UNIVERSITY OF CAPE COAST

BEACH EROSION: A STUDY OF CROSS-SHORE PARTICLE SIZE CHARACTERISTICS AND PROFILE EVOLUTION ALONG THE GHANAIAN COASTLINE

BY

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DECLARATION

Candidate's Declaration

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

Candidate's Signature.............................. Date 18-04-2019

Name: Mabel Anim

Supervisors' Declaration

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

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ABSTRACT

The coastline characterized by the geologic nature of the land and the dynamic power of the sea, is constantly changing as a result of many factors both natural and manmade. The phenomenon is highly influenced by winds waves, currents, and tides that transport beach sediments up and down the profile. However, source material characteristics tend to complicate this mechanism in profile evolution.

Beach profiling and particle size analysis coupled with wind wave analysis were used to analyse beach morphology of five beaches along the Ghanaian coastline within two seasons, (dry and wet seasons) to establish the seasonal variations in beach state and profile evolution that impact on erosion in general along coastal erosion structures.

Findings showed all beaches were moderately sorted with sorting values ranging from 1.70 to 1.85 in both seasons. It was also found out that the dominant grain size along all study sites were the 250 μm in dry season and 500 μm in wet season. The beaches were made up of fine to medium grains. Percolation was minimal due to the dominant grain size and led to increased wave runoff which caused erosion of the beach face. Beaches showed seasonal variability in volume and width. The beaches experienced stormy conditions in the wet season and as a result, erosion was strong during the wet season.

KEY WORDS

Beach profile

Beach morphology

Beach width

Beach volume

Oceanographic forcing

Textural characteristics

Coastal erosion structures

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DEDICATION

To my parents, Mr Theophilus Anim and Mrs Comfort Anim, who passed away in the course of my study and to my son, Ato Entsie,

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ABV	Average Beach Volume
ABW	Average Beach Width
BW	Beach Width
BV	Beach Volume
CES	Coastal Erosion Structures
GSL	Global Sea Level
Hs	Significant Wave Height
HWM	High Water Mark
LWM	Low Water Mark
MSL	Mean Sea Level
Tp	Wave Period
TBV	Total Beach Volume
TBW	Total Beach Width
TSS	Total Suspended Sediment
Wd	Wave Direction

CHAPTER ONE

INTRODUCTION

Background to the Study

The coastline, characterized by the geologic nature of the land and the dynamic power of the sea, is constantly changing as a result of many factors both natural and manmade. One of the most important and valuable assets found along the coast is the beach. Unfortunately, most of the beaches are shrinking due to erosion (Masselink & short, 1993; Senechal et al., 2015). Public awareness on the physics behind coastal erosion is limited and there is a general perception that erosion is always inescapable.

Coastal erosion is a natural process under normal circumstances. The phenomenon is perceived as a problem when there is no room to accommodate the change that comes with it mostly as a result of coastal development (Lenôtre, Thierry, Batkowski & Vermeersch, 2004). Consequently, coastal nations worldwide are embattling coastal erosion in all dimensions. Thus, coastal beach erosion is an emerging concern in all continents.

Reports indicated that the African continent is being reduced by erosion activity. Average rates of coastal retreat along the northwest coast of Africa are between 1 m and 2 m a year (United Nations Environment Programme (UNEP), (2007). Most lowland coastal areas in Northern Africa, especially deltas and islands, are subjected to coastal erosion due to the effects of the rise in sea level predicted as a result of climate change. In addition to inundation of land, sea level rise would also increase coastal erosion, flooding and saltwater intrusion into underground aquifers, altering the quality of underground water supply. The coastal zone is likely to suffer increased impacts from wave action and storm surges due to sea level rise (El Raey et al, 1995, cited in Intergovernmental Panel on Climate Change (IPCC), (1998).

Erosion is a phenomenon caused by winds, waves, currents, and tides that transport beach sediments. Although natural processes contribute to erosion, the rate may be accelerated by human impact or installation of coastal erosion structures (CES) that change the magnitude and direction of sediment transport (Appeaning-Addo, Walkden & Mills, 2008). Similarly, inundation may increase if land subsides due to natural compaction of sediments, sea level rise resulting from climate change or due to withdrawal of subsurface resources, such as groundwater and petroleum (Tralli, Blom, Zlotnicki, Donnellan, & Evans, 2005). Other human activities that increase erosion include dredge and fill operations, wetland drainage, boat traffic, and channel dredging.

Globally, coastal regions are areas that suffer natural hazards of coastal flooding and erosion. Substantial portions are partially or fully protected from the high-energy regimes associated with open coastlines, such as ocean-facing beaches. The continual changing of coastlines from natural processes, have called for certain common human response to erosion such as the stabilization of the beach, or shoreline. This approach usually results in long-lasting consequences for the natural system, not just locally but also affecting surrounding areas (Pilkey & Wright, 1988). There are however many effective alternatives to beach stabilisation and depending on the selections made and the local conditions, the long-term consequences to the area can be positive or negative (Board & National Research Council, 1990).

The pressure to develop and stabilize shorelines in coastal areas is increasing; more people desire waterfront homes, rising coastal property values and creating strong incentives to protect high-priced coastal real estate. This has contributed to several mitigation measures to stabilize shorelines, including structural hardening and alternatives, such as constructed marsh fringes, that are designed to preserve a more natural shoreline (Pethick, 2001). The selection of the type of response to prevent or offset land loss depends on understanding local causes of erosion or inundation (Pilkey & Wright, 1988). The most common response to erosion has been a "hold the line" strategy that relies on technologies that harden the shoreline. A shift away from this approach has been slow in part because there is a greater familiarity with these methods than with alternative approaches such as constructing a marsh fringe or using vegetation to stabilize a bluff.

Contractors are more likely to recommend structures such as bulkheads because they have experience with the technology and know the design specifications and expected performance. Landowners expect that a hard, barrier-type structure will be required to prevent loss of property and protect buildings. In many regions, the regulatory system may unintentionally encourage shoreline armouring because it is simpler and faster to obtain the required permit(s) (Pilkey & Wright, 1988).

Some human activities upstream have further increased the problem. For instance, the construction of the Akosombo Dam in Ghana and the Kainji Dam in Nigeria has lowered the sediment loads in their rivers that reach the coast by up to 40% making less sediment available to replace that eroded in the coastal zone (Ly, 1980). As a result, there has been an acceleration of coastal erosion in the eastern shores of Ghana and Nigeria (Wellens-Mensah 1994). In Togo and Benin, coastline retreat has exceeded 150 m over the past 20 years and is threatening the prospect of future development in the coastal zone despite the introduction of structural methods (UNEP, 2007). However, more serious rates of up to hundreds of metres per year have been observed locally in these countries (Wellens-Mensah 1994).

The changing global climate scenarios for the sub-region predict increases in frequency and intensity of tidal waves and storm surges which will worsen erosion problems by moving greater amounts of coastal sediments (Allersman & Tilsmans 1993). Predictions of a metre rise in sea level would result in land loss of about 18,000 km^2 along the Western African coast (Awosika, Chidi Ibe & Schroeder, 1993). Most coastal cities would be inundated, with damage to infrastructure, and displacement of inhabitants (Awosika, et al, 1993; Jallow, Barrow & Leatherman, 1996). The inundation would create problems of relocation and resettlement (Dennis, Niang-Diop & Nicholls, 1995).

According to estimates about 1.5 to 2 m of the 550 km Ghanaian coastline is eroded annually despite the attempts in coastal reclamation projects undertaken by the government (Environmental Protection Agency (EPA) & World Bank, 1996; Oteng-Ababio & Owusu, Appeaning- Addo, 2011). Severe erosion sites are recorded at the Keta and Ada areas along the Volta estuary. (Anim, Nkrumah & David, 2013). The erosion situation at the eastern shores (annual rate of 4 m was estimated at Ada Foah) compelled the government to embark on the Sea Defence Project which sought to construct a sea defence wall to protect coastal infrastructure and ecosystems from the effects of erosion (Oteng-Ababio et al, 2011). However, other areas along the central and western shores affected by coastal erosion also needs urgent attention. For instance, it was projected that about 82% of Accra's beach is eroding at a rate of 1.13 m/yr. (Appeaning-Addo et al., 2008). Severe cases have been recorded at Cape Coast, Axim, Nkontompo and Elmina (Jonah, Mensah, Edziyie, Agbo, & Adjei-Boateng, 2016). These areas are characterised with coastal tourism and popular beach resorts (Appeaning-Addo et al, 2008; Oteng-Ababio, et al, 2011; Anim et al, 2013). At some locations, concrete structures which happened to be on land were found some meters offshore and roads have been undercut indicating high rates of erosion. Coconut trees which characterized most beaches in Ghana are disappearing (Anim & Nyarko, 2017).

The sea is advancing towards the land with subsequent dire effects on the tourism sector of the country. It is also recorded that many facilities such as hotels and restaurants for tourism and recreation along the coast have to be evacuated or abandoned due to the danger posed by erosion (Oteng-Ababio et al, 2011). Beach recreational activities especially during festive seasons have also been affected leading to low patronage as a result of unattractive narrowing beaches characterised by defence structures. It was reported by Anim et al, (2013) that the effects of coastal erosion discouraged many investors from investing in recreational activities along the coast. In view of this the Ministry of Water Resources, Works and Housing has undertaken quite a number of prioritized coastal erosion projects as part of the National Sea Defence Projects. Among them are the New Takoradi Sea Defence Project, Amanful Kumah, Axim, Cape Coast, Dixcove, Komenda and

Nkontompo Coastal Protection Works in addition to the already existing defence at Keta and Ada (Bagbin 2013). Currently, coastal town such as Teshie, Nungua, Winneba, Bortianor and others along the central and western shores are all suffering from the impacts of sea erosion and there is the need for adaptation and a comprehensive mitigation measures that take into consideration the local mechanisms and causes of erosion to protect the land (Pilkey & Wright, 1988).

Erosion and inundation both result in the landward movement of the shoreline contour. These processes occur over a full range of time scales, including short-term events (waves, tides and storms) and chronic, long-term sea-level rise. Implicit in the definition of erosion is a choice of time scale, with longer events considered erosion and shorter events variance (Dadson et al., 2003). Therefore, according to Zhang, Douglas and Leatherman (2000) a landward shoreline movement that recovers prior to the next storm would not usually be considered erosion, despite the potential loss of property associated with that variation. Since the shoreline is commonly based on movement of a single contour, it is precariously sensitive to details of the dynamics that determine how shore profiles adjust to natural forcing. This can introduce legal and operational difficulties. For instance, in the 1990s, The Netherlands determined a course of action to combat the ongoing threat of erosion of its shores, making it a legal requirement to mitigate erosion beyond the shoreline location defined in a national survey of 1990. Recognizing the sensitivity problems associated with a single contour definition, they instead defined a "momentary coastline" (MCL) based on the mean shoreline location integrated between –5 m and +3 m (approx. –16 ft and +10 ft) from NAP

(Normaal Amsterdams Peil, or Amsterdam Ordnance Datum, which is the Dutch reference for sea level). By basing the mitigation criterion on a shore zone definition, the law became appropriately robust to short-term fluctuations (Waalewijn, 1987).

Inundation refers to the super elevation of sea level above a fixed topography. Short-term inundation (for example due to storm surge or heavy rains) is referred to as flooding, whereas longer-term (from a human perspective) coastal inundation results from sea-level rise. Coastal erosion is often defined in terms of the movement of shore contours and can be caused either by sea-level rise or by removal of geologic materials that make up the shoreline (Board & National Research Council, 1990). Because rising sea levels exposes portions of the shoreline to actions of waves and current, sea-level rise can exacerbate erosion. The principal tool for understanding erosion is the law of conservation of sediment mass, which requires textural characteristics of the sediment (grain size, sorting, shape, roundness) and transport capacity to estimate fluxes of sediment within the nearshore region (Gao & Collins, 1992; Einsele, 2013).

The modification of the coast takes place through erosion, transportation and deposition of materials that are either eroded by waves and currents or brought to the coast by sub-aerial processes such as rivers and run-offs from rainfall (Davidson-Arnott, 2010). Finer sediments occur in small amounts in the inner nearshore and surf zones on energetic coasts. They are kept in suspension and spread uniformly through the water column. They are removed offshore, onshore or alongshore where they settle out of suspension in deep water, in outer shoreface or further offshore (Fredsoe & Deigaard, 1992). Coarser particles are exchanged between the inner nearshore and surf zone and the beach and may sometimes be transported alongshore due to their lack of cohesion (Aagaard & Greenwood, 1995). Larger particles like cobbles and boulders are also cohesionless and requires very large waves in their transport.

Grain size parameters of surficial sediments vary according to sampling location (Gao & Collins, 1992). Such spatial changes in grain size trends result from processes that are present in transportation. This include selective transportation, abrasion and mixing of sediments from other sources (Russell, 1939; Coco, Murray, Green, Thieler & Hume, 2007). This is the more reason why most researchers have linked grain size trends to net sediment transport patterns because, they believe there is a distinct pattern of grain size trends. For example, Pettijohn, Potter, and Siever (1972) observed mean grain size finer along transport paths while Nordstrom (1989) observed a coarser trend.

Cross-shore sediment transport has received considerable attention. A greater number of field experiment and theoretical works have been carried out to describe and evaluate the morphological changes occurring in a beach profile. Recent models concern the definition of the mean flow involved in the cross-shore sediment transport (Medina, Losada, Losada, & Vidal, 1994). This includes waves and wide range of secondary processes at wind-wave frequencies and low frequencies outside the wind-wave band. This has been shown to be very important on cross-shore sediment fluxes (Wright, Boon, Kim, & List, 1991).

The distribution of grain size under breaking waves and across the surf zone is fundamental for understanding sediment transport processes and beach morphology changes. Knowledge on the cross-shore and vertical distribution of grain size is crucial in engineering applications in determining the compatibility of beach nourishment material and design of coastal structures to hold sand. Although there have been earlier investigators on the concentration of suspended sediment in the nearshore zone such as Nielsen (1984), Zampol and Inman (1989), Greenwood, Osborne, Bowen, Hazen, & Hay, (1991), Crawford and Hay (1993), only few addressed the vertical grain size distribution of sediment across the shore.

Despite the efforts undertaken to adequately model the hydrodynamics of the cross-shore sediment transport formulations, relatively little attention has been focused on the modelling of cross-shore sediment size variation and most of the formulations assume that the grain size distribution or the grain related parameters are uniform in the cross-shore direction (Medina et al, 1994).

Statement of the Problem

A hydrographic survey along the coast of Ghana revealed quite a number of submarine canyons alone the Ghanaian coastline and these serve as boundary limits of offshore sand movements (Public Work Division, 1960; Davidson-Arnott, 2010). Thus, the canyons served as sinks in littoral cell for sediment movement both onshore and offshore, hence the deficit in sediment budget leading to the intense erosion along the Ghanaian coastline. Field observation conducted by the researcher also showed wave pattern caused a heavy swash round the projecting flying ends of sea walls. Seasonal tides surge carried sand over the top of the seawalls by waves and deposited there with water draining round the end of the seawalls. This dynamic action enabled the denuded area of the eroded frontage behind the wall to recover completely through accretion at certain times of the year. As a result, build-up of beaches was observed in front of Coastal Erosion Structures (CES) found in the eastern and central portions of the coastline except the western section. One characteristic behaviour of the build-up beach in front of these CES was the continual seasonal changes in beach width and volume and the changing beach profiles.

As indicated by Goa and Collins (1994) and Einsele (2013) that the principal tool for understanding erosion is the law of conservation of sediment mass, which requires examination of source material characteristics (grain size, sorting, shape, roundness etc) and transport capacity to estimate fluxes of sediment within the nearshore region and on the beach, there is the need to study the spatial and temporal cross-shore sediment characteristics and behaviour in profile evolution. Gao and Collins (1994) also put forward variations in grain size parameters at different locations due to the differences in transport mechanisms at these locations. These are vital considerations in management and mitigation of beach erosion. The study sought to investigate the textural characteristics of cross-shore sediment that influenced beach erosion and profile evolution of beaches with CES along the coastline within the two major seasons in Ghana.

Objectives of the Study

The purpose of the study was to investigate the cross-shore sediment characteristics that influence beach profile evolution along coastlines with CES. Specifically, the study sought to:

1. Explain the potential causes of temporal variations in beach morphology
2. Establish the dominant grain size along the Ghanaian coastline
3. Investigate the extent to which grain size influence profile evolution along CES.
4. Highlight the relationship between grain size and sorting in profile evolution
5. Analyse the oceanographic forcing on beach profile evolution.

Research Questions

Erosion continues despite the introduction of coastal erosion structures (CES). This raises puzzling concerns such as:

1. What are the temporal variations in beach morphology along CES?
2. How does grain size affect beach erosion?
3. What are the seasonal variations in beach volume in relation to beach erosion along CES?
4. What is the dominant grain size along the Ghanaian coastline influencing beach slope?
5. What is the influence of hydraulic forcing on profile evolution?

The study sought to find answers to the questions raised above.

Significance of the Study

There is dearth of knowledge on the impact of policy conservation practices along the coast of Ghana. The study is anticipated to seal this gap by creating awareness and making its findings available to stakeholders. There seem to be no or limited studies on the assessment of textural characteristics of beach sediment in Ghana and their influence on profile evolution and beach erosion along CES. Since the principal tool for understanding erosion is the law of conservation of sediment mass, which requires examination of sediment characteristics and transport capacity to estimate fluxes of sediment within the nearshore region and on the beach face, this study will provide a comprehensive review of the cross-shore textural characteristics of sediment in relation to beach morphological evolution that will serve as reference in construction of coastal engineering structures.

The study is expected to provide an insight into coastal erosion and related issues and how best this problem can be managed. It is also anticipated to provide information to environmentalists, coastal communities, policy makers in the formulation and implementation of. It will also serve an important reference material for the uses and management of the coast. The study may also offer an opportunity to provide an in-depth analysis of coastal erosion processes and scenarios in the two major seasons in Ghana. It is such analytical conception that motivated the researcher to undertake such a study.

Finally, the study is significant because it is one of the few pioneering works on the textural characteristics of cross-shore beach sediment in Ghana. There have been comparatively numerous studies on mitigation strategies elsewhere and this study will contribute to scholarly research and literature in the field of applied geomorphology in Ghana.

Delimitation of the Study

Beach profile analysis and sedimentological study are both complex involving a wide range of assessment of different variables. Due to the time and financial constraint the study was narrowed down to the significant factors in the short term (seasonal). These were beach sediment, beach profile and influence of hydrodynamics (waves). The focus on textural characteristics of beach sediments were mainly on grain size (median diameter), sorting and skewness. The influence of rain runoffs was held constant while wave run-offs (swash and backwash) were used to ascertain the impact of percolation on slope, profile evolution and erosion. It was also assumed that the effect of wind is manifested in the wind generated wave along the coastline.

The study was descriptive in nature and focused on five beaches out of about fifteen beaches with national erosion mitigation measures identified along the Ghanaian coastline. Since the study focuses on cross-shore sediment characteristics of beach with CES, beach sampling was delimited to beaches with coastal erosion structure (CES) with accumulation of beach material.

The primary data gathering methods used were purposive and convenience sampling of beach sediments and profiling in which an equal representation for profile length and sediment sampling was applied. Much importance was placed on conveniency due to safety in sampling and profiling.

Limitations of the Study

Although beach profile analysis can be done using short to medium term data, best results are achieved when data involves some relatively longer years (spanning 5 years to over decades). This allows long term trends in beach behaviour, to be determined and applied on different spatial and temporal scales. The study was constrained by time since it was time bound compelling data to be collected within the two seasons. There were no existing profile and wave data for the specific study sites and wave data was generalised and applied to the specific beaches. This limited the study in making strong specific inferences to the beach behavioural changes, although an attempt was made.

Organisation of the Study

The thesis was organised into Chapters with each chapter beginning with an introduction. Chapter One captured the introduction, statement of the problem, research questions and also spelling out objectives of the research and its significance. Chapter Two described the study area. Chapter Three reviewed the recent developments in coastal erosion scenarios, beach sediment and grain size, beach profile and oceanographic forcing of wind waves and other related issues. Chapter Four discussed the materials and methods used to collect data, data description and the conceptual framework underpinning the research. Chapter Five presented results relating to beach profiling. Chapter Six discussed the textural characteristics of beach sediment and hydrodynamic forcing of waves. Chapter Seven presented the major summary, conclusions and recommendations.

Summary of the Chapter

This chapter discussed the coastline as a dynamic feature changing through a complex mechanism that operate alone the zone. It also portrayed coastal beach erosion as a natural phenomenon and how it is perceived as a problem because coastal dwellers are not able to accommodate the change that comes with it. It also highlighted how Ghana as a nation has dealt with the problem of coastal beach erosion and yet the problem still remains, transferring it to other areas within the coastal cell. The chapter also threw light on the need for to reconsider the definition for shoreline commonly based on movement of a single contour since it is precariously sensitive to details of the dynamics that determine how shore profiles adjust to natural forcing.

The problem was to investigate the cross-shore textural characteristics that influence beach erosion and profile evolution within the two seasons. This brought out the need to study sediment dynamics along these mitigated beaches to understand the fluxes that impact on profile evolution in the dry and wet seasons.

CHAPTER TWO

THE STUDY AREA

Introduction

The preceding chapter outlined the background issues that led to the identification and the decision to investigate the problem. This chapter describes and discusses the location of the study site and its characteristics such as the geology, climate and vegetation, population and land-use patterns. Currents and tidal patterns and both historical and current trends in coastal erosion are also dealt with. The rationale for the spatio-temporal examination of the biophysical characteristics of the area is to establish a basis for analysing the past and present rate of beach erosion and how the phenomena can affect these characteristics. Furthermore, relating each of these characteristics to the central theme of the research provides a basis for predicting profile evolution and erosion scenarios in the future.

Location

Ghana lies along the Gulf of Guinea in West Africa. The latitudinal extent of Ghana is between 4.5 ° N and 11.2° N of the Equator and longitudes 3° 5' W and 1° 10' E (Digital Topographic Sheet (DTS), (1996). It shares borders with Cote d'Ivoire in the West, Burkina Faso in the North and Togo in the East. It covers an area of about 239,000 km^2 and a coastline of about 550 km (Figures 1 and 2 on pages 31 and 32) (DTS, 1996; Anim et al, 2013). The study area comprises almost the entire coastline of Ghana, specifically the coastline between Axim and Keta, a distance of about 466 km, approximately 470 km. This is located between latitude 4°51' 59.43" N and longitude 1°4' W and latitude 5° 59' 00.00' N and longitude 1°01'00.00. The area comprises the coastlines of four regions namely Western, Central, Greater Accra and Volta and forms part of the coastal zone.

The coastline under consideration is made up of both open and sheltered beaches. As a result, there are variations in typical physical conditions associated with the coastline. Sheltered coasts associated with relatively low velocity tidal currents and mid-to-low energy wave climates with a limited fetch (Wellens-Mensah, Armah, Amlalo, Tetteh, 2002). These conditions promote the formation of ecological complexes (i.e., mangroves, marshes, and mudflats) that often characterize habitats on sheltered coasts and are generally not found along open coasts. Many of these sheltered areas are major river mouths entering the sea, or drainage features that are protected by headlands or islands. The open coast sections are characterised by relatively high wave energy mostly resulting in high velocity tidal currents occasionally leading to storm surges.

Lithology

The Ghanaian coastline generally comprises a series of sandy beaches and rock outcrops. About 258 kilometres is entirely sandy, forming about 47%. The rest are rocky beaches with intervening sandy beaches in bays (292 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; Anim & Nyarko, 2017). This is particularly true in areas of sandy beaches such as Axim, Saltpond and Keta and beyond where sandy cliffs have retreated significantly (Anim & Nyarko, 2017). Such areas show intensive erosion processes even without human activities. This implies that erosion could intensify on sandy coasts and in areas with human influence and where massive weathering processes operate. Considering the geologic time involved for a change to be significant, it could be said that there has not been much significant change (erosion, submergence or emergence) along the rocky sections of the coastline since the existing "Stillstands" i.e. about 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 plain is underlain by ancient rocks of the Precambrian and the Palaeozoic eras. These include the Dahomean (schist and lavas) and the Togo-Akwapim quartzites (Ghana Grological Survey (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 between Takoradi and Cape Coast and around Accra. Such sandstones are known locally as Sekondean in Cape Coast and Takoradi. The Sekondean 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, Apam and Cape Coast (Dei, 1975, Hughes and Farrant, 1963). Based on the characteristic features of the Ghanaian coast as described by Ly (1980), Armah (2005) and in addition to field survey carried out in December, 2015 by the researcher are described as follows;

- West of Cape Three Points: a flat and wide beach, backed by coastal lagoons, marks this coast. Wave height is generally low (about 1m)
- Between Cape Three Points and Tema: this section is of an embayed coast of rocky headlands and sandbars or spits enclosing coastal lagoons. The surf zone is a medium to high-energy environment with wave heights often exceeding 1 m. The south-westerly prevailing winds cause oblique wave approach to the shoreline, which generates an eastward littoral sediment transport.
- East of Tema: the shoreline is sandy and is characterized by coastal lagoons and the Volta estuary. Wave and sediment dynamics are similar to those between Cape Three Points and Tema.

Rocky portions of the coastline are found between Cape Three Points and Prampram (Armah, 2005). There are rocky promontories at Pepre Point, Prince's Town Dixcove, Takoradi, Sekondi, Komenda, Elmina, Akong, Abandze Cape Coast, Senya Breku, Accra and Prampram. Erosion of the beach material has occurred at places exposing the rocky substratum (Dei, 1972; Field observation, 2015-2017). Areas where the rocks are not resistant enough experience considerable erosion (Anim & Nyarko, 2017).

The sandy portion of the coastline is found at the western shores between Alubo and Axim and also between Prampram and Aflao which is about 244 km (Armah, 2005). Three terraces of about 4.5 m to 12 m, including the most recent in Ghana, are clearly seen along the sandy coastlines at most locations with variation in grain sizes in each terrace. (Dei, 1972; 1975). The surfaces of the particles show a reworking of beach sediment by wave action from ferruginised to polished grain surfaces. The old beach is separated from the two terraces by a well-defined cliff of about 10°-15° (Dei, 1972; 1975; Anim & Nyarko, 2017). The sandy shores which are the dominant coast type and constitute more than 60% of the coast line, are important for beach tourism. The sandy shores from Pampram near Accra to Keta in the east are important nesting grounds for marine turtles.

The central portion of the coastline of Ghana is characterized by medium to high-energy intertidal rocky platforms. At the western and eastern sections of the coastline, the nearshore sediment could be described as being sandy and the offshore as muddy. At Takoradi, information from local fishermen suggests that the near shore is rocky. Rocky shores occur as rocky out-crops alternating with sandy bays.

Lagoons and Estuaries

Most rivers in the country enter the sea forming lagoons and estuaries. The largest river in terms of catchment area and volume is the Volta. More than 90 coastal lagoons fringed by intertidal mud or sandflats and in some places by mangrove swamps along the coastline (Ababio, 2001; EPA, 2004). The lagoons form important vulnerable ecosystems, housing a wide variety of fish, shrimps, crabs, and mollusc and polychaete species. Some of the lagoons and estuaries have been recognized both nationally and internationally as Ramsar sites for migratory water birds whiles some may serve as nursery areas for juveniles of marine fish and shrimp (Ntiamoa-Baidu & Grieves 1987; Ntiamoa-Baidu 1991).

There are two main types of coastal lagoons in Ghana. These are "open" and "closed" lagoons (Armah, 1991). The open lagoons have a permanent opening to the sea and are normally fed by rivers that flow all year round. They occur mostly on the central and western parts of the coastline where higher rainfall results in a more continuous flow of the rivers and streams. The closed lagoons are detached from the sea by a sand barrier. Some closed lagoons open to the sea in the rainy season when floodwaters break the sand barrier (Kwei, 1977). Storm surges may also erode sandbars and open up closed lagoons to the sea (Armah, 1991). Under some circumstances the sandbar may be manually breached during the rainy season to reduce the risk of flooding adjacent settlement where this is considered a threat.

Winds, Waves, Currents and Tidal patterns

The principal current along the Ghana coastline is the Guinea Current, which is an offshoot of the Equatorial Counter Current (ECC). The ECC is driven by westward wind stress. When this subsides during February to April and October to November, the direction of the ECC is reversed. The Guinea Current reaches a maximum strength between May and July during the strongest South-West Monsoon Winds when it peaks at 1 to 2 knots (Wellens-Mensah et al 2002; Xorse, 2013). For the rest and greater part of the year, the current is weaker. Near the coast, the strength of the current is reduced by locally generated currents and winds. The current is less persistent near-shore than farther offshore. Geostrophic effects induce the tendency of the Guinea Current to drift away from the coast especially during its maximum strength.

Winds are mainly south-western. On the average, wind speed range between 3.7 - 4.0 m/s with maximum wind speeds ranging between 8.8 - 10.8

m/s. There is also little wind speeds and directions differences over the course of the year (EPA, 2009). Surface atmospheric circulation is largely influenced by north-east and south-west trade winds and the position of the ITCZ. Onshore wind along the coast is almost consistently from the south-westerly such that the average wind direction from 2002 – 2011 at Axim was measured as from the southwest except for January and February 2006 (Mensah, Amekudzi, Klutse, Aryee, & Asare, 2016). The wind direction in the study area is predominantly southwest. During the day, the wind circulation is generally from southwest while at night it is usually from northwest due to a land breeze which occurs at night. However, inter-annual variability in direction occurs for some months. There was no wind data from the Ghana Meteorological Agency's station at Half Assini thus data from Axim was used. The average monthly wind speed for Axim ranges between 2.4 and 3.2 knots for the past ten years. Over the past ten years, averagely wind speeds tend to be low from November to January and increases in speed from February to October with a slight decrease in May. Winds speeds normally range between 4.3 – 10.8 knots. Daily wind speeds are lowest during the night and early morning and highest in mid-afternoon. Extreme high winds are caused by squalls (storms), associated with the leading edge of multi-cell thunderstorms (Bawole, 2013). The circular ocean currents called gyral drive the oceanographic processes in the region (Merle & Arnault, 1985).

The coastal surface currents are predominantly wind-driven and are confined to a layer of 10 to 40 m thickness. The wave induced longshore currents are generally in the west to east direction which is an indication of the direction the waves impinge the shoreline. The longshore currents average approximately 1 m/s and vary between 0.5 and 1.5 m/s. The magnitude increases during rough sea conditions (EPA, 2009). Waves reaching the shores of Ghana consist of swells originating from the oceanic area around the Antarctica Continent and seas generated by locally occurring winds (EPA, 2009). The significant height of the waves generally lies between 0.9 m and 1.4 m and rarely attains 2.5 m or more. The significant wave height for 50 per cent of the time is about 1.4 m, the period is between 10 to 15 seconds and spring high tide is about 1.26 m. The most common amplitude of waves in the region is 1.0 m but annual significant swells could reach 3.3 m in some instances (Appeaning-Addo et al., 2008). Swells attaining heights of approximately five to six meters occur infrequently with a 10 to 20 years' periodicity. The peak wave period for the swells generally falls in the range of 7 to 14. The swell wave direction is almost always from the south or south-west (EPA, 2009).

The coastal surface currents are predominantly wind-driven and confined to a layer approximately 10 - 40 m in diameter. Littoral drift which is the main driving force behind local coastal circulation, is predominantly generated by breaking waves. These littoral drifts generally flow in an eastward direction, with flow rates of less than 1 m/s. They are also responsible for transporting large volumes of sediments.

Tidal phase is however relatively uniform along the entire coast. Tidal currents are generally low and have very little impact on coastal processes except within tidal inlets and estuaries. The climate along the coast is described as equatorial with significant variation in spatial distribution in precipitation (EPA & World Bank, 2000).

Rainfall and Temperature

Generally, rainfall and temperature along the coastline follows the pattern experienced along the southern belt of Ghana. There are two rainy seasons. The first begins from May to July and the second from somewhere early September to October, in some cases extending to early November. The average annual rainfall is about 730 mm. with Half Assini and Axim experiencing rainfall throughout the year. A bi-modal pattern is observed with peaks in May - June and October - November. Rainfall is generally scanty along the central to the south-eastern coastal belt. Mean annual rainfall is highest along the western coastline (2083 mm) and lowest around Tema (714mm), which lies in the central portion. Areas around Keta in the eastern portion receive mean annual precipitation of about 774mm. Rainfall variability is also lowest in the west (about 26%) and highest in the central portion (40%), and 30% in the east (Owusu &Waylen, 2009). There is clear deficit in rainfall amount between the south-west and the south-east coastal zone.

Temperature is relatively warm with very little variation throughout the year. The average temperature is higher from February to May and from November to December with peak temperatures recorded in March (about 32°C to 35°C). August is known to be the coldest month recording average temperature of about 23.57°C. Mean annual temperature range along the coast is narrow (26°C-28°C) but shows strong seasonal differences (21°C to 22°C in August, and 24°C to 28°C in April) (Mensah et al., 2016).

Population and Economic Activities

Ghana's coastal zone represent about 6.5% of the area of the country, yet it houses 25% of the nation's population (EPA & World Bank, 1997). In the Lower Volta, however, there have been significant population drift of males to the lake area to look for new livelihood opportunities. This followed the impoundment of the Volta River in the early 1960s, which resulted in cessation of the seasonal inundation of the lower Volta floodplains which used to support the agrarian economy. Thus, the demography representation of several areas of the Lower Volta is skewed towards women. The economy of the coastal dwellers is tied to the extractive sector of fishing, salt production and subsistence farming. Subsistence exploitation for fishing, using traditional methods, occurs in coastal lagoons as well as the marine environment. The coastal zone accounts for about 80% of Ghana's annual fish production of over 450,000 metric tonnes (EPA, 2004).

Intensive and extensive salt mining is common in the central and eastern dryer coastal zone at places including Songor, Densu River estuary, Keta, Old Ningo, Prampram, Nyanya, Nakwa, Iture, Brenu, Akyinmu, and Ahwin Lagoons. Salt is marketed locally and in neighbouring countries. Commercial exploitation is becoming widespread under the government's economic drive of Presidential Special Initiative on Salt. Substantial portions of the mangrove areas have also been converted to saltpans, particularly in the Songor and Elmina areas. In other areas such as the Lower Volta mangroves serve as the predominant source of fuel for fish processing and household use. The coastal savannah areas stretching from Winneba in the Central Region to the Volta Region are important for semi-nomadic rearing of cattle. The elevated lands support staple crop and vegetable framing. Shallot farming occurs along the eastern coastal strip lying between the sea and Keta lagoon and constitutes a major source of income for many households. Commercial coconut production occurs mostly in the coastal forest fringes of the Central and Western Regions. It is estimated that 75% of all coconut production in the country comes from the Western Region and 17% of the region's population is dependent on it as principal source of income (Overfield et al. 1997).

The coastal zone is well endowed with natural resources, which are exploited by different sectors of the economy. The major primary activity of the zone is fishing. Other activities of economic importance that occur in the zone are agriculture, transportation, salt production, oil and gas exploration, sand mining, quarrying, recreational and industrial developments. The zone is also known to be important internationally, for the provision of feeding, roosting and nesting sites for thousands of birds, especially migratory species due to the existence of vast wetlands. The lagoon, estuary and delta ecosystems also provide suitable environments for shellfish and fish breeding. The area is also richly endowed with important resources for the promotion of tourism, fishery industry and mining. The coast supports mangroves, which are an important source of fuel wood to local communities. The beaches, cliffs, lagoons, wildlife, cultural and historical sites and coastal landscape also provide an immense potential for tourism development. In addition, salt (Sodium Chloride), deposits, limestone, silica, feldspar and other minerals have been identified within the coastal belt.

There is also the discovery of hydrocarbons, for which prospecting was carried out. Furthermore, copra production is also an important economic activity along the coastal belt. Due to greater infrastructure along the coast, industrialisation and economic activities are heightened. Domestic industries and services provide employment opportunities for coastal populations growing at the rate of 3% per year. (Ghana Statistical Survey (GSS), 2010). Over 60% of industries are located in the zone. Transportation facilities including extensive road networks, rail, air and water are found in the zone. There are also the two main seaports at Tema and Takoradi, which handle most of Ghana's imports and exports.

Ghana's coastal zone is the land area extending to the 30-metre contour and offshore to the 200-nautical mile (320 km) Exclusive Economic Zone (EEZ). The country has 550 km of coastline, a 20,900 km^2 continental shelf and 218,100 km^2 of EEZ, the fifth largest in West Africa (EPA & World Bank, 1996). The coastal zone covers Western, Central, Greater Accra and Volta regions comprising 21 districts (EPA, 2004). The coast of Ghana is divided into four regions and 21 districts of which 17 districts are bordering the coastline while 4 districts are further inland but still considered to be part of the coastal zone. All the coastal districts have at least some portion of their territories that is within the 70 m contour, although some of the districts do not have a coastline. The zone represents only approximately 6.5% of the total area of the country (EPA & World Bank, 1996). Large number of minor towns and settlements are scattered along the coast and the majority are fishing communities. Approximately 185 villages and towns are engaged in fishing activities (Bannerman, Koranteng & Yeboah. 2001). The coastal zone accommodates about 25% of the population with a characteristic of high population densities of over 500ha. /km^2 in the major cites of Accra-Tema, Cape Coast and Secondi-Takoradi. It has a population density of 263 per km^2 as against the national density of 67 km^2 (GSS, 2010). Relative demographic statistics show an urbanization rate of 51.5 per cent compared to a national rate of 35.4 per cent (EPA & World Bank, 1996; GSS, 2010). The economic and social conditions in the coastal zone are relatively prosperous. It has over 70 % of industrial establishments (EPA, 2004). The major ethnic groups in the coastal zones of Ghana include Nzema, Ahanta, Fante, Awutu, Efutu Ga, Krobo, Ada and Ewe. The coastal area of Ghana is the focus of national economic development and found to be relatively prosperous, nonetheless income disparities exist among towns and within many poor settlements. More than 70% of industries in Ghana are located in the coastal area (EPA & World Bank, 1997). Major economic activities in the area include farming, fishing, mining, forestry, commerce, industry, salt production, oil and gas extraction and tourism including historical monuments.

