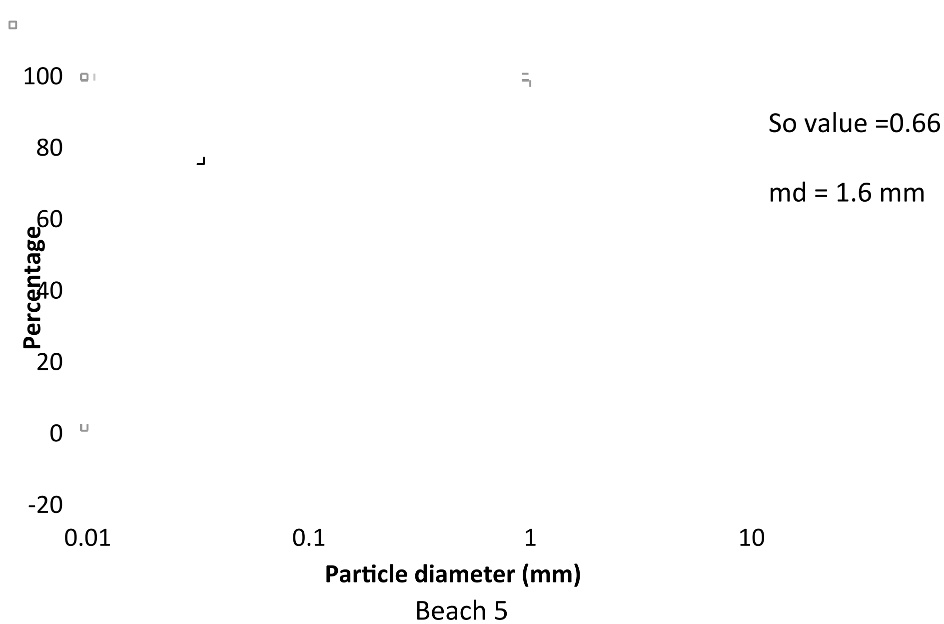

Figure 13: Weighted grain sizes and sorting coefficient of sand samples at Brenu Akyinu 2

Beaches 4 and 5 are sampled beaches from Brenu Akyinu. Both beaches were moderately sorted indicated by their *So* values. Their *mds*, 1.4 mm and 1.6 mm, implied that they had coarse grains. Their asymmetrically sigmoid curves with curvature towards large grains confirm the fact that they had large particles. Erosion was active on the cliff face due to human interference on the beach for recreational activities.

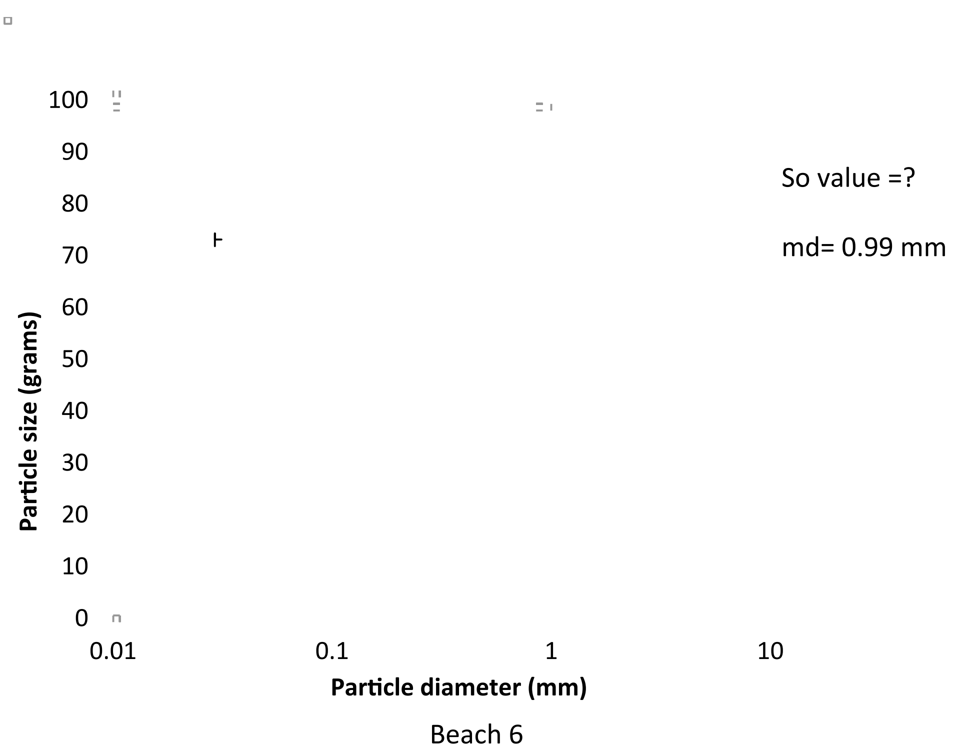

Figure 14: Weighted grain sizes and sorting coefficient of sand samples at Elmina, West of Castle

Figure 14 is a Recent beach at Elmina west of the castle. It had *md* of 0.99 mm and *So* value which could not be calculated because it contained lots of large particles and other materials of anthropogenic origin. A sea defence wall of granite rocks had been built on the coast around the castle and this supplied granitic particles to the beach which became foreign material on the beach because the area was underlain by sandstones.

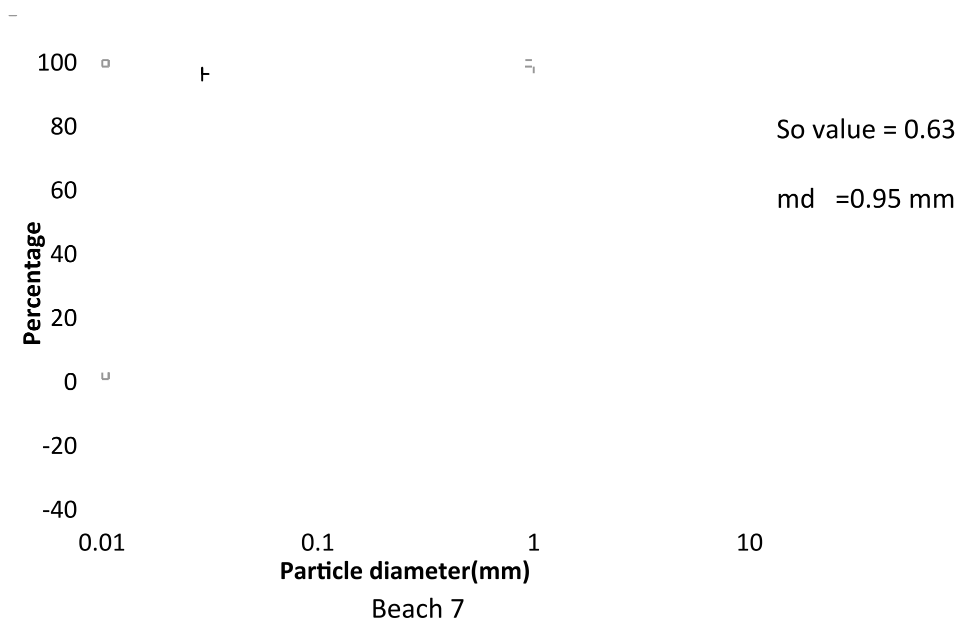

Figure 15: Weighted grain sizes and sorting coefficient of sand samples at Elmina, East of Castle

Figure 15 is the beach at Elmina east of the castle. It was moderately sorted with medium grains as shown by the *So* value 0.63 and *md* of 0.95 mm. Erosion was very active on the rocky promontory around the castle which had led to the accumulation of coarse sand at the west of the castle. However the strong currents were not able to transport these sediments and therefore weak current moved small and medium grains and deposited it in the cove east of the castle. This had accounted for the medium grain sized sediment on the beach.

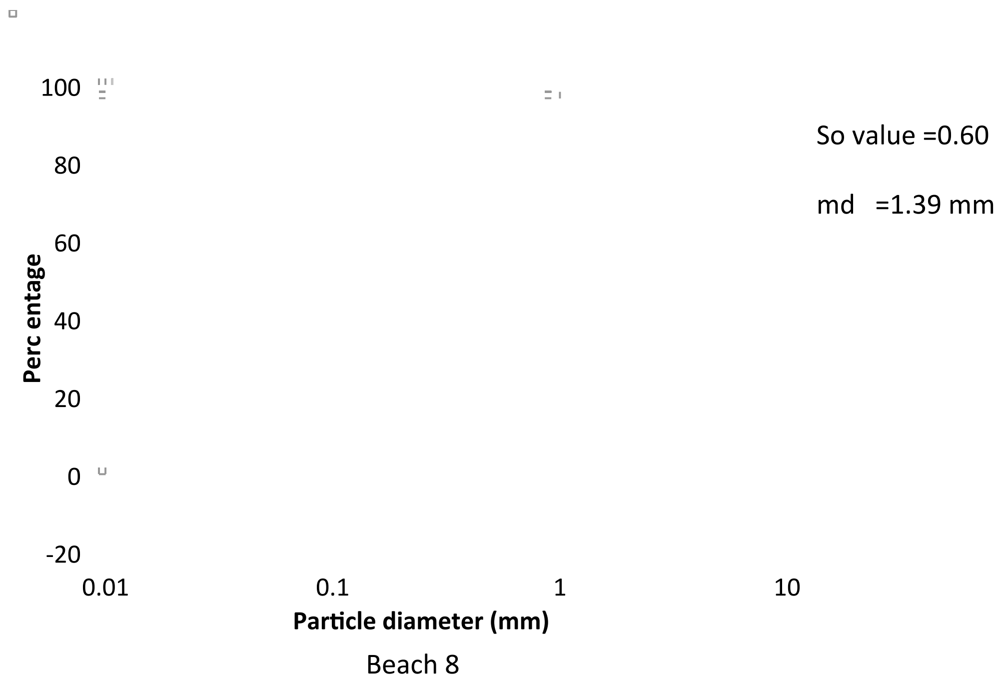

Figure16: Weighted grain sizes and sorting coefficient of sand samples at Iture

Figure 16 is the beach at Iture west where a Recent sandy beach has been formed. It was moderately sorted with *So* value of 0.60 and *md* of 1.39 mm. The beach had large particles as a result of erosion activity in the area. The large grain size is indicated by the *md* and the shape of the asymmetrically sigmoid curve with curvature towards large grains.

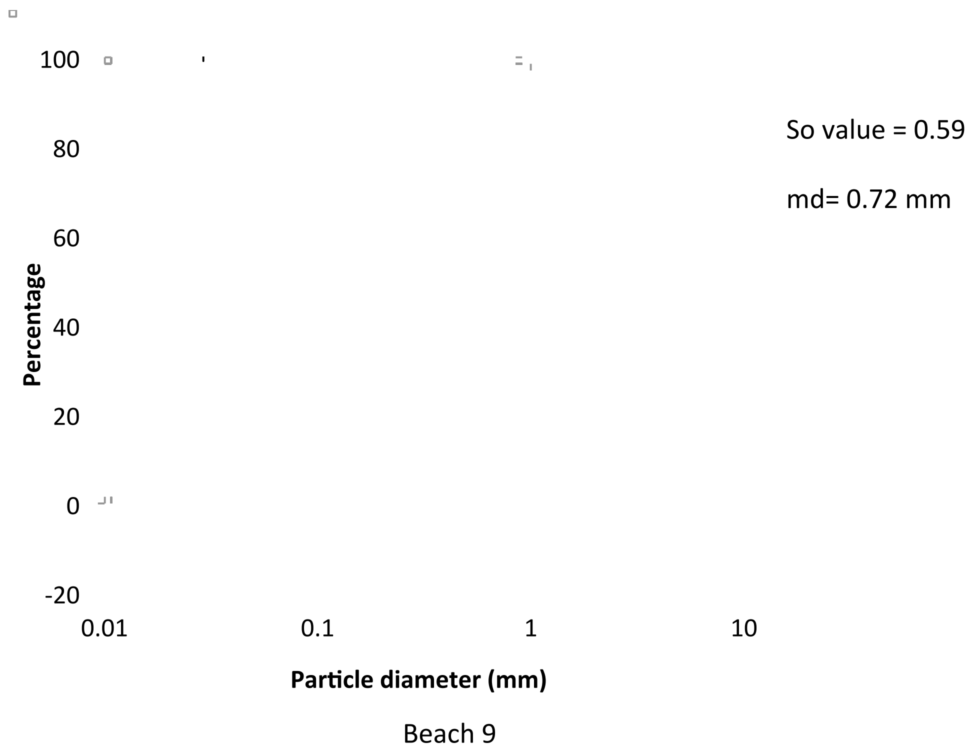

Figure 17: Weighted grain sizes and sorting coefficient of sand samples at Cape Coast, Ola beach

Figure 17 is the raised beach at Ola in Cape Coast. The beach contained foreign materials resulting from the erosion of the sea defence wall. It had medium grains with *So* of 0.59 and *md* of 0.72 mm. The beach showed a marked retreating sandy cliff implying active erosion processes.