Coastal tourism

The coastal area of Ghana offers wide-ranging prospects for tourism and holds significant potentials. The major assets are the broad beaches and cliffs, the coastal lagoons and estuaries having a rich ecological life, historical monuments (forts, castles, light houses etc.) and cultural activities (Anquandah, 1999). The major costal tourism attraction sites are in Keta, Ada, Ningo, Prampram, Tema, Accra, Winneba, Kromantse, Cape Coast, Elmina, Brenu-Akyinu, Komenda, Sekondi-Takoradi, Axim and Busua. Toursim is an emerging foreign exchange earner for Ghana. The coastal area offers varied and significant opportunities for tourism, recreation and hospitality (EPA, 2004). It contributes approximately 5% to the country's GDP. A significant feature of the Ghanaian coast is the presence of historical monuments with three of them, at Cape Coast and Elmina, designated as World Heritage sites by UNESCO (Anquandah, 1999). These sites are significant for tourism because of their rich and diverse history. Overall, there are about 40 forts and castles scattered along the entire coast. These forts and castles contribute financially both to the national and local economies because of the attraction they present to both local and foreign tourists.

There is a growing number of beach resorts and their patronage is on the ascendency in Ghana both on public holidays, special occasions and weekends. There were 18 beach resorts in the country in 1996 with majority in the Greater Accra, Central and Western Regions. The high patronage of beaches has its attendant littering and pollution of beaches and nearshore waters (Nunoo & Quayson, 2003). Tourism encourages the establishment of human settlements and associated industries which, when not properly planned, lead to pollution of beach and coastal environment, unsustainable coastal development, and coastal erosion. This could hamper coastal tourism by the adverse impacts of coastal erosion.

Fisheries

The fisheries sector is estimated to contribute quite a significant amount to the Gross Domestic Product (Sarpong, Quaatey, & Harvey, 2005). Fish is the preferred and cheapest source of animal protein and about 75% of total annual production of fish is consumed locally. The per capita consumption of fish was estimated at about 27 kg per annum; representing 60% of animal protein intake by the Ghanaian populace (Quaatey, 1997; Sarpong et al., 2005). It has been estimated that the fisheries resources in

Ghanaian water bodies supports the livelihoods of a total of 500,000 fishers, fish processors (including fish canneries and cold stores), traders and boat builders, who together support twice as many dependants. These people, together with their dependents, account for about 10% of the population. The fisheries sector supports other industries of the economy. About 40,000 metric tons of fish waste is used in the manufacture of poultry and livestock products annually.

Bathymetry and Sedimentology

Ghana has a continental shelf, which varies from about 20 km off Cape St. Paul (in Keta) towards the east to about 90 km towards the west between Cape Coast and Axim as can be seen in Figures 1 and 2. The shelf generally slopes gently to the edge of the continental slope at about 75 m to 180 m depth (EPA, 2004). From the bathymetry (Figure 1), the continental shelf is more defined around Cape Thee Points. The shelf on the eastern section of the coast is narrow and steep as compared to shelf on the western section. The shelf on the eastern section reaches a maximum of 12 km at some point whiles the western portion has a wide, about 80 km at some points, and relatively gentle sloping shelf as compared to the eastern section (Xorse, 2013).

Areas classified as onshore waters extend between 10 - 50 nautical miles and are characterized by soft muddy bottoms, soft sandy bottoms and hard rocky bottoms. The soft muddy bottoms constitute more than 60% of bottom types in the inshore waters, while the hard-rocky types constitute less than 0.5%. Offshore areas occur between 50- 200 m nautical miles and are predominantly soft bottom types. Hard bottom grounds in the offshore area cover about 2000 km^2.

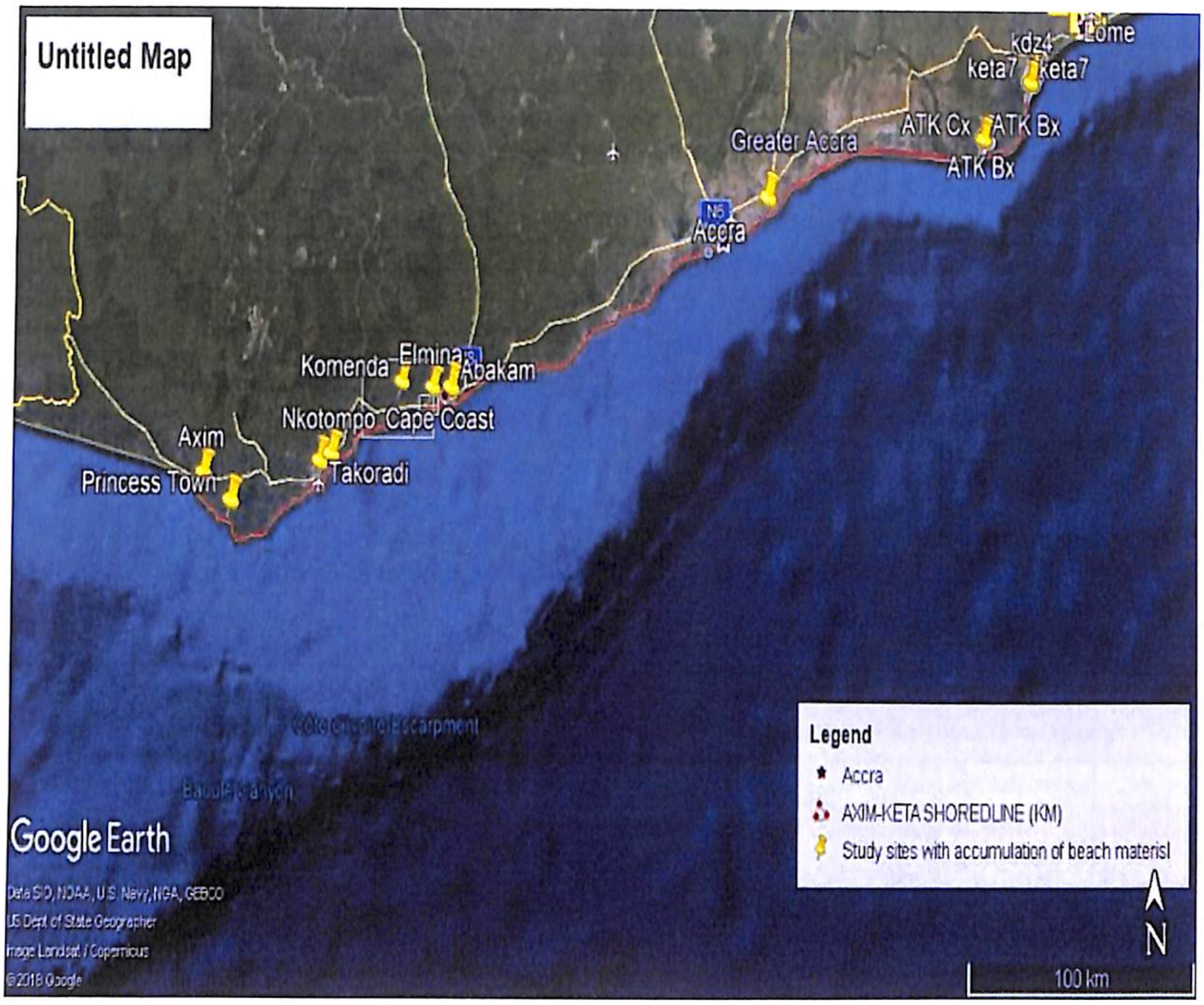

Figure 1:Bathymetric map of the study area showing beaches with CES

Source: Google Earth images (2018).

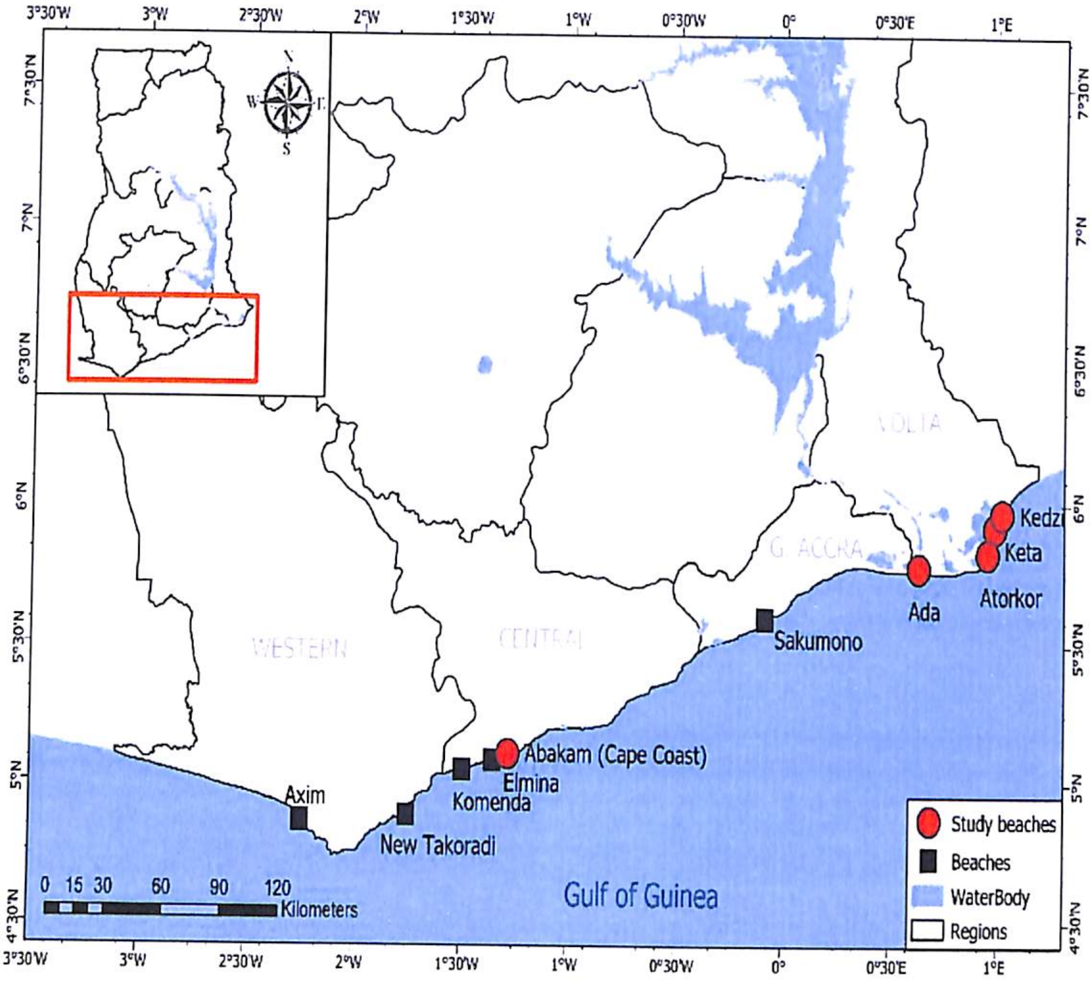

Figure 2:Map of study area showing the coastline of the study sites.

The black squares are the beaches with coastal erosion projects (mitigation structures) while the red dot indicates the selected study beaches with CES.

Source: GIS and Remote Sensing unit, Dept of Geography and Regional Planning (2018).

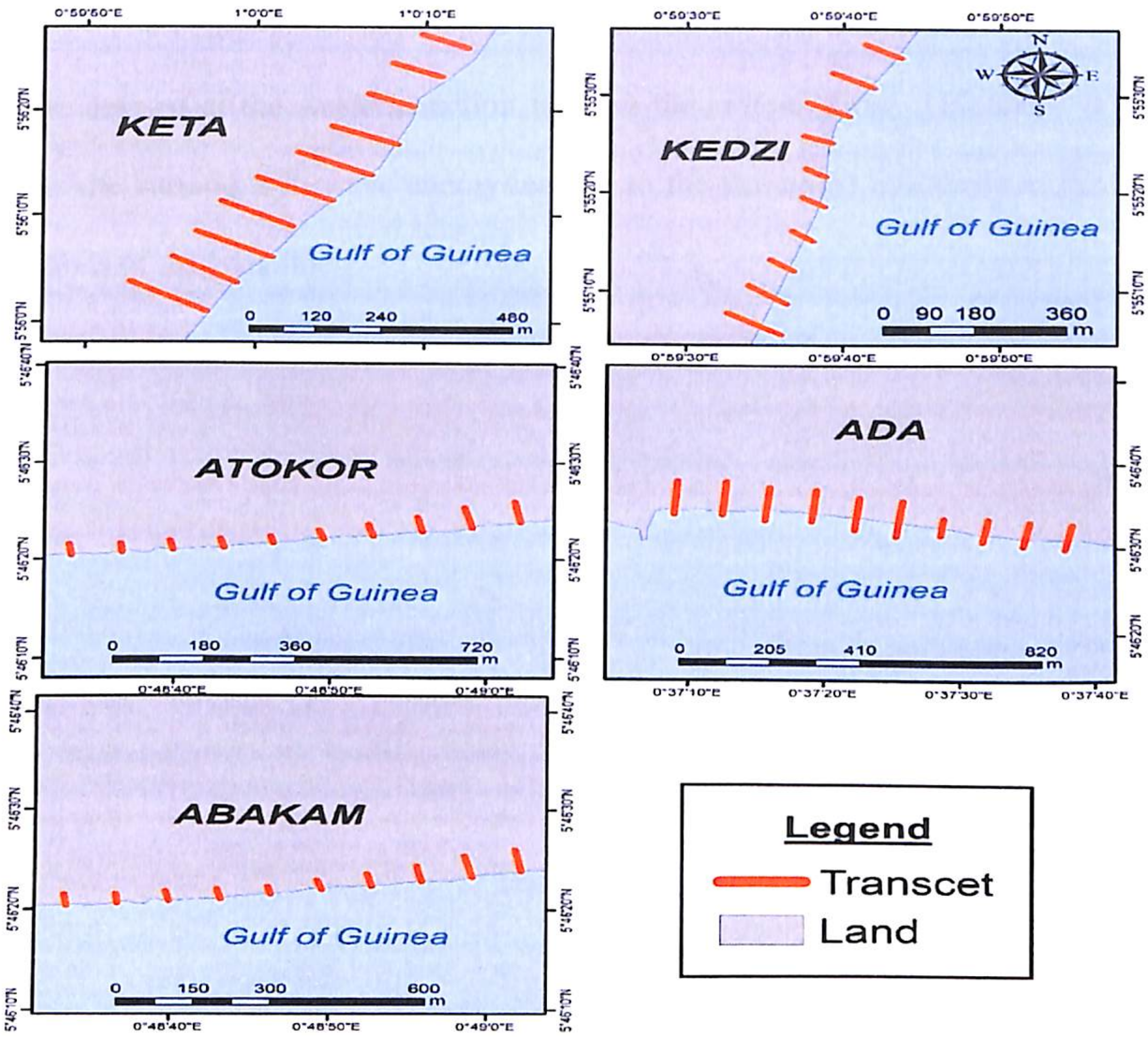

Figure 3:Map showing study beaches with profile lines

Source: GIS and Remote Sensing unit, Department of Geography and Regional Planning (2018).

Summary of the Chapter

The chapter focused on the spatial and cultural characteristics of the study area such as location, geology, climate, population, economic activities and a locational map. It placed the study in a spatial context showing the climatic characteristics of the area, spelling out the hydrodynamic forcing that influenced the morphology of beaches in the area. It highlighted on the natural characteristics of the zone that attracted population growth and anthropogenic influence on the coastline. This indicated the importance of the coastal zone and the need to protect the coastline from the onslaught of erosion.

The bathymetric map of the area showed that the continental shelf is quite defined at the western section than on the eastern shore. This made it clear the variations in wave energy leading to the variations in erosion at the sections of the coastline.

CHAPTER THREE

REVIEW OF RELATED LITERATURE

Introduction

This chapter reviewed related literature and discussed theoretical frameworks and models used in analyzing and predicting coastal erosion and beach morphology. It also provided a brief account of the ongoing discussion and its implication on the coastal environment, the various oceanographic and meteorological factors that influence the beach system and coastal evolution. The rationale behind the review of these forces was to establish the link between these forces and the evolution of the coastal environment and their contribution to beach morpho-dynamics. The literature search provided the theoretical and methodological base of the study and guided the research to attain the ultimate objective. The reviewed literature put the study in its proper perspective in order to demonstrate the state of the art of the discipline as well as help the researcher to learn and benefit from the success and shortcomings of other researchers in the discipline.

Erosion and Accretion

The dynamics of the coastline is to achieve and maintain equilibrium among many opposing natural and human induced forces in the coastal regions. The process has attained several definitions all seeking to arrive at one phenomenon. Davidson-Arnott (2010) and Lee and Fookes (2015) explained coastal erosion as the wearing of land or the removal of beach or dune sediments by wave action, tidal or wave currents and or the indirect activities of man, typically causing a landward retreat of the coastline. Sometimes the terms 'beach erosion' and 'sea erosion' are used in place of 'coastal erosion' to explain the same phenomenon.

Change in the coastline is a natural phenomenon and is being accelerated by the changes in relative sea level, climate and to some extent human activities. Therefore, the disturbing phenomenon could be attributed to both natural and anthropogenic factors. It involves a redistribution of sand from the beach face to offshore and alongshore zones (Davidson-Arnott, 2010). It commonly occurs during coastal storms and strong wind action which may take the form of long-term losses of sediment and rocks, or merely the temporary redistribution of coastal sediments (Wright & Short, 1984) and evolution of beach form and profiles. The erosion in one location may result in the pile-up of sand or sediments elsewhere (Anim et al., 2013).

Coastal erosion results in three different types of impacts or risks; loss of land with economical value, destruction of a natural sea defence (usually a dune system) as a result of a single storm event which in turn results in flooding of the hinterland and undermining of artificial sea defences, potentially also leading to flood risk (Thorne, 2007). Coastal erosion and accretion have always existed and have contributed throughout history to shape coastal landscapes, producing a wide range of coastal types. Erosion of inland soils by subaerial activities such as rainfall and movement along riverbeds offer in some areas, considerable amounts of terrestrial sediments to the coast through stream flows serving as sediment sources in the beach system. These sediments together with those derived from coastal features (such as eroding cliffs and marine sand banks) provide the necessary materials for the development of offshore reefs, mud flats, saltmarshes, sandy beaches, sand dunes, and transitional marshes (Beaumont et al., 2007). In turn, these coastal habitats provide a wide range of outstanding benefits including locations for economic and recreational activities, protection from flooding in low lying areas, absorption of wave energy during storm surges, reduction of eutrophication of coastal waters, nesting and hatching of fauna species.

Coastal erosion is usually the result of a combination of factors - both natural and human induced - that operate on different scales. Most important natural factors are winds and storms, near shore currents, relative sea level rise (a combination of vertical land movement and sea level rise) and slope processes. Human induced factors of coastal erosion include coastal engineering, river basin regulation works (especially construction of dams), dredging, vegetation clearing, gas mining and water extraction (Salman, Lombardo & Doody 2004).

Coastal Erosion and Mitigation in Ghana

There has been a growing concern about coastal erosion by coastal researchers in Ghana. Anim et al (2013) and Appeaning-Addo (2015) estimated that 82% of the beach is eroding at a rate between 1.13 to 8m per annum. The problem is mostly concentrated along the eastern shores with pockets of dire condition along the central and western shorelines. However, Anim et al (2013), Appeaning-Addo (2015; 2009), Angnuureng, Appeaning-Addo& Wiafe, (2013), and Jonah (2014) all agreed that the eastern shores have the highest rates of erosion, approximately 6 m to 8 m/ year. This has been manifested in scarps and undercut asphalt along sections of the coastal infrastructure. Coconut trees which characterized most beaches in Ghana are disappearing. The coastline is being displaced towards the land with subsequent dire effects on the tourism sector of the country (Oteng-Ababio et al, 2010).

According to Oteng-Ababio et al (2010) and Anim et al (2013), changes in the ecological system resulting from coastal erosion, have produced effects which have gravely minimized the effectiveness of the fishing, tourist and other economic activities. It is also recorded that many structures such as hotels and restaurants where tourists reside along the coast must be evacuated due to the danger that erosion poses. Beach recreational activities, especially during festive seasons have also been affected because foreigners and even locals are no more attracted to the beach. It was reported that coastal erosion had turned many investors away for fear of losing their investment as a result. Residential houses have been washed away by the ocean (Anim et al., 2013).

Currently the Ada and Keta shorelines with few locations at the western shores are places receiving both national and international attention. However, there are several problem sites in the country and prioritisation is required to adequately address these issues. Urgent action is required at places such as Teshie, Sakomono, Bortianor, New Takoradi, Amanful Kumah, Axim, Dixcove, Cape Coast, Elmina, Komenda and Saltpond.

A serious situation was recorded at Keta and Ada Foah where it was estimated that the coastline is eroding at a rate of 4 m to 8 m annually (Anim et al., 2013). Hence, in response to these gravely eroded coastlines, the country initiated a mitigating project at the eastern shores, beginning in the 1960s with a recent one in the 2000s, to the building of a 30 km Ada Sea Defence Wall along the 44 km-stretch of the Ada coastline up to Keta

(Mensah, & FitzGibbon, 2013). This project was undertaken to ensure maximum protection of the people and the infrastructure as well as the environment.

With about almost half of the population living in the coastal municipalities, the idea of strategic coastal planning, integrated coastal zone management and risk mitigation strategies should become an integral component of regional spatial planning for effective coastal protection. One of the most effective ways of combating coastal erosion is the adaptation of a soft option such as creating salt marshes, buffer zones and vegetation cover acting as soft defences to absorb the power of storm and prevent flooding (Pretty, 2014).

According to Boateng (2006), Anim et al (2013) and Jonah, Mensah, Edziyie, Agbo, & Adjei-Boateng (2016), there are limited studies on the quantification of the problem and the damage caused and suggested a strategic management framework and control policies which included an ecosystem approach, education, improved research, adaptation of soft protection and a buffer zone. They emphasized on long term management policies which required a holistic approach involving all stakeholders. Currently, the national environmental policy does not include any clear-cut plans but recognises the need to manage the marine and coastal zone. Hence management continues to be traditional, site specific and uses mainly hard engineering approach which are environmentally unfriendly, interfering with natural littoral cell cycles (Appeaning-Addo, 2015; Angnuureng et al., 2013). This promote the transformation of erosion to adjacent coastlines. Pretty (2014) suggested the threats do not work everywhere and therefore management should be a mixture of defence, adaptation and retreat.

Most countries undertaking coastal erosion mitigation measures maintains a large infrastructure of coastal structures. Defence walls, groins and revetments are the dominant coastal erosion structure along the Ghanaian coastline. The rest are localised structure such as sand bags, concrete and wooden structures of various designs based on the materials available. They are used for protecting and reducing wave impact, retaining sediment and shoreline and bluff protection. The major coastal erosion structures in Ghana are state-owned with quite uncountable structures of various design and material that are locally owned and maintained. From the literature, there were no reports on the histories of maintained coastal structures. Most of the existing state-owned structures are few decades old especially that of Keta, Ada and Takoradi while the others are quite recent to have any significant impact for consideration.

The aging structures need to be maintained periodically. Maintenance of existing structures becomes more important each year as coastal populations increase with increasing sea levels. According to Hughes and Hughes (1991), dredging costs can increase at an alarming rate as these structures erode. In addition, maintenance of existing revetments and other shoreline structures is becoming more important with increasing coastal population (Houston, 1996). As a result, inspection, repair, and rehabilitation of existing structures must form a large part of coastal erosion mitigation policy within the framework while new construction of this class of structure represents a diminishing fraction of the projects. The cost of maintaining the existing coastal defence is high and methods for reducing these costs must be developed and employed.

One present focus on reducing the costs of coastal structures is by employing risk, life-cycle, and reliability analysis techniques in both planning and design studies to develop more efficient designs (Mensah, & FitzGibbon, 2013). These design methodologies are becoming more prevalent to focus on life-cycle efficiency as opposed to the historical perspective of "no damage" for the design storm. Sayers, Hall and Meadowcroft (2002) suggested a research work unit to provide tools for predicting coastal erosion structures and to develop computer-based methodologies for risk analysis of coastal structures, predict and prevent deterioration on these structures due to dominant failure mode. In lieu of this, there is the need to investigate and understand the textural characteristics of beach sediment that influence beach forms and evolution. Since these engineering structures end up aggravating the problem of erosion, understanding the source material characteristics of a beach will aid in designing fitting structures.

In Ghana, the attention was mainly towards the Keta erosion site, a project to manage coastal erosion has been carried out by the government, at Ada (the Ada Sea Defence Project), and is even recent (in the 2013). The project employed both hard and soft engineering methods (Government of Ghana, 2016). Aside this, other coastal areas in Ghana experiencing coastal erosion such as in Elmina and Amanful Kumah, (Jonah, 2014) have not been tackled yet, while others are ongoing.

Methods of Coastal Erosion Mitigation

Coastal erosion has become a worldwide problem such that nearly every country with a coastline has to deal with the issue. The many negative impacts of coastal erosion have been discussed and include massive economic effects in the form of loss of revenue to businesses making use of beaches (Alexandrakis, Manasakis, & Kampanis, 2015). As a result, efforts have been made to mitigate coastal erosion. This has resulted in development of many methods and approaches to mitigate coastal erosion globally. Many approaches and techniques have been developed in an effort to mitigate coastal erosion. This has resulted in the categorisations of these approaches which gets confusing at times. Coastal erosion mitigation methods categorized by Board and National Research Council (1990) and Temmerman et al (2013) into structural and non-structural, and their shoreline engineering methods involves the use of hard structures and (e.g. seawalls, revetments, groins, offshore breakwaters, etc.) soft structures (e.g., beach nourishment) to manage coastal erosion.

Structural methods

The hard engineering methods (hard structures) includes groynes, seawalls, revetments, rock armour, gabions, offshore breakwater, cliff stabilization, entrance restraining walls, and floodgates and many others.

Groynes and jetties

Groynes are sill-like structures extending from shore into sea, most often perpendicularly (French, 2001) or slightly obliquely to the shoreline to prevent the continuous movement of waves and sediments from other parts of the area (Neshaei & Biria, 2016). They are usually constructed of timber, concrete, metal sheet piling, or rock, and may be in series called groyne fields or singulars, and typically terminate within the surf zone (French, 2001). The material and design chosen will reflect functional performance, budget, durability, and required lifetime.

It has been indicated elsewhere that the height of the groyne influences its contribution to downdrift erosion such that when groynes are built with heights that suites the beach profile, it reduces downdrift beach erosion. On the other hand, when groynes are built higher or longer much sediment is held, and much longshore current activity occurs, within the surf zone, Thus, longshore transport of sediment is concentrated here. Therefore, any shore structure which is built perpendicular to the shore obstructs all or part of the surf zone and interrupts sediment transport, causing the retention of sediment and subsequent build-up of beaches (Pilkey, Neal, & Bush, 2010; Silvester, 1978).

Unlike groynes, jetties are often built individually or paired with other structures on either side of an estuary, and are more substantial structures, penetrating seaward of the surf zone. An overview of groynes is given by Fleming (1990), Kraus, Hanson and Blomgren (1994), US Army Corps of Engineers (1994), Van Rijn (1998; 2005) and Pilkey, et al. (2010) showed that the groyne length for the purpose of beach protection can be based on the beach width and the general length is about 100 m. The distance between the adjacent two groins usually is two to four times the groin length, flat sandy coast is desirable for three to four times the groin length. Groyne top surface elevation is approximately equal to the mean high tide line or lower, and the slope of seaward groyne surface can be about 1% (Gibson, Atkinson, Gordon... & Smith, 2012). Groynes and jetties have been applied in many countries with differing results.

Seawalls, revetments and bulkheads

Seawalls, revetments and bulkheads are primarily the same. They differ only in functional purpose (U.S. Army Corps of Engineers, 1984). They are shore parallel structures at the transition between the low-lying (sandy) beach and the (higher) mainland or dune. These structures can have a vertical, stepped, or curved face, and typically have a horizontal surface (or cap) at the crest. The height of a seawall fills often the total height difference between beach and surface level of the mainland. In many cases, adjacent at the crest of a seawall a horizontal stone covered part is present (e.g. boulevard, road or parking places). At the initial time of construction, a seawall is situated close to the position of the dune foot. The primary purpose for building seawalls is to reduce wave-induced cliff-toe erosion. Basically, then, seawalls are designed to protect against large wave forces (Douglass & Krolak, 2008). Revetments on the other hand are layers of protection on the top of a sloped surface to protect the underlying soil, whereas bulkheads provide protection against light-to-moderate wave action.

Breakwaters

These are shore-parallel structures located seaward of the shoreline to reduce the wave energy in their leeward side and to control longshore sand transport (Douglass & Krolak, 2008). There are two basic types of breakwaters: rubble mound and vertical breakwaters. Rubble mound breakwaters are generally used in shallow water, whereas vertical breakwaters become more convenient in deeper water (Cuomo, 2013). A typical rubble mound breakwater consists of an armour layer of heavy rocks or concrete units usually protecting a less permeable filter beneath and a core comprising smaller sized rocks; the mound can be submerged or extend above the sea level. When above sea level, the crest of the breakwater can be completed by a concrete crown wall, usually cast in situ. A vertical breakwater consists of a vertical structure of various designs resting on a rubble foundation. Composite breakwaters consist of a combination (either vertical or horizontal) of a rubble mound and a vertical superstructure. Composite breakwaters originally consisted of high mounds and block work superstructures; over large tidal excursions, the mound could nevertheless induce wave breaking onto the structure causing severe damage and destruction of many breakwaters.

The stability of vertically composite breakwaters was later substantially improved with the reduction of the mound and the introduction of taller and heavier superstructures, which was made possible by the use of superimposed blocks, again later replaced by concrete caissons. Recent development of vertical caisson breakwaters includes sloping top, perforated and recurve-wall caissons, respectively, to increase their stability, reduce wave reflection, and transmission. It is mostly equipped with wave energy devices. (Pranzini, Rossi, Lami, Jackson, & Nordstrom, 2018). Breakwaters have a large berm along their seaward face. These are dynamically stable structures made of medium-sized, high-quality rocks and their front reshapes to adapt to wave action during severe storm. Other type breakwaters include piled structures, horizontal plate breakwater, floating breakwater (supported on piles or chained to the seabed), and pneumatic breakwaters, which reduce wave agitation by forcing an airflow.

In all, the hard engineering method for coastal erosion management is viewed by many as the most effective approach to coastal erosion mitigation (Pranzini, 2017; Rangel-Buitrago, Williams, Anfuso, Arias & Gracia, 2017). In addition, for many countries, the hard engineering approach is the only available method of mitigation. Yet, hard engineering methods are not without their own problems. For one thing, hard engineering methods can produce negative impacts such as accelerated bottom erosion in front of the structure and downdrift scouring; disturbance of sediment supply and beach reduction; alteration of alongshore sediment transport; restricted public access; potential risks for bathers; and negative visual effects on the seaside landscape (scenery) (Pranzini, et al, 2018).

Aside these, it is noted that hard engineering methods are expensive to build, and require constant maintenance. Sometimes, some of these hard structures require widening and increasing the height in order to keep in step with the increasing coastal erosion risk. Finally, such hard engineering structures significantly alter the natural adaptive capacity of any coastline (Temmerman et al., 2013). As a result of all these problems associated with hard engineering method to coastal erosion mitigation, soft engineering approach has been developed and used in many countries.

Non-structural methods

Non-structural or soft engineering methods are often less expensive than hard engineering options. They are usually more long-term and sustainable, with less impact on the environment (Hegde, 2010). Soft engineering method are of two basic types: Beach management and Managed retreat. The two basic types include options like sand bypassing, dune rehabilitation, dune vegetation, beach face dewatering, sand fencing, green belts, biorocks, geotubes, geotextile sand containers which are being used extensively these days in place of hard options.

Beach management approach to mitigating coastal erosion involves replacement of beach or cliff material that has been removed by erosion or longshore drift. Using mechanical or hydraulic method to shed sand to beach (above water or underwater) to create a certain width of the beach can effectively consume wave energy, to protect the upper part of the beach; this method is called beach nourishment or artificial beach (Pilkey et al., 2009). This kind of beach has protective effect on the coast. This is also a good method in managing sandy coastal erosion, it does not (like hardening engineering) reduce downstream coastal sediment supply, it does not cause adjacent coastal siltation or erosion, and if it is combined with groynes and offshore dike projects, the effect is better. Even though this approach is cheaper than the hard one, it requires constant maintenance to replace the beach material as it is washed away. There are also pro-active methods such as flood proofing, setback limits, zoning, relocation, abandoning, demolition, do nothing etc., which are used similar to soft options (Hegde, 2010).

Managed retreat

In this method, areas of the coast are allowed to erode and flood naturally. Usually this will be areas considered to be of low value, such as places not being used for housing or farmland. The advantages are that it encourages the development of beaches (a natural defence) and salt marshes (important for the environment) involving a low cost. Managed retreat is a cheap option, but people will need to be compensated for loss of buildings and farmland.

The primary drawback to soft solutions is that they are more temporary in nature and while the initial cost is relatively low, ongoing replenishments is required. New solutions from around the globe are being developed and coming to market as countries around the world share a common threat of coastal erosion. Since the 1970s, some developed countries that have defects due to coastal hardening engineering have turned to the method beach nourishment. In the 1990s, 80% of all the coastal protection funds in the United States were for the beach nourishing (Hu & He, 2008). According to Hanson et al (2002), most coastal sections in the United States, including the Atlantic coast have more than 150 beach nourishing sections. Many erosion beaches have been maintained, promoting the development of coastal tourism. The European beach nourishing using sand was developed in Holland, and between 1952 and 1989, Holland completed a total of 50 beach nourishing plans; Italy, Spain, Germany, France, and other countries also have rapid beach conservation projects. China's beach nourishment project started late, but the development has been very fast. At present, there are more than 40 beach nourishing projects (Zhang et al., 2004), and they are often combined with hardening engineering (groyne, offshore dike) for nurturing beaches.

Functions and Importance of Coastal Erosion Structures

The stability and behaviour of coastal structures around its coastline is of great concern. These structures are considered important assets for the economic and environmental health of many coastal communities. Coastal erosion structures offer protection for harbours and inlets that are important commercial and military navigation links. They also protect shore-based infrastructure, navigation, coastal communities, flood protection, vegetation, roadways, beach and shoreline stability control and stabilisation of navigation channels (Dugan et al., 2011).

Climate Change and Coastal Erosion

Due to the global nature of coastal erosion it is logical to assume that there must be global factor(s) contributing to the loss of beaches (Galgano, Leatherman & Douglas, 2004; Morton & McKenna, 1999). Zhang, Douglas and Leatherman (2004) identified three possible phenomena that could contribute to this trend of global coastal erosion. These, according to them, are sea level rise (SLR), change of storm climate, and human interference. Based on the studies of other authors (Zhang et al., 1997; Zhang, Douglas, & Leatherman, 2000), storm climate (storminess) was ruled out since those studies gave no indication of a significant increase in storminess in this century. Human interference was identified to be neither worldwide in extent nor uniform regionally, implying that anthropogenic factors could not account for the global coastal erosion. Thus, seal level rise caused by climate change (or global warming) was suggested and tested to see if it was a significant driving force of coastal erosion. Yet, the rate of global sea level (GSL) rise has not been accurately quantified, and is subject of much debate (Zhang et al., 2004).

The Intergovernmental Panel on Climate Change, the international body for assessing the science related to climate change, made efforts to find the rate of global sea level rise for the past 20th century. In their third report, global sea level (GSL) was estimated to be about 1–2 mm per year for 20th century GSL rise, and the extreme bounds given for the total 21st century rise are 10–90 cm (IPCC, 2004). Per the figures given out, if the lower bound is correct, little effect will be felt. If the upper bound occurs, the results will be disastrous, since more than 100 million persons today live within one meter of mean sea level. The economic scale involved is equally vast.

It is clear though that the effect of GSL rise is beyond what is expected for the lower boundary figure and lesser than the upper boundary figure, the relatively large difference in the range of GSL indicates the uncertainty around GSL, which fuels the controversy surrounding it. Due to the uncertainty surrounding the GSL, attempts made by different researchers to estimate the effect of global sea level rise on coastal erosion have resulted in conflicting results. For example, Mimura and Nobuoka (1995), found contrasting results about the impact of GSL on coastal erosion to Pilkey and Davis (1987), even though they both applied the same model in their estimation. Paralleling Mimura and Nobuoka (1995), Zhang et al., (2004) found that sea level rise induces beach erosion, and further that the rate of erosion is about two orders of magnitude greater than the rate of sea level rise, given further support to the premise that climate change (GSL) is the main driving force of global coastal erosion.

Although the approach and logic of Zhang et al. (2004) seemed good, it was inadequate to explain the global level of coastal erosion. The World Bank Group (2016) gives a more holistic picture. Their report captures all the human activities which affect and worsen coastal erosion both directly and indirectly. For example, the group aptly indicated that human activity can exacerbate erosion in multiple ways. According to them, human activities can affect the removal of sediment, through direct extraction or the creation of surfaces that disrupt the natural processes. Much more important is the disruptive effect on the supply of sediment, caused largely by dams, which interrupt the natural flow of rivers, preventing sediment from reaching coastal areas. The decline in coastal mangrove populations, which trap sediment where it is needed also contribute to coastal erosion, and climate change can affect natural resources such as these through changing temperatures, increasing salinity of groundwater and coastal estuaries, and alterations in river dynamics. The combination of these factors has led to severe land and shoreline loss. The socioeconomic impacts are massive, because coastal areas are home to millions of people and billions of dollars of infrastructure. In addition, rising sea levels, intensifying storm surge, and extreme precipitation are likely to accentuate coastal erosion events.

From the above review, it is clear that coastal erosion is a serious problem with many effects both economic and ecological. For this reason, efforts have been made to predict coastal erosion even before it starts or gets worse. This has led to a number of mathematical models and frameworks.

Coastal Erosion Mitigation Models

Given the economic and societal impacts of climatic change on eroding coasts, there is a need for techniques and tools which can be used to predict erosion and quantify the associated risks. At present, few of such tools exist. On sandy coasts the Bruun rule (Bruun, 1962) has been widely used to predict future erosion due to rising sea-levels. The rule states that, with other factors held constant, an active beach will displace its equilibrium profile form upwards and landwards in response to rising sea-levels, causing erosion and deposition of equal volumes on the upper and more extensive lower shorefaces respectively.

The simplicity of the Bruun rule limits its application to quite specific circumstances, although Cooper and Pilkey (2004) noted that this requirement has not always been observed. More importantly, the Bruun rule does not consider the effect of cross- or long-shore gradients in sediment transport, and other sediment sources and sinks (Stive, 2004). Zhang et al (2004) considered such limitations in a study of sandy beaches along the United State' east coast and concluded that approximately one-third of beaches were suitable for assessment using the Bruun rule. Of those, Bruun predictions made using historical tide gauge records agreed well with historical shoreline erosion rates, suggesting that beach erosion rates are likely to be about two orders of magnitude greater than rates of SLR.

Despite such advocacy, Cooper and Pilkey (2004) contend that the Bruun rule does not work and cite three main groups of reasons: (a) the assumptions behind it are so restrictive that they probably do not exist in nature; (b) it omits many important variables; and (c) it relies on outdated and erroneous relationships. Cooper and Pilkey (2004) conclude that the Bruun rule is an overly simplistic model of the response of shorelines to SLR, and that it has outlived its usefulness and therefore should be abandoned. The Bruun rule was derived for sandy coasts, but Bray, Hooke and Carter (1997) used it to examine the possible impacts of changing SLR on eroding cliffs by modifying it to include sediment exchange (e.g., through cross- and long-shore transport). This method was compared to others including historical trend analysis and Sunamura's shore platform geometrical model (Sunamura, 1992).

Of these they concluded that the modified Bruun rule appeared especially suitable for testing the sensitivity of eroding cliffs to future climate change. The rule indicated that SLR could increase cliff recession rates on the south coast of England by 22 to 133% by 2050. The rule further implied that erosion rates would be highly site specific, with less erosion predicted for cliffs that release sediments that build up beaches, and higher sensitivity observed in energetic open coast environments than in sheltered embayment.

Stive (2004) cautioned that coastal response to SLR is a complex morphodynamic issue, and many feedbacks are to be expected beyond the simple profile translation envisaged by the Bruun rule. Similarly, Bray et al (1997) commented that the complexity of cliff, beach and hydraulic processes that interact over variable time scales in producing recession have so far forestalled the development of numerical, process-based models on eroding consolidated coasts.

Dubois (1977) attempted to modify the Bruun model so as to better correspond to observed zones of beach-profile erosion versus deposition. The zone of erosion mainly involved an evenly sloping beach face while deposition occurred over the landward side of the offshore bar and intervening trough. The pattern corresponded with profile changes observed by Dubois (1976) in Lake Michigan. With respect to his suggested changes to the basic Bruun model, Dean and Maurmeyer (1983) concluded that they were already inherently present though not explicitly stated. Other subsequent authors tried and modified Bruun's rule, following the example of Dubois (1977) (e.g. Dean and Maurmeyer, 1983).

Beyond Bruun's rule, Dean (1982) has developed a series of beach response models based on the beach-profile relationship h(x) = Ax where h is the water depth at the offshore distance. This relationship has been shown to agree reasonably well with natural profiles, where A is a scale factor that depends primarily on sediment characteristics. Its chief failing occurs at the shoreline (x= 0) where it predicts a profile slope dh/dx = 0. The recession rate derived by Dean, expressed in dimensionless form, as a function of the storm-tide level and storm-wave breaker depth. Dean also provides a modified analysis to account for the presence of a seawall. In all of the analysis, there is again a balance between the volume of sand eroded from the upper beach and that deposited in the shallow offshore.

Kriebel and Dean (1985) have developed a model that includes a computational procedure for predicting beach and dune erosion during severe storms and elevated water levels. As presented by Kriebel and Dean (1985), the analysis utilized the h(x) = Ax equilibrium profile, but the most recent developments employ a modified profile having a uniform beach face slope within the inner surf zone (Kriebel, 1990). Their models represent a conceptual advance in that they include evaluations of cross-shore sediment transport due to the disequilibrium of wave-energy dissipation produced by the storm and higher water levels. The transport equation together with a relationship for sediment continuity are solved numerically to predict the time-dependent, two-dimensional beach and dune erosion. Since the analysis considers sediment-transport processes, the models can account for time variations in wave heights and water levels, and therefore can be used to examine response times of beaches.

The models predicted, for example, that for the same forcing conditions, beaches composed of fine sand respond with longer time scales and erode greater distances than do beaches formed of coarse sand. The results indicate that time scales of natural beaches may be on the order of 10 to 100 hours for storm conditions, and on the order of 1,000 to 10,000 hours when the effective limit of sediment motion is far offshore, as would be the case for erosion induced by a sea-level rise. The lag of the profile response can, therefore, be significant and in general results in the actual erosion during a storm surge being only 15 to 30% of the potential erosion predicted by equilibrium models based on simple shifts of beach profiles.

All of the above analyses are two-dimensional treatments that conserve the quantity of sand within the cross-shore profile. The investigators were aware of this assumption, and most provide some discussion of potential longshore movements of sand that might affect the cross-shore balance. Such a consideration involves the development of a budget of sediment for the beach section being analysed, with various potential sand gains and losses that can alter the total sand volume within the profile.

The above discussed models fall short in that the application of the models were limited to specific sites and beach type (sandy beach as in the case of the Bruun's rule). Therefore, a model that will look at general types of coastal form, rather than attempting to model the evolution of a specific site was still necessary to develop. Hence, in recent times, Walkden and Hall (2005) developed a model called the Soft-Cliff and Platform Erosion (SCAPE). The model was designed to include the effects of longshore sediment exchanges over relatively broad scales, providing a capacity for simulating plan-shape evolution of coastal cliffs. SCAPE is physics-based, but processes are represented in relatively simple terms in order to allow the representation of a 'whole' system and to minimise run times (Dickson, Walkden, & Hall, 2007). This also eases interpretation of the model's emergent properties, and therefore to some extent those of the site being modelled. A thorough review has been carried out by the authors (Walkden & Hall, 2005).

Waves

Wind-generated waves are the most important energy input into the littoral zone and, together with wave-generated currents, they are responsible for coastal erosion and sediment transport. They are thus the primary force leading to modification of the coast and the creation of erosional and depositional landforms (Wright & Short, 1984; Davidson-Arnott, 2010). A wind wave is simply a vertical displacement of the surface of a body of water that results from the transfer of energy from the wind to the water surface (Wright & Short, 1984). Wind-generated waves are periodic, in that they appear as undulations on the water surface characterised by a high point, or crest, followed by a low point, or trough. They are also progressive in that the wave formed travels across the water surface in the direction that the generating wind blows. The energy transferred from the wind is expressed in the potential energy resulting from the displacement of the crest and trough of the wave above and below the original still-water surface, and in the kinetic energy of the circular motion of water particles within the wave (Waugh, 1995).

In addition to waves generated by winds, a variety of other waves are found in oceans and lakes ranging from very long period waves, such as the tidal waves generated by the gravitational force of the moon and sun, to waves with much shorter periods, such as the standing waves produced by reflection of wind waves from seawalls.

The height, length and period of waves increase with increasing wind speed and with the length of time and distance over water that the wind blows. While the exact mechanism of energy transfer is still not fully understood, there are now computer models that permit forecasting of wave conditions based on knowledge of wind conditions and the subsequent transformation of the waves as they travel across a lake or ocean. These models also permit us to hindcast wave conditions from past weather data and thus to construct the wave climate for a particular coast. This provides critical data for input into coastal zone management and the construction of sea defences and harbours.

Wave, tides, surge interaction

Waves are the dominant forcing mechanism for most coastal processes. Consequently, accurate wave information is of vital interest to essentially all coastal planning and operations. Design and planning considerations, for almost all coastal structures in coastal areas, are influenced more by waves than by any other environmental factor (Wei, Rafiee, Henry, & Dias, 2015).

All bodies of water experience waves. These may range from long waves, such as tides (caused by the gravitational forcing of the Sun and Moon) to tiny wavelets generated by the wind's drag on the water surface. A critical look at the distribution of energy for waves indicates a considerable variability ranging from 12 hours to 0.5 seconds. A significant contribution of this energy is found in the band from 0.5 to 30 seconds and is commonly referred to as wind waves (Grant & Madsen, 1979). These waves are of interest to engineers and scientists in discussing wave measurements. Measuring these waves accurately often comes down to how well this band is represented by the measurement method. This 0.5–30 second band that defines wind waves has variability that makes characterizing waves non-trivial. To point out the obvious, waves begin both small in height and short in length, created by local winds, and grow as a function of wind strength, duration of wind, and distance. As a result, the wave environment at a particular location may be composed of a combination of local wind waves from a sea breeze and long waves (swell) generated by storm events hundreds or thousands of kilometres away. Implication in measuring waves is that need to appreciate the fact that the local sea state is composed of waves with different amplitudes, periods, and directions. Understanding this is the first step towards making accurate wave measurements.

Wave currents and water levels interact in several ways affecting each other. This is summarised by Peregrine and Jonsson (1983) into the effects of water level and currents on waves and the waves on storm surges. Wave transformation is affected by water levels (Grant & Madsen, 1979). As waves enter shallow waters in the absence of currents, the processes of shoaling and refraction change the wave length and speed with constant wave period. This occurs at depth less than half of the wavelength. Wiegel (1964) postulated that the wave height decreases and later increases as energy propagates at group velocity. The effect of wave breaking and bottom friction is the limitation on wave height.

Changes in water levels have a corresponding effect on wave height (Grant & Madsen, 1979). The resultant effect of increases in water depth is penetration of waves inland (storm surge). Storm surge and tide have impact on wave propagation, generation and dissipation with significant effect on surface stress. However, a submission by Soulby and Clarke (2005) claim it is insignificant. By means of radiation, waves affect the mean flow and water level in nearshore zones (Longuet-Higgins & Stewart, 1962; Osuna & Wolf, 2005). Waves may affect the generation of surges by affecting surface roughness while enhancing bottom friction experienced by currents in shallow water (Grant & Madsen, 1979).

Longshoredrift

Longshore drift is the movement of material along the shore by wave action. Longshore drift happens when waves move towards the coast at an angle. The swash (waves moving up the beach) carries material up and along the beach at an oblique angle. The backwash carries material back down the beach at right angle. This is the result of gravity. This process slowly moves material along the beach. Longshore drift provides a link between erosion and deposition. Material in one place is eroded, transported then deposited elsewhere (Davidson-Arnott, 2010). Longshore drift moves material along a coastline in a zig-zag pattern. Where there is an obstruction or the power of the waves is reduced the material is deposited. Where rivers or estuaries meet the sea deposition often occurs. The sediment which is deposited usually builds up over the years to form a long ridge of material (usually sand or shingle). Such a ridge is called a spit.

Coastal and Shelf Sediment Transport

According to Yalin (1972), sediment transport and shoreline change at the site should be construed within a regional context, as there may be a far-flung effect on the project from processes quite distant from it with the reverse being applicable. For easy understanding of the ongoing processes affecting the project, it may be analysed within the context of a littoral cell. A littoral cell is a coastal area defined by known or well-estimated sediment fluxes at lateral boundaries. Examples of good lateral boundaries are large inlets and entrances, harbour breakwaters and long jetties, and regions that have experienced little shoreline change. A sediment budget is made for the littoral and analysed leading into modelling. Such a simple budget analysis gives an integrated and regional perspective of the dominant processes to serve as guidance in interpreting the more extensive and quantitative results produced by shoreline change analysis. Significant variables to look out for are estimates of direction and amounts of net longshore sediment transport; gross sediment transport; trends in shoreline change; and seasonal variations in waves, winds, currents, sediment transport, and beach volume change

Sediment transport rate, also called the sediment discharge is the mass of sedimentary material, both particulate and dissolved, that passes across a given flow-transverse cross section of a given flow in unit time. Sometimes the sediment transport rate is expressed in terms of weight or in terms of volume rather than in terms of mass.) The flow might be a unidirectional flow in a river or a tidal current, but it might also be the net unidirectional component of a combined flow, even one that is oscillation-dominated (Nakato, 1990). Only in a purely oscillatory flow in which the back-and-forth phases of the flow are exactly symmetrical is there no net transport of sediment. In this study the focus is on the particulate sediment load of the flow, leaving aside the dissolved load, which is important in another context.

Quite a number of procedures involving equations have been proposed for predicting sediment transport rate or discharge. According to Gomez and Church (1989), given the complexity of turbulent two-phase sediment transporting flows and the wide range of joint size-shape frequency distributions that are common in natural sediments, none of the proposed methods does a perfect job of estimating or predicting sediment transport rate/discharge.

The need to understand and predict morphodynamic and morphological changes, such as beach erosion, shifts in navigation channels, and interpretations of the stratigraphic record has generated interest in sediment dynamics. This is due to the fact that coastal and shelf sediment dynamics are of extreme importance to coastal zone management (Collins & Balson, 2007). Over the years, various approaches and techniques have been applied to the determination of sediment transport pathways and the derivation of erosion, transport, and deposition rates. Such wide-ranging approaches include the refinement and application of numerical modelling, and the development of new and more efficient field equipment.

According to Collins and Balson (2007), sediment transport can be defined on the basis of direct observations, indirect observations and by modelling. They classified direct observation methods to include acoustic backscatter, optical backscatter, sediment traps, artificial tracers (for sand and pebbles), natural tracers or labelled sediments (for silts and clays) and the determination of water movements, using drifters, suspended particulate matter and remote sensing. The indirect observational methods were sediment characteristics, including rain size trend analysis and mineralogy, geomorphology, including coastal landforms, estuarine volumes and asymmetric bedforms (ripples, sandwaves and sandbanks), and, finally, the internal structure of the sediment bodies (cross-bedding and accretionary sequences). Based on these various approaches and techniques, it may be concluded that:

- no single method for the determination of sediment transport pathways provides the complete picture;
- observational evidence needs to be gathered in a particular study area, in which contemporary and historical data, supported by broad-based measurements, is interpreted by an experienced practitioner
- the form and internal structure of sedimentary sinks can reveal long-term trends in transport directions, rates and magnitude;
- complementary short-term measurements and modelling are required, to second point (above) - any model of regional sediment transport must account for the size, location and composition of sedimentary sinks (Soulsby, 1997).

On the basis of the above summary, it is evident that it is timely to review a representative selection of the different approaches, by reference to recently undertaken coastal and shelf investigations. There are quite a number of studies covering at a variety of temporal and spatial scales, within different regions of the continental shelf. Watanabe, Riho and Horikawa (1980) proposed the concept of different scales, in relation to sediment dynamics for classifying coastal phenomena into three categories that are temporal and spatial. These are macro, meso, and micro scales. The macroscale spanning through years/km, mesoscale in days/hr/m while the microscale is in seconds/mm. Following this, Horikawa (1981), came up with three observations that:

- the approach of the geologist and geomorphologist is helpful for understanding the general tendencies of the coastal processes in treating the macroscale phenomena
- changes in shoreline and sea-bottom topography, bar and cusp formation, together with nearshore currents, all fall into the category of mesoscale phenomena
- within the context of a microscale approach, extensive research needs were identified such as, in particular, various aspects of wave-current interaction.

Interestingly, the observation is made that, theoretically, the complete superposition of microscale phenomena should compose the mesoscale phenomena and that of the macroscale phenomena. The above concept has been developed further by Larson and Kraus (1995), in relation to spatial and temporal scales for investigating sediment transport and morphological processes. Microscale is seen to refer to changes from sub-wave period to several periods, over lengths of millimetres to centimetres. At mesoscale, net transport rates over many wave periods are evaluated for distances of metres to a kilometre. Macroscale involves seasonal changes and a space scale of kilometres, whilst mega scale describes decade to century changes over coastal sub-reaches and reaches, e.g. over a littoral cell. The concepts applied here are applicable, equally, to the inner continental shelf (< 60 m water depth) - at the very least. The main conclusions reached (Larsen & Kraus, 1995) are that calculations at different scales can be related and reconciled, if limitations in the predictions of initial and boundary conditions and in the fluid flow, are recognised.

A similar approach based on the original synthesis of Holman (2001) was adopted by Dronkers (2005). He came out firstly, that at small spatial scales, seabed morphology and water motion adapt to each other, with a short delay, but at a large spatial scale, the adaptation period can be very long. Secondly, if erosion and sedimentation are balanced, averaged over large temporal and spatial scales, it may happen that these are imbalances at smaller scales or otherwise. This implies that the phenomena of erosion, sedimentation and sediment transport always have to be defined with respect to particular spatial and temporal scales. Thirdly, the physics of sedimentary coastal environments is related to temporal and spatial scales - the physical processes that determine coastal morphology span a range of temporal scales, covering more than ten orders of magnitude.

For large temporal, but small spatial scale processes, time-series are restricted; sometimes, they are not of sufficient high quality to overcome any uncertainties, that is, separating processes from background noise. From an engineering perspective, on the basis of the scientific limitations in understanding, the best available method to predict sediment transport rates in the marine environment may not be able to achieve much better than a factor in the case of rivers (Soulsby, 1997).

Changes in shoreline morphology in a wave-dominated coastline are investigated by Hinton, Townend and Nicholls (2007). Their analysis showed that coupling the upper, middle and lower shoreface is significant in understanding long-term coastal-evolution. Surficial nearshore sediments are described then, in terms of their distribution and spatial patterns. Seasonal bedform development and facies boundary migration is depicted by temporal changes in substrate and bed forms (Collins & Balson, 2007).

Extreme storm events are of much importance and it appears to vary according to the location of a particular environment, within the overall sediment dynamics system. The episodic nature of sediment transport, within the coastal zone, has been described (Seymour & Castel, 1985). On the basis of 1 to 3 years of nearshore directional wave measurements from seven US west coast beaches, time series of daily net longshore transport rates were derived. Transport was found to be very episodic, with approximately only 10% of the time required to move half of the sediment transported during a year. Elsewhere, measurements of large-scale coastal response to multiple storms on three coastal beaches have revealed a heterogeneous response, with isolated hotspots of erosion (List, Farris & Sullivan, 2006). Within a few days, these hotspots of erosion are reversed rapidly by post-storm accretion. Such observations provide a new view on the coastal response to storms, at scales much larger than site-specific experiments (List et al., 2006).

In contrast to the importance of storms in controlling the morphology of the coastline, the effect of wave/current interaction on sediment transport from the inner continental shelf (less than 60 m water depth) area revealed a different pattern. Using a high-quality data set of waves and currents, from a particular site, the contribution of different combinations to long-term transport, has been assessed (Soulsby, 1997). Under such conditions, waves act as a stirring agent to move sediment, whilst it is transported by the current. The conditions analysed ranged from calm seas and neap tides, to major storms coupled with spring tides. Interestingly, the following conclusions were reached: (a) waves enhance transport, by up to a factor of 10, compared with transport in the absence of waves: and (b) in terms of long-term (sediment) transport, the largest contributions were provided by relatively large but not infrequent waves, superimposed upon currents lying approximately between the peak speeds of mean neap and spring tides.

Nonetheless, because the sediment transport rate depends non-linearly on the current speed, also because the effect of wave-stirring is important, the direction of the long-term transport may be very different from the residual current direction (Soulsby, 1997). The very strong currents and very large waves were found not to make significant contributions to long-term transport. As such, the transition between storm-induced processes at the coastline, compared with the influence of various non-linear wave/current interactions offshore, is an important area of sediment dynamics research.

However, it should be remembered that sediment transport is still an inexact science on the basis of: biological effects; the presence of (mixed) sediments, containing a wide range of grain size components; time-history effects; and wave-current interactions. Finally, it is speculated that strong non-linear processes, such as sediment morphodynamics, may exhibit chaotic behaviour (in a mathematical sense), in the same way as the weather (Soulsby, 1997)

Littoral Cells

A littoral cell is a coastal compartment that contains a complete cycle of sedimentation including sources, transport paths, and sinks. The cell boundaries delineate the geographical area within which the budget of sediment is balanced, providing the framework for the quantitative analysis of coastal erosion and accretion (Akpati, 1975). The sediment sources are commonly from streams and rivers, sea cliff erosion, onshore migration of sand banks, and material of biological origin such as shells, coral fragments, and skeletons of small marine organisms. The usual transport path is along the coast by waves and currents (longshore transport, longshore drift, or littoral drift). Cross-shore (on/offshore) paths may include windblown sand, overwash, and ice-push. The sediment sinks are usually offshore losses at submarine canyons and shoals or onshore dune migration, rollover, and deposition in bays and estuaries (Waugh, 1995).

The boundary between cells is delineated by a distinct change in the longshore transport rate of sediment. For example, along mountainous coasts with submarine canyons, cell boundaries usually occur at estuaries and rocky headlands that intercept transport paths. For these coasts, streams and cliff erosion are the sediment sources, the transport path is along the coast and driven by waves and currents, and the sediment sink is generally a submarine canyon adjacent to the rocky headland. In places, waves and currents change locally in response to complex shelf and nearshore bathymetry, giving rise to sub-cells within littoral cells (Dietrich & Dunne, 1978).

The longshore dimension of a littoral cell may range from one to hundreds of kilometers whereas the cross-shore dimensions are determined by the landward and seaward extent of the sediment sources and sinks. Littoral cells take a variety of forms depending on the type of coast. Cell forms are distinctive of the following coastal types: collision (mountainous, leading edge), trailing edge, marginal sea, arctic, and coral reef. The first three types are determined by their position on the world's moving plates while the latter two are latitude dependent. The Ghanaian coastline can be divided into a set of distinct, essentially self-contained littoral cells or beach compartments. These compartments are geographically limited and consist of a series of sand sources (such as rivers, streams and eroding coastal bluffs) that provide sand to the shoreline; sand sinks (such as coastal dunes, estuaries, mudflat, coastal marshes and submarine canyons) where sand is lost from the shoreline; and longshore transport or littoral drift that moves sand along the shoreline.

Sediment within each cell includes the sand on the exposed or dry beach as well as the finer-grained sediment that lies just offshore. Beach sand moves onshore and offshore seasonally in response to changing wave energy, and also moves alongshore, driven by waves that usually approach the beach at some angle. Most beach sand along the coast of Ghana is transported from west to east as a result of the dominant waves approaching the shoreline from the southwest, although alongshore transport to the west occurs in some locations and at certain times of the year in response to waves refraction and interference of structures such as groynes and revetments (Boateng. 2006; Appeaning, 2009).

According to Einsele (2013), sand budgets can be developed for many of the littoral cells by calculating or estimating the amount of sand added annually from each source or lost to each sink, and by documenting the volume of sand moving alongshore as littoral drift by using harbour dredging records as proxies. It is the balance between the volumes of sand entering and leaving a littoral cell over the long-term that govern the long-term width of the beaches within the cell (Dietrich & Dunne, 1978). Where sand supplies have been reduced through the construction of dams or debris basins in coastal watersheds, through armouring the sea cliffs, by mining sand or restricting littoral transport through large coastal engineering structures, the beaches may temporarily or permanently narrow.

Coastal Erosion, Sediment Budget and Regional Geology

Rivers and erosion of shore cliffs are the main sources of sediments to the littoral zone and the shore. Other sources are biogenous deposition. Sediments are transported through cross-shore transport mechanisms. It has been estimated that sediment yields of rivers along the Ghanaian coast, ranges between 30 and 80 tonnes/km2 per annum (Xorse, 2013). While the South west river system delivers the bulk of the sediment input to the littoral zone, dammed rivers such as the Volta and the Densu do not contribute significantly to the volume of sediments. Overall, the coast receives about 430,000 m^3 of sediments per annum from river discharge (Ly, 1980).

Collection and analysis of geologic and geomorphic data are linked with the study of regional transport processes in development of the sediment budget. Typical subjects of the regional geology include estimation of the effects of inlets, both as sources and as sinks of littoral material, river discharges, special sources of littoral material such as cliffs, sea level rise, subsidence and analysis of grain size. The geologic history of the coast, the when, how, and of what it was formed, also provides important background material (Abuodha, 2003; Abdulkarim, Akinnigbagbe..., & Appiah, 2015).

Water Level

If the tidal range is large, wave refraction and breaking will vary significantly according to the water level. For micro- and mesotidal coasts, use of either the MSL datum (which appears on NOAA bathymetric charts) is considered sufficient (NOAA, 1995). If the tide variation is appreciable, refraction simulations with different water levels may be necessary. Water level also plays a role in wave overtopping and transmission through breakwaters, sediment overtopping and bypassing (shoreward and seaward) at groins, and interpretation of shoreline position from aerial photographs. However, changes in breaking waves as caused by variations in water level can be represented in the wave input.

Extreme Events

The aim of shoreline modelling is to simulate long-term change in shoreline position; effects of extreme events are assumed to be accounted for in the verification process. An extreme event is a natural process or engineering activity that causes a substantial, perhaps irreversible, change in the shoreline position. Without documentation of such events, interpretation of shoreline change could be mistaken. Examples of extreme events are storms of record that greatly erode the beach and dredging during construction of coastal structures. It is possible that one or more extreme events may have dominated shoreline change over the interval between shoreline surveys. This is particularly likely if the calibration or verification intervals are relatively short and an extreme event is bracketed. It is important to have documentation on extreme events so that shoreline and beach processes can be properly interpreted. If possible, time intervals that span known extreme events (including, for example, beach fills of unspecified volume) should be avoided in the calibration/verification process.

Beaches

Beaches are simply the accumulation of sediment along water bodies, especially oceans. They are classified based on a number of factors. Based on the influence of waves, beaches may be divided into three sections; backshore (upper), foreshore (lower) and nearshore (Davis, 1985). Beaches serve as buffer zones between waves and the coast. If the beach proves to be effective in buffering, it will dissipate wave energy without experiencing any net change itself. However, because of its composition of loose material, a beach can rapidly adapt its shape to changes in wave energy. It is therefore in dynamic equilibrium with its environment (Davidson-Arnott, 2010).

Beach change

Changes in the coastline may be classified as progressive changes resulting in recession of the shoreline over a long period of time and short-term variations which reflect the fluctuating nature of the forces acting on the beach (Kench, 2008). An examination of both these aspects would require a study of the forces acting, the type, quantity, source and behaviour of the beach material, the submarine contours, and the regional geology. It is reasonable to suppose that if waves of given characteristics act on a beach composed of particles which are capable of being moved under the action of the wave forces, then the beach will take up a configuration or profile characteristic of the waves and of the beach material. This relationship was remarked upon by Cornish (1898) who defined the final beach configuration due to a given set of wave conditions as the equilibrium profile or regimen of the beach. Fenneman (1902) defined such a profile as "that which the water would impart if allowed to carry its work to completion" (p 1). This equilibrium form is probably seldom attained in nature. Whereas the hydraulic model is a valuable aid to the understanding of beach processes, the variability of wave conditions in nature, together with the lack of complete reaction by the beach, makes the problem of correlating model and prototype measurements correspondingly difficult.

Beach Profile

Beach profile is described by McKenna (2005) as a cross-sectional trace of the beach perpendicular to the high-tide shoreline and extends from the backshore cliff or dune to the inner continental shelf or a location where waves and currents do not transport sediment to and from the beach. Morton (1982) simplifies the definition by indicating that beach profiles are basically survey lines perpendicular to the shoreline in order to record the form of the beach at a given moment in time. By means of reviewed methodologies, profiling can be done to a point where safety allows (Maine Beaches Conference, 2011). Although McKenna's definition is best, it is not mandatory to profile to reach offshore limits where sediment transport seizes. Surveying techniques employed to measure beach slope is referred to as beach profiling. In other words, beach profiling is a simple surveying technique used to measure changes in the contour of a beach.

Beach profile applies to perpendicular cross-section with reference to the given beach contour. It may include the face of a dune or sea wall, extend over the backshore, across the foreshore, and seaward underwater into the nearshore zone or where safety may permit (Maine Beaches Conference, 2011). Beach profiling is a simple surveying technique used to measure changes in the contour of the monitored beach. Measurements are conducted along profile transects. The profile transect is a straight line running from the crest of the dune or other high point on the beach such as a seawall (starting point) to the waterline (Kench, 2008). Along the transect, measurements are taken at regular intervals allowing observations of the beach to be made. Each monitored beach has a number of profiles transects and each transect has a different number so that comparisons can be made between these various lines (Pethick, 1984).

Beach profiling is carried out to make it possible to measure changes in the distribution of sand on the beach. Tracking these changes over long provides data to identify seasonal, annual, and even track long-term trends in beach erosion and accretion. This data is used to inform beach management decisions at the local and state level. Beach profiles change depending on the time of the year within the annual beach cycle and, also, the elapsed time after a storm. Beach profile shapes are determined by waves, water level, and sediment grain size (McKenna, 2005). Beach profile studies give information on cyclic or seasonal morphological changes in the coastal area which are essential to identify the erosional and depositional features, which in turn help to understand changes in oceanographic processes in the coastal areas. (Anthony, Vanhee & Ruz, 2006).

Beach profile has several terminologies used to describe different aspects of it. For ease of reference, McKenna (2005) provides details on these terminologies. The backshore runs from the seaward-most dune or the cliff to the land and water intersection. One or more berms may appear on a beach, depending on seasonal changes in water level. Berms are flat areas created during times of accretionary wave conditions, typically during summer. The beach intersects the water at the foreshore, and the foreshore is typically a plane slope that extends over a water level range from low tide to high tide. During a storm, a vertical step or scarp may form on the berm (Selby 1985). The inshore covers the surf zone from the seaward end of the foreshore to past the seaward-most longshore sand bar, joining to the offshore. Several bars and associated troughs may appear on the beach profile.

Beach profiles fall between two extremes: those which are wide and relatively flat; and those which are narrow and steep. The gradient of beaches is dependent on the interrelationship between two main variables, wave energy and particle or grain size.

Methods of beach profiling

Different profiling techniques have been developed and used over the years, each one having its own merit. The exact techniques used for collection of the data can be decided on the degree of accuracy that each measurement requires and on the monitoring costs. For the case of the beach and intertidal zone the best method is beach profiling that provides both high accuracy and low cost (Serra & Medina, 1997). The accuracy of a beach profile is determined, by and large, by the spacing between the beach profiles (Irish & Lillycrop, 1997).

For the years preceding the 21st century, conventional techniques were employed for beach profiling. Very popular of such conventional methods was the Emery method, which was developed in 1961 (Cooper, Leggett, & Lowe, 2000). This method is based on the use of two graduated rods, whose alignment and reading of the intersection with the horizon allow for the determination of differences in level along the profile (Andrade & Ferreira, 2006). It proved to be cost effective and easy to use such that even with the development of modern technological equipment, the Emery-Method is still widely used (Chowdhury, Hossain, & Sharifuzzaman, 2014). As such, several beach profiling monitoring programs have employed it. For example, Turner et al (2016) used the Emery method to determine beach profiles of beaches in southeast Australia. Data was collected for 40 years (from 1976 to 2016), and the results showed that the Emery method was reliable. Similarly, Krause (2010) employed the Emery-Method (Emery, 1961) with some modifications for the repeated measurements of beach profiles between the years 1997 and 2001 in a coastal environment adjacent to mangrove in Brazil. The error measurements from their exercise showed that the method and the added modifications fulfil the need for a good beach profile measurement technique: It is (i) repeatable, (ii) accurate, and (iii) comparable with other method.

Despite the usefulness, ease of use, and cost effectiveness, the Emery method had it cons. Emery (1961) himself highlighted 3 of the shortfalls of the use of his proposed method:

- For long profiles, it requires a correction for the curvature of the Earth's surface (the horizon): when the correction is applied, the true slope is steeper than the measured apparent slope.

- When the horizon is not visible (e.g., in a lake, behind a tall dune, or on a foggy day), the approximate distance to a reference point must be known.
- Errors accumulate because elevation is obtained from the sum of differences of pairs of readings

As a result, some authors proposed and designed alternative profiling techniques that harness the advantages of the Emery method and eradicates its shortcomings. For example, Andrade and Ferreira (2006) designed a method which is based on the physical principle of communicating vessels, which states that a fluid in communicating vessels forms a surface in hydrostatic equilibrium. If both ends of a hose filled with water (communicating vessel) are equally graduated and placed vertically side-by-side, different readings of water level in them will indicate differential elevation.

Details of the materials, assemblage, and operations of his technique has been detailed elsewhere (Krause, 2010). The authors found that the differences observed between the proposed method and the total station readings were on the same order of magnitude as those reported by Emery (1961). It further constitutes a valid alternative to the Emery method because it shares most of its advantages over professional alternatives and overcomes a number of its shortcomings. The method (i) is faster, because the distance between the rods is adjustable to the shape of the beach profile and to the amount of detail required; (ii) does not require the horizon to be visible, allowing the use of this method over a broader range of situations, such as in lakes and in other situations of limited visibility either because of beach relief or weather conditions; and (iii) requires no correction for the Earth's curvature.

Delgado and Lloyd (2004) also demonstrated an improved method using a set square and horizontal bar; the equipment can be operated by one person and does not require use of the horizon.

Another alternative was employment of a frame of two horizontal and two vertical rods assembled crossing each other at right angles and an additional horizontal rod equipped with a spirit level; the elevation difference between the vertical arms was determined by applying the Pythagorean theorem on a triangle formed by the two horizontal and one of the vertical rods Puleo Pietro and O'neal et al. (2008).

Many of these alternative tools and methods to the Emery method have been specifically designed to be used on firm shores, i.e., sand or gravel beaches. However, muddy shores, which are sometimes covered with knee-deep sticky mud, have difficult working conditions. The soft substrate does not support the weight of the most commonly used equipment. These shores are generally wider than other types of shores, and longer profiles need to be measured. In addition, areas with semidiurnal tidal patterns with a macro-tidal range demand an easy, fast method, because the advancing tide inundates the lower shore relatively quickly. As such, Chowdhury et al. (2014) developed a method that uses simple equipment for shore profiling; the method is particularly suitable for mud flats with difficult working conditions, and where use of other simple methods is not convenient or is prone to errors because of unstable ground.

In more recent years (since the 21st century), beach profiling has been monitored to a large extent by remote sensing and GIS techniques. The use of RS and GIS for beach profiling has helped to eliminate the common problem of lack of information on the temporal scale at which beach profiles from conventional and alternative ways were considered. A number of authors have employed this sophisticated technique in beach profiling, with results of higher accuracy than conventional methods

Wave Energy

Field studies have shown a close relationship between the profile of a beach and the action of two types of waves namely constructive and destructive waves (Waugh, 1995; Davidson-Arnott. 2010). Constructive waves cause sediment to build up above the low water mark (LWM). They result from swell and are most common where the fetch is large. The wave length is large (up to 100m between crest) in relation to wave height (often less than 1m). Individual waves break near the shore and due to their flatness, are low in energy. As constructive waves commonly occur on beaches with a low angle, they have a wide area to cross and so the energy in the swash is soon dissipated, leaving a weak swash (Pethick, 1984). Consequently, sand and shingle are slowly but constantly moved up the beach. This will gradually increase the gradient of the beach and lead to the formation of berms at its crest, and especially on sandy beaches, ridges and runnels (Clayton, 1989).

On the other hand, destructive waves comb materials down the beach, depositing it below the LWM. They are common with beaches with short fetch. They are high and steep with small wavelength in relation to wave height. Individual waves break much offshore and due to their steepness are high in energy. As they are likely to occur on beaches with steeper angle their energy is concentrated upon a smaller area (Taylor & Stone, 1996). Although some shingles may be thrown up above the high water mark (HWM) by very

Beaches with fine sand are gentle in slope. The reason being that the smaller nature of the grains allows the sand to become compact when wet, significantly restricting the rate of percolation. In addition, the pore spaces in sandy beach stores water which further inhibits percolation allowing most swash to return as backwash (Clayton 1992; Waugh, 1995), there is little loss of energy here as smooth surface of sandy beach reduces friction and sediments are carried down the beach. These materials down the beach build up to form longshore bar at the low tide mark of many sandy beaches. This caused wave to break further from the shore, giving them a wider beach over which to dissipate their energy.

Beach sediment and particle size

Beach sediments are derived from a wide variety of sources, including cliff erosion, rivers, glaciers, volcanoes, coral reefs, sea shells, the Holocene rise in sea level, and the cannibalization of ancient coastal deposits. The nature of the source and the type and intensity of the erosional, transportation, and depositional processes in a coastal region determine the type of material that makes up a beach. In turn, the characteristics of the sediments strongly influence beach morphology and the processes that operate on it (Trenhaile, 1997).

The particle (grain) size of pebbles and other large clastic material can be measured with callipers while sieves are used for sand and other coarse beach sediments. A number of techniques are used to determine the size of finer sediments including Coulter Counters, pipettes, hydrometers, optical settling instruments, and electron microscopes. The grain size can be expressed using the Wentworth scale, which is based on classes that are separated by factors of two, so that each is twice the size of the one below. The term "grain diameter" can refer to several different things (Sleath, 1984):

- the mesh size of the sieve through which the grains are just able to pass;
- the diameter of a sphere of the same volume;
- the length of the long, short, or intermediate axes of the grain, or some combination of these lengths; or
- the diameter of a smooth sphere of the same density and settling velocity as the grains.

The weight-percentages of the sediment can be plotted against the diameter in phi units in the form of histograms or frequency curves. Grain-size distributions are most frequently represented, however, by plotting the grain size data on a probability, cumulative percentage ordinate, and the phi scale on an arithmetic abscissa. The percentiles on the cumulative size distribution can be used to estimate the mean, standard deviation, and other simple descriptive statistical measures, although the calculations can also be made by computer. For comparative purposes, sediment samples can be represented by the mean or median grain size, or by the size of the grain that is coarser than some percent- age of the sample.

There have been many attempts to identify origin, transport and depositional processes of sediments based on their size distributions. The grain-size distributions of beach sediments often consist of three straight-line segments, rather than the single straight line of a normal distribution plotted on a Gaussian probability axis. The three segments have been variously interpreted as representing: coarse bed load, fine suspended load, and intermediate-sized grains that move in intermittent suspension; the effect of packing controls on a grain matrix, the larger grains being a lag deposit, with the finest grains resting in the spaces between grains of median size; and different laminae in the beach, representing several depositional episodes.

A further possible explanation is that the segmentation of grain-size distributions on log-normal cumulative probability paper may reflect the use of an inappropriate probability model. The log-normal model poorly represents the extremes of natural grain-size distributions, which may conform much better to a hyperbolic probability function (Trenhaile, 1997). Some workers believe that the four parameters of a logarithmic hyperbolic distribution are more sensitive to sedimentary environments and dynamics than the statistical moments of the normal probability function, but others have found that there is little difference (Sutherland & Lee, 1994). Grain sizes may also be fitted to a skew Log-Laplace model, a limiting form of the log-hyperbolic distribution which is essentially described by two straight lines, and is defined by three parameters (Fieller, Gilbertson, & Olbricht 1984).