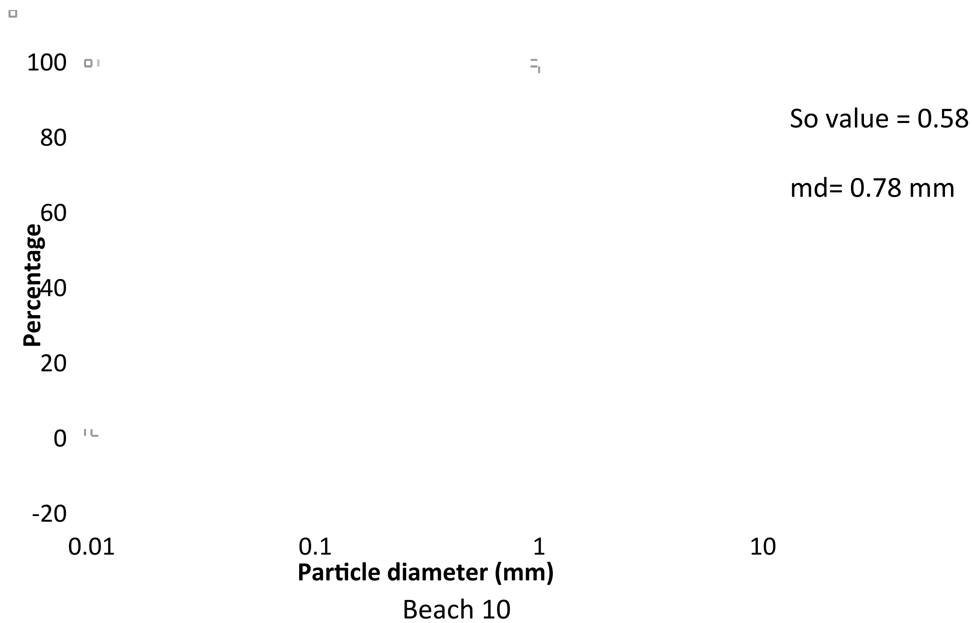

Figure 18: Weighted grain sizes and sorting coefficient of sand samples at Cape Coast (Bakaano) Fosu Lagoon

Figure 18 represents a sample collected from the mouth of the Fosu lagoon in Cape Coast. Beach 9 had medium grains with *So* of 0.59 and *md* of 0.72 mm while beach 10 with *So* value of 0.58 had *md* of 0.78 mm. Both were moderately sorted with lots of foreign materials resulting from the erosion of the sea defence wall in the west side. The beaches showed a marked retreating sandy cliff implying active erosion processes. Beach 10 (Baakano beach) had a mixture of sea and river sand supplied by the river forming the lagoon.

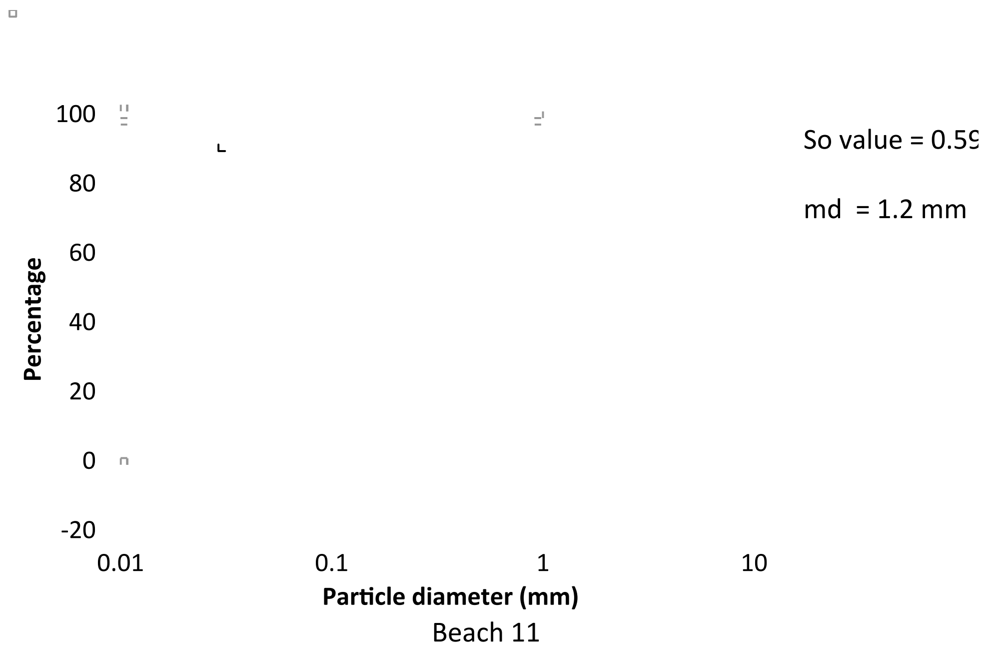

Figure 19: Weighted grain sizes and sorting coefficient of sand samples at Cape Coast West of Castle (Oasis)

West of the Cape Coast castle lies a coarse grained beach with coarse sand accumulation. This is an implication of a relatively strong current around the castle area which had deposited sediments eroded from the rocky outcrop on which the castle was built. However this current was deprived of the sediments and had led to the accumulation of coarse grained sand on the beach. It had *So* value of 0.59 which indicated a moderately sorted beach and *md* of 1.2 mm showing that the particles were coarse.

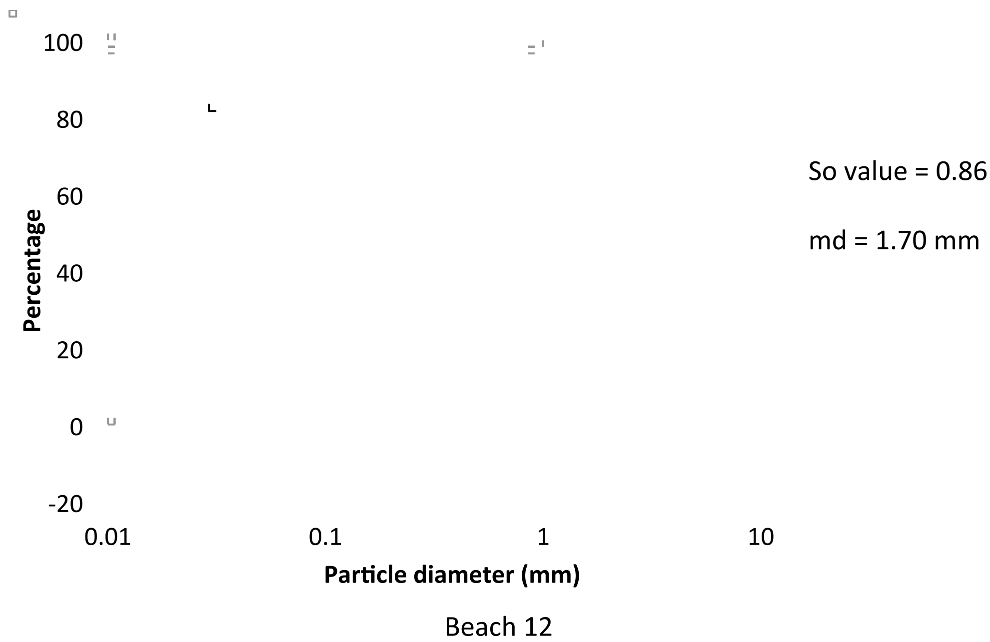

Figure 20: Weighted grain sizes and sorting coefficient of sand samples at Akong (Queen Anne's Point)

Figure 20 shows a beach at west of Akong where a Recent sandy beach had been developed. It was moderately sorted with *So* value of 0.86 and *md* of 1.70 mm. It had large particles which had been sorted between 1.0 and 1.1 due to a relatively long fetch distance from the castle. Even though it was asymmetrically sigmoid, it had a large curvature towards large grains. There was severe sea erosion at this locality which had led to the development of notches and collapsed caves. The collapse of caves had supplied rock debris on the beach.

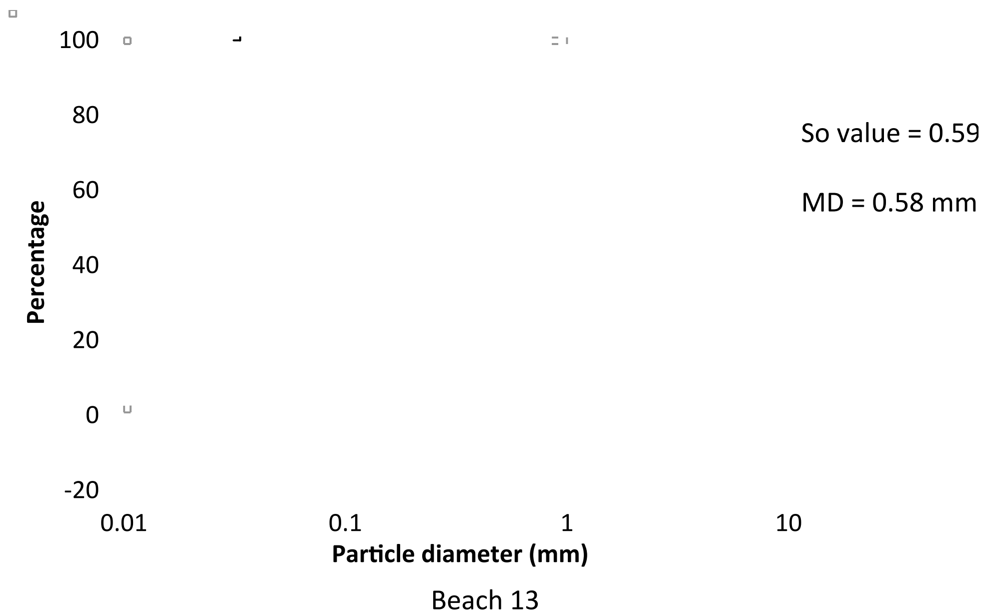

Figure 21: Weighted grain sizes and sorting coefficient of sand samples at Moree West

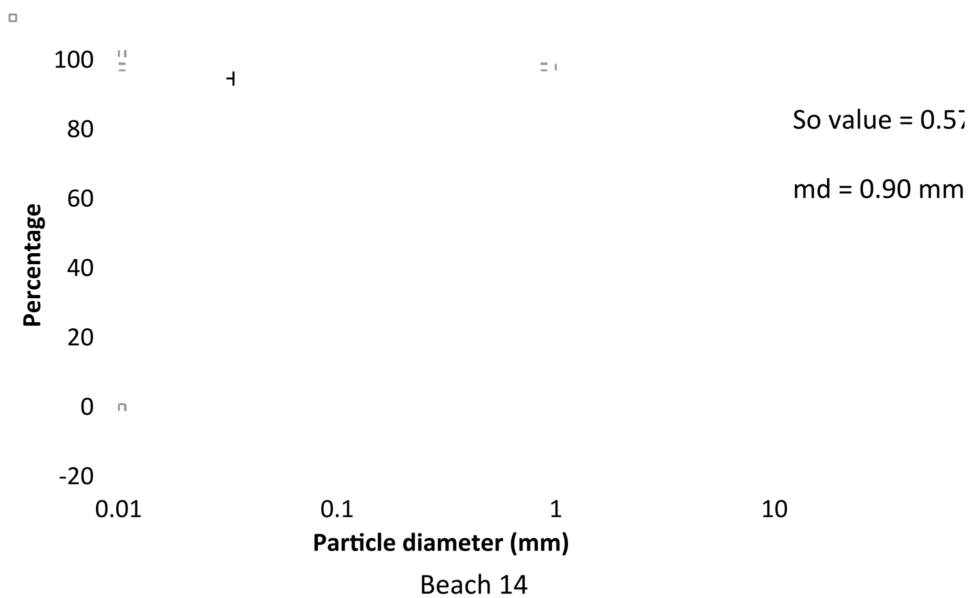

Figure 22: Weighted grain sizes and sorting coefficient of sand samples at Moree East

Figure 21 and 22 were sampled beaches from Moree. Both beaches were moderately sorted with *So* values of 0.59 and 0.57 respectively. Nevertheless beach 14 had medium grains compared to beach 13 as shown by their *mds*. This implied that two different currents operated in these two locations. It could be inferred from the graph that a relatively strong current deposited the sediments on beach 14 (Biriwa east) while that of beach 13 (Biriwa west) was by a relatively weak current.