Textural Characteristics of Sediments

Different authors have conducted different beach profiling assessments in different countries and have arrived at different results, mainly due to differences in methodologies. Abdulkarim et al (2015) in Nigeria used the Traditional grain size measurements to evaluate the beach profile of Badagry and Alpha beach sand to establish the variability in grain sizes along beaches. Similarly, Abuodha (2003) in Malindi Bay coast, Kenya used the traditional beach profiling technique to establish grain size, heavy mineral content and source of sediment. In South-West England, Oyedotun (2016) also used the traditional grain size measurements to measure the degree of sorting, skewness and median grain size. A principal component analysis, supported by a cluster analysis, shows that 82% of the variance in the grain size distribution is represented by fine-medium-coarse sand, and 14% is represented by the coarse/very coarse sand component. The results reflect the combination of a marine sediment source and higher energy processes. Also, Preoteasa and Vespremeanu-stroe (2010) evaluated the beach profile and their results showed that, with a slight increase of the grain size from a south- north beach ridge plain a net difference in sorting pattern along transverse profiles from the northern side of the study area occurred. In addition, the results showed that beaches and foredunes exposed to the resultant wind drift direction respectively to the north and north-east, are better sorted than those disposed discordant to the resultant wind drift direction.

Rashedi and Siad (2016) established that sand that is characteristically fine grained are moderately well sorted to extremely poorly sorted. The sand distribution is strongly coarse and leptokurtic in nature. Abundance of the medium sand to fine sand shows the prevalence of comparatively moderate- to low-energy condition in the study area. Linear discriminate function of the samples indicates an Aeolian, shallow marine deposition environment and less influence of fluvial process.

Other authors used other beach assessment techniques other than the traditional ones. For example, Reniers et al (2013) used the rip current exchange experiment and Image analysis in California. Their results showed that grain size sorting is dominated by the wave-breaking-related suspended sediment transport which removes finer sediment from the shore and transports it both on-shore and offshore. Pentney and Dickson (2012) employed Photo-sieving (digital image analysis) together with traditional grain size measurements in Hawke Bay, New Zealand. Their results showed that Considerable portion of the manually sieved sample was less than 0.6 mm whereas digital processing resulted in a negligible portion of sediment smaller than 0.6 mm. Manual sieving confirmed a high proportion of sediment between 14 mm and 16 mm, whereas the digital image implied that the greatest amount of sediment was found at approximately 6 mm. In general, the image analysis method was not able to provide an accurate presentation of the grain size distribution, relative to the traditional method. However, some distributions did match closely, while other distributions had little resemblance.

Relationships between Morphological Parameters of Beach Sediments

Studies have shown a relationship between morphological parameters of beach slope, sorting and grain size of cross-shore sediment. Increasing slope angles are associated with increasing particle dimensions (gravel beaches are steeper than sandy beaches). According to Inman and Bagnold (1966) and Shepard (1963) grain size exert primary control on beach slope. McLean and Kirk (1969) also pointed out two additional factors that can influence beach slope aside grain size. These are the degree of exposure of the beach to wave action and the rate of erosion and accretion. Therefore, based on these, exposed beaches are gentle in slope compared to sheltered beaches. Episodic erosion results in the lowering of the beach profile with periodic accretion resulting in steeper slopes. This dynamic mechanism was confirmed by Wright and Short (1984) in their submission that high energy waves erode sediment from the back beach and redistribute on the beach face. Therefore, beach slope appears gentle during episodic erosion and steeper during low energy waves where there is accretion. It is therefore difficult to predict the slope of beaches based solely on the mean grain size diameter due to other controlling factors (McLean & Kirk, 1969).

The relationship between grain size and slope of beaches has been proven by many studies but its equivalent in shingle beaches are unknown or difficult to prove. It is even more difficult to prove it in beaches with mixed sand (Zenkovitch, 1967; McLean & Kirk, 1969). For the above reasons the condition of the beach during the time of sampling must be considered. Other morphological features such as sorting, skewness and shape parameters would also be significant. Sorting is likely to be more important on a mixed sand-shingle beaches where, because of the large variability in size present, the mean grain diameter can disguise a wide spread in sampled material (McLean & Kirk, 1969). Therefor three variables, beach slope, mean grain size and sorting are appropriate to be considered in beach sediment analysis.

Sorting is of great importance because there is a correspondence between grain size and sorting (Folk & Ward, 1957) and has been interpreted in two different ways by Inman (1949) and (Folk & Ward, 1957). Inman examined sorting in view of the fluid mechanism and concluded that the degree of bottom roughness, settling velocity and threshold velocity were the three controlling factors (that is sorting can be attributed to hydraulic forcing on the beach). On the other hand, Folk and Ward postulated a sinusoidal relationship between grain size and sorting. They attributed it to a source area effect, the constituent of beach sand whether gravel, sand or mixture of the two will influence sorting. Folk and Ward's hypothesis was confirmed by Blatt (1959) and thus Folk (1966) portrayed mean grain size to be a first order controlling factor making hydraulic forcing a second order controlling factor. It is therefore reasonable to conclude that, if Folk's hypothesis holds, then beaches with large variability in sediment grain size characteristics, grain size and beach slope relationship patterns may exist as a response to grain size and sorting variations. Specifically, if there is a characteristic curvilinear relationship between mean grain size and sorting, it is reasonable to expect equally characteristic effect on beach slope with sorting being dependent on size and beach slope dependent on sorting and size (Bascom, 1951; Medina et al, 1994).

Summary of the Chapter

The literature focused on the empirical and theoretical studies on the major areas of the study with the objectives in mind. Coastal erosion and mitigation in Ghana were reviewed to bring to bare the various methods used in holding the beach in place. It was found out from the review that the problem remains by transferring it to adjacent coastlines. This threw much light on the problem of the study. It also reviewed literature on the methods used to study the major issues such as beach profiling, textural characteristics and sediment budget. This gave an insight into the importance of employing the appropriate methodologies to achieve the objectives of the study. The model and conceptual framework showed the relationship between the dependent variable (beach slope) and the independent variable grain size and hydrodynamic forcing (waves). The framework enabled the work to be situated in its theoretical context.

CHAPTER FOUR

METHODOLOGICAL ISSUES

Introduction

This chapter presents the various methodologies applied to coastal erosion studies and discussed sample of analytical conceptual framework of the mitigation measures in order to choose a suitable methodology to guide the study. The chapter also provides a detailed description of the research design and strategies employed in the study including data acquisition, presentation and analysis.

Description of Data and Sources

The study employs a mixed approach using quantitative and qualitative data. Quantitative data consisted both primary and secondary sources with observations on the field. Primary data was on beach profiles and native sand samples collected on the field along profiles. The secondary data was collected on waves. Wave data was downloaded from the public dataset at the ERA Interim website from the year 2000 to 2017 at the grid point 1x1 facing the beach at the coordinates 6° N 2^0 W 5° S and 2^0 E, at a 12-hour interval. The parameters used were the 10 metre U wind component, 10 metre V wind component at a Step zero (0), the significant wave height (Hs) of combined wind waves and swell, the mean wave period and direction. The commonly used peak over threshold method (POT) was applied on Hs to select large wave conditions and identify local storms surges (Dorsch, Newland, Tassone,, Tymons, & Walker, 2008; Angnuureng et al, 2017). A 5–10% exceedance Hs is commonly adopted in scientific studies to define storm events (Dorsch et al., 2008; Rangel-Buitrago & Anfuso, 2011; Splinter, Carley, Golshani &

Tomlinson, 2014; Castelle et al., 2015). In this work, Hs values with a probability of occurrence < 5% were considered as major storms, ranging from Hs of 2.5 m to 3.0 m, based on a local definition of storm (compared to global figures of about 9m to 18m and above). A single storm is defined as a continuous period of Hs exceeding this threshold and lasting at least one tidal cycle (12 h), consistent with Senechal, Coco, Castelle and Marieu (2015) approach and particularly to account for the impact of tides.

Sampling Techniques and Procedure

The entire Ghanaian coastline was divided into three geomorphologic zones based on the coastline classification by Armah (2005) and Ly (1980). The West Coast which is about 95 km consists of fine sand, gentle beaches and coastal lagoons. The Central Coast is mainly an embayed coast of rocky headlands, rocky shores, littoral sand barriers, coastal lagoons and it is approximately 321 km. And lastly the East Coast, about 149 km, is mainly sandy beaches, characterized by coastal lagoons and the estuary of the Volta River (Armah, 2005).

Major coastal erosion structures (CES) of national projects along the entire Ghanaian coastline were to be included in the study for textural and profile analysis. This was to ascertain the impact of the different lithological units and hydraulic forcing on the coastline through cross-shore characteristics of sediments. However, the criteria for the selection excluded most beaches with CES, especially those found at the western and central shores. Abakam beach was the only central coast beach included in the study. Although several sections of the central coastline showed massive erosion activities with CES, most areas were noted for local mitigation measures that covered a lesser extent to meet the criteria for selection (less than a kilometre). They were mostly made up of sand bags, wooden structures and concrete materials that do not last long. For instance, the CES at Anomabo Beach Resort which was beautifully constructed, was privately owned, extend less than a kilometre and could not meet engineering standards. This was so because within a year of its construction, it was destroyed by wave action leading to severe erosion activity. No accretion and beach berms were observed hence their exclusion in the study.

Localities with well-defined mitigation measures (national projects), were considered for observation and analysis. A survey conducted by the researcher revealed that there were six major national mitigation measures along the entire coastline and these were located at Keta, Kedzi, Atorkor, Ada, Tema, Cape Coast (Abakam) and Takoradi. That of Amanful Kumah and some part of Elmina is ongoing and were not considered for observation. In addition, localised mitigation measure from the central section of the coastline (private project at Anomabo) was selected for observation. The mitigation measures were classified based on two options (hard and soft measure) of the shoreline management options by Brewster (2006).

Purposive sampling was used to select the coastal erosion structures (CES). In all, a total of five (5) CES at five (5) locations were selected based on the build-up beach in front of the CES. These build-up beaches were present at Kedzi, Keta, Atorkor, Ada, and Abakam, hence their consideration for observation.

Mapping and cataloguing of coastal erosion structure

Almost the entire coastline of Ghana was mapped to identify coastal erosion structures (CES) of both national projects and localised measure. The Google Earth platform was used to identify areas with CES. The limitation in using this platform was catered for by means of a field survey carried out to identify the localised measures which were so small in scale to appear on google map. In order to make it easier for identification and cataloguing the coastal erosion structures along the coastline of Ghana, the study area was divided into three sections; western, central and eastern based on the lithological make up (Armah, 2005). The western shore, comprising sedimentary formations is from Axim to Elmina, the central shore made up of igneous intrusions is from Cape Coast to Accra and the eastern shore is from Accra to Keta mainly sandy.

According to Wallens-Mensah et al., (2002) and Appeaning-Addo (2013), sheltered coasts are associated with the western shore of Ghana. These are associated with relatively low velocity tidal currents and mid to low energy, a condition that has led to the formation of marshes, mudflats that characterised the western shoreline. Beaches along the Western shoreline had different morphological settings that made it impossible to include in the study. Beach materials were mostly muddy with no accretion and berms due to the nature of the coast (sheltered coasts) mostly made up of estuaries and lagoons. Most CES were all the time reached by the mean sea level (MSL). The relatively shorter fetch (Figure 1) also reduced accretion along these beaches. Most of the CES found were very recent while others were ongoing. These were found at Elmina (some very recent and others ongoing at the time of survey), Takoradi (Nkontompo), Amanful Kuma (on going at the time of survey), Princess Town and Axim.

A basic database was constructed and filled with data from both existing records and field investigation. With these protocols the database was filled with information from all sections of the coastline on both localised and national mitigation measures that could be identified along the coastline from both secondary sources and from field observation. Once the data collection was complete, the data was analysed to identify overall findings with regard to the impacts and effectiveness of CES along the Ghanaian coastline.

Data Collection Instruments

The data collection instruments describe a set of instruments used in the various methodologies in the collection of the data. These include both traditional simple and modern sophisticated instruments. This include the Trimble Juno GPS, the Abney level, magnifying glass, a quadrant, oven, electronic scale, mechanical shaker, sand sack, crucible and crushing spoon. The purpose and importance of some of these instruments have been described below.

Abney level

The Abney Level is an instrument used in surveying which consists of a fixed sighting tube, a movable spirit level that is connected to a pointing arm, and a protractor scale. The Abney Level is an easy to use, relatively inexpensive, and, when used correctly, is an accurate surveying tool. The Abney Level is used to measure degrees, percent of grade, topographic elevation, and chain corrections. By using trigonometry, the user of an Abney Level can determine height, volume, and grade. The Abney Level is used at the eye height of the surveyor and is best employed when teamed with a second surveyor of the same eye height. This allows for easy sighting of the level and greater accuracy. A ranging pole can be marked at the eye height of the level user or the approximate location of the eye height of the level surveyor must be known of the ranging surveyor.

Magnifying glass

A magnifying glass (called a hand lens in laboratory contexts) is a convex lens that is used to produce a magnified image of an object. The lens is usually mounted in a frame with a handle. This was used to read values on the Abney Level since they were very small.

Quadrant

The quadrant was a piece of metal divided into equal sections. It was placed at the sampling spot to take samples from a specific section all the time to ensure consistency in sampling.

The global positioning system

The Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations. GPS uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters. The GPS was used to take coordinates of profile lines and sample spots to draw the map of the survey areas.

The oven, electronic scale, mechanical shaker, crucible and crushing spoon are instruments used at the laboratory on grain size analysis. The oven was used to dry the beach sediments which was quickly weighed in a crucible after drying since beach sediment attracts atmospheric moisture and becomes wet again. When the sediments became bulky, the crushing spoon is used to make the sediments loose before weighing. The sediments were place in a sieve with sizes ranging from 4000 μm to 63 μm. the mechanical shaker was used to separate the grains according to their sizes.

Data collection sheets

These sheets were designed to record information (data) on the field (profiling and sediment sampling) and in the laboratory (weighted grain sizes). In order not to forget information gathered on the field, they were entered right away on the data collection sheets. The profile data sheet was used to record any observed occurrences such as erosion from storm events, human activities and interference. It also indicated the date or period of survey, the study site/location (study beach), and the surveyors' names.

Table 1: Beach profile data sheet

Beach profile data sheet

Site Name:
Date: Surveyors:
Observations:

Measurement down from the top of the reference mark: ......m

Beach segment	Length of segment/distance (meters)	Slope angle (degrees & minutes)
A-B		
B-C		
C-D		
D-E		
E-F		
F-G		

Source: Adapted from Woods Hole Oceanographic Institution Sea Grant

The weighted grains size sheet was used to record the weight of grain sizes under each sieve ranging from 4000 μm to 63 μm. This was done in accordance with segment across the beach. Therefore, grain sizes that fell under each size description were recorded under each segment.

Table 2: Weighted grain size sample sheet

Location:

Season : Date:

Profiles segments	Weighted Grain sizes (μm)						
	4000	2000	500	250	125	63	Below 63

Source: Author's own construct

Data Collection Methods

The following methods were used in collecting beach morphological data. This includes beach profiling, sediment sampling, pre-testing of the instruments and designed methodologies, and considerations and possible limitations during data collection.

Method of beach profiling

A number of authors have employed sophisticated techniques in GIS and Remote Sensing and conventional traditional methods of beach profiling, with results of higher accuracy. Since the study was time-bound the researcher devised a method by combining GIS and traditional method due to financial constraint, inadequacy of some equipment, and lack of personnel in handling sophisticated tools.

Protocols and schema for beach profiling

Precise measurement of beach volume and width of a beach which, when repeated over time, illustrate how the beach is eroding or accreting. Any changes occurring on the beach can be measured through profiling. The following protocols were used in profiling beaches.

A local reference point/starting point was selected. This was either a seawall, groyne, a dune crest or a tree (any physical object showing highest of the beach slope). The reference point was kept well identified by taking a photograph and measurement from the reference point to the starting point in order to use same point for future/subsequent measurement.

The profile was divided into segments based on the break in slope on the beach, signify a difference in beach slope. This was followed by the identification of the segments using both alphabets and Roman numerals tagged on a ranging pole. (e.g. Ai, Aii, Aiii, Bi, Bii etc). The vertical distance from the top of the reference point to the ground level and the observer's eye level to the ground were all marked and measured.

Next a telescopic levelling rod was placed at the first break on the slope with the sand covering only the tip (metal part) of the levelling rod (rod vertical and aligned with the reference point). The point on the rod that conforms to the observer's eye level was marked with a bright band, (in this case a red band) was tied around the rod (so it can be sighted with the Abney Level from a distance for angular readings). This was followed by using the Abney level to locate the observer's eye level on the rod. The distance between the poles was then measured as well as the angle by means of the Abney level. Moving a tape measure along the ground distance from the base of the reference point to the base of the telescopic levelling rod (length of slope) was determine. At this point a regular rod was placed in the exact position where the first segment ends. The telescopic levelling rod was moved to the next break in the slope. An observer stands next to the regular rod and use the Abney Level and the tape measure to take the slope and the horizontal distance respectively. This was repeated in all segments through the transect and measurements recorded on a data sheet. The data sheet contained a column for Observation where erosion, construction or any event that might affect the beach or unusual social gatherings were recorded. GPS points were taken along the segments where sand samples were collected, at where there was a break in slope.

Protocol for sand sampling

Sand sampling followed the same profile transects on the beaches. It was conducted across shore from the foreshore zone where safety permits to the reference mark or starting point for the beach profile. Using a ranging pole, a starting point was marked on the foreshore. Sections on the beach transect were marked with ranging poles ensuring a consistent interval between them (100 m apart). The Abney Level was used to measure the angles of the segments and recorded on a Data Sheet. Deciding on the sampling strategy is very important in reducing subjectivity and increasing the validity of results. In view of this a quadrat was used to select sediment for sampling.

The quadrat was placed in front of the ranging poles landward and sediment samples were collected from a designated square in the quadrat throughout the segments, after which sand samples were labelled according to location, date, and time (season) of collection. Anything which may affect the results was noted, for example, recent storms or management structures which may alter the composition of beach material.

Pre-testing of Data Collection Instruments

Instrument for data collection was designed and pretested at Anomabo and Abakam beaches. During testing it was realised that measurement was best during low tides and there was the need to start early in order to catch the two low tides periods of the day. Difficulties that arose from testing of instruments were addressed and corrected before setting out for actual data collection and this has been highlighted in the section on Consideration and Possible Limitations.

Considerations and Limitations

The varying tidal conditions affected access to beach and safety therefore tide times were taken into consideration before embarking on the fieldwork. Low tide times offered the best period to measure beach profiles but places a time constraint on the entire activity. This was overcome by starting measurement early (latest by 6-9 am and between 3-4pm to about 5:30 pm to 6 pm) and conducting most profiles at different locations simultaneously with the help of field assistants. It was important to ensure that the ranging poles were held straight and prevented from sinking into sand, both of which may affect height and angular readings. User error in taking readings with the Abney Level was catered for by using a magnifying glass and always made sure the Abney level was upright and the clamp was free before reading. Cleaning of the instrument after every field measurement was important to ensure the regular and effective functioning of the instruments.

It was necessary to use field assistants who were knowledgeable in the study area. However, picking field assistants without knowing them properly also posed danger to the researcher. In view of this, assemblymen and opinion beach slope and profile evolution based on the following regression equation (1):

$$Y = co + \sum_{1}^{n} c_k z_k + \mathcal{E} \qquad (1)$$

where *Y* is the response variable (slope), z_k the predictor or causative variable (grain size), *n* is the number of sample points (n $=42_{(d)}34_{(w)}$), *co* and $c_k$are the non-standardized regression coefficients and *ε* is the residual term. Forcing terms are considered independent. The relative contribution P(Z) of each forcing parameter is estimated from the ratio of individual variance to the total following Eq. (2):

$$P(Z) = 100\sqrt{\frac{\mathrm{Sk}}{\mathrm{Sy}}} (k = 1, 2, \dots 42_d 34_w \qquad (2)$$

where *Sk* is the variance of c_k $z_k$and *Sy* is defined as the sum of variances of all causative components $Sy = \sum_{1}^{k} c_n z_n$ to insure a total of 100%.

Beach volume analysis

In terms of management of the beach sediment sources, understanding the volume of material in the beach is critical. Consequently, beach volume and beach width were estimated. The beach profiles captured in the study were 2D cross section surveys of the beach surface, depicting the morphology of the beach at the time of survey. Such profiles can be used to provide an estimate of sediment volume contained within the beach by calculating the area underneath each profile. In order to achieve this the beach was modelled in a 3D to enable the calculation of beach volume since beach volume cannot be calculated from a 2D model profile. For this analysis, the landward horizontal position was fixed at either the known survey benchmark location or known location at the back of the beach (in this study, the seawall). The seaward boundary was also determined using the end of the shortest profile (so that the greatest temporal comparison could be made). Ideally this type of analysis would capture the entire active beach system, extending to offshore limit of about 2m below sea level (less than the normal depth of closure ,5-10 m below MSL), in order to evaluate the volume of sediment that can contribute to a beach.

However, the surveys were much shorter in extent, generally only capturing the back beach and upper intertidal portion of beaches excluding the vegetation zone. Consequently, the practicalities of the survey data have limited the analysis to the upper portions of the active beach system to the mean sea level (MSL). In this study, results are reported as volume of beach material per metre length of beach. It is reasonable to assume that longshore variations in beach morphology are unlikely to induce error over a width of one metre. The output from this analysis is expressed in terms of cubic metres of sediment per metre of longshore beach width (m3/m). The trigonometric formula used to calculate beach volume is stated below:

$$BV = \tfrac{1}{2}(bh)l \qquad (3)$$

Where b is the base area of the profile, h is the elevation, l is the length (horizontal distances between profiles). BV under each cell (segment) within the profile was calculated due to differences in elevation. Using the average elevation would introduce much error in the calculation. The total BV was estimated by summing the BV for the individual cells.

Wave analysis

Ocean energy comes in diverse forms such as marine currents, tidal currents and waves. Ocean waves transfer energy over a fetch distance with little energy loss. According to Vining, 2005; Angnuureng et al, 2013) waves are a steady source of power with an intensity that can be accurately predicted. Vining (2005) mathematical models were adopted to compute the wave energies from the wave data.

$$E = \rho_w g H_s^2/8 \qquad (4)$$

where E the energy in joules, ρ_w is the density of the sea water, Hs the significant wave height in meters and g, acceleration due to gravity.

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

Further a parametric analysis of wind wave data was done using the MATLAB platform to estimate the significant wave height (Hs), peak period (Tp) and wave direction (Wd) to establish storm surge levels within the survey periods. This enabled the estimation of the wave energy and storm duration and its impact on beach width, volume and erosion in general.

Analysis of grain size

Grain size parameters can be compared between pairs of sampling sites, considering the increase or decrease in three parameters at the time: mean size (*m*), sorting coefficient (*s*) and skewness (*sk*) (Pedreros, Howa, & Michel, 1996). Consequently, McLaren and Bowles (1985) and Gao and Collins (1992) presented eight cases that were theoretically possible out of which two were representative for a physical reality in non-extreme marine environment. If transport occurs from one point to the other, the possibilities are that:

- $S2 < S1$, $M2 > M1$ and $Sk2 < S1$. Meaning, in downstream direction sediment becomes finer, better sorted and more negatively skewed.
- $S2 < S1$, $M2 < M1$ and $Sk2 > S1$. Meaning, in downstream direction sediment becomes coarser, better sorted and more positively skewed.

Therefore, descriptive statistics were used to describe the textural characteristics of cross-shore sediment for skewness, sorting and median diameter. This was based on a combination of the GRADISTAT grain size distribution and statistic by Blott and Pye (2001) for skewness and the Trask's sorting index (sorting (*So*) and median diameter (*Md*)). GRADISTAT skewness is presented in Table 3 as follows:

Table 3: Skewness values for grain size

Description	Value(s)
very fine skewed	<-1.30
fine skewed	-1.30 to -0.43
symmetrical	-0.43 to 0.43
coarse skewed	0.43 to 1.30
very coarse skewed	>1.30

Source: Adopted from Blott and Pye (2001)

Classification of grain size

Grain sizes are classified by means of a grade scale. Sedimentologists have come up and used quite a number of grade scales for sediment size classification. Such scales include the Atterberg's, the Wentworth and the

Udden-Wentworth scales. The Wentworth's grade scale is a geometric grade sale with a constant ratio of half (1/2) between the classes. Each size grade differs from each other by the constant ratio half (1/2) (Krumbein & Sloss, 1963). This gives equal significance to size ratios whether in gravel, sand, silt or clay. Both the Atterberg's and the Wentworth grade scales sought the fundamental physical properties of sediment and provided means of standardising terminology. In this study the Udden-Wentworth scale which provides more details on the particle size was used.

The Udden-Wentworth Grade Scale

The Udden-Wentworth Grade Scale has been used for decades to describe the size of clastic sedimentary particles (Udden 1914; Wentworth 1922). Although some sedimentologists and geomorphologists consider it to be problematic in classifying extremely large sediments involving blocks slabs, monolith and megalith such as coastal boulders in storm and tsunami hazard assessments (Paris et al. 2011; Etienne and Terry 2012), it is accurate to use with grain sizes smaller than 4096 mm (Terry & Goff, 2014). Most sedimentologists have adopted the logarithmic Udden–Wentworth grade scale (Udden, 1914; Wentworth, 1922), where the boundaries between successive size classes differ by a factor of two.

Table 4: The Udden-Wentworth grain size scale for sediment

Sieve size	Millimeters	Microns	Phi	Wentworth size class
	4096		-12	Boulder
	1024		-10	
	256		-8	Cobbles
	64			
5	16		-4	Pebbles
	4		-2	
6	3.36		-1.75	Granules
7	2.83		-1.5	
8	2.38		-1.25	
10	2.00		-1.0	
12	1.68		-0.75	Very coarse sand
14	1.41		-0.5	
16	1.09		-0.25	
18	1.00		0.00	
20	0.84		0.25	Coarse sand
25	0.71		0.50	
30	0.59		0.75	
35	0.50		1.00	
½				
40	0.42	500	1.25	Medium sand
45	0.35	420	1.50	
50	0.30	350	1.75	
60	0.25	300	2.00	
1/4		250		
70	0.210	210	2.25	Fine sand
80	0.177	177	2.50	
100	0.149	149	2.75	
120	0.125	125	3.00	
1/8				
140	0.105	105	3.25	Very fine sand
170	0.088	88	3.50	
200	0.074	74	3.75	
230	0.0625	63	4.00	
1/16				

Source: Krumbein and Sloss (1963).

Analysis of sorting characteristics of sediments

Sediment textural parameters were also determined using the Trask's sorting index and the formula used in calculating the textural parameters was by both mathematical equation and graphical methods. The weighted sand samples were plotted on semi-logarithmic graph (semi-log graph) generated within the Microsoft Excel platform. This type of graph is best used in plotting exponential variables against a constant variable. In this analysis, the sieve sizes gave the exponential variables since each successive figure represents half of the preceding one. The semi-log graph or semi-log plot is a way of visualizing data that are changing with an exponential relationship. This kind of plot is useful when plotted over variables with 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.

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 (Krumbein & Sloss, 1963). Therefore, the corresponding cumulative curves were used to determine the sorting characteristics by means of the Trask's Sorting Index.

$$\text{The Trask's Sorting Index, } So = \sqrt{Q1/Q3} \qquad (5)$$

Where *So* is the Sorting Coefficient, *Q1* is the lower quartile i.e. 25% value, *Q3* is upper quartile i.e. 75% value (Krumbein & Sloss, 1963). The sorting coefficient (*So)* applies to silt, clay, gravels and sand. The sorting coefficient (*So*) and the median diameter (*md*) give clue about the formation of the clastic sediments. The *md* gives knowledge about the strength of the current that moved the material to their deposition sites whereas the *So* is an index of a range of conditions present during transportation of the sediments by the fluid (sea waves/currents). These include degree of turbulence, velocity, and distance of transportation.

The *md* 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 *md*, yet one sand may have a much wider range than the other. The difference is shown by means of the shape of their respective cumulative 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 curve) is a measure of the spread of the distribution.

Folk (1974) used standard deviation to describe the sorting characteristics of beach sediment. He described beach sediments with standard deviation less than 0.35Ø (phi) as very well sorted, 0.35-0.50 as well sorted, 0.50-1-00 as moderately sorted, 1.00-2.00 as poorly sorted and values greater than 4.00 as extremely poorly sorted. However according to Trask (1932) well-sorted marine sediments have *So* 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* index of 1.0 means a perfectly sorted beach profile. Therefore, the more nearly equal the two quartiles are, the more closely the *So* approaches 1.0, implying a perfect beach profile which is difficult to achieve (Dei, 1972; Krumbein & Sloss, 1963).

Here Trask's sorting index was adopted and generally, beaches with *So* values less than 1 were considered moderately sorted marine sediments

However, in describing beaches the terms “well sorted”, “moderately sorted” and “poorly sorted” were used relatively in this work. *So* values of wells sorted particles ranged from 0.10-0.59, moderately sorted from 0.60-0.99, 1.0 is perfectly sorted and above 1.0 are considered poorly sorted.

Theoretical and Conceptual Framework

The theoretical and conceptual frameworks help situate the stud in its theoretical sense. It helps brings out the relationships between the dependent and independent variables, the stokes laws explains the settling velocities of sediments in nearshore zones and the Total Suspended Sediments (TSS), their implications on erosion and accretion of beach materials.

Stokes Law and Total Suspended Sediments

For all particles, the forces of friction and buoyancy have a different dependency on size. Buoyancy is controlled by the particle’s volume which varies as diameter cube, while friction involves the cross-sectional surface area and so varies linearly with diameter (Hearn, 2008). This means that large particles are dominated by negative buoyancy and sink faster than smaller particles that are dominated by friction and positive buoyancy which suspends more easily. The application of this is in relation to the Total Suspended Sediment (TSS) in coastal basins. Smaller sediments are kept in suspension and larger ones are deposited onshore or offshore. The higher the TSS the more saturated the water becomes and erodes less. Locations with finer sediments have increased TSS and hence less erosion is experienced while locations with coarser sediment will increase erosion activities. However, this may be influenced by turbulence and local factors such as the presence of a cove, estuary and leads to deposition of the suspended load and erosion resumes as the water gets less saturated (Davidson-Arnott, 2010; Anim & Nyarko, 2017).

Conceptual Framework

The framework used in this study was adapted from McLean and Kirk (1969), with the original framework shown in Fig 4 and the adapted framework illustrated in Fig 5. The arrangement makes more explicit the relationships among the elements mentioned previously. Foreshore slope is seen as the. It is therefore the primary purpose of the study is to examine the relationships between size/slope and size/sorting in the light of hydrodynamic forcing, using morphological data from five beaches located along the Ghanaian coast.

The arrangement brings out clearly the relationship between the variable. Beach slope is the ultimate response variable, the dependent variable influenced by all the factors. It is seen from the framework that the level of dependency increases from the initial controls through beach material factors to the beach slope. In this arrangement, both textural (source area) characteristics and hydraulic factors are the initial controls

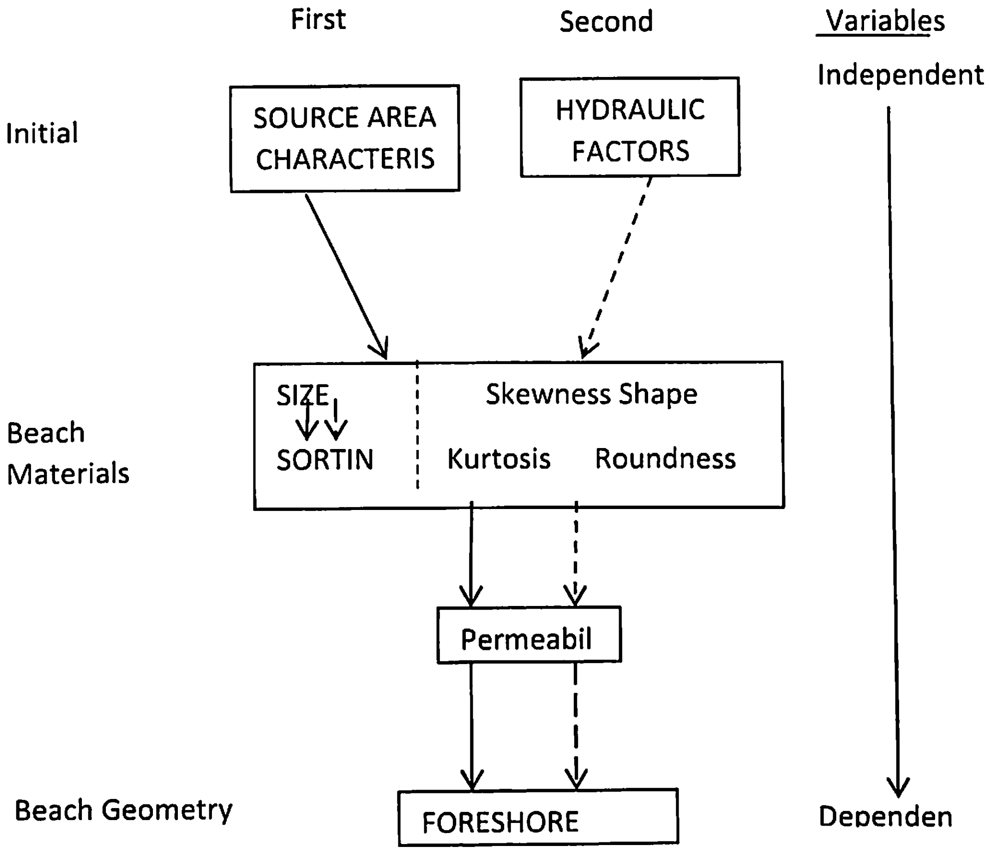

Figure 4:Conceptual model relating initial controls, textural characteristics and beach slope to show levels of dependency.

Source: McLean and Kirk (1969)

The first factor for consideration, the beach material contribution (provenance, erosion, and weathering) and provision of material to the shore, are considered in this context as constant. Following Folk (1966), the beach material properties itemised in the second row in Figures 4 and 5 closely reflect textural characteristics. The properties include particle size parameters of median grain size, sorting, skewness and kurtosis, as well as particle form characteristics such as shape, roundness, shape-sorting, etc. Of these, only the grain size (the significant and dominant) median grain diameter and sorting were investigated with the introduction of the median diameter in the adapted framework (Fig. 5). The median diameter is very useful in determining the sorting and the granulometric texture of the beach sediments, hence its introduction in the adapted framework. This made it easier to determine how fine or coarse the sediments were.

The small arrow from size to sorting indicates the dependence of sorting on size. Permeability intervenes between these material factors and foreshore slope; it is included for the sake of completeness, as it is via permeability that size and sorting influence foreshore slope. Krumbein and Monk (1942, *in* Shepard, 1963) have demonstrated that permeability varies with the square of the geometric mean grain diameter and in an inverse exponential fashion with degree of sorting. In the above manner, beach material characteristics are reflected in foreshore slope characteristics, via grain size and sorting and permeability as indicated by the solid arrows in Figure 4. It is argued that the overall beach slope patterns reflect these steps.

The second factors to be considered in the framework are hydraulic factors. Although shown in Figure 4 as an initial control, hydraulic factors are regarded as having a second order influence (McLean & Kirk, 1969) as indicated by the broken arrows. The overall energy environments of the five sites described are similar and can be roughly regarded as constant. However, significant variability within this broad pattern exists in both seasons with significant fluctuations in wave height, period and direction. It is anticipated that such variability in hydraulic conditions will be reflected, not so much in the overall size-slope or size-sorting patterns, but in their variability or spread. That is, fluctuations in hydraulic conditions will be represented in the variability in size-sorting values, which in turn will be reflected in beach slope-size variability.

With the introduction of the median diameter showing how the middlemost grain portrays sorting, the adapted framework for the study is illustrated in Figure 5.

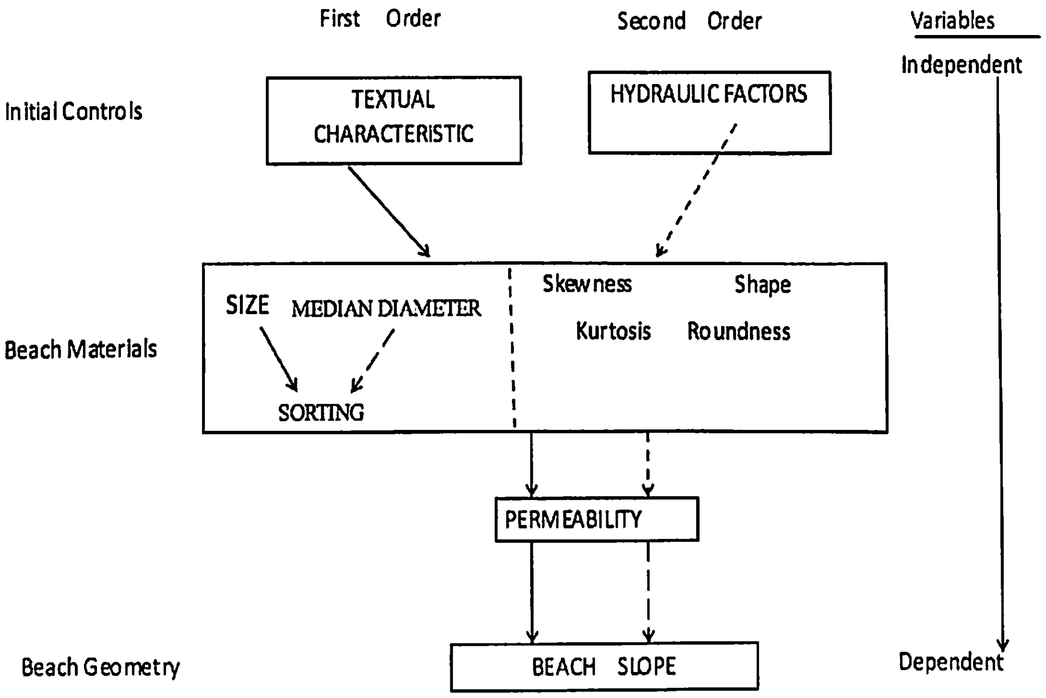

Figure 5: Conceptual framework for the study

Source: Adapted from McLean and Kirk (1969)

Utility of the Conceptual Framework

Fundamentally, frameworks are mental constructs representing some aspects of the real world. The conceptual framework was chosen and adopted for the study because of its ability to guide the study in observation, description, analysis and explanation of the relationship between grain size, sorting and beach slope in profile evolution that influence beach erosion in general. The framework is expected to simplify and facilitate the understanding of the processes that operate in the coastal basin (beach environment), factors influencing it and the impact on beach erosion in general. The framework also aids and facilitates the understanding of source material characteristics (textural characteristics) of beach sediments and the influence of hydrodynamic forces on these textural parameters that influence beach slope. The utilisation of basic principles underlying beach behaviour and the application of appropriate inferential statistics also informed the study to suggest a plausible cause and effect explanations for changes in beach behaviour and to provide the basis for predicting some outcomes of beach behavioural changes in the study sites and the coastal environment in general.