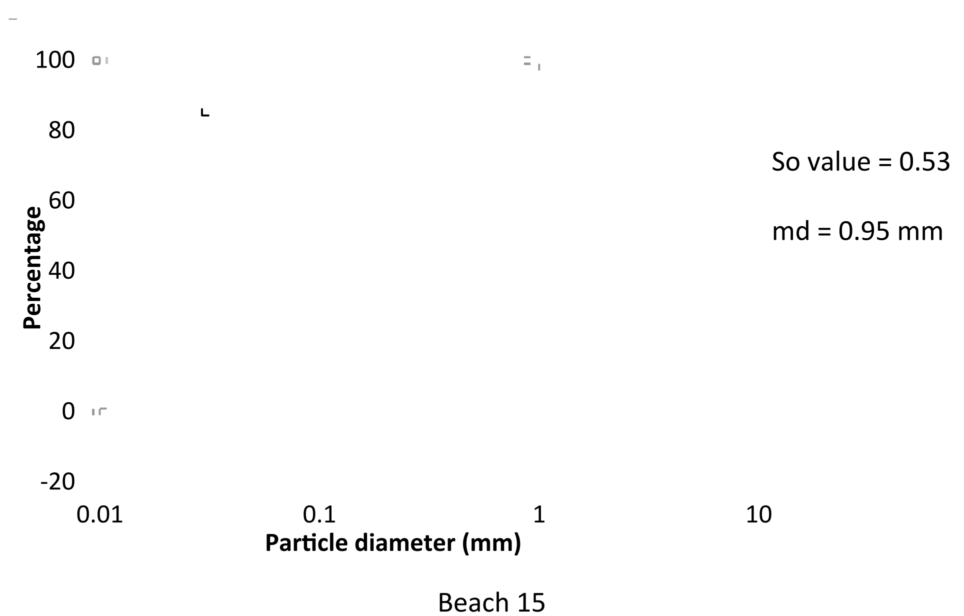

Figure 23: Weighted grain sizes and sorting coefficient of sand samples at Biriwa Resort

Beach 15 is a sampled beach from Biriwa resort. It was moderately sorted with *So* value of 0.53 and *md* of 0.95 mm. The graph showed that a relatively strong current deposited the materials but it had ample time to deposit the materials according to the particles' diameter, hence it was moderately sorting.

The large particles were eroded and transported from the rocky promontory at the extreme west of the town.

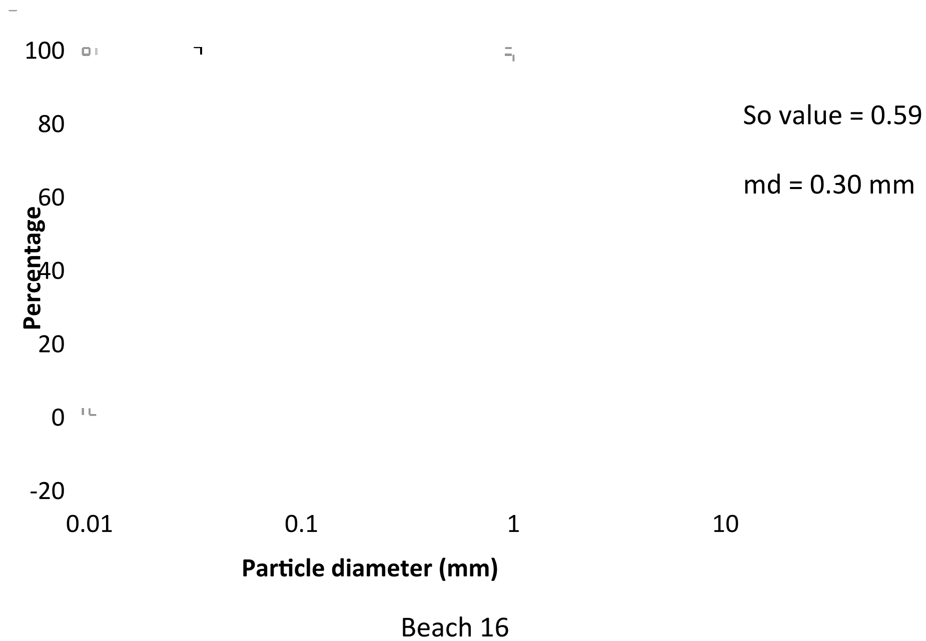

Figure 24: Weighted grain sizes and sorting coefficient of sand samples at Biriwa East

Figure 24 represents a beach at Biriwa east showing a strange curve. It was a moderately sorted beach with *So* value of 0.59 and very fine in grain size indicated by the *md* of 0.30 mm. There was a mix-up of the sediments as shown by its curve which deviates from the normal sigmoid curve due to much human interference. The fine granulometric nature of the sand attracts sand mining for construction and this had affected the distribution curve.

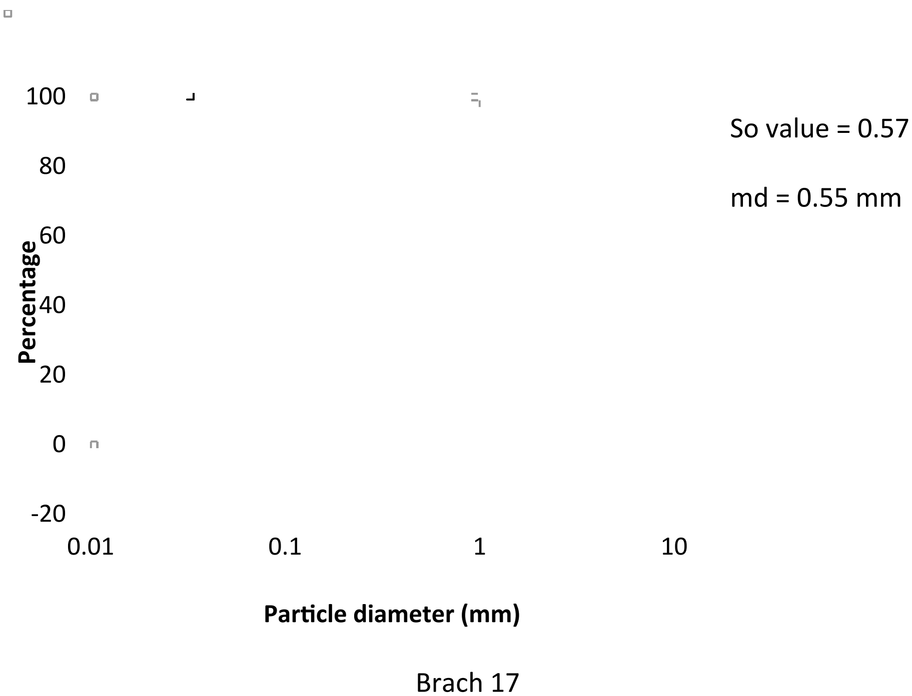

Figure 25: Weighted grain sizes and sorting coefficient of sand samples at Anomabo, West of Anomabo Beach Resort

Beach 17 is located at Anomabo west of the resort in a cove. Its *So* value was 0.57 and *md* of 0.55 mm. It had fine to medium grains. Even though these grains were moved by relatively weak currents, the sediments were moderately sorted. This was indicated by the *So* value of 0.57.

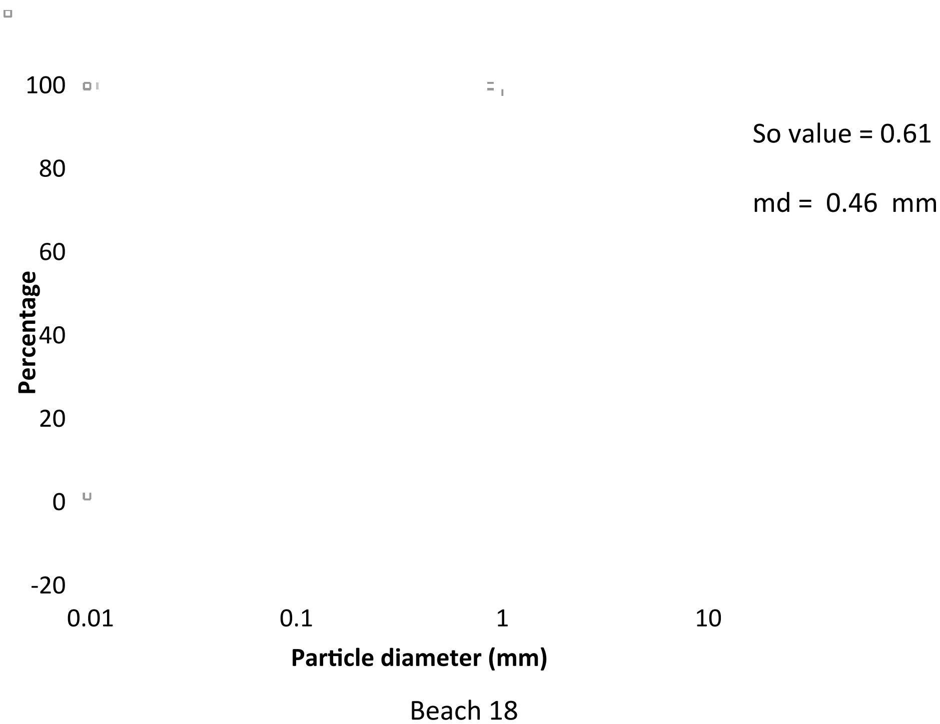

Figure 26: Weighted grain sizes and sorting coefficient of sand samples at Anomabo Beach Resort

Figure 26 represents the beach at Anomabo resort which showed increased erosion activity. The beach had fine sediments indicated by the *md* of 0.46 mm and a moderately sorted beach by means of the *So* value of 0.61 and the asymmetrical sigmoid curve. However, erosion was greatest at this point and beyond, towards Anomabo town. The reason was that, at the west of the resort were rocky outcrops and a cove. Sediments eroded from this point were deposited in the cove and the current became less saturated with sediments upon reaching the resort. The less saturated current was therefore able to erode much sediment at the resort, hence the extremely increased erosion activity at the resort and beyond, towards the east

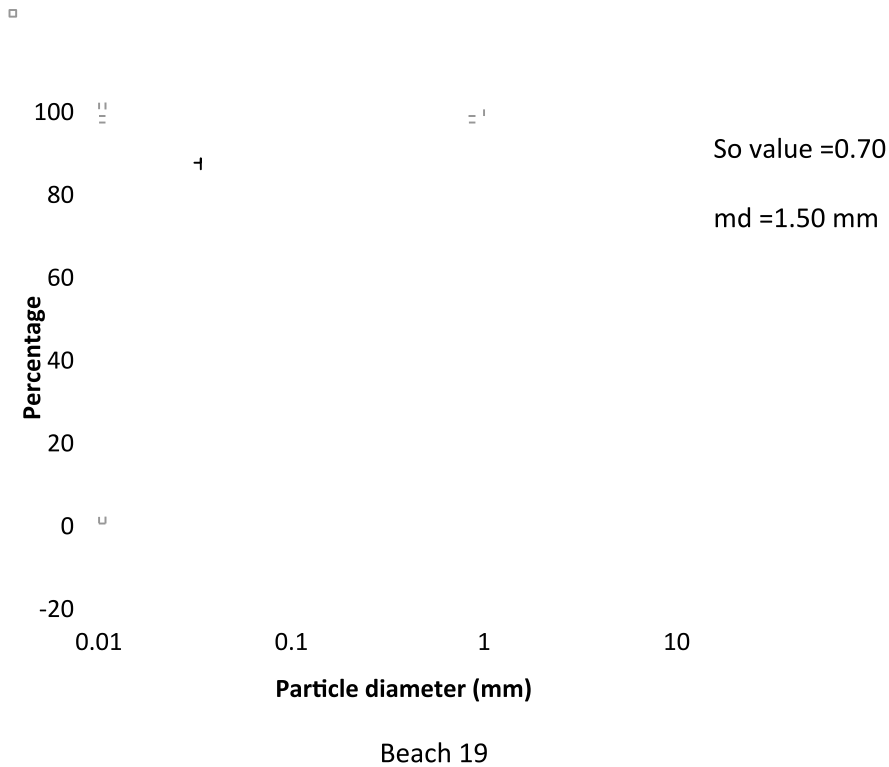

Figure 27: Weighted grain sizes and sorting coefficient of sand samples at Anomabo town

Fig. 27 is a sample collected from Anomabo town, east of the fort. It was well sorted with *So* value of 0.70 and *md* of 1.50 mm indicating a strong current and a coarse grained sand. It was well sorted because of selective deposition reflecting an increase in fetch distance that allowed the sediments to be deposited in succession. The dominance of large particles resulted from erosion of the rocky outcrop west of the resort.

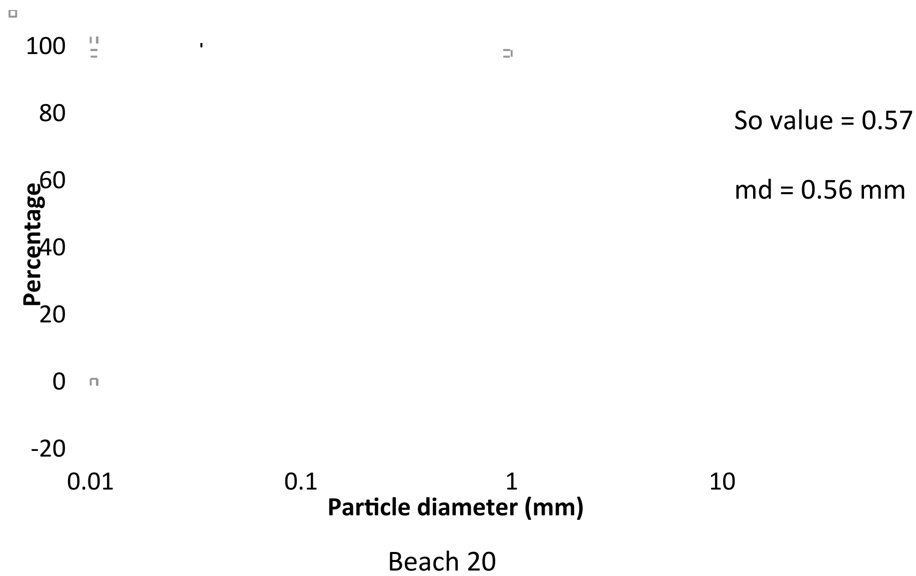

Figure 28: Weighted grain sizes and sorting coefficient of sand samples at Agyaa No 2

Figure 28 is a sandy beach at Agyaa No 2. It was moderately sorted and composed of medium grains as shown by the *So* value of 0.57 and the *md* of 0.56 mm. The increase in fetch distance allowed the sediments to settle in succession according to their grain sizes.

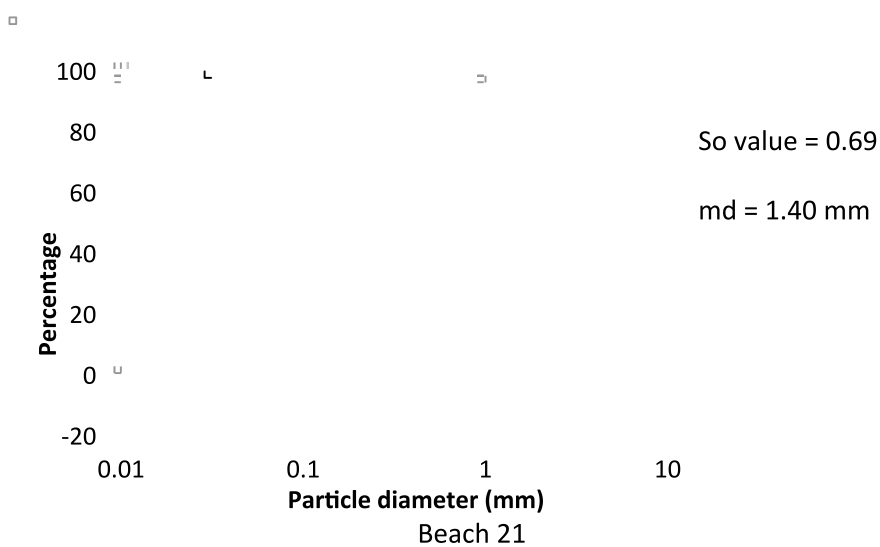

Figure 29: Weighted grain sizes and sorting coefficient of sand samples at Abandze west of headland

Figure 29 represents the beach west of the Abandze headland. It was moderately sorted with very coarse grained sand and shell fragments. The *md* of 1.40 mm implied that they were deposited by a very strong current. However this current was deprived of the sediments from further transportation eastwards. A weak current therefore transports relatively small particles to the east of the headland. Erosion was very intense at this location resulting from increased fetch distance and wave energy.

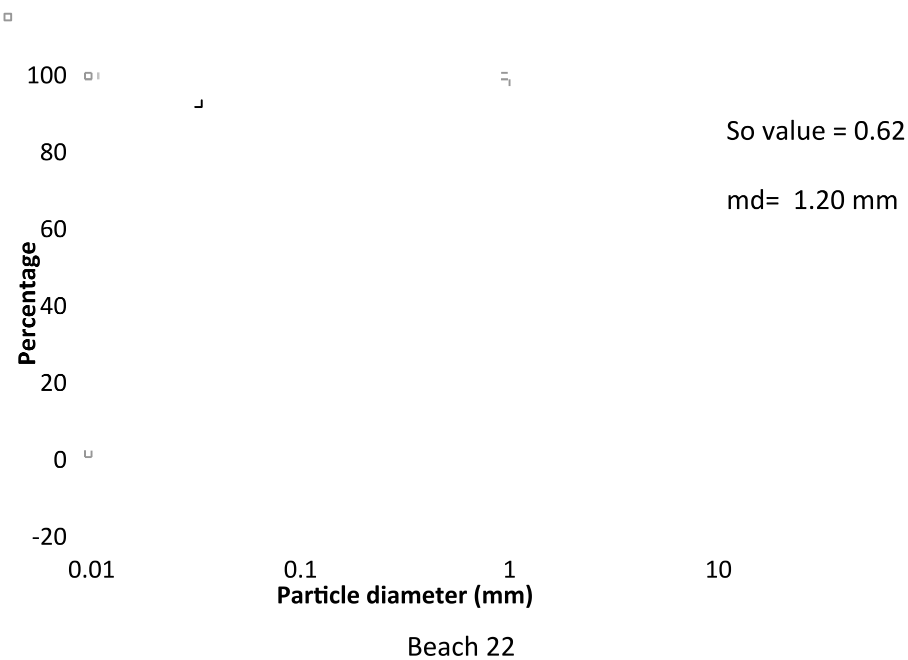

Figure 30: Weighted grain sizes and sorting coefficient of sand samples at Abandze town

This is a beach from Abandze town. The *So* value of 0.62 showed that the particles were moderately sorted. However the *md* of 1.20 mm implied increased erosion at the Abandze headland.

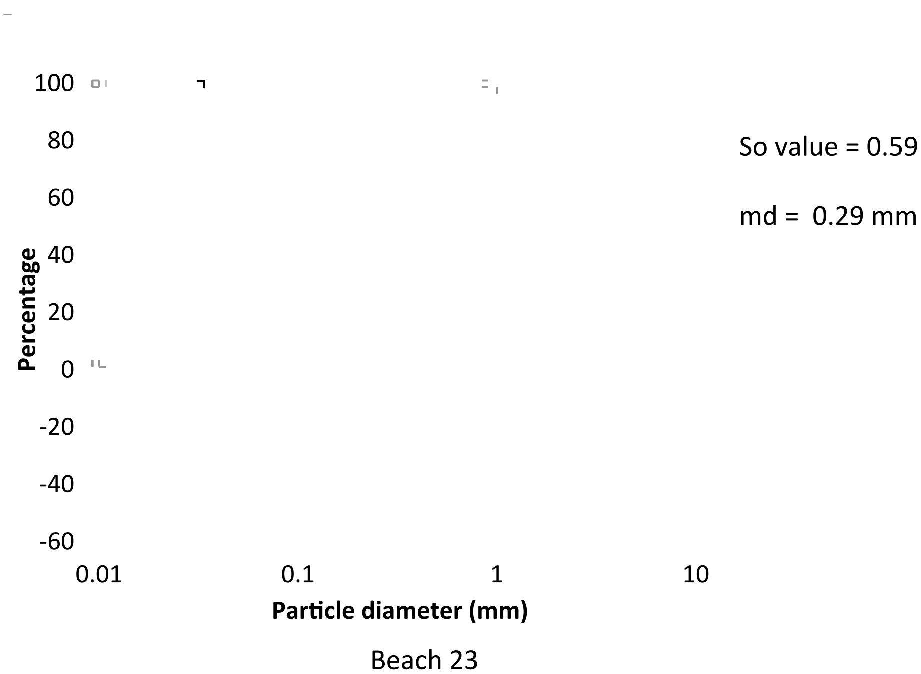

Figure 31: Weighted grain sizes and sorting coefficient of sand samples at Abandze Beach Resort

The beach at Abandze resort had very fine sediments implying a weak current that operated along the beach. That explained why the sea was able to deposit at the mouth of the lagoon. It was moderately sorted with *So* value of 0.59 and *md* of 0.29 mm. The curve showed that there was very fine but a mixed-up of sediment due to human interference on the beach. The beach was therefore disturbed greatly by human activities such as sand mining due to the granulometric texture of the sediments

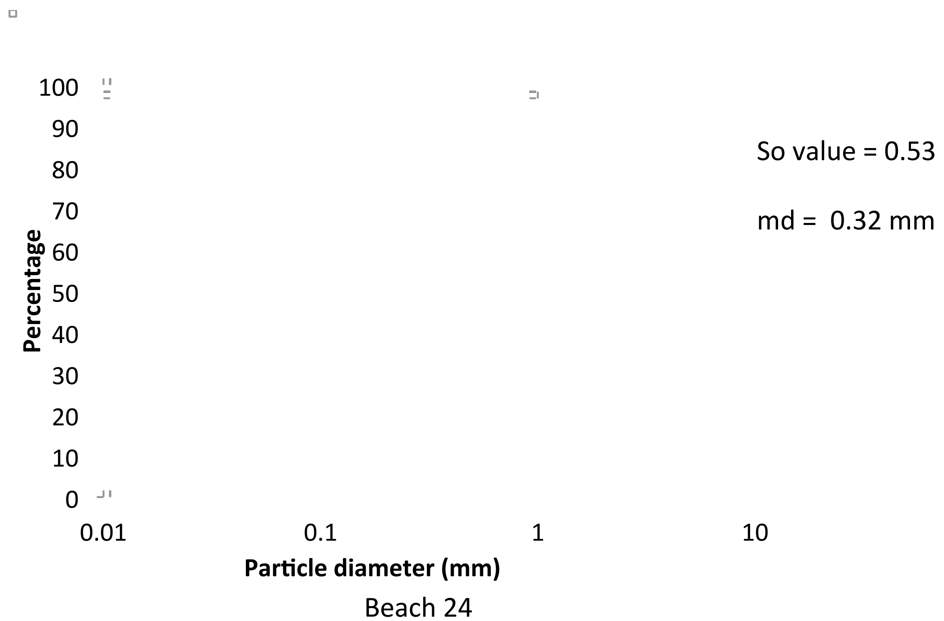

Figure 32: Weighted grain sizes and sorting coefficient of sand samples at Kormantse

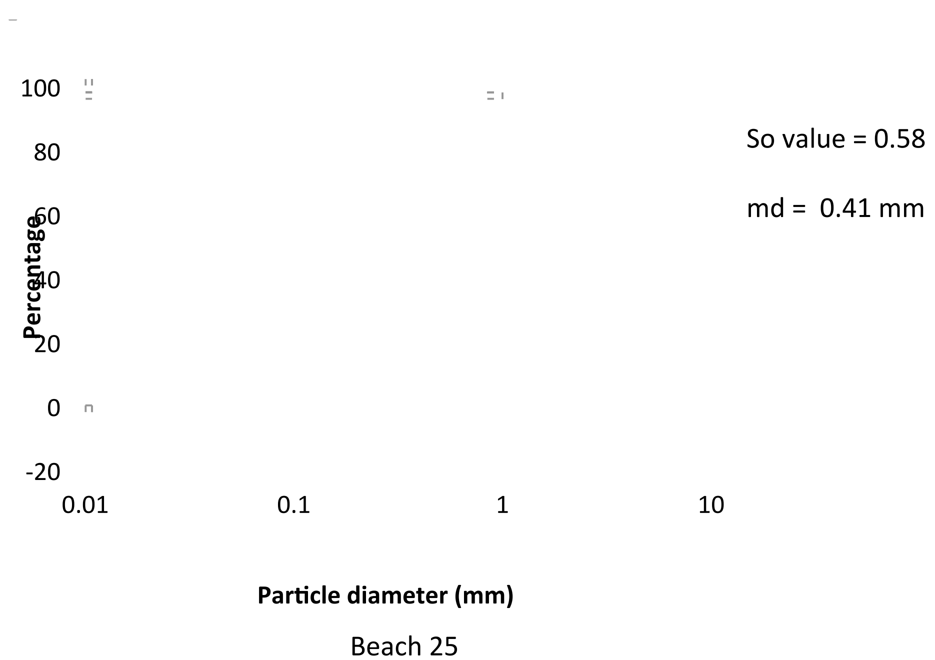

Figure 33: Weighted grain sizes and sorting coefficient of sand samples at Saltpond Redevelopment Institute (SRI)