Summary of the Chapter

The chapter described the nature of study, the philosophical concept underpinning the research and data and their sources. The study was descriptive using the positivist approach where techniques for investigating phenomena based on gathering empirical and measurable evidence, subject to specific principles of reasoning. Primary data was on morphology of beaches and grain sizes while secondary data was waves downloaded from ERA Interim website. Mapping of coastal erosion structure was done through survey aided by the Google Earth platform.

The study employed a set of methodologies in collecting morphological data which included beach profiling, sediment sampling and weighted grains sizes to analyse beach morphological changes. This was made possible with the use of instruments such as the GPS which transferred profile lines on the study area map, the Abney Level, a quadrant, magnifying glass and data sheets. The data collection instrument was pre-tested to know the appropriate time and boundaries for measurement on the selected beaches.

The conceptualisation of the of the study made it more explicit the relationships between the variables. With the foreshore slope is seen as the response variable, the study was able to examine the relationships between size/slope and size/sorting in the light of hydrodynamic forcing.

CHAPTER FIVE

BEACH PROFILE

Introduction

This chapter discusses the outcomes of morphological data on beach profiles analysed for the five study sites with major coastal erosion structures (CES). A summary of the changes in beach volume and width are presented in Table 5. The results showed the current state and dynamics of each beach and identified whether there were any trends in beach behaviour. The analysis and interpretation of data collected for the beach profiles were intended to:

- Report basic status (beach condition) and trends in coastal profile for each beach.
- Discuss differences and similarities among the beaches analysed.
- Consider the beach budget and whether the beach is in a state of equilibrium or flux.
- Establish the spatio-temporal variations in beach width
- Discuss where appropriate, potential causes of changes in beach morphology
- Discuss the potential for each beach to contribute to the protection of the coastline and highlight areas where coastal erosion may require management action in the future.

Morphological Changes in Beach Profiles

The data were used to calculate the changes in beach volume and width, computing the averages for both variables. This helped establish the variations in beach state and to indicate beach conditions at the various study sites. Table 5 shows a summary of the morphological data on beach profile bringing out the change properties in both seasons.

Table 5: Summary of beach change properties in both dry and wet seasons

Study site	Season	TBV (m^3/100m)	ΔTBV (m^3)	ABV (m3/100m)	ABW (m)	ΔABW (m)
Abakam	Dry	10682.12	8197.79	1068.21	43.57	18.69
	Wet	2484.32		248.43	24.88	
Ada	Dry	27232.43	-1638.87	2723.24	76.81	-12.77
	Wet	28871.30		2887.13	92.58	
Atorkor	Dry	22115.14	2045.05	2211.51	62.04	7.82
	Wet	20070.09		2007.00	54.22	
Kedzi	Dry	2902.84	1301.59	290.28	106.47	34.39
	Wet	1601.25		-160.12	72.08	
Keta	Dry	3691.90	-3010.99	369.19	91.90	44.78
	Wet	680.91		-176.14	47.12	

Source: Field measurement, 2016-2017

Changes in beach width

The change in beach width (BW) was estimated by finding the difference between the width in dry season and that of the wet season. There was a general variability in beach width in all the five study sites, both spatially and temporally. The beach width of Abakam fluctuated about a mean position of 43.57 m in the dry season and 24.88 m in the wet season. There was a change in mean beach width of 18.69 m. This was an indication of a general increase in BW in the dry season.

Atorkor, Keta and Kedzi also appeared to follow the short-term trend of increased beach width in the dry season and a decrease in the wet season.

Atorkor had an average width of 62.04 m and 54.22 m (Table 5) in dry and wet seasons respectively with a change in ABW of 7.82 m. Kedzi and Keta had oscillatory mean width of 106.4 m and 72.08 m and 91.90m and 47.12 m (in dry and wet seasons respectively). The change in ABW of 34.39 m and 44.78 m respectively were all indicative of increase in BW which also implied accretionary state of the beaches involved. The mean values showed variability in beach width for both seasons with high variability in wet season (Table 5). Keta had the highest decline in BW in the wet season implying massive erosion. It was noted that ABW decreased substantially at the end of the wet season and increased post dry season in four study sites with the only exception being Ada beach. Short period oscillations are likely a function of periods of increased wave energy resulting from storms surges.

There was much variability evident at Ada. The Ada beach had a relatively wider width with a mean of 76.81 m and 92.58 m (Table 5) in dry and wet seasons respectively. This did not follow the usual trend of increased BW during the dry season. Ada beach increased considerably in width from 76.81 m in dry season to 92.5m (Table 5) in the wet season. Firstly, it suggests an adjustment in the longshore direction responsible for some of the variability seen within the seasons and is expressed as beach rotation according to Kench (2008). It is noticeable that through time these large variations are dampened and the beach readjusts resulting in little long-term change in beach width. Secondly, textural characteristics (beach material) may be a contributing factor and that will be discussed with the textural analysis of the beach in the subsequent chapter.

Changes in beach volume

Beach volume analysed under all five study sites showed considerable variability throughout the survey period. This was noticeable at all the five sites. The TBV at Abakam in the dry and wet seasons were 10682.12 m^3/100 m and 2484.32 m^3/100 m with ABV 1068.79 m^3/100 m. A change in TBV of 8197.79 m^3/100 m was significant to imply accretion in the dry season. The beach at Atorkor showed a considerable change in TBV up to 2045.05 m^3/100 m between successive surveys (Table 5), an indication of accretion in the dry season, while large variability in volume was noticeable within this short period. The TBV for Atokor in the dry and wet seasons were 22115.14 m^3/100 m and 20070.09 m^3/100 m respectively. It was noted that there was a sudden decrease in BV between the survey periods from June to July, 2016 where BV decreased by 2045.05 m^3/100 m by the end of the season. This was a function of a major storm event occurring between survey period from June, 2016 to July 2016. This was confirmed on the wave analysis in Figure 40 on page 163. At Ada, TBV for both dry and wet season were closer (27232.43 m^3/100 m and 28871.30 m^3/100 m respectively), with a deficit of 1638.87 m3/100 m. This implied less variability and rendered the beach quite stable throughout the survey period. Although BW increase substantially in the wet season (Table 5) it was not reflective in BV in the wet season. This was as a result of the textural characteristics of the beach which will be discussed in the next chapter.

The variation in beach volume at Kedzi was significant (2902.84 m^3/100m and 1601.25 m^3/100 m) at the end of the dry and wet seasons respectively) with change in BV amounting to 1301.59 m^3/100 m. The TBV in dry and wet seasons for Keta were 3691.90 m^3/100 m and 680.91 m^3/100 m respectively. This location was the most variable among the five study sites with a deficit of 3010.99 m^3/100 m. It was observed from the profile data that most portions of the Keta township were below sea level and this accounted for the high rate in erosion, hence the high variability.

Table 5 suggests some element of seasonality in BV which conformed to the seasonal variation in BW. There was an increase in both BW and BV in the dry season whereas these parameters reduced in the succeeding season. This suggests a host of variables, one of which being hydraulic forcing, impacted on beach BW and BV in all five study sites. These fluctuations (the highest at the end of the dry season and lowest in wet season) were noticeable in all the sites.

However, it is difficult to define consistent patterns in beach behaviour due to the short period of survey. The analysis does suggest that while the beach is stable in the long term, it is likely susceptible to seasonal variations based on changes in energy conditions between dry and wet seasons. It is however difficult to establish long-term trends in beach behaviour and therefore this was considered as seasonal variations due to the short length of record. The volume of sediment contained in all sites appears devoid of a long-term trend within the short dataset. However, there is a noticeable fluctuation in the volume in the short term. This readjustment showed a degree of seasonality. The volume was highest after the dry season (March surveys), whereas after wet season (October surveys) the volume was generally lower. The occurrence of a storm event increased the dynamic nature of the beach surface, explaining observed changes in BV. These observed changes showed the fluxes in beach state (erosion and accretion) which involved the redistribution of sediment from the beach face to offshore and along shore zones during storm periods (Davidson-Arnott, 2010). Although beaches showed a significant degree of seasonal variability with regards to volume, there was no underlying long-term trend with regards to volume due to the short duration involved, although there appeared to be a seasonality in beach volume between the survey period. The seasonality in beach volume explained why the mouth of most lagoons were closed to sea during the dry season and are opened during the wet season when storms erode the sand bars (Kwei, 1977; Anim &Nyarko, 2017).

In order to understand the dissipation of wave energy prior to reaching the cliff, the focus was on the cross-shore changes to the beach and, in particular, the variability of beach slope and the elevation of the beach. These morphological changes are discussed with the beach profiles subsequently.

Morphological Profile of Beaches in the dry and Wet Seasons

The morphological profiles of beaches in the five study sites in both seasons are presented in Figures 6 to 15. They depict the morphology of beaches in both the dry and the wet seasons.

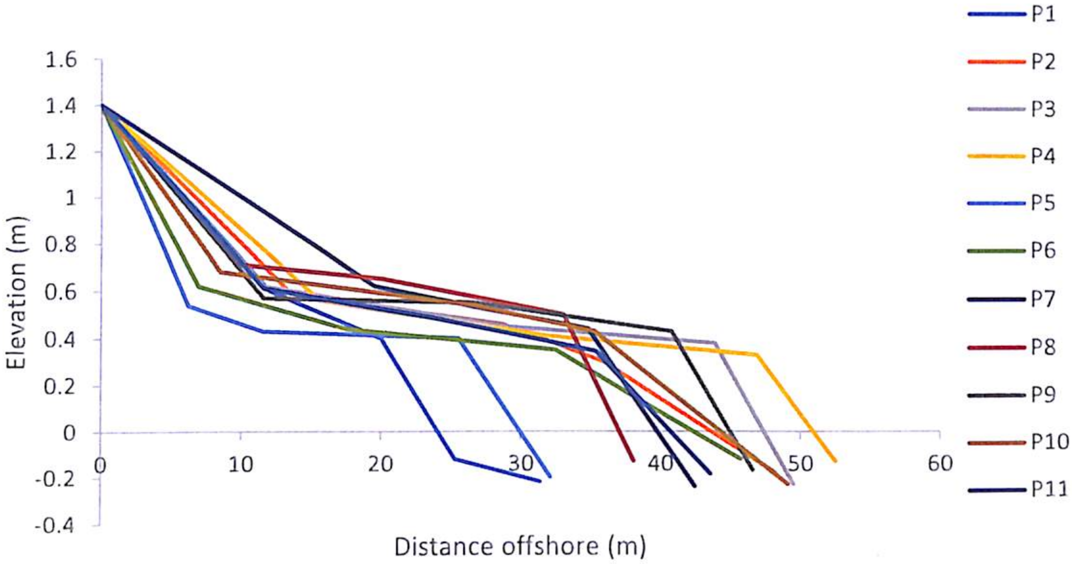

Figure 6: Beach profile of Abakam in the dry season

Source: Field investigation, 2016-2017

Figure 6 shows the profile at Abakam in the dry season indicating a short-term net beach accretion. The beach was generally gentle sloping, with steeper slopes towards the foreshore. This implied a low wave energy during dry season which mostly caused deposition of sediment. Beach width was generally increased with berms clearly formed indicating changes in tide levels.

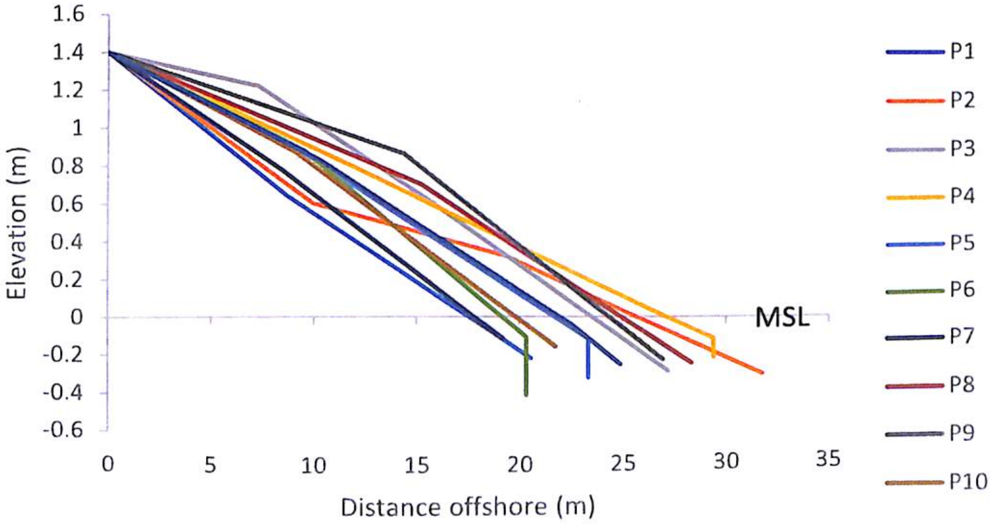

Figure 7:Beach profile of Abakam in the wet season

Source: Field investigation, 2016-2017

Figure 7 shows the beach profile at Abakam in the wet season. It showed a steeply sloping beach with few berms nearshore. Some profiles showed no change in slope (no berms formed) and only a single or two points were located, hence the almost straight profile lines. The beach showed active erosion which was indicative at the base of the defence walls which were exposed due to wave scouring.

The slope of the beach at Abakam remained 0.07^0 to 0.08^0 in dry and wet season respectively. The general elevation was 0.31 m to 0.17 m for both seasons. There was a decrease in elevation at the end of the wet season by 0.14 m (Table 14). The mean slope was close in both seasons while the elevation of the beach fluctuated in both cross-shore and along-shore with the lowest elevation and maximum cliff-toe exposure during the wet season (April 2016–October 2016). The decrease in the cliff toe elevation of 0.14 m between seasons was as a result the stormy conditions between June and July, 2016.

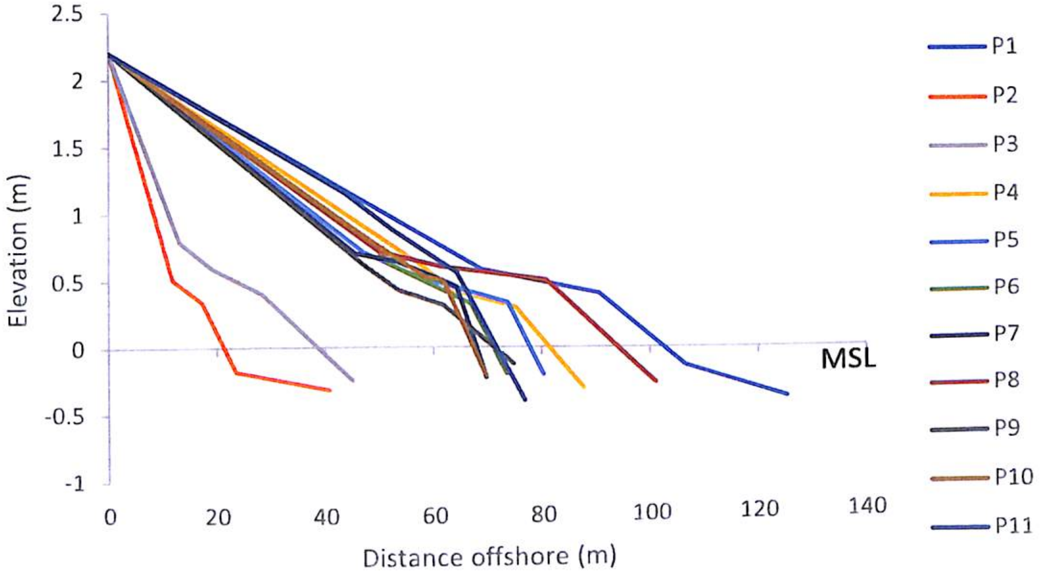

Figure 8: Beach profile of Ada in the dry season

Source: Field investigation, 2016-2017

Figure 8 is the beach profile of Ada in the dry season. The beach slope was generally low and gentle at the backbeach and increased slightly towards the foreshore zone. This implied dissipation of wave energy before reaching the backbeach in dry season. Hence the gentle slope at the backbeach. Berms were also confined to the foreshore zone. There was evidence of an increase in sediment volume contained within a number of profiles at Ada. However, increases in sediment volume are only noticeable on individual profiles and were not consistent across the beach.

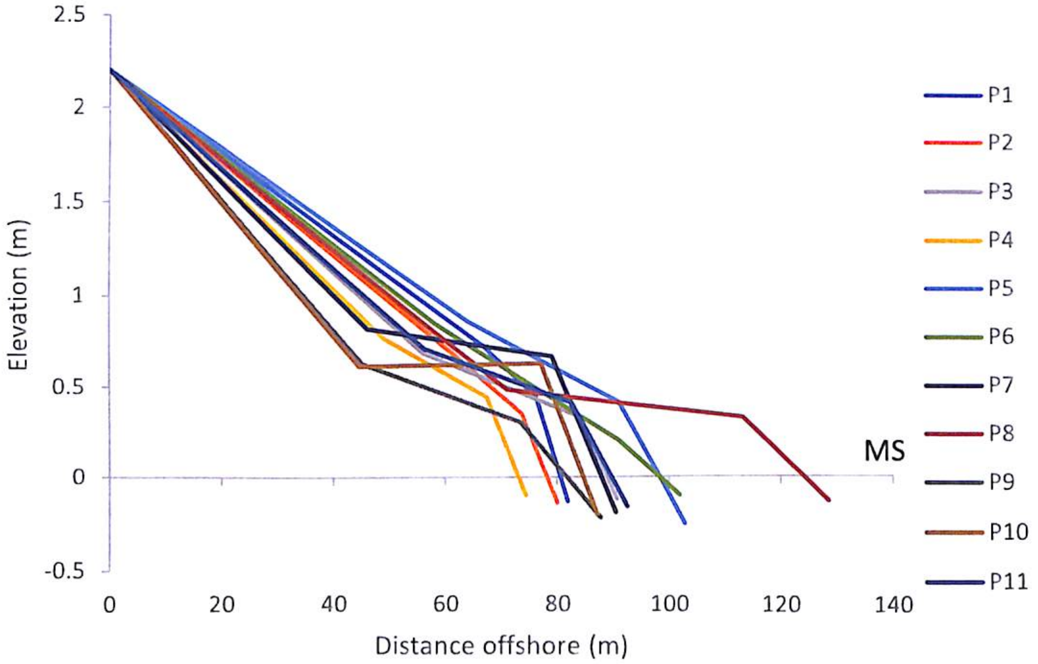

Figure 9:Beach profile of Ada in wet season

Source: Field investigation, 2016-2017

The Ada beach showed a general gentle backbeach slope with steep slopes shoreward. Development of berms were shoreward showing tide levels. The beach showed dissipation of wave energy as it approached the beach.

The general elevation of Ada beach was much higher in both the dry and wet seasons (0.54 m and 0.31 m in dry and wet season respectively) with a mean slope of 0.03^0 and 0.02^0 (Table 14). This implied relative consistency in wave energy while the elevation of the beach fluctuated slightly across shore and along-shore throughout the year with the lowest elevation and maximum cliff-toe exposure during the wet season (April 2016–October 2016). The stormy conditions between June and July led to considerable changes (decrease) in the cliff toe elevation of 0.23 m (Table 14) within a six to seven months' period.

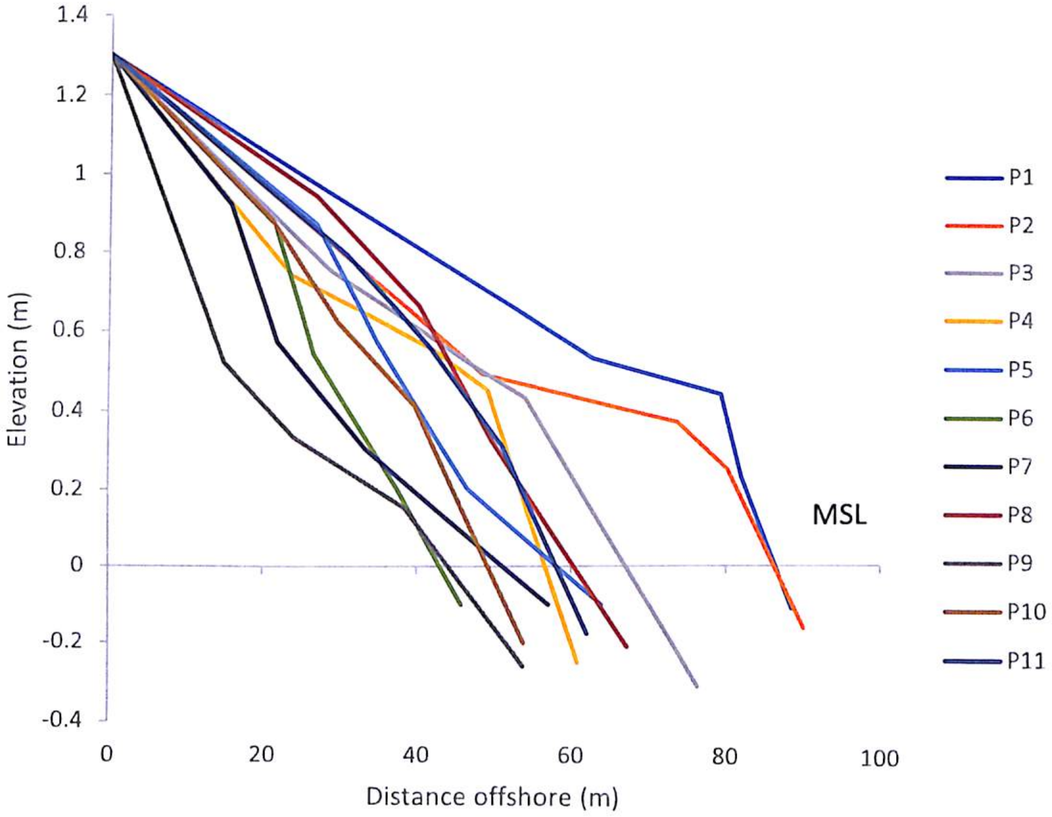

Figure 10: Beach profile of Atorkor in the dry season
Source: Field investigation, 2016-2017

Beach slope at Atorkor also followed the general gentle slope at the backbeach with steep slope foreshore. Berms extended from the backshore through to the foreshore zone indicating a regular and weak current during the dry season. There was a general increase in beach width (Table 5). Atorkor

(Figure 10) showed net increase in sediment volume in profiles and beach width resulting from accretion in the dry season.

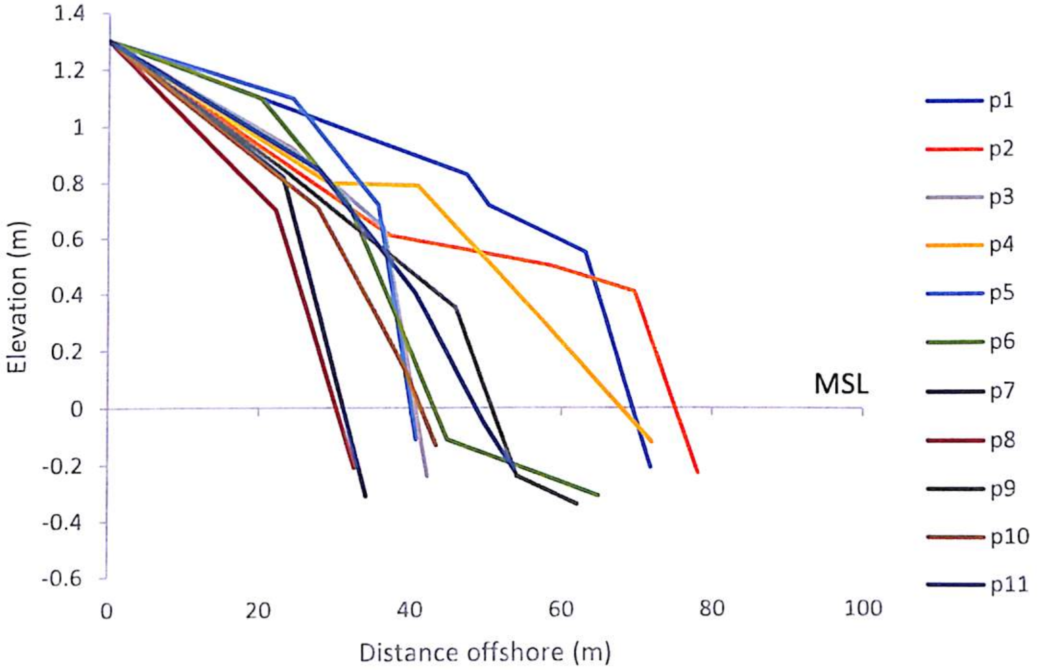

Figure 11:Beach profile of Atorkor in the wet season

Source: Field investigation, 2016-2017

The beach profile at Atorkor in the wet season (Figure 11) was steep slopping through the entire beach face. High wave energy reaching the backbeach eroded the cliff face and rendered the beach in its erosive state. This resulted from the strong backwash that carried sediment down the beach.

The mean elevation of Atorkor beach in the dry season was 0.37m as against 0.24 m in the wet season. Here again the general elevation was higher in the dry season compared to the wet season. A mean slope of 0.05^0 and 0.04^0 (which were close) were established for the dry and wet seasons respectively (Table 14). At Atorkor the mean slope remained almost the same while the elevation of the beach fluctuated across the whole beach in the cross-shore and along-shore. The morphological changes were similar to that of Abakam and Ada discussed earlier.

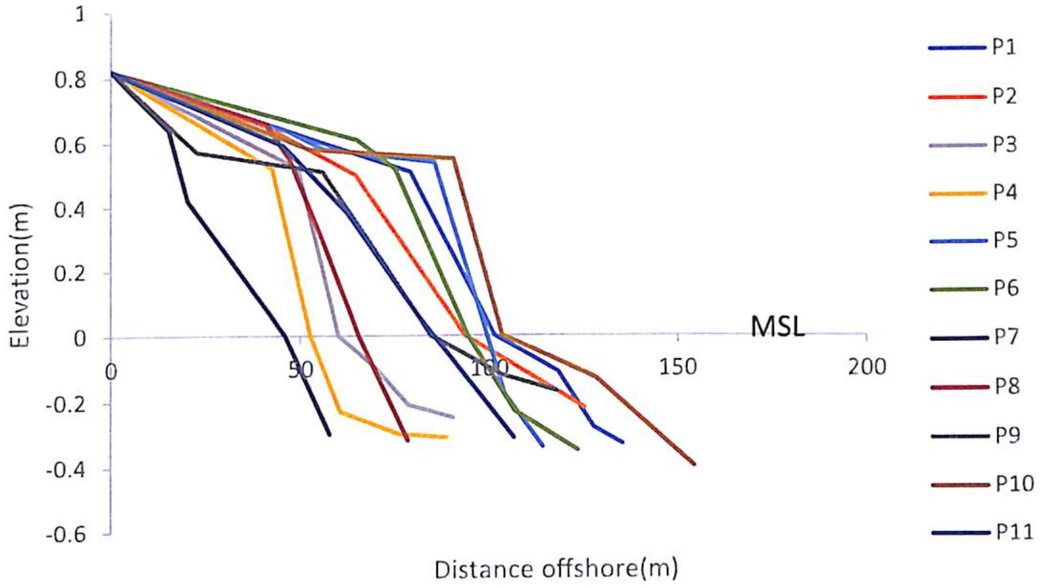

Figure 12: Beach profile of Kedzi in the dry season

Source: Field investigation, 2016-2017

The beach profile at Kedzi shows the beach undergoing active erosion and was considered less stable. The beach slope appeared relatively steeper compared to the other sites in the dry season. Some portions of the beach at Kedzi were below sea level and this led to active erosion even during dry season when the beach experienced low wave energy.

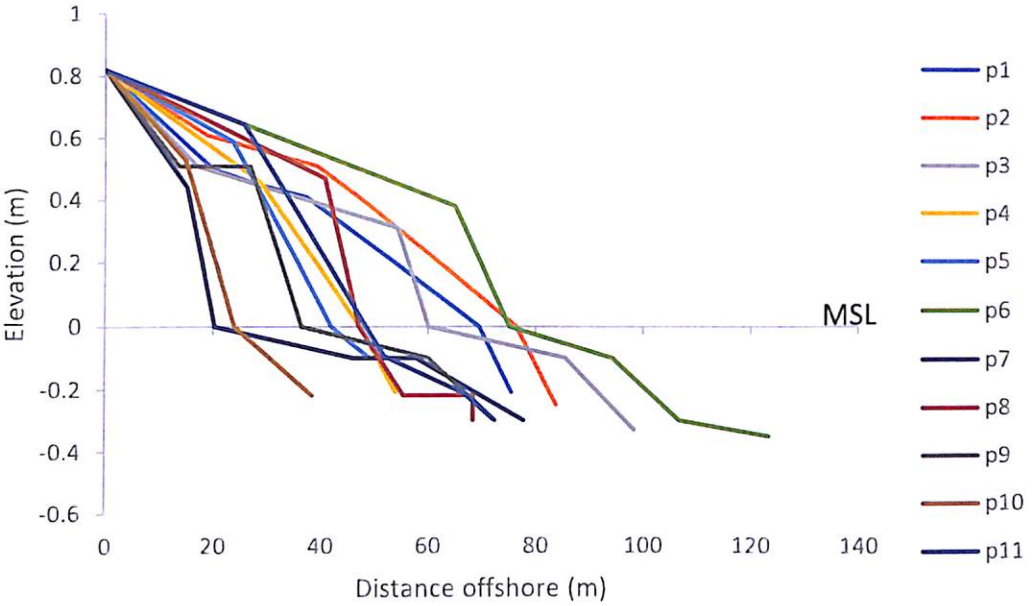

Figure 13: Beach profile of Kedzi in wet season

Source: Field investigation, 2016-2017

Erosion was much intense during the wet season depicting steeper slope through the entire beach face. Berms were very low in height with a reduced beach width in general. The strong backwash was able to erode sediment from the beach face and carried offshore, thus reducing the elevation. Both beach width and volume reduced drastically (Table 5).

The general elevation of Kedzi in dry season was low (0.11m) compared to the other sites. This reduced to 0.05 m in the wet season with a 0.06 m change in beach width. Beach width even reduced much more than what was established in the wet season (Table 5, Figure 13). The mean slope was 0.02^0 in the dry season and 0.05^0 in the wet season. It was observed that beach slope was steeper than in the dry season ($0.02^0 < 0.05^0$).

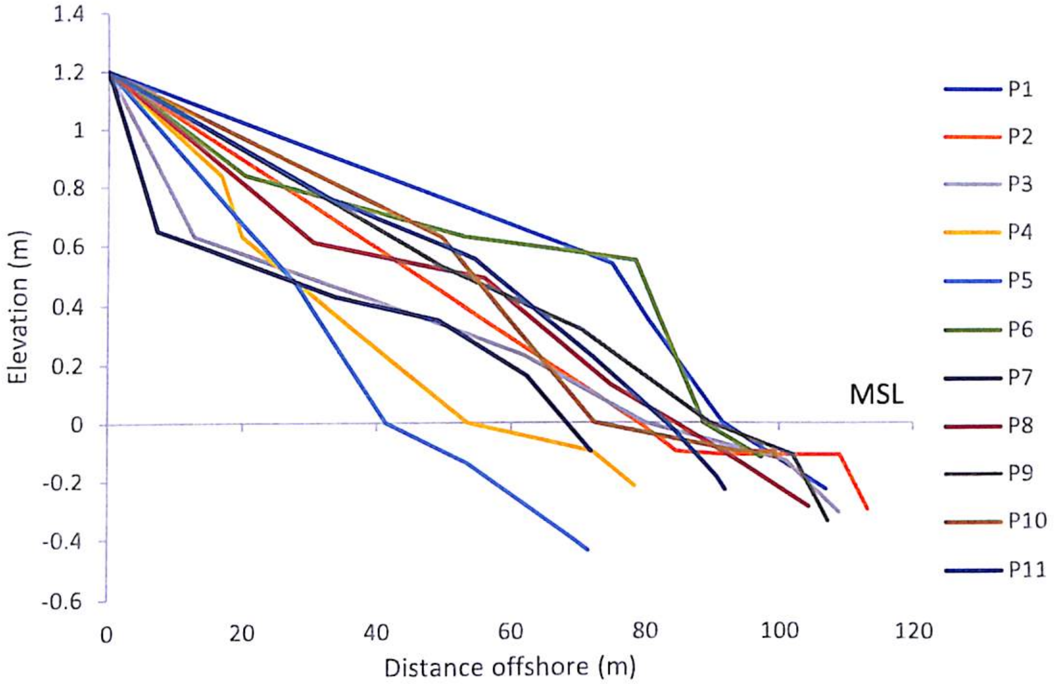

Figure 14: Beach profile of Keta in the dry season

Source: Field investigation, 2016-2017

The Keta profile in the dry season showed constructive waves. Most beaches berms of varying heights were generally low compared to berms developed in wet season. The domain in the upper part of the profile was a well-developed berm, a large runnel and a distinct ridge at the low tide level.

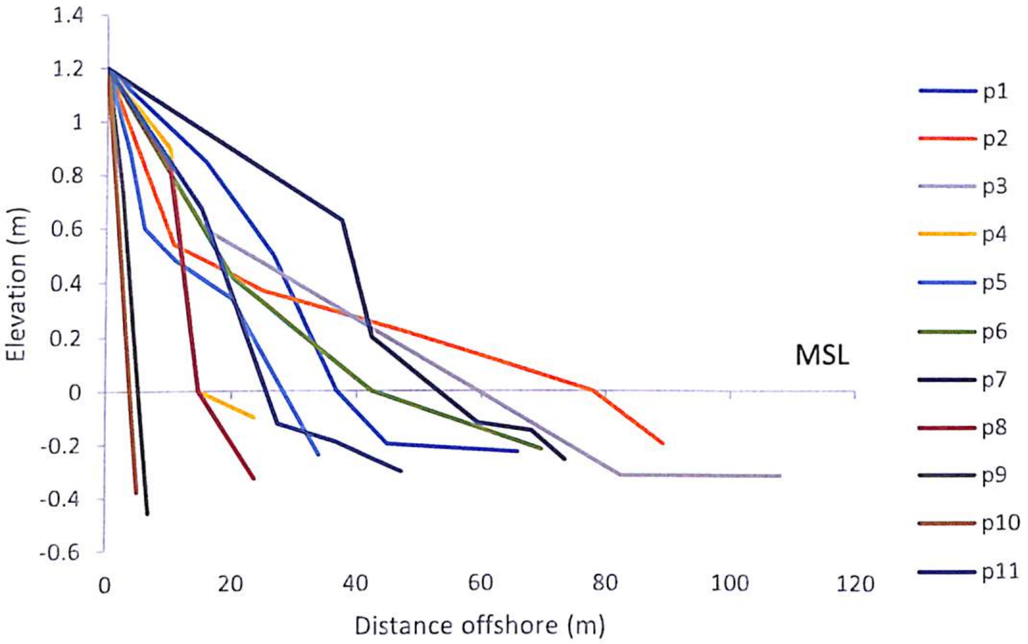

Figure 15: Beach profile of Keta in the wet season

Source: Field investigation, 2016-2017

The profile at keta indicated that most portions of the land were below sea level (Figure 15). As a result, change in TBV resulted in a deficit of -1930.4 m^3/100 m with an average beach volume of -176.14 m^3/100 m. Beach width also decreased substantially from 91.90m in the dry season to 47.12m in the wet season, a decrease of 44.78m, the highest reduction in beach width in all five sites. (Table 5). This implied active erosion in the area, hence the nation's attention towards the area.

The general elevation of Keta beach in both seasons were low (0.18 m) with the wet season having elevation below sea (-0.04 m) (Table 14). Keta is known to have portions of the land below sea level and this was confirmed in the beach profiles conducted. With a mean slope of 0.03 and 0.08 in dry and wet seasons respectively, the area experienced active erosion during the wet season. This was also confirmed in the beach volume analysis which showed a deficit of 176.14 m^3 /m (Table 5). The stormy conditions experienced in the wet season (June and July, 2016) led to considerable changes.

Morphological changes in mean profiles

The following figures present the morphological changes in the mean profiles of beaches in the five study sites.

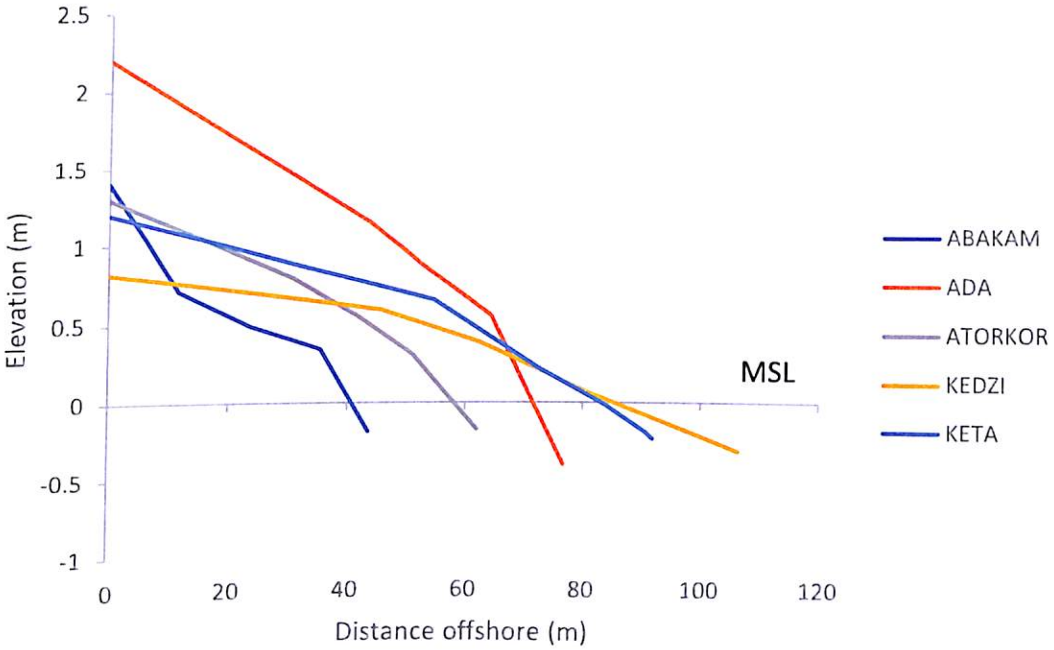

Figure 16: Mean profiles of the five study beaches in dry season

Source: Field investigation, 2016-2017

Beaches in dry season showed convexity in slope. The implication was accretion of sand that moved up the beach in response to low energy waves. Constructive waves caused sand to build up above the LWM. They resulted from swell which breaks nearshore and are flat (Davidson-Arnott, 2010). With a large fetch distance, as in the case of the study sites (Figure 1), the energy is soon dissipated leaving a weak swash (Pethick, 1984). Consequently, the weak swash slowly but constantly moved sediments up the beach. This gradually increased the gradient of the beach and led to the formation of berms at its crest, and because they were sandy beaches, ridges and runnels formed nearshore (Clayton, 1992). Table 4 indicated an increase in BV of leading to their generally increased elevation.