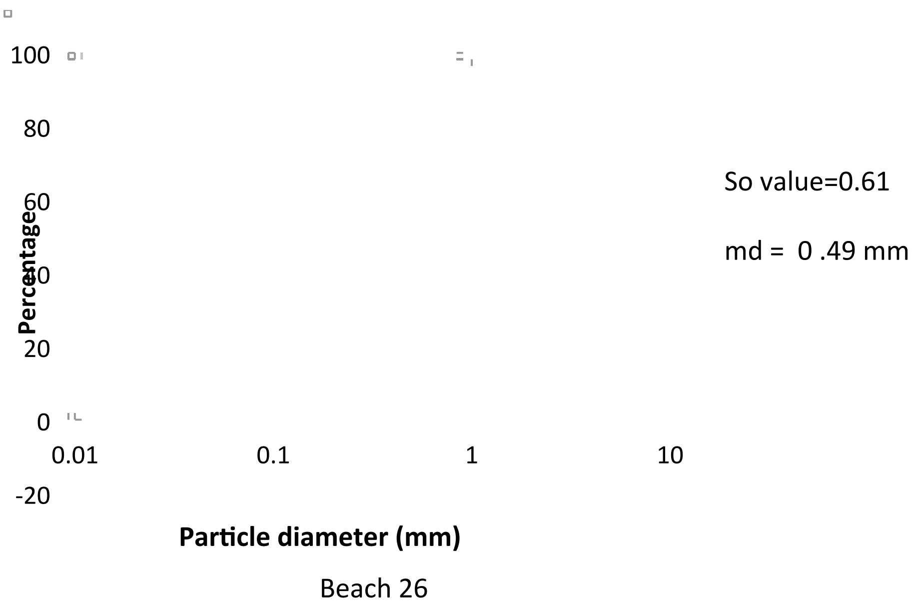

Figure 34: Weighted grain sizes and sorting coefficient of sand samples at Ankaful- Saltpond

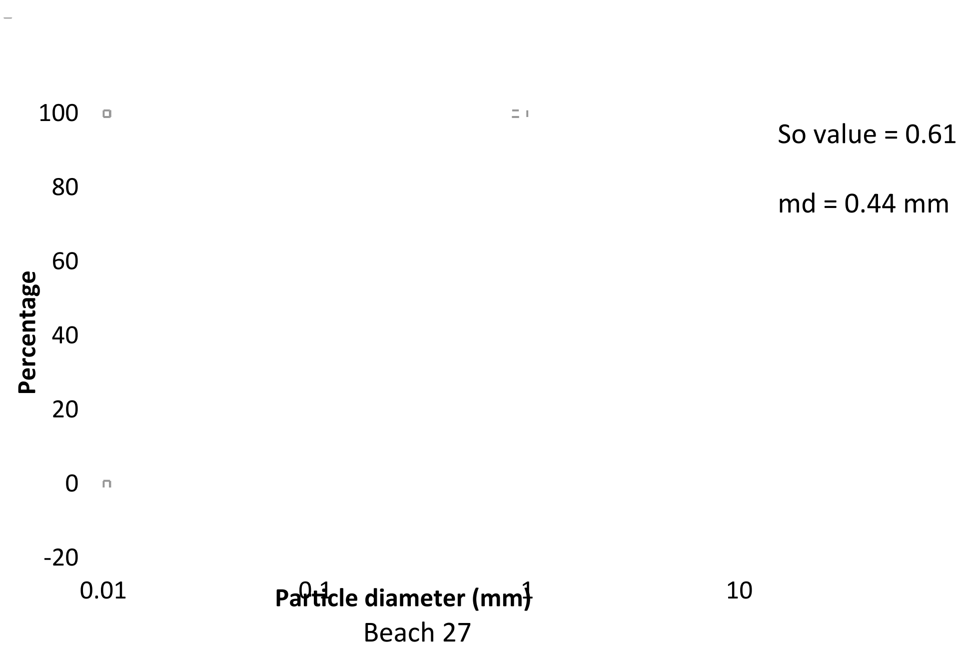

Figure 35: Weighted grain sizes and sorting coefficient of sand samples at Pabi, Saltpond

Beaches 24 -27 are sampled beaches from Kormantse, Saltpond SRI, Ankaful and Pabi. They had fine grain sediments and they were well sorted indicated by their *So* values and mds. The increased fetch distance eastwards allowed the sediments to be deposited according to their diameters and it also indicated regularity and strength of the currents that deposited the materials (Dei, 1972). Nevertheless the beaches showed increased erosion activity due to increased wave energy as a result of the long fetch distance

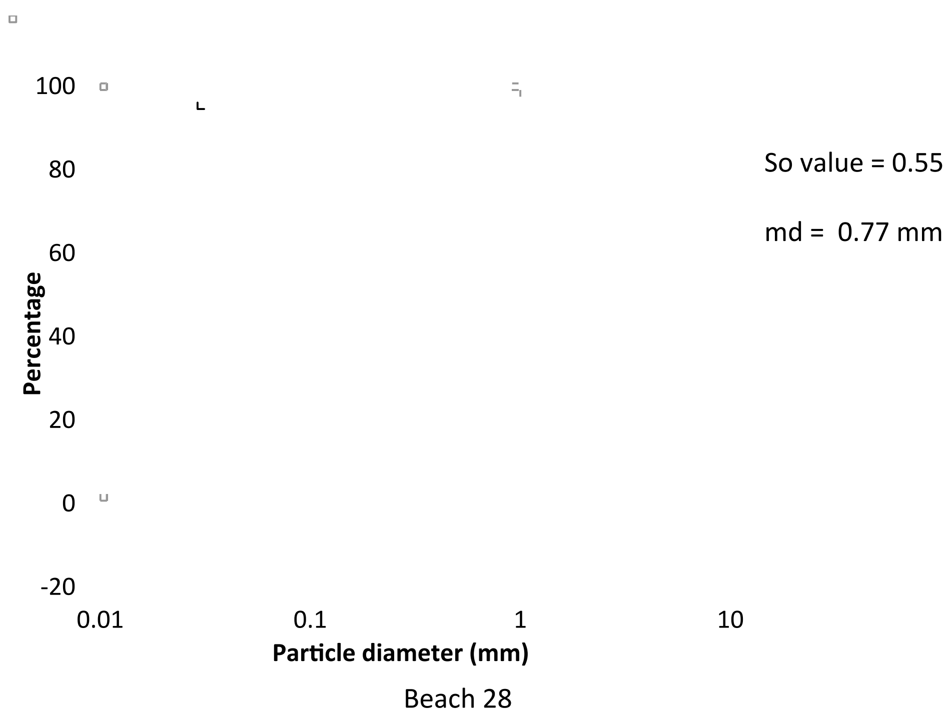

Figure 36: Weighted grain sizes and sorting coefficient of sand samples at Hini - Saltpond

Figure 36 is the beach at Hini, a location close to the estuary. The asymmetrical curve with its large curvature towards medium grains showed that the beach was composed of medium grains. The sediments were a mixture of sea sand and river sand supplied by the river Amissa.

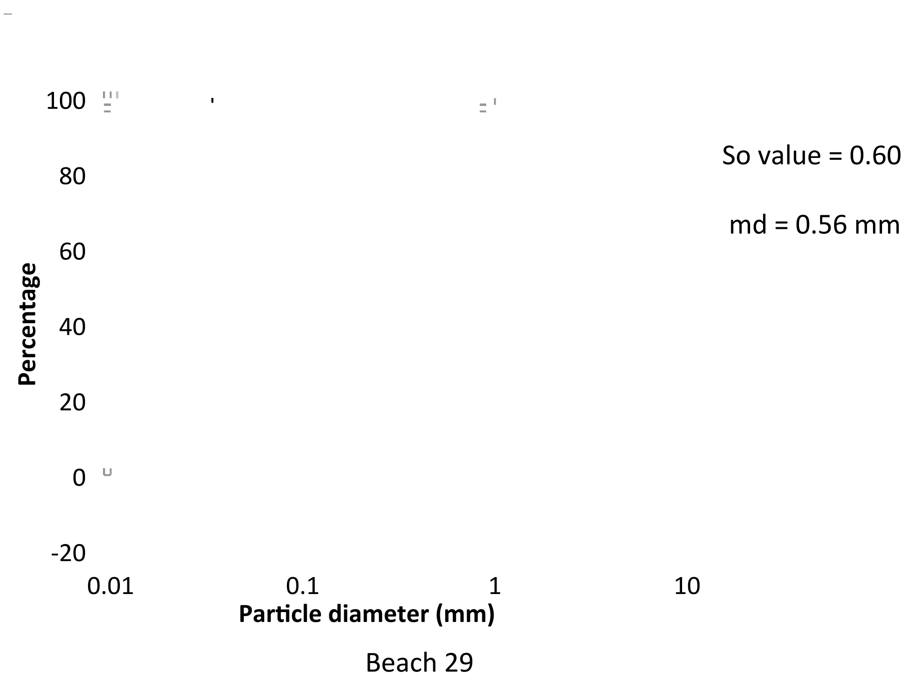

Figure 37: Weighted grain sizes and sorting coefficient of sand samples at Amissano west of estuary

Beach 29 had *So* value of 0.60 and was well sorted. The *md* (0.56 mm) indicated a medium grain size which was a mixture of river and sea sand. Erosion was profound on the sandy cliff face located at the estuary. There was evidence of a retreating sandy beach.

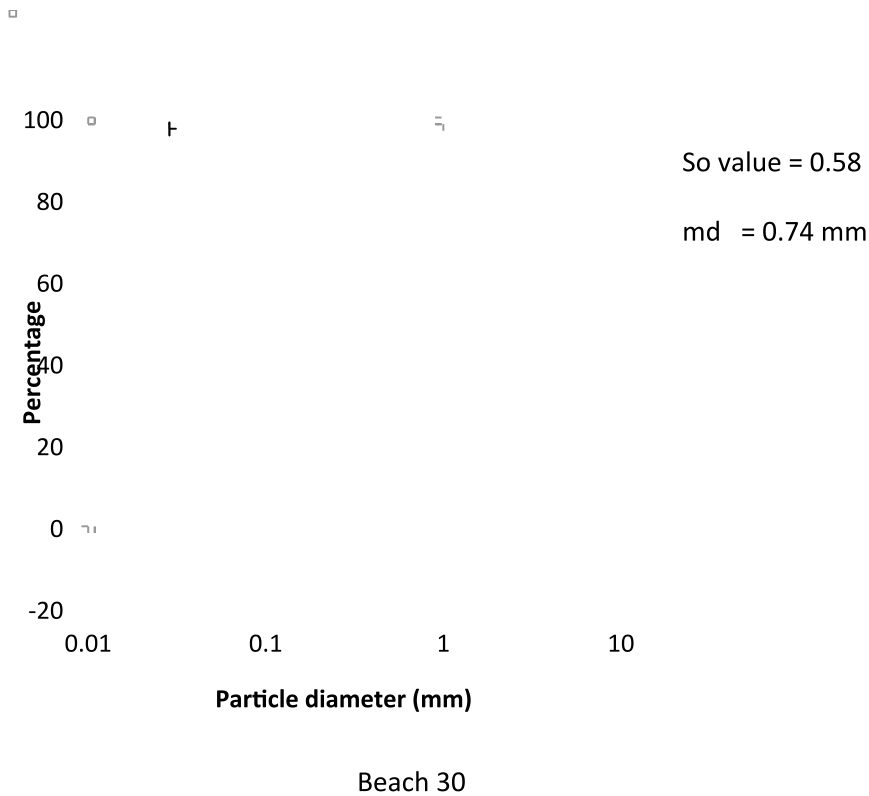

Figure 38: Weighted grain sizes and sorting coefficient of sand samples at Amissano estuary

Beach 30 is the beach at the Amissano estuary. The *So* value of 0.58 showed that it was moderately sorted. The *md* implied a medium grain size which was made up of a mixture of sea and river sand supplied by the river. Beaches 29 and 30 had the same type of beach material which was a mixture of sea sand and river sand. Their *So* values were quite close but the relatively large difference between their *mds* was as a result of the beach's location close to the estuary and the direct influence of the estuary, had supplied it with more river sand. This accounted for the increase in the *md* of 0.74 mm.

General observation

All the above beaches were of the Recent type. Their So indices showed that they were well sorted. For the purpose of this study, *So* value which is less than one (1) is considered well sorted. Majority of the beaches were moderate to well sorted (in a relative sense) as confirmed by their cumulative percentage graphs showing moderately asymmetrical sigmoid curves. Their *So* indices (which were less than one) were close to unity which means they were close to perfect beaches. Abandze town, Anomabo town, Cape Coast West of the castle (Oasis) and Iture had higher median diameters all indicating a stronger wave current. All these locations had rocky promontories which might have been partly the source of sediments to the beach zone. The rocky outcrops also increased wave energy. Increase in wave energy could also mean an increase in sea level.

Lithological groupings of sorting characteristics

The coastline of the study area consisted of different lithological make up. Basically, it consisted of rocky coastline with intervening sandy beaches. However the rocky part was made up of two distinct rock types namely igneous and sedimentary rocks including the recently deposited beach sand. Based on this lithological make up, the coastline was divided into three lithological zones. Therefore, sorting characteristics were grouped according to the lithological zones to ascertain the characteristics of sand grains, wave energy and the fetch distance in each zone. Below were lithological groupings of sorting characteristics in each zone.

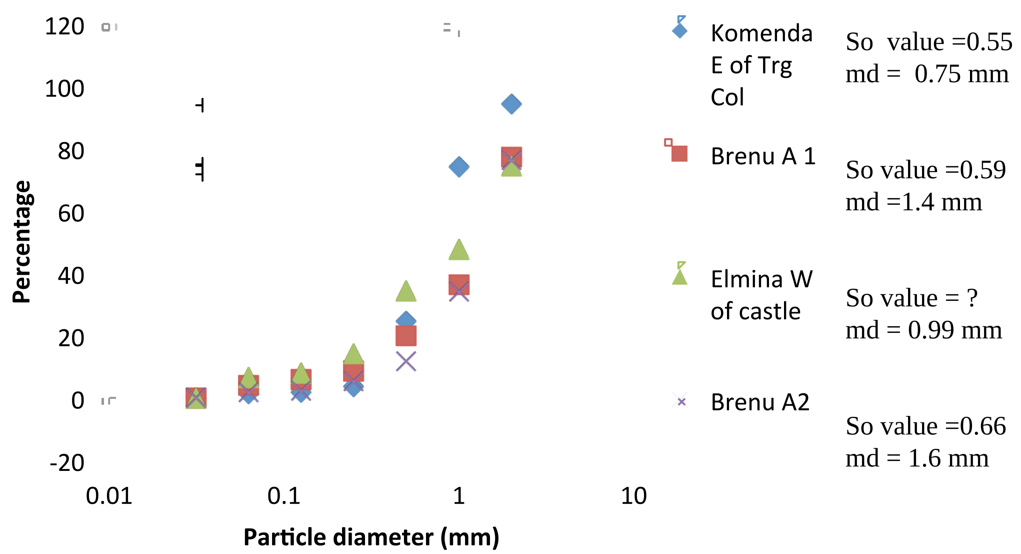

Figure 39: Sorting characteristics of zone A - Rocky coastline mostly comprising sedimentary rocks

Figure 39 shows well sorted beaches with *So* values ranging from 0.55 to 0.66 indicating that they were recent beaches. The average *md* was 1.19 mm which shows characteristically coarse grained sand. Their cumulative percentage curves, asymmetrically sigmoid curves, indicated a large curvature towards medium to large grains, which confirmed this fact. In addition, the beaches contained a lot of shell fragments. Most of the sediments were derived from previously existing older beaches with the sediments reworked due to increased wave action resulting from SLR (Dei, 1972).

The rocky promontories, especially at Gold Hill and Elmina west of the castle, increased the strength of the wave and might have added more to the sediment through attrition of sediments and abrasion of the rocky cliff. This implied that sea erosion was very active on rocky coastlines but due to the fact that some of the rocks were resistant, erosion was not all that profound on rocky coastlines compared to sandy coastlines. Field observation also showed that the selective action of the sea had led to the accumulation of very coarse grain on wave-cut platforms at the backbeach whiles the medium grains were found at the forebeach and nearshore waters with finer ones washed away by the backwash. The coarse grain sediments on the platforms were moved along the beach by strong currents or submerged during high tides.

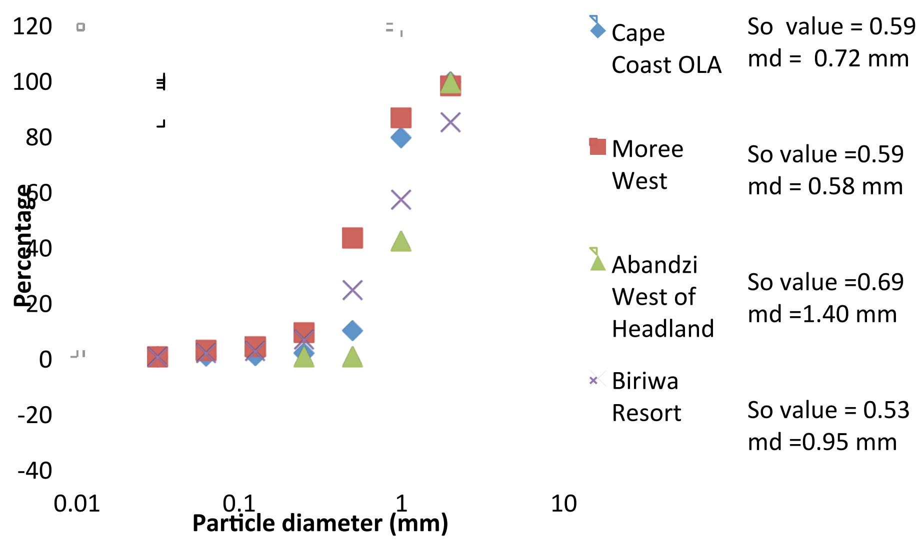

Figure 40: Sorting characteristics of zone B - Rocky coastline with granite intrusions

These were sampled beaches from zone B. The beaches in this zone had medium to fine grains sediments with an average *md* of 0.91 mm. Abandze west of the headland had the highest median diameter. It is assumed that the headland increased the wave energy thus intensifying erosion and transportation. Pebbles from this location showed higher roundness indices confirming the increased erosion activity. There were very large grain sizes with shell fragment west of the headland whiles a weak current washed the other side of the headland and deposited relatively fine particles from the west of the headland onto the beach on the other side. This also implied decrease in particle size eastwards.

The average *So* value of these beaches was 0.6 which indicated that they were moderately sorted as a result of the relatively increase in the fetch distance. Cape Coast-Ola and Moree west had the same sorting value but different *mds*. This means that the currents that washed along these two beaches have different strength. That of Moree west was relatively weaker than the current at Cape Coast- Ola. The beaches in zone B in general had relatively medium sized grains compared to that in zone A. This was as a result of the particles being subjected to prolonged abrasion as they moved eastwards.

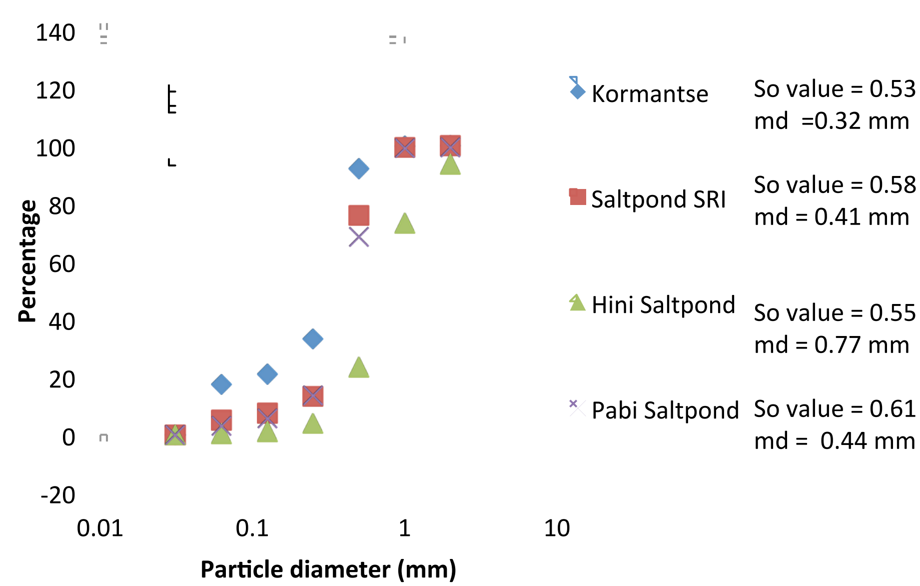

Figure 41: Sorting characteristics of zone C - Sandy beaches

Zone C is made up of sandy beaches without rock outcrop. Their cumulative percentage graph showed an asymmetrically sigmoid curve with a characteristic large curve towards fine sand grains (Figure 41). It was mostly made up of fine sand, silt and a very low content in coarse sand. The average *md* was 0.53 mm. This confirmed its fine granulometric texture.

These beaches could be said to be well sorted with average *So* value of 0.56. Earlier work by Dei (1972) classified these beaches to be moderately sorted with *So* values between 1.2 and 2.8. It is possible that post depositional changes in the sediment, reworking and further abrasion and transportation by longshore drift have reduced its granulometric texture further and this has rendered the findings quite different from the previous work by Dei (1972). From the graph the cumulative curves of Kormantse, Saltpond and Pabi were very close to each other, nearly the same shape and they were almost superimposed on each other. Hini which was close to the estuary and might have been supplied with course river sediments had medium grains and its curve lies quite far from the others.

The coastline was predominantly made up of sandy cliff and the absence of rock outcrops and increase in fetch distance explained the fine granulometric texture of the beach sand. Erosion which could be attributed to SLR was active on the soft cliff and the coastline was bordered with receding sandy cliffs. A reasonable conclusion was that the sediments were derived from the soft cliff and older or pre-existing beaches which have been reworked.

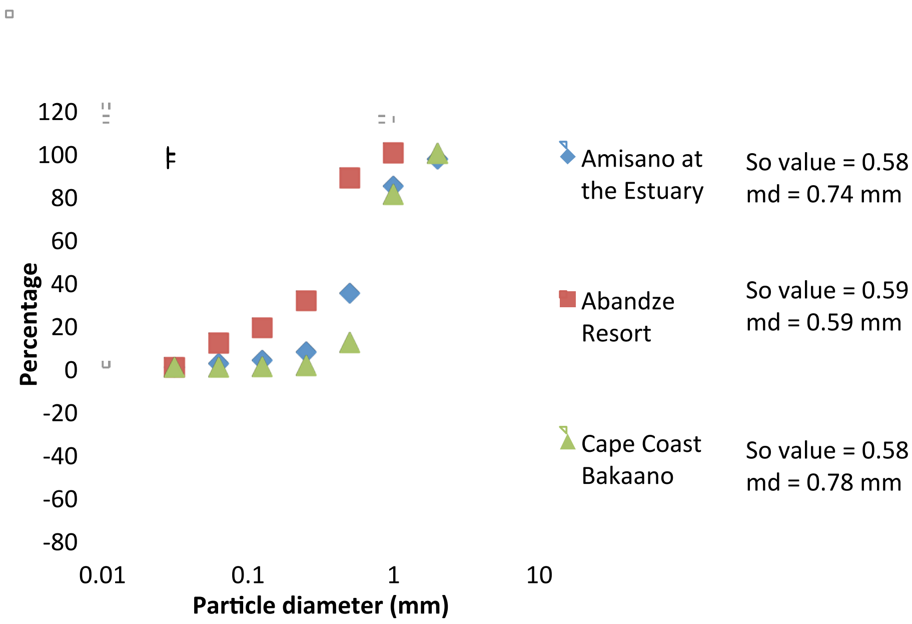

Figure 42: Sorting characteristics of barrier beaches

These samples were collected from barrier beaches at the mouth of estuaries and lagoons. It was assumed that these samples have similar or a common characteristic in the sense that they were all barrier beaches. The deposited sediments were occasionally removed either by the effort of man, the river or the sea and replaced by the sea during low tides. Amissano estuary and Cape Coast, Bakaano had the same *So* value but with different *mds* which were quite close. From the graph these two beaches had almost the same shape with Abandze resort having an entirely different shape. There was a mixed up of sediments at Etsi lagoon at Abandze resort as a result of human interference, principally sand mining.