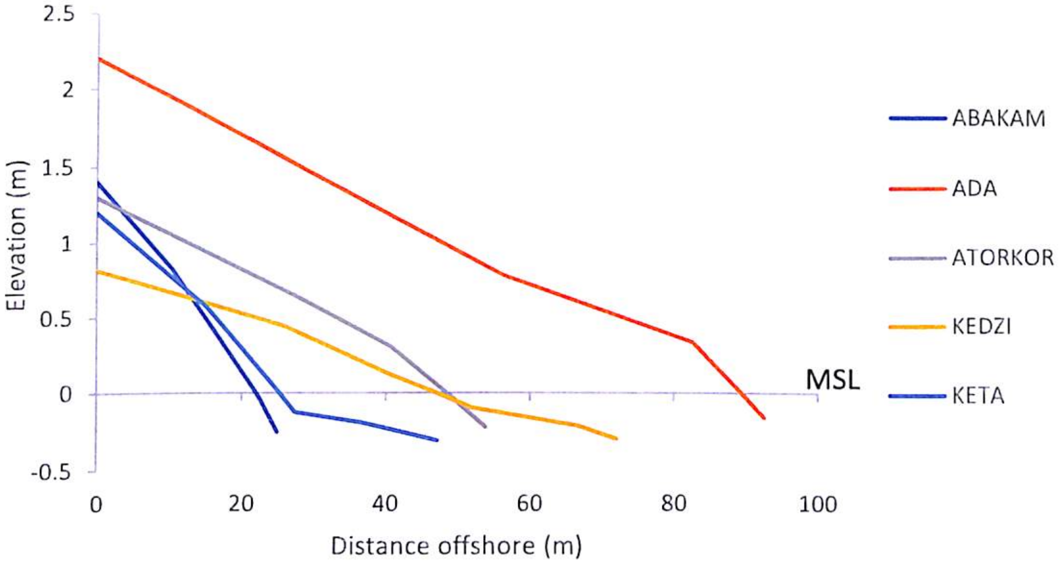

Figure 17: Mean profiles of the five study beaches in wet season

Source: Field investigation, 2016-2017

A critical observation of beaches in the wet season showed a concave slope profile. Despite their concavity they could not be said to be distinctively dissipative due to their generally gentle slope profile. However, they were rendered 'dissipative' type due to storm activities rendering them very steep. It showed a regularized concave profile, where the relief has been smoothened by higher waves reaching the upper beach. Destructive waves comb materials down the beach, depositing it below the LWM. Although individual waves break nearshore, due to their steepness, are high in energy as the energy is concentrated upon a smaller area (Taylor & Stone, 1996). Although some shingles may be thrown up above the High Water Mark (HWM) by very large waves, forming a storm beach, the strong backwash carries most material to form a longshore bar or a breakpoint bar. As material are constantly moved down the beach, the beach profile becomes increasingly gentler at the lower section. sediments were eroded from the upper beach and deposited on the beach face and offshore zone. Because it was indicated in Table 4 that deficit in sediment budget resulted in the wet season, it could be said that most sediments were lost offshore and alongshore with few being distributed on the beach face. Hence the generally low profile with steep slopping backbeach in the wet season.

During storm, a vertical step or scarp formed on the berms (Selby 1985). The inshore covers the surf zone from the seaward end of the foreshore to past the seaward-most longshore sand bar, joining to the offshore. Several bars and associated troughs appeared on the beach profile.

Summary of the Chapter

The analysis of the morphological changes in beach profile indicated variations in morphological parameters of beach width (BW) and beach volume (BV). Beach volume and beach width varied both spatially and temporally in all the five study sites in both seasons. Variability was seen within individual profiles and intra beach profiles. This brought about a characteristic change in individual beach state.

Beaches in dry season showed convexity in slope implying accretion of sand that moved up the beach in response to low energy waves, whereas a critical observation of beaches in the wet season showed a concave slope profile

However, erosion was noticeable in the wet season while accretion was in the dry season. Therefore, BW and BV generally increased in the dry season whereas there was a decline in the wet season.

CHAPTER SIX

TEXTURAL CHARACTERISTICS OF BEACHES

Introduction

This section discusses the textural characteristics of cross-shore sediment samples (first order control as indicated in the framework, Figures 4 and 5) in relation to profile evolution and their impacts on variation in beach width. Oceanographic forcing of waves (second order control) that generate storms, responsible for beach erosion and bringing variation in beach width, volume and profile evolution were also analysed in details. This helped examine the cross-shore particle size (grain size) distributions along the beach face and to find out the relation to the morphological changes in beach slope and profile in both spatial and temporal scales. This is also to find out the dominant and significant grain sizes that meaningfully influenced beach profile evolution and responses to hydrodynamic processes. The study related to the mechanics of the short-term variations in beach profile and grain size characteristics as depicted in the conceptual frameworks in Figures 4 and 5. This chapter thus examines how the initial controls of both first order and the second order affected beach slope. Therefore, analysis and interpretation of data in this chapter seeks to:

- Establish the significant grain size that influences beach slope
- Discuss the relationship between grain size and beach slope that influence profile evolution.
- Highlight the relationship between grain size and sorting in profile evolution.

- Examine, if possible, with the current dataset, potential relationships between grain size, beach profile and environmental variables such as changes in climate and hydrodynamics that needs to be considered in coastal erosion mitigation.

Influence of Particle Size on Beach Morphology

The influence of particle (grain) size on beach morphology was of two domains; the significant grain size influencing beach slope and the dominant grain size within all segments across the beach in the dry and wet seasons. These varied spatio-temporally and have been presented in Tables 6 to 9.

Table 6 is the summary of the significant grain size that influence beach slope in the dry season.

Table 6: The significant grain size influencing beach slope in the dry season

Study site	Grain size in μm					
	4000	2000	500	250	125	63
Abakam			45.89	42.83	11.26	
Ada		0.29	33.75	57.23	8.72	
Atorkor		24.34	10.81	59.13	5.69	
Kedzi			50.05	7.46	12.47	
Keta		13.19	77.99	7.15	1.65	

Source: Field and laboratory investigations, 2016-2017

Table 6 shows percentage values from regression analysis on grain size against beach slope in the dry season. This was run to determine the significant grain size that influenced beach slope. The analysis showed with a regression coefficient of 0.74, 0.64, 0.71 and 0.69 (all significant at 95% confidence level) for Abakam, Ada, Atorkor, Kedzi and Keta respectively, that significant grain size that influenced beach slope were the 500 μm and 250 μm in the dry season. This indicated a fine to medium sand grain based on the significant influence on beach slope compared to 500 µm and 250 µm. The 4000 µm and the 63 µm were practically insignificant on beach slope evolution in all the five study sites in the dry season.

With the significant grain size being the 250 µm and 500 µm beach slope was generally low and gentle. It also implied a relatively cohesive sediment indicating low permeability which increased wave runoff on the beach face, this moved sediments down the beach, further reducing the beach slope.

Table 7 Summarises the significant grain size that influenced beach slope in the wet season.

Wentworth size class (Table 3) for sediment (Wentworth, 1922) with scattered coarse grains sediments. From Table 6 it could be stated, generally that, significant grain size that influenced beach slope in dry season was the 500 μm since three out of the five study sites had their significant grain size to be 500 μm (that is Abakam (45.89%), Kedzi (50.05%), Keta (77.99%). At Ada and Atorkor, the 250 μm significantly influenced the beach slope in the dry season with 57.23% and 59.13% respectively (Table 6). The next grain size to have a significant influence on beach slope was the 2000 μm (coarse sand) at Atorkor and Keta (24.34% and 13.19% respectively). This exerted a relatively significant influence on beach slope compared to 500 μm and 250 μm. The 4000 μm and the 63 μm were practically insignificant on beach slope evolution in all the five study sites in the dry season.

With the significant grain size being the 250 μm and 500 μm beach slope was generally low and gentle. It also implied a relatively cohesive sediment indicating low permeability which increased wave runoff on the beach face, this moved sediments down the beach, further reducing the beach slope.

Table 7 Summarises the significant grain size that influenced beach slope in the wet season.

Table 7 depicts the influence of grain size on beach slope in the wet season. A large variability was observed in grain size that significantly influence beach slope both spatially and temporally in all the five study sites. The significant grain size that influenced beach slope ranged from 125 μm to 2000 μm, based on a regression coefficient of 0.64, 0.68, 0.76, 0.69 and 0.72 (all significant at 95% level) for Abakam, Ada, Atorkor, Kedzi and Keta (Table 7). Only Abakam showed consistency in both seasons with the significant grain size of 500 μm followed by 250 μm and 125 μm in succession. By implication the beach slope remained the same in both seasons.

The beach at Atorkor almost showed some consistency with significant grain size influence on beach slope. However, this trend was not consistent in the wet season and hence the beach slope varied in both seasons (very gentle in the dry season and relatively steep in the wet season). An interesting observation was at Ada beach where the significant grain size influencing beach slope was 2000 μm. This indicated a very coarse sand composition in beach material, thus a steeply sloping beach in the wet season. Coarser grans increased permeability or percolation as Waugh (1995) termed it. Increased permeability reduced wave runoffs (wave run-up) on the beach face. This reduced beach face erosivity and increased the beach slope (0.03^0) and elevation of 0.31 m, (Table 14), the highest beach elevation in wet season in all five sites). Reduced erosion due to increased permeability (percolation) was evident in the ABW at Ada (where beach width rather increased in wet season (Table 5) The coarse-grained sediment influx may be due to riverine sediment from the Volta estuary that were transported by alongshore drift. Also, high energy resulting from storm surge may have contributed to coarse sediment influx. High waves reaching the backbeach (mostly composed of coarser particles) eroded and redistributed sediment of the beach face (Wright & Short, 1984; McLean & Kirk, 1969) and this accounted for the coarse grain sediment in the wet season.

Again, there was much variation in significant grain size that influenced beach slope at Kedzi. Here the significant grain size was 125 µm, followed by 500 µm, 63 µm and 250 µm. It could be seen from Table 7 that the significant grain size did not constitute half of the beach material (less than 50%). This implied a mixed up of sediment (moderately sorted) confirmed in Table 10. Keta had 250 µm (44.63%) as the significant grain size in the wet season and its influence on beach slope was relative since it does not contribute to 50% of beach material (compared to dry season which was 77.99%). Per the percentage values of significant grain size at Keta it was assumed a mixed up of sediment which were moderately sorted (Tables 7 and 10), ranging from 500 µm to 63 µm in appreciable quantities. Human interference was also observed.

The 125 µm at Kedzi and 250 at Keta all signify fine particles. Therefore, permeability of percolation was minimal in these two sites. Minimal permeability means increased beach slope. The gradient of the beach was generally steep in the wet season where beaches experienced wave run-up and led low accretion (Imnan & Bagnold, 1966; Shepard, 1963).

Minimal permeability means increased beach slope. The gradient of the beach was generally steep in the wet season where beaches experienced wave run-up and led low accretion (Imnan & Bagnold, 1966; Shepard, 1963).

Dominant grain size within beach segments

The dominant grain size was analysed to establish which particle size dominated the beach segments. Table 8 shows the dominant grain size in the dry season.

Table 8: The dominant grain size in all segments in dry season

Study site	**Grain size in µm**					
	4000	2000	500	250	125	63
Abakam			21.6449	69.4939	8.8612	
Ada		5.3090	24.0403	64.2141	6.4366	
Atorkor		7.3824	20.2889	55.7569	16.5718	
Kedzi			34.9021	59.7869	5.3110	
Keta		13.6176	30.8993	31.3863	24.0968	

Source: Field and laboratory investigations, 2016-2017

Table 8 presents the dominant grain size across-shore in the dry season. Generally, the 250 µm dominated cross-shore sediment within segments across the beach in all five sites. This was followed by the 500 µm and 125 µm while the 63 µm, 2000 µm and the 4000 µm were insignificant (Table 8). This implied very fine grain size. The primary control that particle (grain) size exert on beach slope was confirmed in the analysis and field observations on beach in all five sites (Imnan & Bagnold, 1966; Shepard, 1963). All beaches in the five study sites appeared gentle sloping in the dry season due to the dominant fine granulometric size of the beach sediment. In effect, these beaches could be described as dissipative beaches.

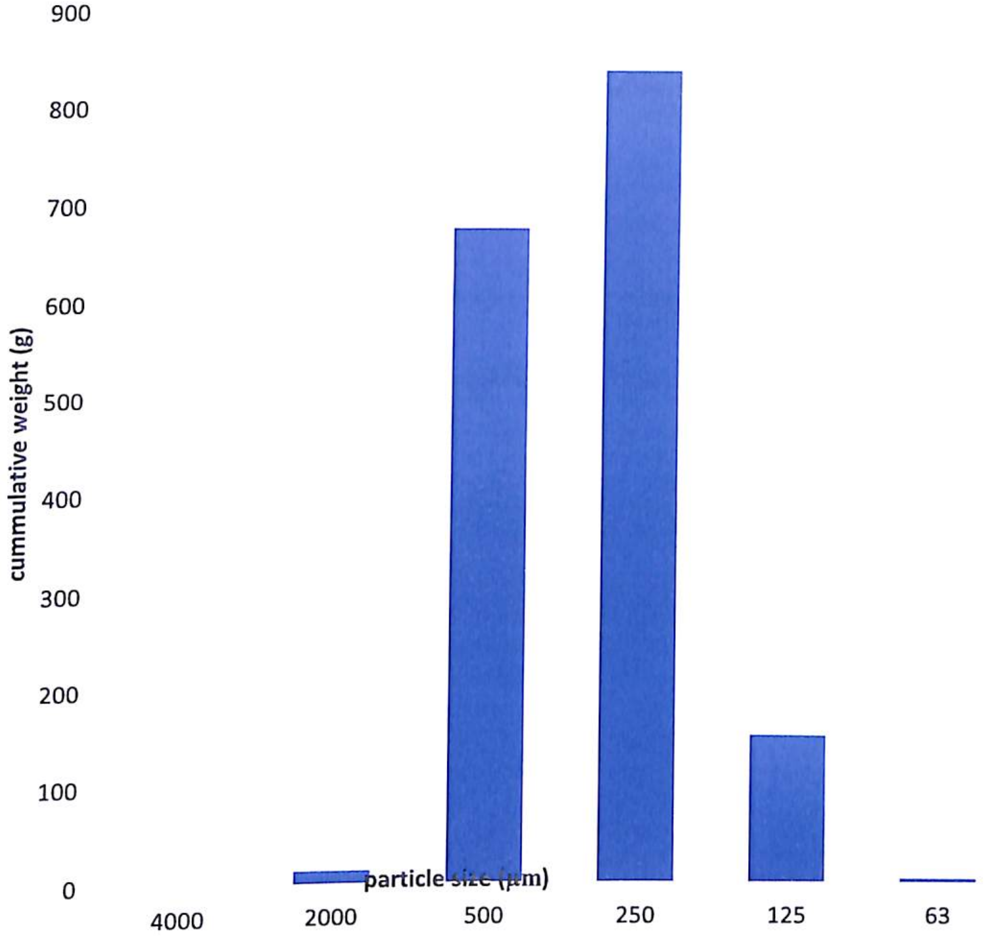

Figure 18: Dominant grain size at Abakam in the dry season

Source: Field investigations, 2016-2017

Figure 18 presents the dominant grain size at Abakam in the dry season. From Fig. 18, the dominant grain or particle size was the 250 µm, followed by the 500 µm, 125 µm, 2000 µm and traces of the 63 µm. The 4000 µm was absent in all the segments.

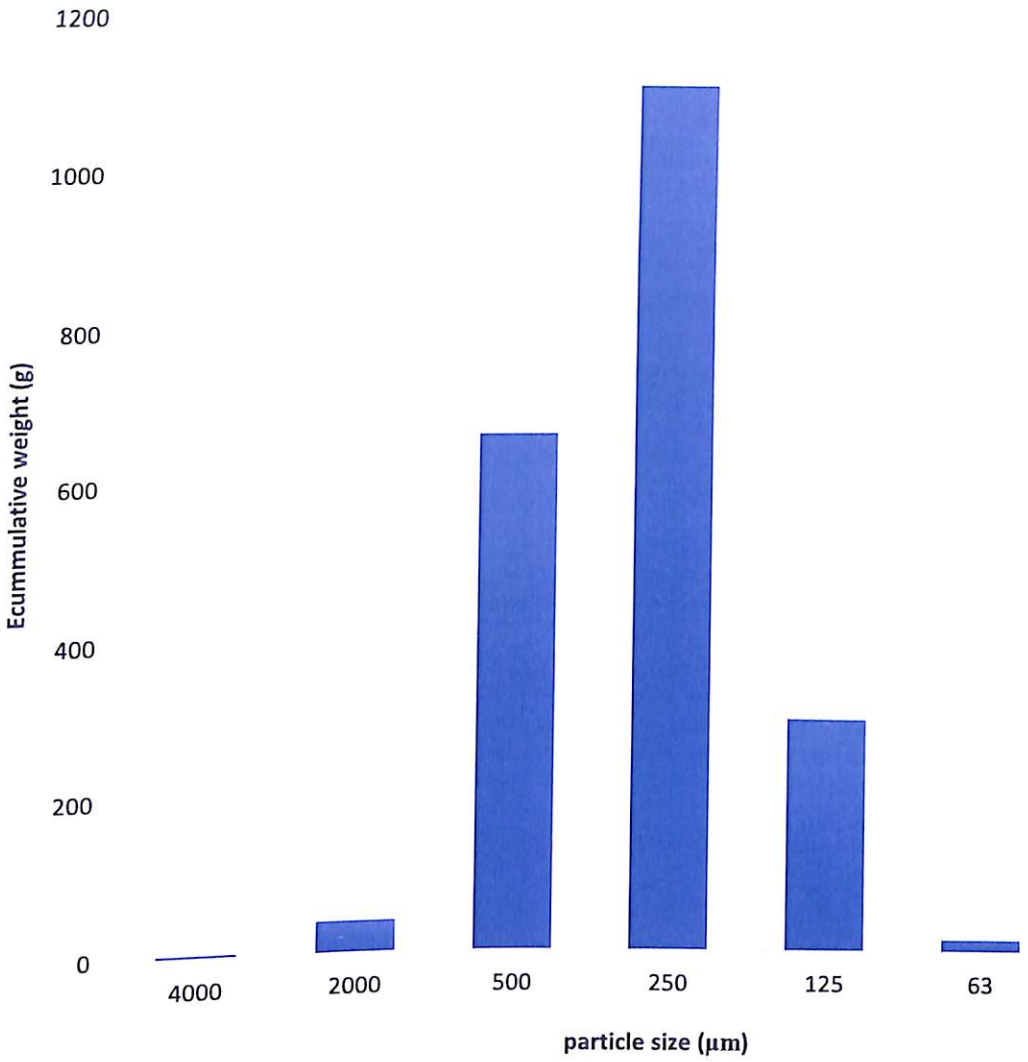

Figure 19: Dominant grain size at Ada in the dry season

Source: Field investigations, 2016-2017

Figure 19 shows the dominant grain size at Ada in the dry season. From Fig. 19, the dominant particle size was the 250 µm, followed by the 500 µm, 125 µm, 2000 µm and traces of the 63 µm. The 4000 µm was almost absent in all the segments.

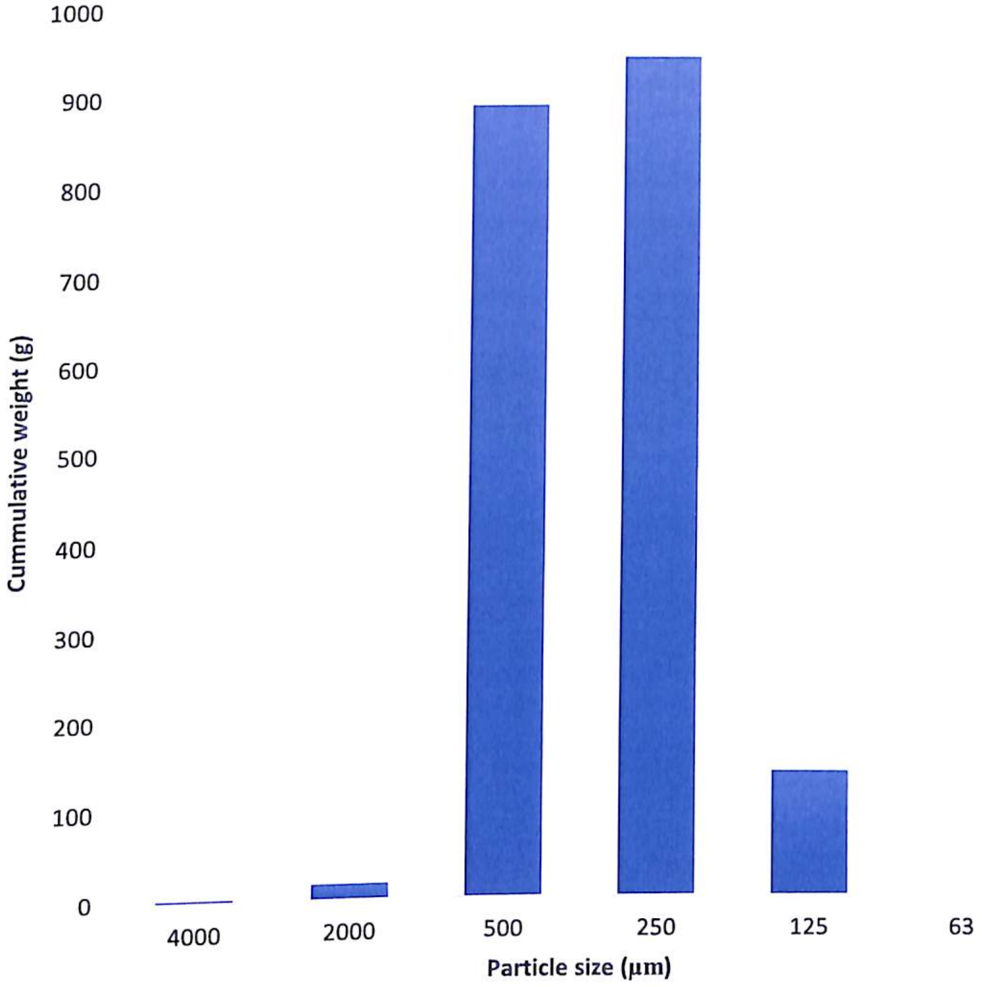

Figure 20: Dominant grain size at Atorkor in the dry season

Source: Field investigations, 2016-2017

At Atorkor (Fig 20), the dominant grain size in the dry season was the 250 µm, followed by the 500 µm, 125 µm, 2000 µm with the 63 µm and the 4000 µm almost absent in all the segments.

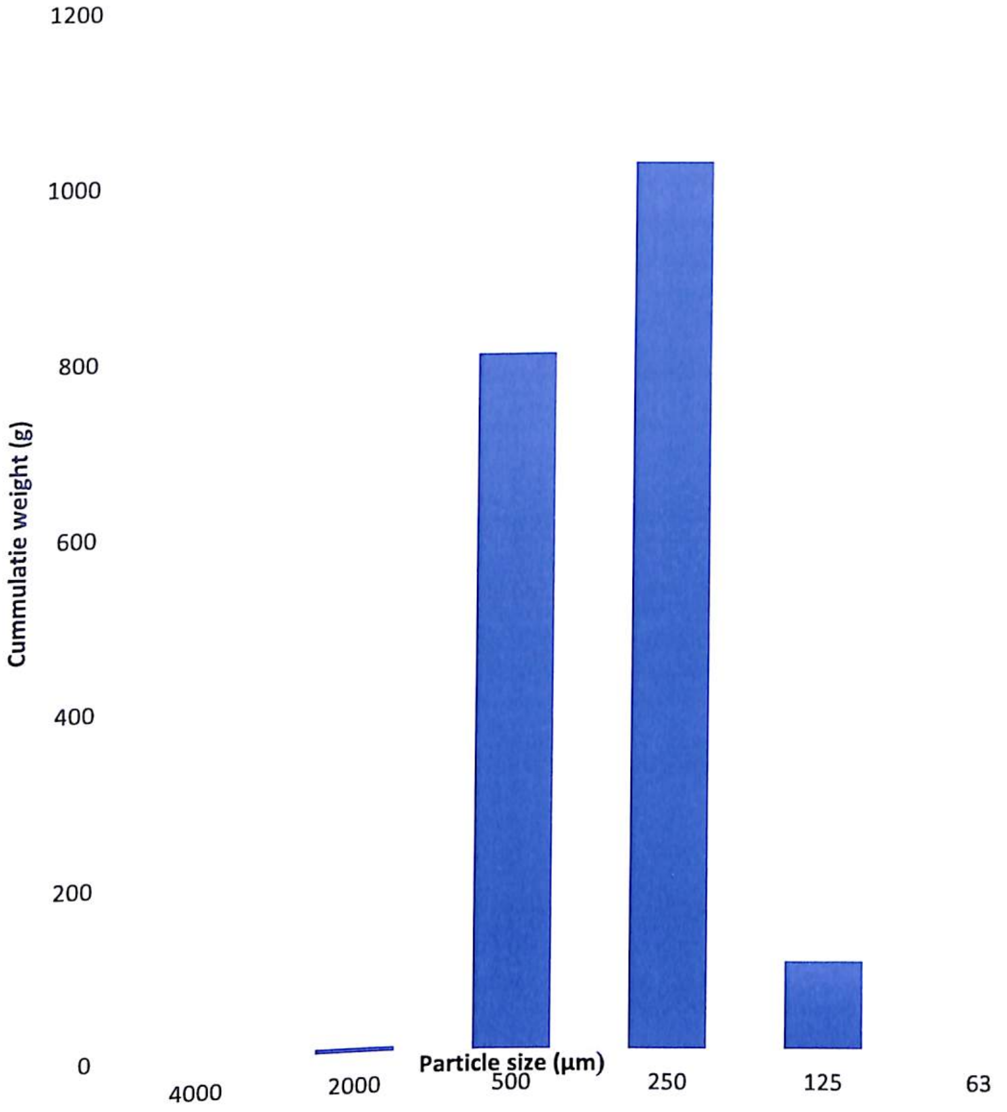

Figure 21: Dominant grain size at Kedzi in the dry season

Source: Field investigations, 2016-2017

At Kedzi in the dry season, dominating particle size was the 250 μm, 500 μm and the 125 μm. The rest (4000 μm, 2000 μm and 63 μm) were insignificant.

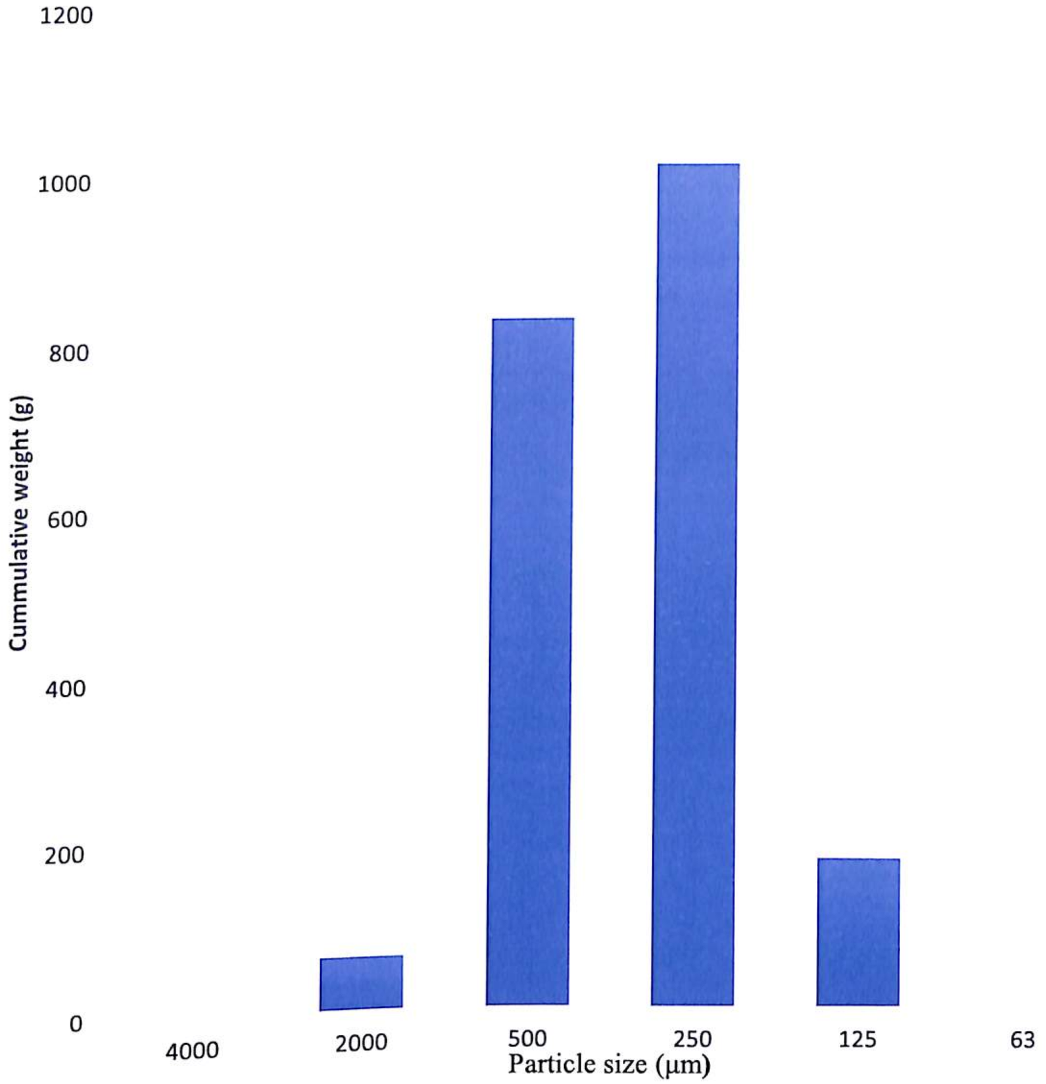

Figure 22: Dominant grain size at Keta in the dry season

Source: Field investigations, 2016-2017

The trend at Keta followed the same trend in the other four study sites with the 4000 µm and 63 µm being insignificant.

Sediment samples in the wet season were also analysed to establish the dominant grains size. Table 9 presents a summary of the dominant grain size in all segments in wet season.

Table 9: The dominant grain size in all segments in wet season

Study site	Grain size in µm					
	4000	2000	500	250	125	63
Aba			43.2977	35.5889	21.1134	
Ada		9.1839	54.3369	24.3738	12.1053	
Atorkor		1.7324	51.2454	42.0635	4.9587	
Kedzi			46.5207	48.0122	4.9372	0.5299
Keta			50.9127	29.1924	19.8949	

Source: Field and laboratory investigations, 2016-2017

Graphical presentation of dominant grain size in wet season

Unlike the dry season, there was variation the dominant grain size in the beach segment in the wet season. The dominant grain size ranged 500 and 250. However, it could be inferred from the frequency that the dominating grain size in the wet season was the 500 µm since one study site (Kedzi) had 250 µm as the dominant particle size. A summary of this is presented in Figures 23 to 27

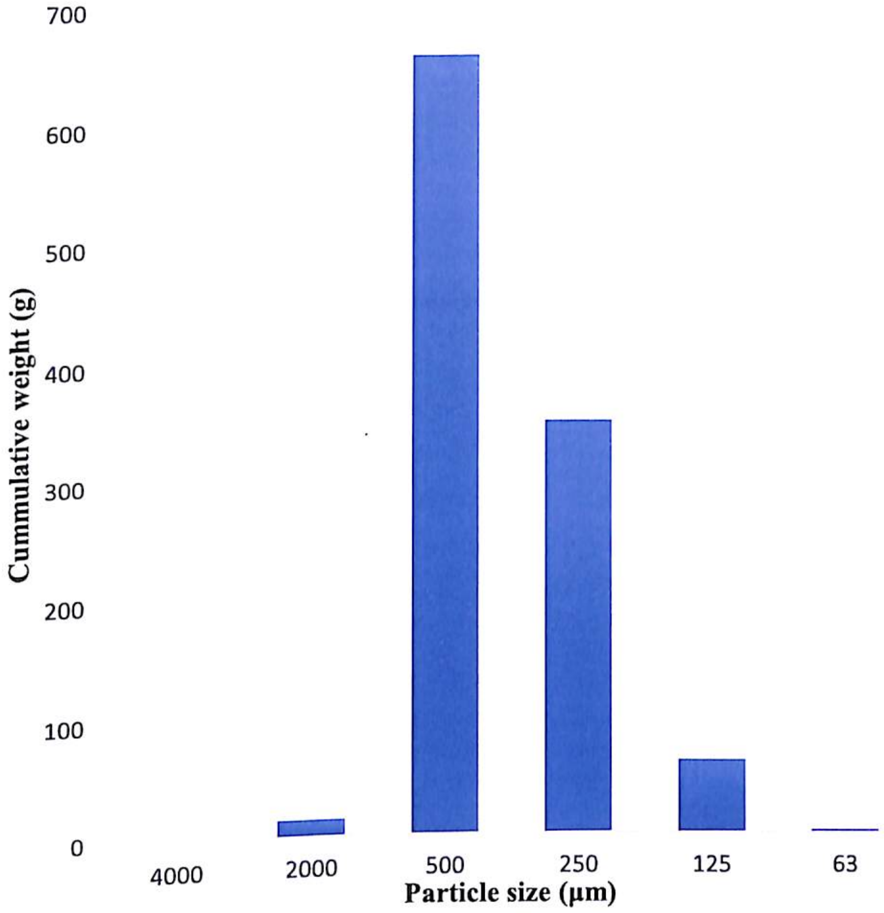

Figure 23: Dominant grain size at Abakam in the wet season

Source: Field investigations, 2016-2017

Figure 23 shows the dominant grain size at Abakam in the wet season. From Fig. 23, the dominant particle size was the 500 µm, followed by the 250 µm 125 µm, 2000 µm. The 4000 µm and 63 µm were absent in all the segments

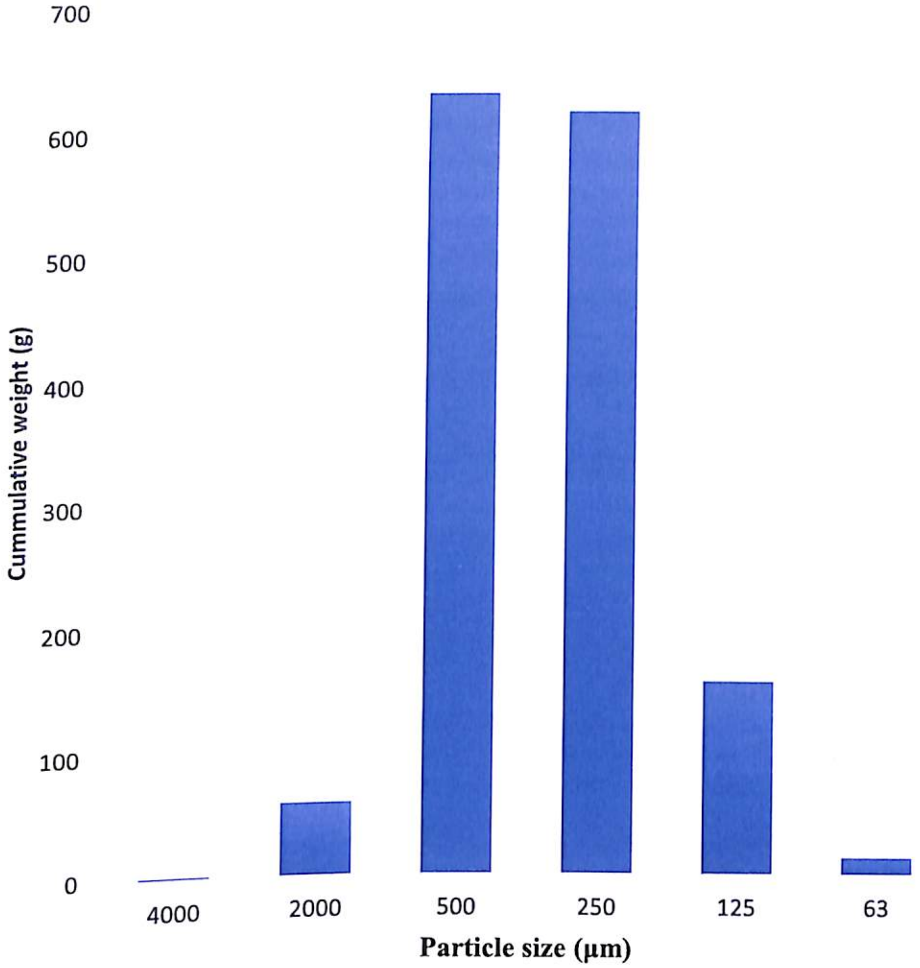

Figure 24: Dominant grain size at Ada in the wet season

Source: Field investigations, 2016-2017

At Ada (Figure 24), the dominant grain size in the wet season was the 500 µm, followed by the 250 µm 125 µm, 2000 µm and traces of the 63 µm. The 4000 µm was absent in all the segments.