Both indices gave some clues to the conditions of formation of the clastic sediments. The *So* values depict that they were well sorted, had fine to medium grain sizes and were recent beaches whereas the *mds*, which represents the middlemost grain size, gave an idea about the strength of the current or wave that moved the material to its deposition site. It could therefore be deduced from the Figure 42 that, the strength of the current that moved the sediments to the current position at Cape Coast, Bakaano (in zone B) was stronger than that of Amissano estuary in zone C. This may be as a result of the presence of granitic promontories at zone B, which had led to increased erosion activities. Taking the *md* of Amissano estuary (0.74 mm) into consideration, it could be said that the current at Amissano estuary was stronger than that at Abandze resort which had the least *md* (0.29 mm). This may be attributed to the combined action of the river and the sea as the river entered the sea, thus producing a counter current responsible for the strong current.

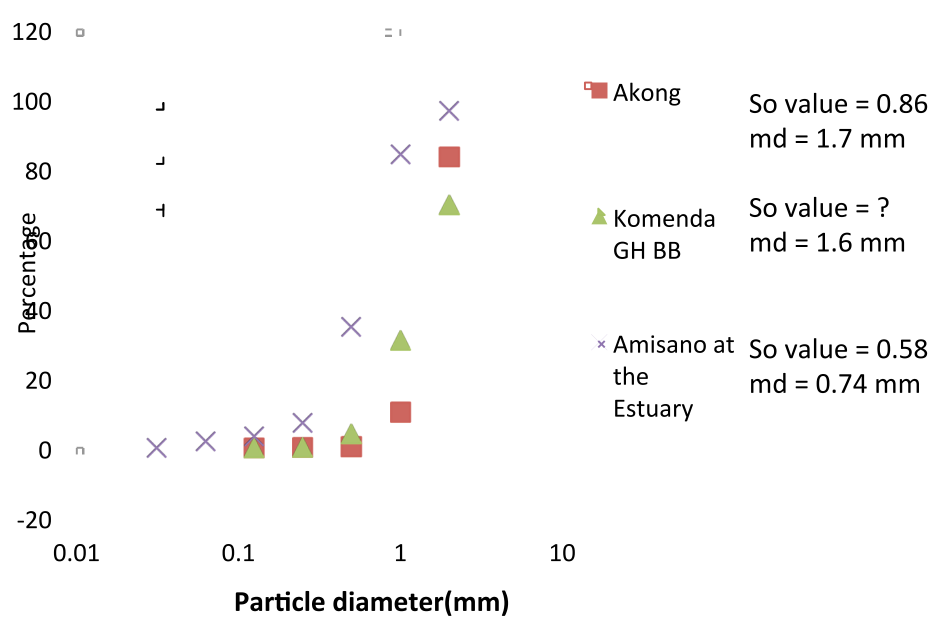

Figure 43: Sorting characteristics of beach samples from all zones

The figure above shows samples beaches from all the Lithological zones in the study area. The *So* index for Komenda Gold Hill- Backbeach could not be calculated because the cumulative curve does not add up to 75% and above where the 3rd quartile could be read. This was as a result of the presence of shell fragments and extremely larger sediments which did not fall into the description of sand particle in the Atterberg's grade scale used for the definition of particles.

According to Crowley (2006), the shape of a beach depends on whether or not the waves are constructive or destructive, and whether the material is sand or shingle. Constructive waves move material up the beach while destructive waves move the material down the beach. On sandy beaches, the backwash of the waves removes material forming a gently sloping beach. On shingle beaches the swash is dissipated because the large particle size allows percolation, so the backwash is not very powerful, and the beach remains steep. The shape of the curves for Komenda Backbeach and Akong showed that the waves that were present in these areas were very destructive hence their steeply sloping curves towards large grains.

From Figure 43 above, the beach at Amissano estuary in zone C had asymmetrical sigmoid curve indicating finer grain sizes compared to the steeply sloping almost non-sigmoid curve at Akong and Komenda GH BB in zones A and B. Beaches in zone A had coarse grain sands while those in zone B have medium grains with zone C being finer in grain sizes, implying that grain sizes decrease with distance eastwards. This answers the concerns that rose in chapter one about the relationship between fetch distance, particle size and intensity of erosion.

Field measurements

Field measurements conducted on cliff face on a sandy beach in zone C yielded the following results shown on the table below.

Table 10: Field measurement on cliff face during high and low tide

period	**Month**	**Recordings**
High tide	10^{TH}-31^{ST} May, 2010	2.3cm
(Mainly erosion)	1^{st}-30^{th} June, 2010	4.7cm
	1^{st}-31^{st} July,20101	5.3cm
	1^{st}-31^{st} Aug, 2010	6.1cm
Total		**18.4cm**
Low tide		
(Mainly deposition)	1^{st}-31^{st} Dec,2010	2.5cm
	1^{st}-31^{st} Jan,2011	6.1cm
	1st-28^{th} Feb,2011	3.9cm
	1^{st}-31^{st} Mar,2011	3.3cm
Total		**15.8cm**

Source: field measurement, 2010-2011

Table 11: Deficit in sediment budget during erosion and deposition

Period	Months	Diff. in Recordings b/n months
High tide		
	May, 2010	-
	May and Jun,2010	2.4cm
	June and July, 2010	0.6cm
	July and Aug, 2010	0.8cm
Total		**3.8cm**
Low tide		
	Dec, 2010	-
	Dec and Jan., 2011	3.6cm
	Jan and Feb., 2011	-2.2cm
	Feb and Mar., 2011	-0.6cm
Total		**0.8cm**

Source: field measurement, 2010-2011

These measurements were conducted on the depth of cliff face and where accumulation was quite stable. The readings were quite affected by sand mining activities as shown in the recordings during low tides from December 1st, 2010 to March 31st, 2011. From Table 10, a sediment budget deficit of 2.6cm was recorded with a net deficit of 3cm for the eight month period as shown in Table 11. This implied that erosion outweighed deposition or accumulation on the beach in Zone C. Hence the supply of beach sand unto the beach was less than amount eroded. This deficit may be as a result of the erosive action of the sea and sand mining on the beach. It could be inferred from the table that sand mining resumed right after there had been an appreciable deposition. This was shown in Table 10 when deposition increased during low tides from December, 2010 to January, 2011 but kept reducing in the subsequent months (i.e. from 2.5 cm to 6.1 cm then 3.9 cm and finally 3.3 cm). High tide periods were mostly characterised by exposed coconut roots, the foundations of other concrete structures close to the shore were exposed but these were almost covered by deposition of sand during low tides.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter deals with the summary of the work done, conclusions drawn from the study and some recommendations based on the major findings from the study. The conclusions placed emphasis on the objectives and concerns raised in the study.

Summary

The study was to examine the responses of lithology to erosion. The various types of rocks and sand samples were examined in response to erosion, bringing out some of the major characteristics of the sediments and rocks that made them resistant or non resistant to sea erosion

The study area was drained by a major river (Amissa/Ochi) and several minor ones with their tributaries. This had led to the formation of 13 lagoons and estuaries, which absorbs most of the river sediments. However these estuarine conditions permitted marine influence upstream. This had two resultant effects; the exchange of reworked marine sand and river sand and changes in the estuary circulation and salinity gradient through increasing tidal and wave action resulting from SLR. The turbulent flow that characterised these estuaries resulted in the fragmentation of sediments which were later reworked by tidal abrasion to achieve medium grain sizes. The cumulative curves of the barrier beaches in Figure 42 confirmed this fact. The changes in estuarine salinity gradient were also confirmed in an informal interview conducted among the natives at Hini and Amissano who used the estuary water for domestic purposes.

The coastline of the study area had different lithological and mineralogical make up as shown in Figure 1 and 2. A close observation of the pebbles and the sand grains collected from the beaches indicated that the sediment were derived from pre-existing geological forms such as underlying rocks of the substratum and rock outcrops or promontories with few originating from sub-aerial processes. This was a proposition put forward by Dei (1972) and the study confirms it. Typical evidence was found on the polished surfaces of rounded quartzite pebbles from Abandze which showed matt surfaces and ferruginised coatings that indicated that the pebbles had undergone renewed abrasion with increased wave energy resulting from increasing sea levels.

The study also found out that there was a progressive decrease in grain sizes eastwards with an increase in pebble roundness from Elmina down to Abandze. This could be as a result of the increase in fetch distance eastwards from Komenda towards Amissano estuary. The effect was the successive reworking of beach sediment as wave energy increased. This also implied increased wave energy eastwards. The fine granulometric texture of sand grains of beaches in zone C may be partly due to increased wave energy which resulted in increased abrasion processes eastwards and partly to the absence of rock outcrops on the beach to supply freshly brecciated sediments from pre-existing rocks. Here the same sediments were reworked with no “plucking” of new ones from rock outcrops.

Another established fact made through field observation was that differences in lithology of the coastline had resulted in different rate in erosion activities. Some areas showed minimal evidence of erosion activity. Thus not all locations with rocky outcrops exhibited erosion features such as caves, benches, stacks, arches etc. These features were completely absent in zone C which was entirely sandy. Therefore the reworking of the sediments in this zone was purely on the beach sand, hence its fine granulometric texture.

It was observed on the field that some benches had micro structures which were believed to be once filled with softer secondary material or sea lichens (Dei, 1972). These fillings were later eroded by sea action when sea levels started rising. These features were found in the Elmina sandstone and also in the granitic outcrops at Anomabo.

All the above findings were evidences attesting to the fact that erosion was ongoing and the level of the sea has risen. There were inadequate written document on SLR in the area. Since the phenomenon is global and not regional, global figures for SLR were used in this study. However the opinions of people staying along the coastline were sought in an informal interview and they all confirmed that the level of the sea has increased. Besides these, concrete structures found some few meters into the sea in some locations added up to the fact that the level of the sea has increased. Examples could be found at Anomabo, Cape Coast and Biriwa among others.

The mitigation measures taken to check and reduce erosion as sea levels rose were the construction of groynes, wooden and concrete structures and defence walls found in all zones. This means that sea erosion cuts across all locations no matter the lithology. Despite these efforts made by the local communities erosion continued with the advancing sea.

According to Carter (1998), headlands, rivers and estuaries have control on wave refraction. The presence of structures such as groynes, sea defence walls and other concrete structures behaved in a similar manner and influenced the movement of sediments. Deposition was greatest at the western sides of these structures, especially the headlands, groynes and concrete revetments, while erosion was more profound at the eastern sides.

Human activities in the study area were mainly fishing and sand mining. There was some amount of tourism which was evidenced in the proliferation of both major and minor beach resorts. There were also salt production sites identified within the coastal zone between Elmina and Komenda. These activities had influence on sediment transport and erosion. Human contact with the beach especially sand mining, fishing and tourism to some extent had led to less accretion levels. This partly explains why some resort centres experience intense erosion event. Examples could be sited at the Anomabo Beach Resort, Brenu Akyinu, Oasis near Cape Coast castle, and Kokobongo Beach Resort in Saltpond. Some resorts centres established on rocky promontories of the coastline have minimal access to the beach and these locations showed minimal erosion activities. Examples were the Elmina and Biriwa Beach Resorts.

Zones A and B seemed relatively stable throughout the period of observation although these zones displayed some amount of shoreline retreat which had taken place some decades back. During the period of observation, quite a large amount of sediment moved on and off underlying rock platforms in some locations in these zones, especially at Komenda (Gold Hill), Amoakofua, Moree, Agyaa , Abandze and Biriwa. In several instances, following high tides, sediments were completely stripped off from the beach leaving an extensive platform exposed. The relatively strong current did not make way for progressive deposition and accretion. It is expected that these zones will show massive shoreline retreat in some decades to come because the rocks were weathered, appeared brittle and quite fragile when touched, coupled with the increased wave energy resulting from rocky outcrops. Some amount of erosion activities were observed but these seemingly resistant rocks despite their appearance somehow reduced the rate of erosion compared to that in zone C.