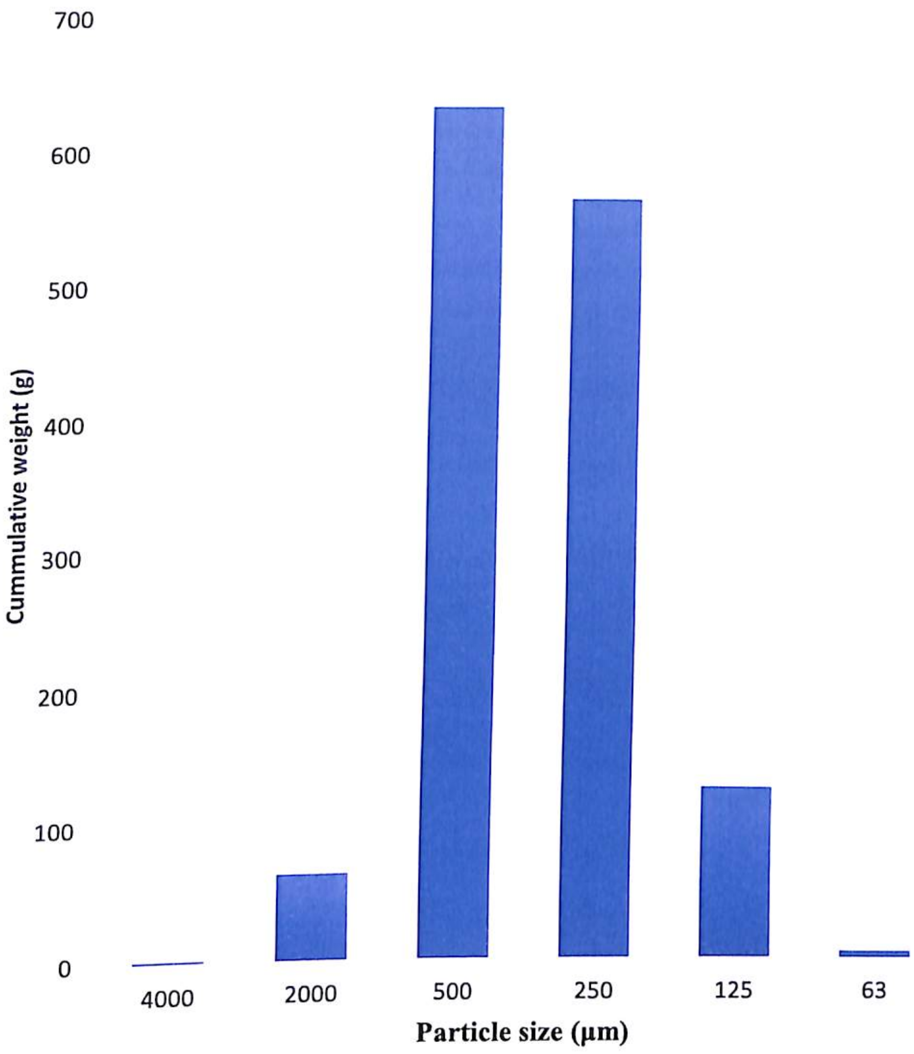

Figure 25: Dominant grain size at Atorkor in the wet season

Source: Field investigations, 2016-2017

Atorkor (Fig 25) followed the same trend with the dominating particle size being the 500 µm. Here too the 4000 µm and the 63 µm were insignificant in the segments.

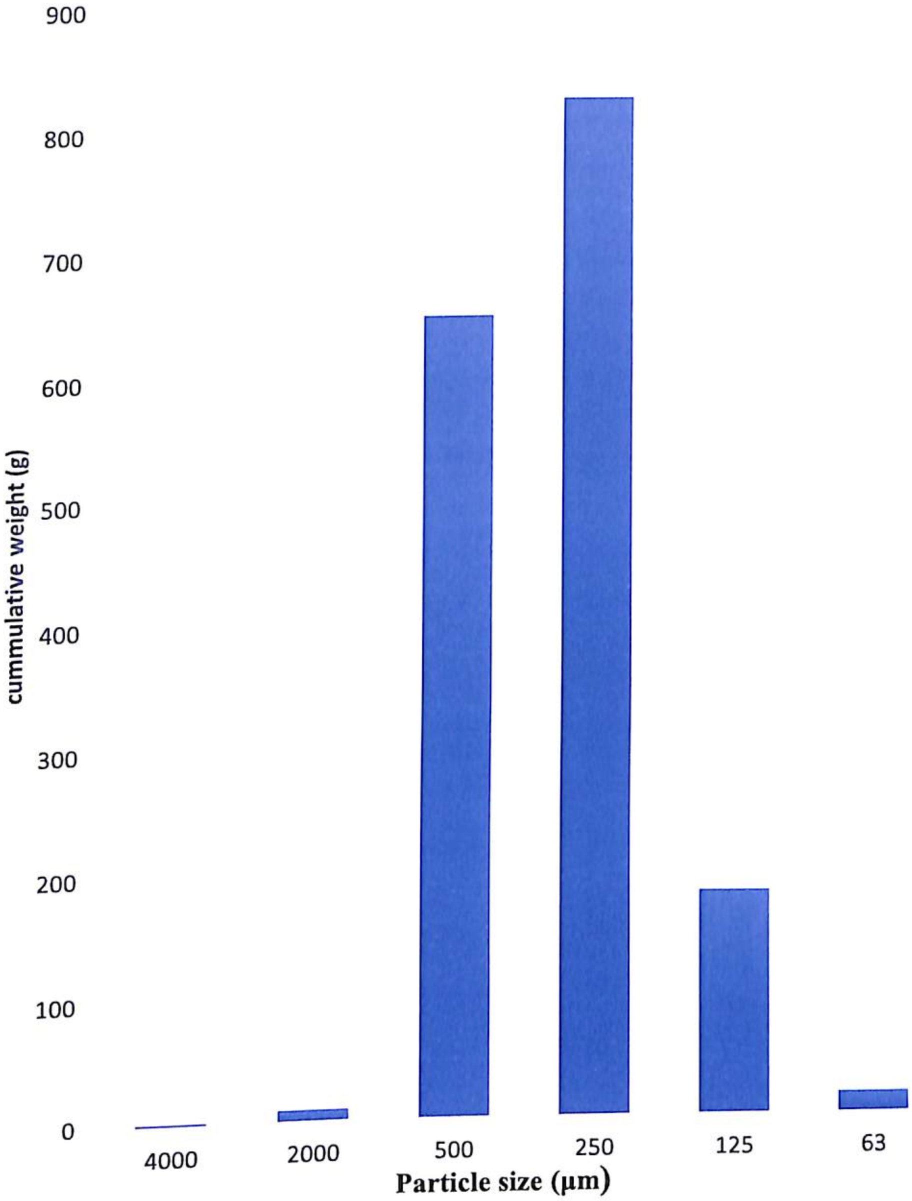

Figure 26: Dominant grain size at Kedzi in the wet season

Source: Field investigations, 2016-2017

Variation was observed at Kedzi where the dominant grain size was the 250 µm, followed by the 500 µm, and 125 µm. Again the 4000, 2000 and 63 were insignificant in the beach segments. This signifies a fine granulometric texture of the beach sediments.

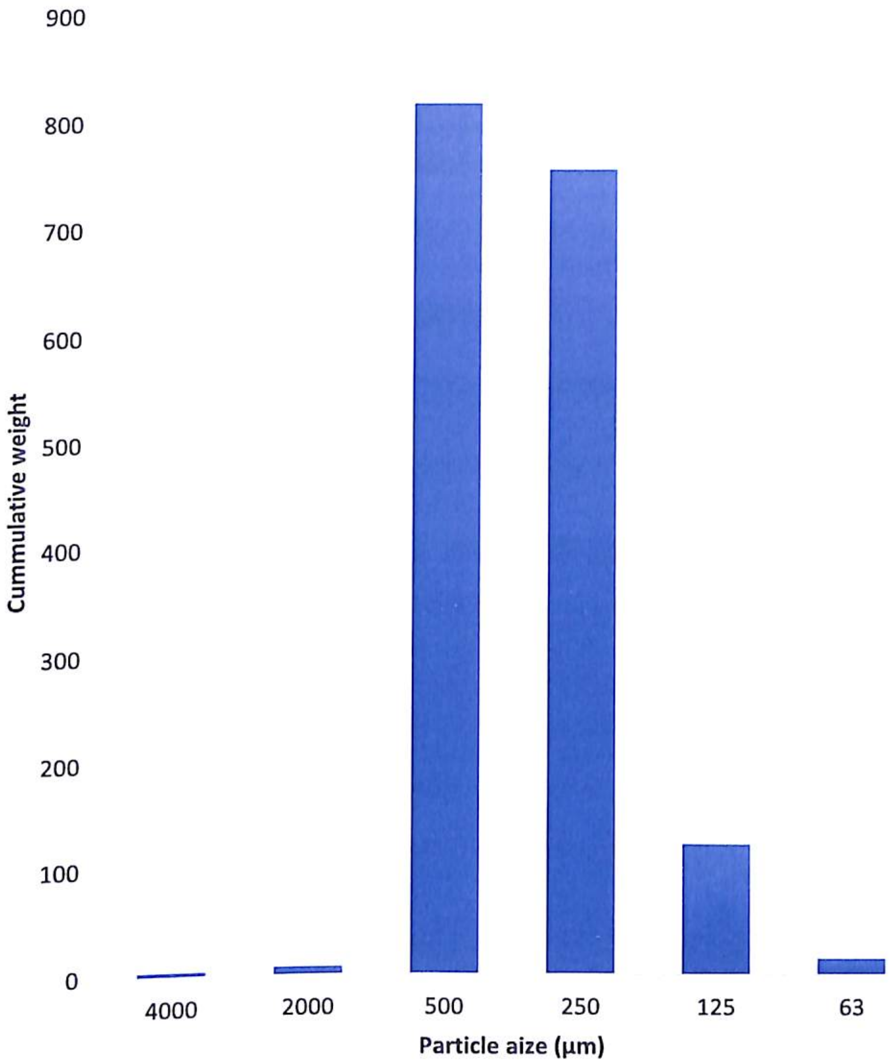

Figure 27: Dominant grain size at Keta in the wet season

The trend at Keta also followed the usual trend where the 500 µm dominated the segment, followed by 250 µm, 125 µm. There were traces of the 63 µm with the 4000 µm and 2000 µm almost absent through all the beach segments.

A slight variability was seen in the dominant grain size in wet season in all five study sites. Generally, the dominant grain size was the 500 µm in four study sites (Abakam, Ada, Atorkor and Keta), followed by 250 µm, 125 µm, 2000 µm, 63 µm and 4000 µm. In some locations the 4000 µm, 2000 µm and 63 µm were insignificant and this was evident at Abakam, Kedzi and Keta. There was a mixed-up of sediment in all five study sites indicated by the percentage of grain sizes. Episodic erosion resulted in the lowering of the beach profile. This dynamic mechanism was confirmed by Wright and Short (1984) in their submission that high energy waves eroded sediment from the backbeach and redistribute on the beach face. Therefore, beach slope appears gentle and during episodic erosion in the wet season.

The dominant grain size of 500 µm implied decreased permeability. This allowed wave run-up which eroded the beach face in the wet season. This confirmed the dominant significant grain sizes influencing beach slope in Tables 6,7,8 and 9.

Sorting Characteristics of Beaches

Sorting characteristics of beach sediment is vital in the estimating beach morphological changes. In flux of sediment on the beach face that influence the rate of erosion is dependent on the textural characteristics especially sorting which has a direct bearing on the particle size. The study examined the sorting characteristics of beach sediment to ascertain the particle size influence on beach morphology. The following graphs presents the sorting characteristics of the five study beaches in the dry (Figures 28-32) and wet seasons (Figures 33-37) respectively.

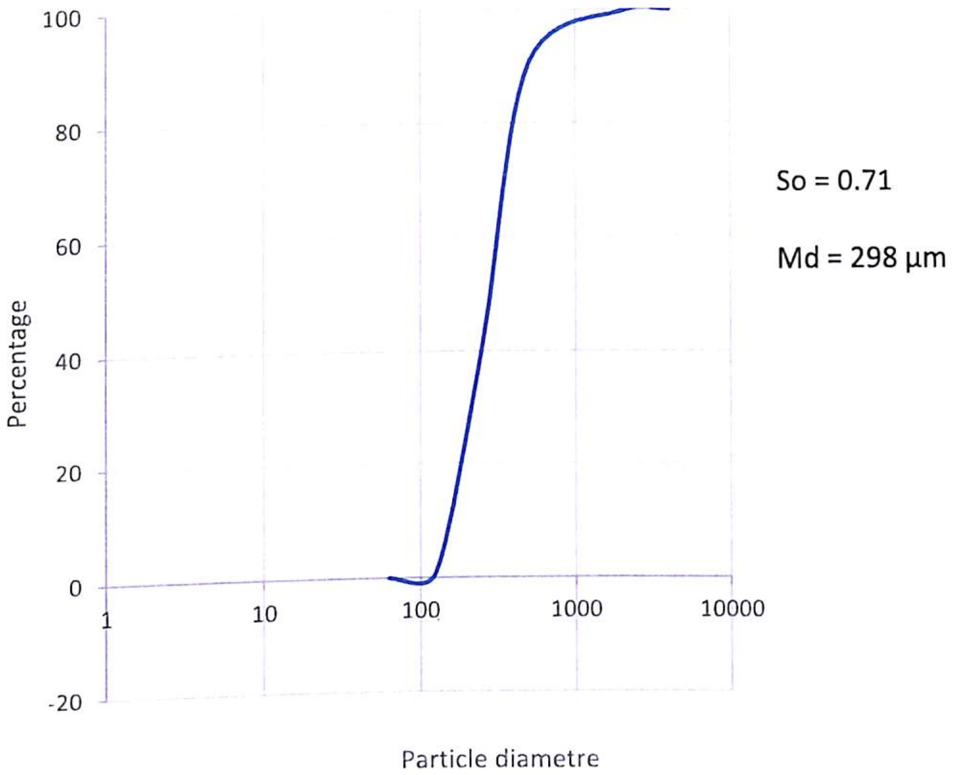

Figure 28: Textural characteristics of Abakam beach in dry season

Source: Laboratory investigations, 2016-2017

Figure 28 represents a beach at Abakam in the dry season, where a sandy beach had been developed in front of the CES. It was moderately sorted with *So* value of 0.71 and *md* of 298 µm. It had fine to medium grains which had been sorted due to a relatively long distance of transport. 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 cliff erosion and removal of stones used for the defence wall. The removal of this stone had supplied granitic rock debris on the beach.

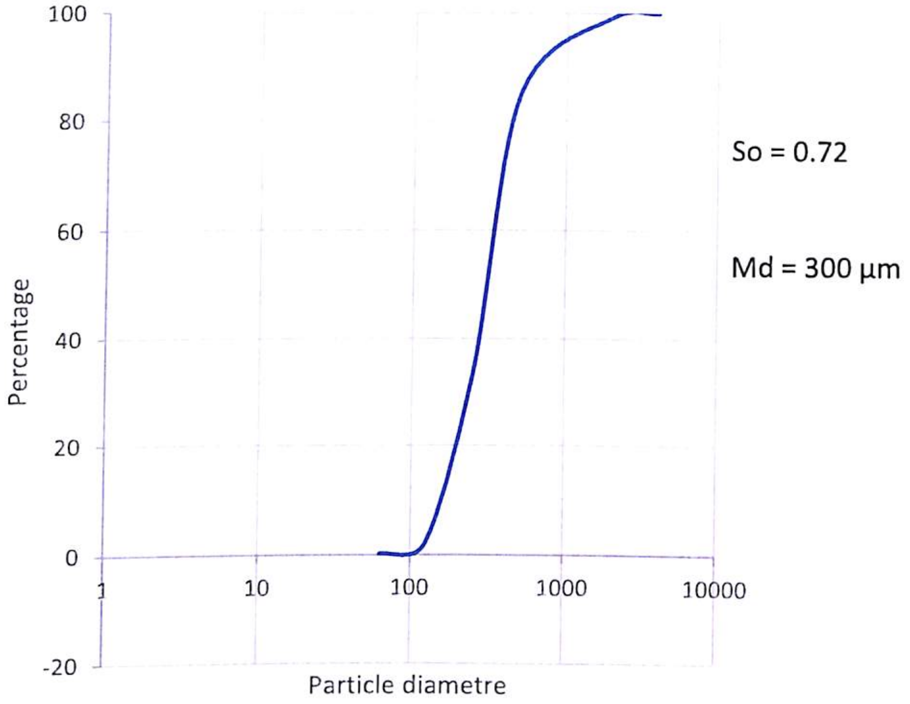

Figure 29: Textural characteristics of Ada beach in dry season

Source: Laboratory investigations, 2016-2017

The beach at Ada (Figure 29) had medium sediments indicated by the *md* of 300 µm and a moderately sorted beach with *So* value of 0.72 and the asymmetrical sigmoid curve. However, erosion was greatest at this point and beyond, towards Kpokporgbor where storm surges were experienced during the wet seasons in previous years and the year of survey. Sediments eroded from this point (Ada beach) were deposited in a submarine canyon at the estuary of the Volta after which the current became less saturated with sediments upon reaching nearby village eastwards across the estuary. The less saturated current was therefore able to erode much sediment and hence the extremely increased erosion activity at Atorkor and beyond. The combined action of the major river and the sea at the estuary resulted in the relatively strong counter current at Ada which had led to seasonal alongshore drift of sediment.

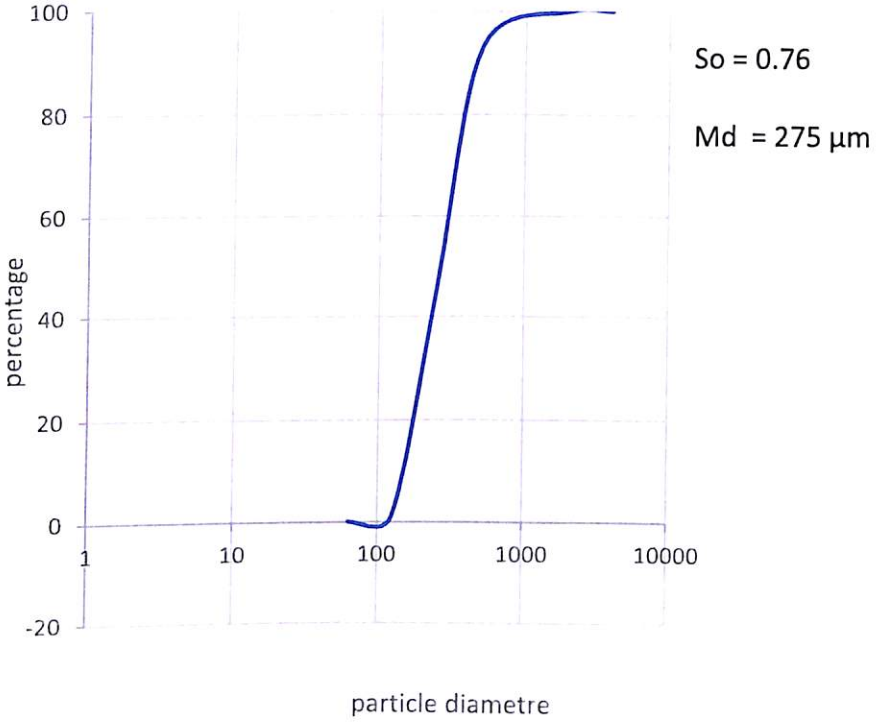

Figure 30: Textural characteristics of Atorkor beach in dry season

Figure 30 shows Atorkor beach where there was an extensive beach in front of the CES. It was moderately sorted with *So* value of 0.76 and *md* of 275 µm. It had medium grains which had been sorted due to a relatively long distance of transport. Even though it was asymmetrically sigmoid, it had a large curvature towards medium to large grains. There was severe sea erosion at this point which had led to the of CES. According to an opinion leader and natives contacted, the main road leading to the nearby town have been reconstructed several times due to inundation of the coastline through erosion. This is as a result of unsaturated current that flowed eastward from Ada. The current after being deprived of suspended sediment is able to erode more at this point.

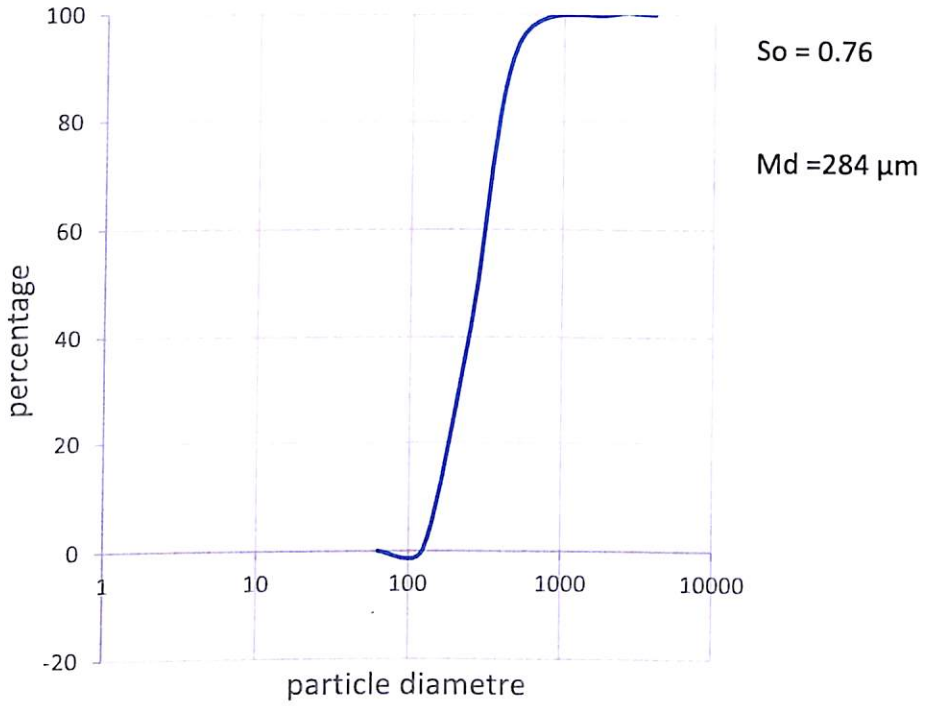

Figure 31: Textural characteristics of Kedzi beach in dry season

Source: Laboratory investigations, 2016-2017

From Figure 31 the beach at Kedzi had a perfectly asymmetrical sigmoid curve indicating finer to medium grains as shown by the *md* of 284 µm and moderately sorted (*So* = 0.76). Erosion was severe due to less saturated current from Ada in the west. There was a mixed up of sediment due to human interference. The fine granulometric texture of sediments attracted sand mining.

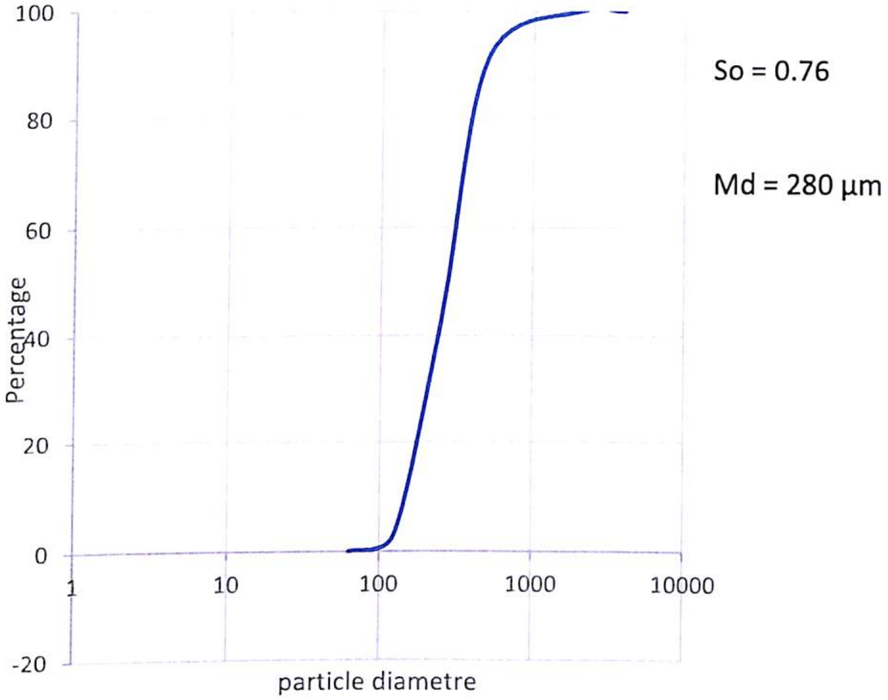

Figure 32: Textural characteristics of Keta beach in dry season

Source: Laboratory investigations, 2016-2017

Keta beach in Fig. 32 was a moderately sorted beach with *So* of 0.76 and fine to medium grain sediment (md of 280 µm). It had an asymmetrically sigmoid curve indicating fine to medium grain. There was a mix-up of the sediments due to much human interference. The fine granulometric nature of the sand attracts sand mining for construction and this had affected the distribution.

In order to establish the spatio-temporal changes in beach state, the sorting characteristics of particles were analysed in the wet season Figures 33-37 shows the outcome of the analysis.

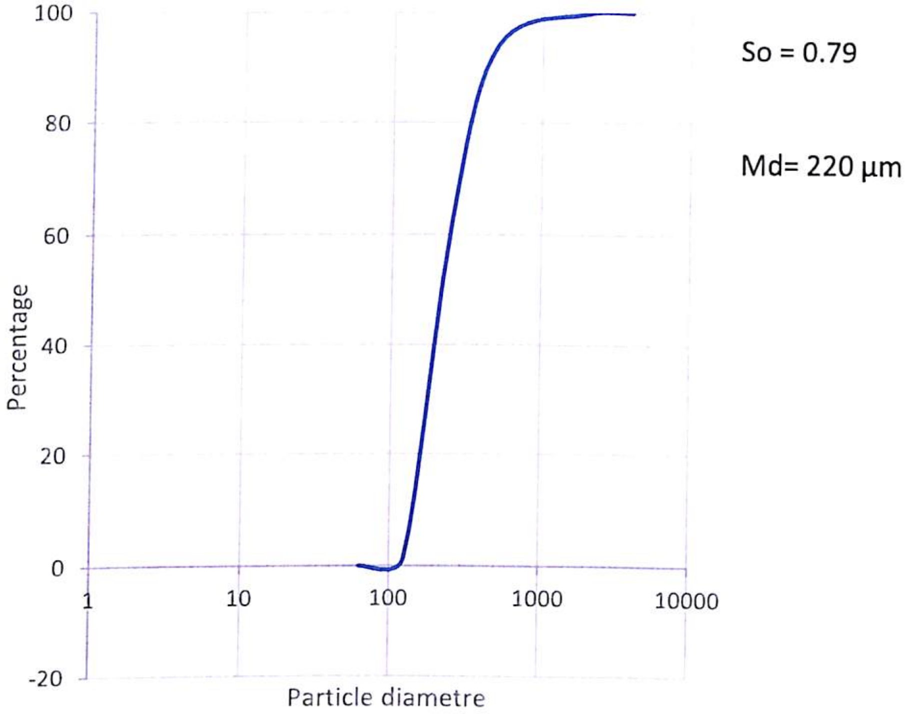

Figure 33: Textural characteristics of Abakam beach in wet season

Source: Laboratory investigations, 2016-2017

Figure 33 represents a beach at Abakam. It was a moderately sorted beach with *So* value of 0.79 and very fine in grain size indicated by the *md* of 220 µm.

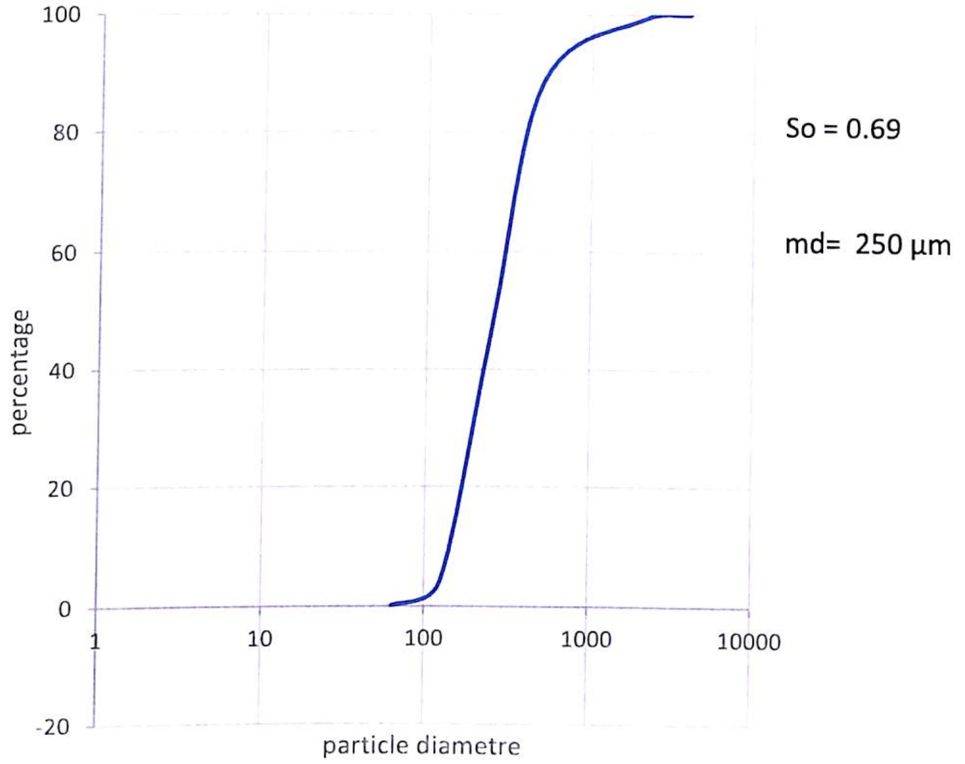

Figure 34: Textural characteristics of Ada beach in wet season

Source: Laboratory investigations, 2016-2017

Figure 34 is the beach at the Ada. The *So* value of 0.69 showed that it was moderately sorted. The *md* of 250 µm implied a medium grain size which was made up of a mixture of sea and river sand supplied by the river. The relatively coarse-grained sediment 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. Coupled with the relatively coarse sediment that significantly influenced the beach increased percolation in the wet season which led to decreased erosion activity, hence the increase in beach within the wet season.

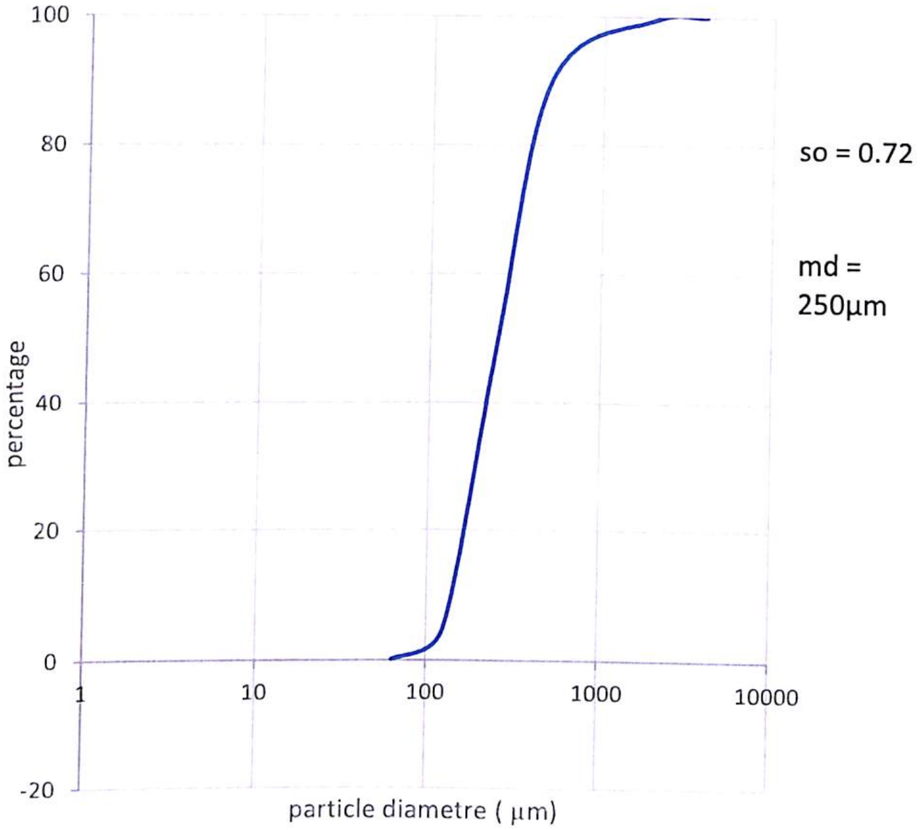

Figure 35: Textural characteristics of Atorkor beach in wet season

Source: Laboratory investigations, 2016-2017

Figure 35 is the beach at Atorkor. It has Sorting Coefficient of 0.72 and an *md* of 250 μm. This implied moderately sorted sediment with medium grains. Here the longshore drift had time to draw the sediments in succession according to the particles' diameter.

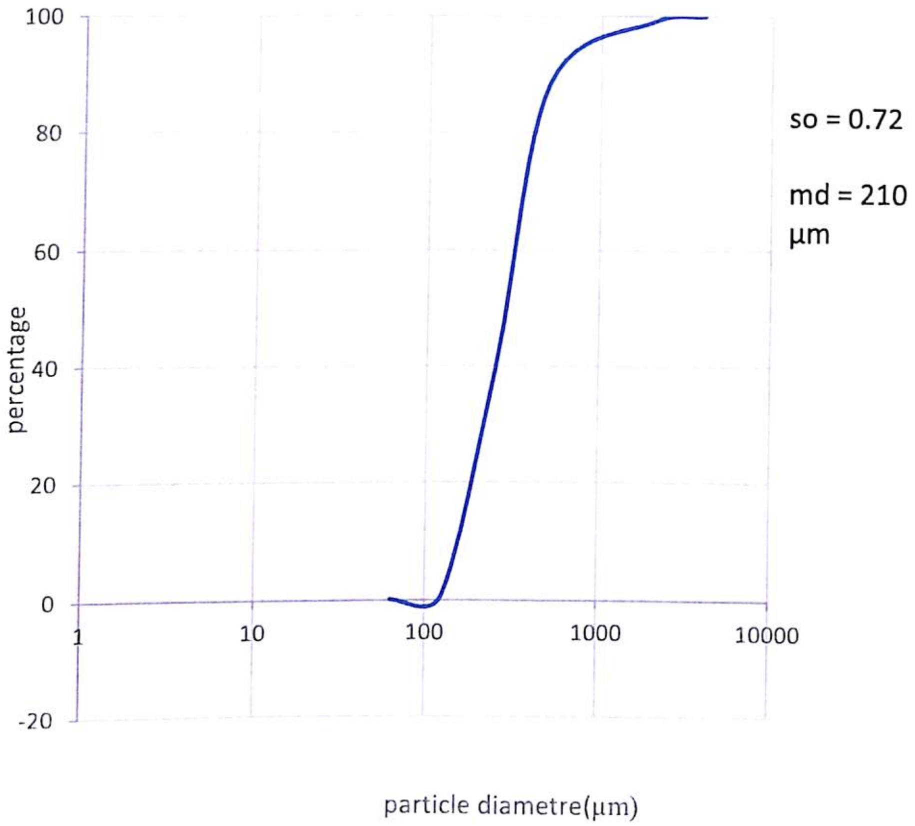

Figure 36: Textural characteristics of Kedzi beach in wet season

Source: Laboratory investigations, 2016-2017

The beach at Kedzi in the wet season had fine to medium sediments. It was moderately sorted with *So* value of 0.72 and *md* of 210 µm. The curve showed a very fine but mixed-up sediment due to human interference. The beach was therefore disturbed greatly by human activities such as fishing and sand mining due to the fine granulometric texture of the sediments for domestic purposes.

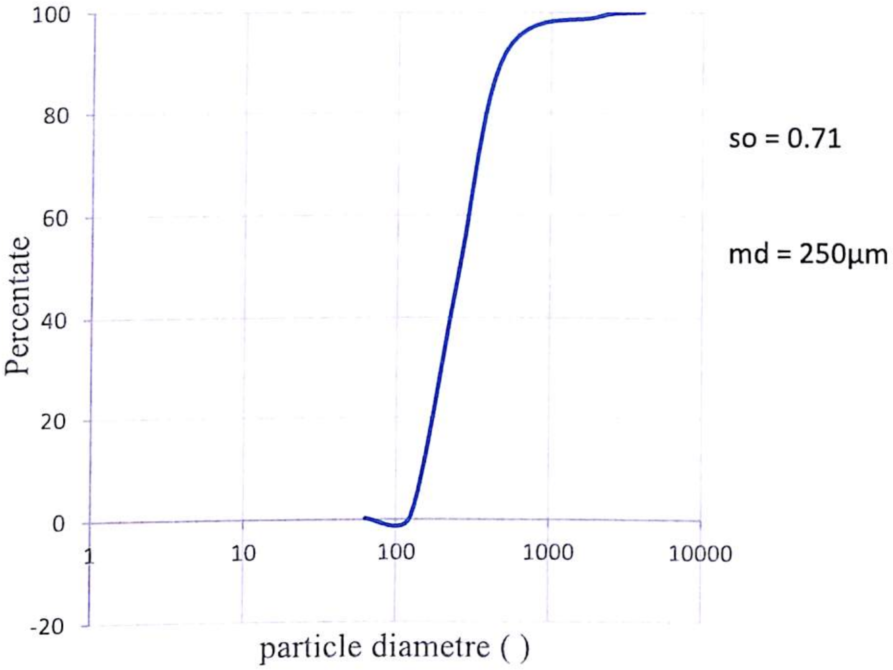

Figure 37: Textural characteristics of Keta beach in wet season

Source: Laboratory investigations, 2016-2017

Textural characteristics of beaches

Descriptively, the textural parameters of beaches were used to analyse a hypothetical scenario put forward by McLaren and Bowles (1985)

Table 10: Descriptive statistics of textural characteristics of beaches in dry season

Descriptive stats	Abakam	Ada	Atorkor	Kedzi	Keta
Sorting	0.71	0.72	0.76	0.76	0.76
Median diameter	298	300	275	284	280
Skewness	2.80	0.31	-0.11	0.22	0.22

Source: Field and laboratory investigations, 2016-2017

In the dry season beaches were moderately sorted with sorting values ranging from 0.71 to 0.76 and symmetrically skewed with values ranging from -0.14 to 0.3 with Abakam being the only coarse skewed (Table 4). The variations in median grains in all five study sites were closer implying similarities in textural characteristics. It was established in Table 8 that beach materials were mainly of fine to medium grains.

Table 11 presents a summary of the textural parameters of beaches in the wet season.

Table 11: Descriptive statistics of textural characteristics of beaches in wet season

Descriptive stats	Abakam	Ada	Atorkor	Kedzi	Keta
Sorting	0.79	0.69	0.72	0.72	0.71
Median diameter	220	250	250	210	250
Skewness	0.32	0.04	-0.04	0.08	-0.15

Source: Field and laboratory investigations, 2016-2017

Beaches in the wet season showed similarity in sorting as in the dry season. They were moderately sorted with sorting value from 0.69 to 0.79. These implied moderately sorted medium grains. The median diameter of grains also confirmed the fine granulometric texture of sediments as indicated in Tables 8 and 9. There was consistency in sorting in both seasons although the wave energy reaching the shore varied. The spatial changes in grain size trends results from processes present in transport such as selective transport abrasion, beach material characteristics and mixing (Russell, 1939; Coco et al., 2007). Skewness was symmetrical with values ranging between -0.14 to 0.31(Tables 4 and 13). Here the longshore drift had time to draw the sediments in succession according to the particles' diameter.