Zone C was the most variable zone within the study area. Erosive event and accumulation of beach sand were recorded during high and low tides in May, June, July, August and December, January, February, March respectively between the years 2010 and 2011. This was undertaken following erosion and accumulation of beach sand at Saltpond Redevelopment Institute (SRI)-Saltpond. The recordings showed a net accumulation of 0.8 cm and net erosion of 3.8 cm. A deficit of 3 cm was recorded for the eight months period of observation. The accumulation of beach sand was eroded completely during the high tide bringing about a deficit in the sediment budget (leaving a recession of the cliff surface). During accumulation period, beach cusps were clearly seen showing their crescent shapes and their seaward slopes increased their heights. On the other hand these features were virtually absent during high tide when erosion was so intense. Sandy cliffs retreated significantly to the extent that a concrete structure and coconut tree collapsed in the presence of the researcher during observation. These structures, the researcher strongly believe, were several meters away from the sea and now have become so close to the shore to the extent of collapsing to the action of the sea.

Increasing sea levels will result in high deficit in the sediment budget in zone C. This will lead to flooding and further erosion which will bring about the collapses of many structures. The zone was noted for sand mining activities and this affected the erosion and accretion rate and processes. In fact, some part of the sandy cliff at Saltpond SRI has been removed and replaced with refuse or waste material. The re-accumulation of sediment on the beach was by longshore drift which brings eroded sediment from other locations that were either stable or had equally been disturbed

According to Davidson-Arnott (2010), the beach profile changes seasonally due to the change in wave energy experienced during different times of the year. The beach profile was higher during the dry season (low tide period) where there was little or no rainfall and run-offs. This led to gentle wave action during this season. Field measurements conducted on the beach in zone C attest to this fact. The lower energy waves deposited sediment on the beach berm and dune, adding to the beach profile. Conversely, the beach profile was lower in the rainy seasons due to the increased wave energy associated with storms. Higher energy waves eroded sediment from the beach and deposit it off shore (Davidson-Arnott, 2010).

By means of quantifying the gains and losses of sediment from the beach and nearshore regions, the study identified possible sources of the changes in beach sediment. The main sediment gains were from cliff erosion, coastal rivers, longshore transport, and cross-shore sediment transport from the continental shelf. The main sediment losses were due to offshore transport from the beach to the continental shelf. The views of the natives that the sea replenishes beach sand, and that sand mining could have no effect on the coastline was wrong. It was observed from the field and sand sampling analysis that longshore drift moved beach sand from undisturbed locations and deposited it on locations that have been greatly disturbed by sand mining and other erosion activities.

One human influence on the beach that was so disturbing and appalling was the use of the beach for refuse dump and as a place of convenience by people of all ages staying along the coastline. Apart from making the observation work quite difficult and uninteresting, it also reduced the aesthetic value of the beach environment.

Conclusions

The findings from the study indicated that erosion was ongoing in the area. Pebble roundness and flatness were indicative of the phenomenon. These indices were influenced by mineralogy and atmospheric conditions such as weathering in addition to the nature of rocks. The flatness and roundness values gave an idea about the distance travelled and the intensity of erosion. From the analysis, it was found out that roundness increased while flatness decreased eastwards.

The analysis showed that fine sand grains were concentrated in zone C and it was an indication of massive reworking of beach materials. Sand samples reduced in grain sizes from Komenda towards Amissano estuary. The two indices of wear and tear also showed increased wave energy eastwards which also implied increase in fetch distance and in erosion towards the eastern coast. This answers the concern raised on the relationship between fetch distance and erosion. Therefore erosion increases with increases in the fetch distance eastwards.

The reworking of the sediments into finer grains made their removal and transportation easier. The influence of particle size on erosion was manifested in the way some locations with finer grain sizes showed intense erosive activity such as the beaches at Anomabo and Abandze resorts. Thus the finer the particles the more easily they were transported by littoral drift. Therefore beaches with smaller particle size or fine granulometric texture that were washed by a relatively strong current will experience massive erosion activities. This explains and answers the concern raised on the relationship between particle size and erosion

The effect of erosion on lithology is dependent on a number of factors such as weathering, type of rock, vegetation cover and the nature of coastline (whether sheltered or not). It was realised that rocks at sheltered coast appeared “decayed” and weak due to chemical weathering through the release of humic acid from dead organisms. These rocks were easily eroded. On the other hand rocks on exposed coast appeared quite resistant due to the absence of humic acid to cause chemical decomposition of the rocks. Also the fissility of schist and its frequent fragmentation rendered it vulnerable to erosion. This is because the platy-like nature of schist makes it easy for transportation. However massive rocks that do not break easily were quite stable unless atmospheric conditions acted on them to make them less resistant to erosion. The mineralogical component and texture of clastic sediments brought out variations in the rate at which they responded to these atmospheric conditions and erosion. Thus areas with less resistant rocks will experience greater erosion activity. Therefore the response of lithology to erosion is dependent on the aforementioned factors. Lithology responded differently to erosion. This was confirmed by a field observation on lithology and erosion in the study area. Hence with increasing sea levels and erosion, the coastline will retreat at different rate at different locations assuming more inlets and promontories, changing the shape of the coastline in the study area and that of Ghana as a whole in some years to come.

Changes in sand levels at the majority of locations especially in zone C were in response to an ongoing cycle of gradual change. However, there were few locations where shoreline erosion and flooding issues needed to be addressed.

With annual increase in sea levels of 18 centimetres to 58 centimetres (IPCC, 2007) and a deficit of about 3 centimetres in the sediment budget of the study area, an estimated annual retreat of 4 centimetres to 8 centimetres of the coastline is expected and it will lie at about 10 metres to 15 metres inland, especially in Zone C, by the year 2100.

Estuaries provide habitats for a large number of organisms and support very high productivity. They provide habitats for many fish nurseries, depending upon their locations in the world, such as salmon and sea trout. Also, migratory bird populations, such as the black-tailed godwit, sea herons and cranes make essential use of estuaries (Bird, 1993; Warrick & Oerlemans, 1990; Tsyban et al., 1990). Erosion at estuary mouths will result in changes in estuary gradient and circulation which will also affect organisms living in it. Estuarine circulation regulates the salinity and PH levels of the estuary water which makes it suitable for organisms living in these water bodies. With increasing sea levels and erosion, the conditions of the estuaries are likely to change as a result of salt water intrusion, making life more uncomfortable for these organisms (Day et al., 1993). The Amissano estuary is a home to many migratory bird, insects and amphibians that depend mostly on other organisms in the estuary for survival and these unfavourable conditions will be disastrous for such organisms. SLR and erosion at the mouth of estuaries will also have implications on the water which was used for domestic purposes for the people living around. Therefore coastal communities will be forced to find alternative sources of freshwater

In humid equatorial climates, gradual sea level rise would cause a brackish-water zone to migrate inland. As sea level rises, the tidal saltwater zone penetrates further upstream. The zone then becomes unfit for tidal harvests such as swamp rice (Gornitz, 1991). Salinity has also been found to decrease seed germination in a variety of wetland species and higher salinities may decrease seed bank species (Balwin et al., 1996). Some small animals burrow into the sand and feed on material deposited by the waves. Crabs, insects and shorebirds feed on these beach dwellers. The endangered piping plover and some species rely on beaches for nesting. Sea turtles also lay their eggs on ocean beaches. Sea grasses and other beach plants grow on undisturbed areas of the beach and dunes. Therefore the inundation of the coastline will destroy these ecosystems.

There has been an increase in the adoption of private shoreline measures at most locations due to the advancement of shoreline erosion. However the problem seems to overshadow whatever measures taken to curb it. This is because the structures employed were not designed to meet coastal engineering standards and failure may occur during future storm events.

Recommendations

The issue of sea erosion along the Ghanaian coastline needs further assessment, with the possibility of extending the survey programme and defence projects to cover new areas of active cliff erosion in the Central Region and for that matter the study area.

The construction and use of concrete structures, groynes and revetments must be reconsidered to meet the engineering needs of the beaches. The EPA in conjunction with the local beach authorities must ensure continued monitoring of the structures to determine the effect these structures have on sand movements.

Shoreline erosion at the study area and the entire central coastline also needs to be considered for possible future protection measures while these beaches should be controlled by well-defined authorities in order to avoid further abuse through human activities.

The local authorities and the EPA must see to it that the buffer zone between the sea and human settlement is maintained as the zone was being used for construction purposes. If possible certain human activities must be prohibited on the beach or coastline.

Natives living along the coast should be educated through the media, chiefs, M/DCEs, churches, schools, clubs and societies on the consequences of human activities on the beach, especially sand mining, in order to reduce the anthropogenic influence on sea erosion. To this, the writer used the classroom as a medium to educate students on the importance of the beach and the adverse effect of sand mining in order to desist from such practices.

Since the study centred on the lithological responses to sea erosion, much emphasis was not placed on the effect sea erosion has on coastal resources. Therefore further research must be conducted on the effects of sea erosion on coastal resources and the impact of tourism on the coastline.

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APPENDIX

Plate 1: A pictures of eroding cliff face with buildings built close by at Brenu Akyinu. There were stone revetment buried some metres deep on the beach at the resort centre. These revetment were used to check erosion but has been buried as erosion and deposition intensifies (Field Observation, 2008-2011). Some natives had to abandon their homes as the sea advances and this puts economic hardship on the natives.

Plate 2: A picture of eroding soft cliff at Anomabo Beach Resort (Field Observation, 2008-2011). Some facilities such as summer huts and other structures are washed away as erosion continues on the beach.

Plate 3: Outcrops of Takoradi sandstone which is friable, massive and embedded with shaly sandstone at the beach at Komenda. The rocks show concentric ferruginous bandings on the limonitised surface (Field Observation, 2008-2010).

Plate 4: A natural cave entrance at Gold Hill, Komenda. This leads to a gloup which is overgrown with weeds about 10m from the cave entrance (Field Observation, 2008-2010).

Plate 5: A natural cave at the beach at Gold Hill, Komenda (Field Observation, 2008-2011).

Plate 6: Circular holes, polygonal patterns and long channels on the feldspathic sandstone outcrops at Komenda, Elmina and Iture. These structures were also found in the granitic outcrops at Anomabo (Field Observation, 2008-2011).

Plate 7: Outcrops of granites, pegmatites and metamorphosed schists between Cape Coast and Akong (Amoanakofoa). There were also rounded and semi-rounded pebble and this could have resulted from the collapse of the roofs of caves and the fragments subject to some amount of erosion (Field Observation, 2008-2011).

Plate 8: Course grained pegmatite and quartz on the beach at Anomabo near the Anomabo Resort. (Field Observation, 2008-2011).

Plate 9: Eroding sandy beach found in zone C between Saltpond and Kormantse. Retreating sandy cliffs are common in this area with excavated coconut roots. This could easily be observed in the picture above (Field Observation, 2008-2011)

Plate 10: shows efforts being made by natives to prevent further erosion. However these efforts have been proved futile since the structures are being eroded and buried on the beach (Field Observation, 2008-2011).

Plate 11: Residues of laterite cappings which were formed under sub-aerial conditions. These residual are regarded as erosion surfaces (*coastal* surfaces) believed to be the coastal extensions of the *Akumadan* surface (Dei, 1972; Field Observation, 2008-2011).

Plate12: The Amissano estuary (Field Observation, 2008-2010).

Plate 13: showing the Etsii lagoon at Abandze. The accumulated sand at the outlet of the lagoon has been removed at the time the image was taken and it was being rebuilt by the sea with beach sand. Observe how the other side of the outlet close to the resort centre was left high above the ground unexcavated (Field Observation, 2008-2010).

Plate 14: A Picture of mangrove vegetation in the study area. Note how the strength of the wind has casted the vegetation into a west- east (west-north east) direction. The west-east direction of the wind and the increased fetch distance eastwards have all contributed to the increased erosive activity eastwards, hence a reduction in sand grains and pebbles eastwards. (Field Observation, 2008-2011).

Plate 15: Fishing is one of the major activities in the study area

Plate 17: A picture of a sandy beach in the study area.

Plate 18: Kormantse beach. A combination of public carelessness and official negligence has turned this beach at Kormantse into an open rubbish dump, posing a risk to public health.

Plate 19: Picture of Amissano estuary which is a home to several migratory birds

Plate 20: A retreating sandy cliff at SRI beach at Saltpond in zone C

Plate 21: An uprooted coconut tree by the advancing sea on the beach near Kormantse. The natives tie fallen coconut trees to standing ones backbeach to prevent it from being carried away by the sea during high tides

Plate 22: Three weeks after observation, the above coconut tree was buried deep in the beach sand following accumulation during low tide.

Plate 23: A retreating refuse cliff in zone C.