Table 11 shows a summary of the textural parameters in both seasons. From Table 11, S_1, Md_1 and Sk_1 represents the sorting, median diameter and skewness in the dry season while S_2, Md_2 and Sk_2 are the sorting, median diameter and skewness in the wet season.

Table 12: A comparison between textural parameters in both seasons

Textural parameters	Study site				
	Abakam	Ada	Atorkor	Kedzi	Keta
S_1	0.76	0.72	0.76	0.76	0.76
S_2	0.79	0.69	0.72	0.72	0.71
Md_1	298	300	275	284	280
Md_2	220	250	250	210	250
Sk_1	2.80	0.31	-0.11	0.22	0.22
Sk_2	0.32	0.04	-0.04	0.08	-0.15

Source: Field and laboratory investigations, 2016-2017

Table 12 compares the textural parameters of the five sites in both seasons. Size parameters can be compared between pairs of sampling sites, considering the increase or decrease in three parameters at the time, *md*, *So* and *sk* (Pedreros et al., 1996). Following McLaren and Bowles (1985) and Gao and Collins (1992) presention of cases that were theoretically possible for a physical reality in non-extreme marine environment in relation to transport of sediment from one point to the other, the following hypothetical scenarios were put forward. If :

- $S_2 < S_1$, $Md_2 > Md_1$ and $Sk_2 < Sk_1$. Meaning, in downstream direction sediment becomes finer, better sorted and more negatively skewed.
- $S_2 < S_1$, $M_2 < M_1$ and $Sk_2 > Sk_1$. Meaning, in downstream direction sediment becomes coarser, better sorted and more positively skewed.

From Table 12, the following scenarios were established: at

- Abakam: $S_2 > S_1$, $Md_2 < Md_1$ and $Sk_2 < Sk_1$.
- *Ada:* $S_2 < S_1$, $Md_2 < Md_1$ and $Sk_2 < Sk_1$
- Atorkor: $S_2 < S_1$, $Md_2 < Md_1$ and $Sk_2 > Sk_1$
- Kedzi: $S_2 < S_1$, $Md_2 < Md_1$ and $Sk_2 < Sk_1$

- Keta: $S_2 < S_1$, $Md_2 < Md_1$ and $Sk_2 < Sk_1$

It was observed from Table 12 that four of the study sites did not meet any of the hypothetical scenarios presented by McLaren and Bowles (1985) and Gao and Collins (1992). This implied no variation in grain size, sorting and skewness in the downdrift direction. Therefore, similar conditions and processes prevailed in the downdrift direction. It is therefore anticipated that fluxes in beach state are transferred further downstream of the four study sites. Hence there is the need to consider extension of protection measures, as implemented in the sites, downdrift of the beaches. This confirms the findings of Appeaning- Addo et al., (2008), Anim et al (2013) and Angnuureng et al., (2013) that erosion is transferred to adjacent coastlines of mitigated sites. Field visits confirmed the construction of a new defence structure at Blekuso, downdrift of Kedzi-Keta defence wall, towards Togo by a construction firm named AMANDI.

Atorkor was the only site that met the second hypothetical scenario; meaning, in downdrift direction sediment becomes coarser, better sorted and more positively skewed. Therefore, variability is expected to prevail in processes and conditions downdrift (better sorting, coarse sediment and positive skewness). With improved sorting and the composition of coarser sediments, there is the likelihood of a reduction in TSS as coarser sediments are deposited easily as per the Stokes Law (Hearn, 2008). Hence the current becomes less saturated and erosion increased. Therefore, downdrift direction of Atorkor is expected to experience increased erosion activity. Therefore, both scenarios implied erosion downdrift of the CES.

Oceanographic Forcing of Waves

The contribution of waves on beach erosion and accretion (morphology) were analysed using wave data along the coastline from the year 2000 to 2017. Due to little or no specific wave data for the study beaches, wave data for the entire coastline was used assuming homogeneity of the oceanographic forcing along the coastline of Ghana. Figure 37 shows the variations in wave direction, height and period along the Ghanaian coastline.

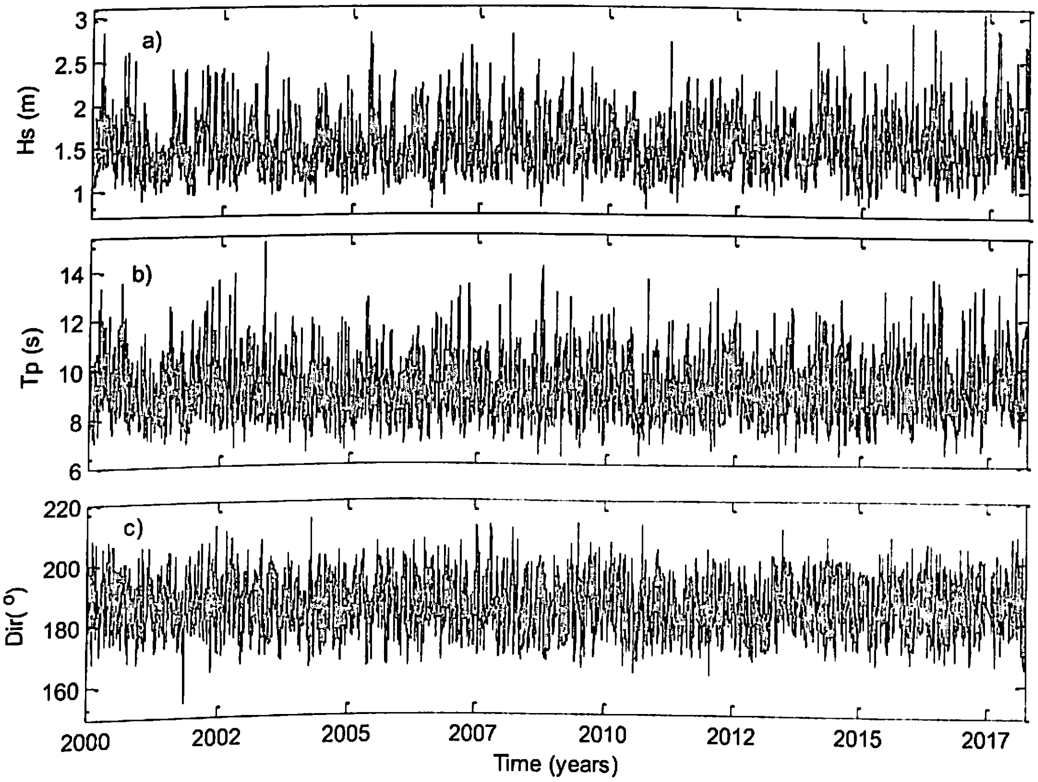

Figure 38: Parametric variations in waves along the Ghanaian coastline from 2000 to 2017

Source: ERA Interim ,2000-2017

Figure 38 shows wave energies that influenced the coast of Ghana from January 2000 to December 2017. From Figure 38a) stormy conditions were experienced in the years 2000, 2005, 2010, 2016 and 2017 with significant Hs of 2.8 m occurring in 2000, 2010 and 2016. The Tp ranged from 6.0s to 15.25s (Figure 38b) with averaged period of 9s. The peak direction ranged between 155° to 215° (Figure 38c) which is in conformity with Appeaning-Addo et al (2008).

Figure 39 gives the parametric variations in waves energy along the coastline in the dry season. This was from the month of November 2016 to March 2017 representing the dry season.

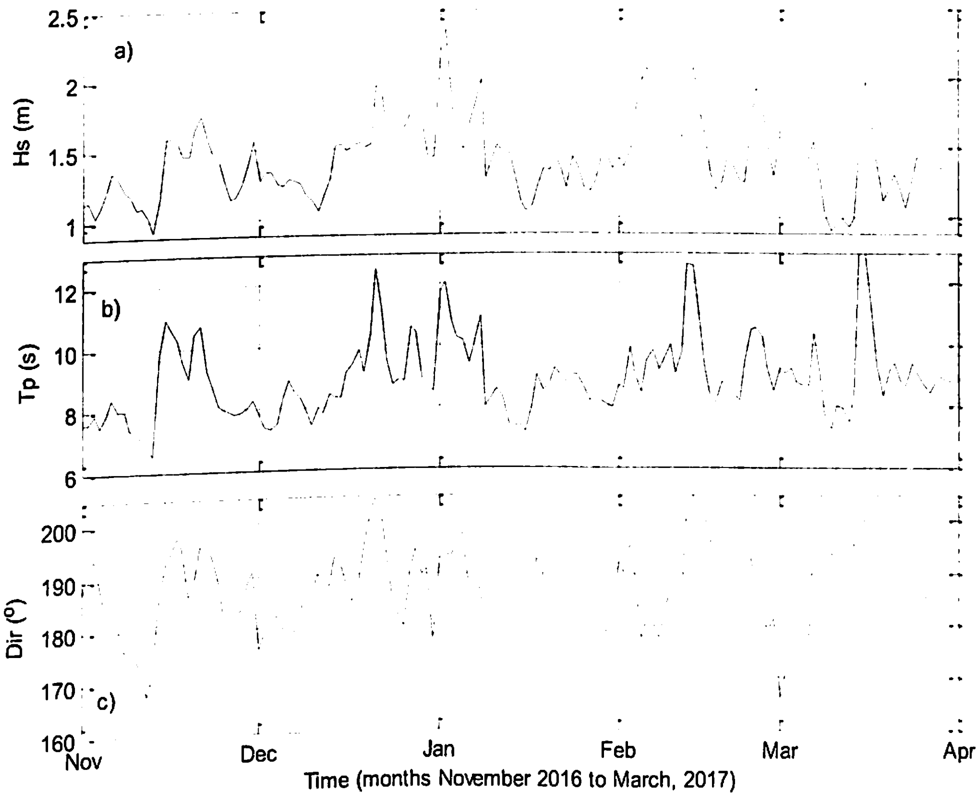

Figure 39: Parametric variations in waves along the Ghanaian coastline in dry season.

Source: ERA Interim (2000-2017)

Figure 39 shows a significant wave height of 2.3 (Fig 39a), mean peak period of 13.3s (Fig 39b) and a mean direction of 205° (Fig 39c) which is eastward direction. Table 13 gives a summary of the parametric variations in wave energy during the dry season.

Table 13: Summary of wave parameters in dry season

Statistic	Hs (m)	Tp (s)	Wd (°)
Max	2.3	13.3	205
Min	0.9	7.2	168
Mean	1.5	9.0	187

Source: ERA Interim (2000-2017)

Figure 39 shows the *Hs, Tp* and direction for the two seasons. The *Hs* for the dry season was 2.3 m and *Tp* ranged between 7.2s and 13.3s occurring in February with *Wd* which ranged from 168° to 205° (Figure,39, Table 13). The *Hs* ranged from 0.9-2.2 m. This is in line with Appeaning-Addo (2008), Short (2012) and Xorse (2013).

The parametric variations in waves energy along the coastline in the wet season are shown in Figure 39. This was from the month of April, 2016 to October, 2016, representing the wet season.

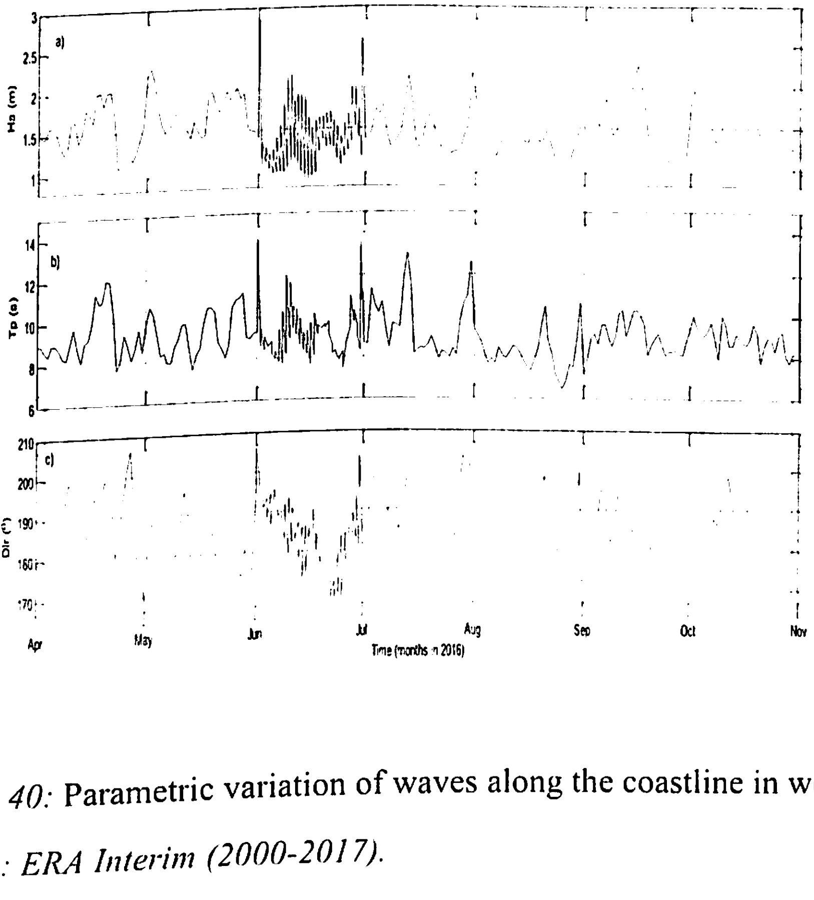

Figure 40: Parametric variation of waves along the coastline in wet season

Source: ERA Interim (2000-2017).

A summary of the wave parameters in wet season are shown in Table 14

Table 14: Summary of wave parameters in wet season

Statistic	Hs (m)	Tp (s)	Wd (°)
Max	2.8	13.3	206
Min	0.9	6.5	170
Mean	1.5	9.0	185

Source: ERA Interim, 2000-2017

The significant Hs was high in the wet season (2.8m), occurring between June and July, 2016. The *Tp* ranged from 6s to 13.7s and *Wd* of 170^0 to 206^0 (Figure 40, Table 14). Figures 39 and 40 depict seasonal variations in wave regime with low and high energy in dry and wet seasons. The *Hs* ranged from 0.9 to approx. 3m in the wet seasons. The *Tp* ranged from 6s to13s in both seasons with significant *Wd* between 168^0 -205^0 . From Table 14, the mean *Tp* was 9s for both seasons. It is clearly indicated from Table 14 and Figure 40 that the wet season experienced storm condition with *Hs* of 2.8m.

Wave Energy and its Impact on the Coastline

Waves are primary driving mechanism for erosion and deposition along the coast. The swash carry sediment onto the beach at oblique angles while the backwash sends sediments down the beach at right angles due to gravity (Davidson-Arnott, 2010; Xorse, 2013). This process slowly moves material along the beach in the form of longshore drift or alongshore movement of sediments. Longshore drift provides a link between erosion and deposition. Material in one place is eroded, transported then deposited elsewhere (Davidson-Arnott, 2010; Anim et al, 2013) as evident in the study sites (occurring at CES and continues downdrift side of CES). The direction of drift changes where there is an obstruction such as CES and when the power of the waves is reduced the materials are deposited (especially when the current is highly concentrated with sediment (high saturation rate).

Wave energy reaching the shores of Ghana varied through the two major seasons. The mean wave energy values in the dry and wet seasons were estimated at 6609.85J and 9796.64 J, respectively. Wave energies less than the mean constituted 41% and 48%, respectively for the dry and wet seasons. On the other hand, wave energy above the mean formed 59% and 52% in dry and wet seasons, respectively. Although majority of the waves have wave heights lower than the mean, the few higher ones contributed to greater energy. This also shows the Ghanaian coast is dominated by high energy waves. Seasonal wave energies also followed the same trend as wave heights in both seasons. For wave data collected for the two seasons in 2016-2017, annual wave energy trends may be described as a bell-shaped where energies were low at the start of the year increased and peaked in July (wet season) then began to decrease to low in December (dry season). Therefore, maximum sediment transport occurred in wet season with low transports during dry season due to decrease in wave energy. This was in line with profile, BV and BW data analysed. Average wave energy of 1399.44J within the wet season was significant to cause a strong longshore transport of sediments along the beaches of Ghana.

When beach volume losses (Table 4) are equated to alongshore sediment transport, the seasonal longshore transport is close to Boateng, Bray and Hooke (2012) who estimated that Ghana's longshore transport exceeds 764554.9 m3 per year. It should be however noted that wave details are often recorded well offshore or taken from global wave models well offshore where the hindcast wave parameters are considered free from nearshore bathymetry that is coarsely represented or assume deep water in these models due to their scale. These values will vary in real terms thus may be higher or lower depending on nearshore morphological features.

Impact of waves on the coastline was assessed using impact, coastal geology shore bathymetry, direction of wave and wave energy. By the nature of the Ghanaian shoreline as per the classification by Armah (2005) based on the angle of incident waves, moderately oblique and very oblique waves have the potential to transport large net transport of sediment. This adds up to other confirmations such as Wiafe (2010) and Xorse (2013) that the coastline is dominated by erosion. The maximum wave directions of 205^0 and 206^0 in dry and wet seasons respectively (Tables 13 and 14) also indicated a net eastwards littoral drift. Although wave energies were not specifically calculated for specific areas along the coastline, this suggests that waves with full energy reach the coast on the eastern section as these waves would have experienced little shoaling for them to lose some energy. On the contrary waves on the western section would have dissipated a considerable amount of their energy before reaching the shore. This is as a result of bathymetric features (Figure 1). Hence the increase in erosion on the eastern section (Ada and Keta areas) as compared to the western section.

Changes in Mean Beach Morphology

The combined forces of textural parameters and waves led to changes in beach morphology in terms of elevation and slope. These were analysed to establish the influence of these independent variables on beach elevation and slope (profile evolution). A summary is presented in Table 15.

Table 15: Mean beach elevation and beach slope in both seasons

Study sites	Beach elevation dry season (m)	Beach elevation wet season (m)	Beach slope dry season (^{0})	Beach slope wet season (^{0})
Abakam	0.31	0.17	0.08	0.07
Ada	0.54	0.31	0.02	0.03
Atorkor	0.37	0.24	0.05	0.04
Kedzi	0.11	0.05	0.02	0.05
Keta	0.18	-0.04	0.03	0.08

Source: Field measurement, 2016-2017

Table 15 shows the general elevation and beach slope of the five study sites in both seasons. All beaches were subjected to considerable morphological changes from one season to the next, both cross-shore and along-shore. However, the duration of survey did not allow estimation for the envelope of change which is the range between the maximum and minimum levels measured over the years.

The general observation made at all five study sites with respect to elevation, slope, beach width and volume changes were that; although mean elevation of beaches increased during dry season and decreased in wet season beach slope remained almost the same. Specific elevation of the beach fluctuated across the whole beach in the cross-shore and along-shore direction throughout the survey period. The lowest elevation and maximum cliff-toe exposure occurred during the wet season (April 2016 to October 2016). The stormy conditions between June and July led to considerable changes (decrease) in the cliff toe elevation within this period. Relative to the tidal water level, the mean elevation of the cliff toe at Ada (0.54 m above MSL) was the highest in the dry season compared to 0.31 m (Abakam), 0.37 m (Atorkor) 0.11 m (Kedzi) and 0.18 m (Keta). The trend was almost the same in the wet season with Ada having the highest elevation of 0.31 m above MSL as against 0.17 m (Abakam), 0.24 m (Atorkor), 0.05 m (Kedzi) and -0.04 m (Keta). Keta had the lowest elevation (below sea level) in the wet season. This attests to the fact that Keta areas experienced more than twice the erosion observed at the Abakam, Ada and Atorkor (Tables 5).

Mean slope of beaches remained almost the same in both seasons with slight variations. Among all the five sites, Keta experience the most variation in beach slope with 0.03° in the dry season and 0.08° in the wet season (Table 15). This is an indication of erodibility of the beach in the wet season rendering the beach steeply in slope. This confirms the submission made earlier with regards to elevation implying massive erosion at Keta.

The influence of the first order (textural characteristics) and second order (hydraulic factors (waves) control on beach slope (geometry) in the conceptual framework (Figure 5) was evident in the morphological changes in beaches. The significant grain size that influenced beach slope portrays the rate of permeability (percolation) on the beach. The analysis on grain size showed that all five beaches have fine to medium grains. Due to the relative cohesion of the sediments, they were compact and does not allow waves runoff to percolate downwards. Therefore, wave runoff increases on the surface and cause erosion of sediment on the beach face. As a result, erosion reduced beach slope generally in the wet season which further led to a decreased beach width (BW).

However, the situation was different at Ada beach in the wet season where BW increased instead of reducing and following the normal seasonal trend as a result of stormy condition in the wet season. Here the significant grain size that influenced beach slope was the 2000 μm (Table 7). This implied high permeability as the pore spaces between the larger particles make it less cohesive and allows water to percolate (Waugh, 1995), reducing wave runoff on the beach face. Decreased wave runoff led to decreased erosion, hence the increase in BW in the wet season despite the stormy conditions.

The influence of sorting was significant on beach slope. The fine to medium grains sediment of the beaches would have given it a very gentle low profile, but because they were moderately sorted signifying a mixture of sediments of all sizes, their slopes were not clearly defined as 'very gentle' sloping or 'very steep sloping'.

The second order control factor substantially influenced beach slope (geometry). In the dry season where wave energy reduced, sediments were consequently deposited on the beach face increasing the general beach slope. On the other hand, when wave energy increased in the wet season, wave reaching the upper beach caused erosion on the beach face thereby reducing beach slope. However, the rate of erosion was dependent partly on the grain size and partly on the wave energy. From the analysis, beach slope is dependent on the initial controls (textural characteristics and hydraulic factors (wave energy) with an intervening element in the form of permeability (Figure 5).

Summary of the Chapter

The textural analysis of beaches showed that beaches in all five sites were made up of fine to medium grains. The dominant grain sizes were the 250 μm and the 500 μm. However, the 250 μm dominated the dry season while the 500 μm was the dominant grain size in the wet season. This was due to the variations in wave energy. The significant grain size that influenced beach slope in the dry season were the 500 and 250 while there was large variability in the wet season (2000 μm, 500 μm and 250 μm). Therefore, variation in grain size was spatio-temporal.

Permeability, which influence the rate of erosion, was determined by grain size. Coarser grains increased permeability while fine grains reduced permeability due to cohesion. Finer to medium grains in the study sites reduced permeability which lead to increased erosion and TSS along the Ghanaian coastline.

Size was confirmed as the primary control of sorting trends in the sedimentary environments whilst hydraulic effects contribute to variability. Since size and sorting exert a primary influence on beach slope through permeability, it was further suggested that trends in the size/slope relationship clearly reflect the characteristic local distributions of size and sorting.

Annual wave energy trend was bell-shaped. Seasonal wave energies followed the same trend as wave heights in both seasons. The mean wave energy of 6609.85 J and 9796.64 J were significant to cause accretion and erosion in the dry and wet seasons respectively. It was observed that maximum sediment transport occurred in the wet season while there was a decline in the dry season.

CHAPTER SEVEN

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter discusses the summary of the main findings from the study and to draw conclusions. The study sought to use the impact of oceanographic forcing on beach profiles and textural characteristics of sediments to investigate the variations in beach morphology (width, volume and slope) that influence profile evolution and beach erosion. It also suggested possible recommendations to be the underlying principles in coastal monitoring for coastal erosion mitigation.

Summary

The study investigated the textural characteristics of beaches fronting CES along the Ghanaian coastline. With the onslaught of erosion and its consequent mitigation, the problems still remain, transferring it to other coastal cells. Hence the need to study and understand the sediment fluxes during the two seasons to have an idea of sediment conservation on the study beaches.

The study specifically sought to; explain the potential cause of temporal variations in beach morphology, establish the dominant grain size along the Ghanaian coastline, investigate the extent to which grain size influence profile evolution, highlight the relationship between grain size and sorting and analyse oceanographic forcing (waves) on beach profile evolution.

The study employs a mixed approach using quantitative and qualitative data. Quantitative data consisted both primary and secondary sources with observations on the field. Primary data was on beach profiles and native sand samples collected on the field along profiles. The secondary data was collected on waves. In addition, an observation of features, human activities and storm events were used to record the state of beaches in the study sites.

Beaches chosen for the study are located at the eastern shores and are more of open coast, characterised by high wave energy, resulting in high velocity tidal currents which has led to quite a number of storm surge incidents (Wallen-Mensah et al., 2002; Appeaning-Addo, 2013) and flooding coastal communities such as Kporkporgbor, Ada, Kedzi and Keta.

The objective one sought to find the potential causes of beach changes. Although the precise mechanisms causing beach change at this short timescale was unclear, it was possible to make inferences from the data analysed that hydraulic forcing and beach area characteristics (textural characteristics) contributed to some extent the variation in beach state. Given the length of survey records such observations showed seasonal oscillations in beach volume and width as opposed to a net longer-term addition of sediment to the coastal system. It is possible that the small inputs of sediments reflected the onshore movement of sediment stored in the subtidal environment. The profile surveys did not capture this much larger sediment component of the beach systems. Nonetheless, most profiles reflected the magnitude of short to medium-term variability. This made detection of unambiguous long-term trends problematic. Therefore, both the length of shorter records, truncated nature of the profiles and high levels of variability in beach morphology prevented firm conclusions on long term budgetary status of the beaches. However, fluxes observed reflected a short-term condition of beaches, that is, a state of erosion within the wet season and accretionary state in the dry season.

The data collected suggests there were no long-term trends with regards to the beach morphology (beach accretion or erosion). However, there appeared to be noticeable fluctuations in beach state as a result of seasonal oscillation in wave energy. Results of profile analysis of the five study sites showed that all beaches exhibited morphological variability. It was also apparent that the magnitude of this variability varied both between and within beaches. Between beaches variations broadly corresponded to the different morphological settings as discriminated by wave energy. This answered the concern raised on the basic status and trends in beach form in the first objective.

Beach width analysed showed variability within and between beaches in both seasons. It was observed generally that beach width increased during the dry season and decreased in the wet season. Some profiles in dry season exhibited decreased beach width while other profiles in wet season also showed increased beach width. Local morphology such as the presence of coves, estuaries, headlands accounted for these variations.

The analysis of beach width through the survey period supports the trends observed with respect to beach volume. Beach volume increased in the dry season and decreased remarkably in the wet season. Therefore, a deficit in sediment budget was observed in all study sites. This implied erosion state of beaches during and immediately after the wet season and accretion after the dry season.

Beach width showed the same apparent seasonality as beach volume. In general, this was characterised by a wider beach present at the end of the dry season and a narrow beach post-wet season. Although there was insufficient length of time (survey involving only 2 seasons within a year) to determine the exact nature of this seasonality, the study was able to establish a clear seasonal variation in beach state.

In this analysis of survey record involving five beaches along the Ghanaian coastline, protocols were established to examine beach status using changes in beach width and beach sediment volume. The envelope of beach change was not established for each beach profile due to length of survey period. Results generated valuable information on the short-term and seasonal scale variability in beach morphology. It was apparent that the magnitude of this variability differs both between beaches and within beaches. Between beach variations broadly corresponded to the different coastal settings as discriminated by wave energy. The shorter datasets (between two seasons) were currently of insufficient length to determine net medium to long-term erosion or accretion trends. However, there were signs of chronic erosion or accelerated accretion in the beach systems analysed in both seasons. The beach records revealed some seasonal trends in beach behaviour:

- At Abakam some profiles indicated net short-term shoreline erosion whereas other profiles indicated net beach accretion.
- At Ada long-term trends were difficult to determine due to lack of significant short-term and medium-term variability. However, the beach profiles appeared to be undergoing active erosion and are considered unstable.

- There was evidence of an increase in sediment volume contained within a number of profiles at Atorkor. However, decreases in sediment volume were noticeable on individual profiles which were not consistent across the beach.

- At Kedzi and Keta there was clear evidence of seasonal scale oscillations in beach behaviour (Table 5). However, the precise mechanisms causing beach change at these timescales was unclear.

The objective two sought to establish the dominant grain size along the Ghanaian coastline. It was established from the grain size analysis that the dominant grain size that influenced beach morphology varied from season to season. The dominant grain sizes were the 250 μm and 500 μm which indicated that the beach materials in all five sites were made up of fine to medium sand. This was in line with the submissions by Trenhail (1997) and Oyedotun (2016) on the dominant and significant grain size that influenced beach profiles of many beaches. In the application of the Stokes Law that states that negative buoyancy associated with larger particles sink faster than smaller particles that are dominated by friction, beaches dominated by fine to medium grains coupled with high energy to the coast (Xorse, 2013), the concentration of the total suspended sediment (TSS) is increased and the more saturated the water becomes. This has two implications on the beach; a) high sediment concentration implied erosion on the beach (eroded beach material (fine sediments) in suspension, b) the highly concentrated sediment causes less erosion downdrift. However, this may be influenced by local factors such as the presence of a cove or inlet, estuary, submarine canyon and led to deposition of the suspended sediments and erosion resumes as the currents gets less saturated (Davidson-Arnott, 2010; Anim & Nyarko, 2017).

Unlike the dominant grain size across shore, the significant grain size that influenced beach slope varied greatly both spatially and temporally. The dominant grain size may not necessarily be the significant grain size that influenced beach slope. The significant grain size that influenced beach slope showed the rate of permeability.

The spatial distribution of grain size parameters in all beaches were closely linked to foreshore morphology by Pedreros et al (1996). The berm consisted of finer, better sorted, whereas coarser and less sorted sediment was found in runnels. On the ridge, sediment characteristics were similar to those of the lower part of the berm.

The third objective was to investigate the extent to which grain size influence profile evolution. Coarser grains increase permeability while fine grains reduce permeability due to cohesion. Since reduced permeability increased erosion on the beach face, it led to gentle profiles. On the other hand, increased permeability decreased erosion resulting in steeper profiles. Beaches in the study sites exhibited steeper profiles in the dry season due to a decrease in erosion) and gentle profiles in the wet season resulting from increased erosion on the beach face. These variations in erosion resulted from variations in wave energy in the two seasons which brought about of variations in wave on the beach face.

By implication of the Stokes law, beaches in the study area (which are made up of finer grains) increased the Total Suspended Sediments in the nearshore zone. This has two implications; a) an increase in erosion on the immediate beach face and b) a decreased in erosion downdrift as the current gets saturated with beach material. A saturated current cannot erode more sediment and this led to deposition on the downdrift sides of beaches.

Significant grain size depicted permeability on the beach face. There was regularity in the currents that deposited beach material in the dry season. However, variability existed in the wet season due occasional to storm events. Therefore, significant grain size that influenced beach slope varied spatio-temporally.

The objective four highlighted the relationship between grain size and sorting. Although beaches were moderately sorted in both seasons, beaches in dry season had higher median diameter (*Md*) which ranged from 270 µm -300 µm (Figures 28-32, Table 8) compared to the wet season which ranged between 210 µm -250 µm (Figures 33-37, Table 10). This reflected the impact of grain size on sorting and the associated relationship on beach slope as indicated in the conceptual framework (Figure 5). The slopes of well sorted beaches consisting of entirely fine or coarse grains were much more defined than on beaches with mixed sediments (McLean & Kirk, 1969). Therefore, on moderately sorted beaches such as beaches in the study sites, the slopes were defined in a relative sense. The dominant grain sizes (fine to medium grains) gave a relatively gentle slope in both seasons. However, the slight difference in sorting (*So*) and *Md* coupled with wave energy showed that beaches in dry season were steeper than in the wet season.

The fifth objective of the study was to analyse oceanographic forcing on beach profile evolution. The analysis highlighted varying levels of variability which was expected given differences in wave climatology along the Ghanaian coastline and differences in susceptibility to storms (exposure). The study recorded a marked reduction in beach sediment volume and beach width that likely corresponded to storm impacts on beaches. In particular, storms in June 2016 promoted significant reduction in sediment volume and beach width at all five study sites in the wet season. With measures of beach change, Keta beach appeared more dynamic than any other site.

High wave energy setting exhibited the largest fluxes of sediment and substantial changes in beach width exhibited the smallest variations in sediment flux. These findings indicated that beaches within similar energy settings have similar morphodynamical characteristics. This suggested that monitoring multiple sites in each sub-environment may not be warranted and that effort may be better directed at identifying sentinel sites among a broader spectrum of coastal settings. The survey records within the two seasons highlighted that beach morphology varied at a range of spatial scales. Acknowledging the limited length of the datasets (a couple of months) it was clear that beach morphology varied at seasonal timescales. The extension of these records (monitoring records) would likely establish longer-term variations in morphology at the decadal to multi-decadal timescale.

According to Waugh (1995), dissipative beaches are characterised as being high energy beaches with a wide surf zone, a low-sloping and wide beach face consisting of fine sand. Observation showed that wave break further offshore, losing energy (dissipate) as they travel as breaking waves across the wide surf zone. Beaches in all five study sites analysed could be described as dissipative with their generally low angles. With this description constructive waves were expected but for the temporal variations in wave energy during the seasons, destructive waves caused erosion on the beaches.

The beach at Abakam showed a slight difference in beach face with respect to dissipative beach. It had a relatively narrow beach face and a relatively steeper backbeach.

Although the coast of Ghana is described generally as a high energy coast (Xorse, 2013), Figures 39 and 40 indicated seasonal variability in energy regime along the coast. The study sites experienced low energy during the dry season and high energy in the wet season. During lower energy conditions in the dry season the beach experienced a marked increase in deposition of sediment. In contrast, higher energy conditions associated with the wet season (stormy condition in June-July, 2016) stripped off sediment from the beach and the beach remained in a state of erosion. Storm surge associated with wet season (Figure 40) contributed to the erosional state of the beaches in wet season. During stormy conditions, high energy waves reaching the upper beach eroded sediment and distributed it over the beach face. This confirmed the submission by Wright and Short (1984). Thus, beaches appeared to be low in height with decrease in slope (Table 15) in the wet season compared to the dry season.

Conclusions

The fine granulometric texture of particle (grain) size along the Ghanaian coastline makes is very susceptible to erosion. The finer grains inhibit permeability thereby reducing percolation and build up wave runoff on the beach face and transports beach material offshore. This explains why the nearshore waters along the Ghanaian coastline is always concentrated with sediments, giving its dirty (brownish) colouration which inconvenience swimming.

Local conditions and features such as the presence of coves, estuaries, mudflats and marshes also influence longshore transport, thereby influencing erosion. A typical example was found at Ada where the estuary served as an interruptive littoral cell, changing the direction of the alongshore transport. This had an impact on the dominant grain size and beach slope in the wet season.

In order to effectively mitigate coastal erosion along the Ghanaian coastline, there is the need to understand the mechanisms of erosion along sheltered coast. It was observed that the mechanisms of erosion along sheltered coasts found at the eastern shores were quite different.

There were a lot of human interference on the coastline in the form of building close to the shore and sand mining. A construction on the beach at Ada by one of the famous construction companies in Ghana was perversely close to the sea. There were other construction activities by individuals which were also close to sea. This calls for a buffer zone to be set to limit human interference on coastline to reduce erosion.

In areas where rivers or estuaries meet the sea deposition often occurs. The sediment which is deposited usually builds up over the years to form a long ridge of material (usually sand or shingle), a spit. Such is the case at Kedzi and Keta which is situated on an extensive sand bar, probably of geological age, on which the entire Keta and Kedzi townships are built. As it has been the usual behavior of sandbars, eroding and redepositing due to their temporal nature, the supra sandbar is eroding in response to sea level rise. It is therefore advisable to relocate these communities or construct a harbor to accommodate the erosion problem.

Based on the analysis and findings of the study it could be concluded that all beaches in the five study sites exhibited almost the same morphological characteristics in terms of significant grain size and sorting of sediment that influence beach slope (profile evolution). Differences may occur when there is a change in oceanographic or hydraulic forcing and local factors such as estuaries, cove and headlands. This will cause variations in beach morphology

Recommendations

According to Dadson, et al., (2003), erosion occurs over a full range of time scales, including short-term events and chronic, long-term sea-level rise. Implicit in the definition of erosion is a choice of time scale, with longer events considered erosion and shorter events variance. In view of this, Zhang, et al., (2000) did not consider landward shoreline movement that recovers prior to the next storm as erosion, despite the potential loss of property associated with that variation. So there seems to be some form of controversy over shoreline movement that are regarded as erosion on the different time scales.

Because the shoreline is commonly based on movement of a single contour, it is precariously sensitive to details of the dynamics that determine how shore profiles adjust to natural forcing. This can introduce legal and operational difficulties. For instance, a legal requirement to mitigate erosion beyond the shoreline location can be defined. It is highly sensitive to associate a single contour definition for a coastline. Consequently, it is recommended to the Coastal Zone Management (CZM), the Environmental Protection Agency (EPA) to use a momentary coastline can be used based on the mean shoreline location integrated between a certain limit (example between –5 m and +5 m). Therefore, by basing the mitigation criterion on a shore zone definition, the law will be appropriately robust to short-term fluctuations as observed in the study.

Recognizing how sensitive a single contour definition of the shoreline is, a momentary coastline based on the mean shoreline location integrated between a limit should be used by the EPA and the CZM to base the mitigation criterion on to cater for the short-term fluctuations in erosion.

Beaches profiled revealed the current beach state of individual sites. It was established that some location with massive erosion such as Kedzi and Keta had greater portions of the land below sea level. As a result, these sites experienced significant variation in beach width and volume. Therefore, in physically managing the beach sediment reservoir, the CZM, the EPA and the government should conduct research to understanding the volume of beach material that is critical in beach material fluxes, taking into consideration all possible factors that may cause beach change. The seasonal trends in beach volume and the dominant grain size gave a clue on the behaviour of beach material under different forcing. This calls for a consideration of other beach management options to be implemented.

It is important to note that it is extremely difficult to identify causes of erosion or accretion on coastal systems from monitoring data alone. There are a number of causes of coastal change that are natural (change in wave climate, sediment supply and sea-level rise) and human-induced (e.g. sand mining, shoreline modification). Accurate detection of the causes of shoreline change require complementary monitoring of key environmental variables (wave climate being of highest priority) and field investigation of human activities and modifications at the coast. It is therefore recommended to CZM to conduct a complementary monitoring of the environmental variables and human activities to come out with a comprehensive coastal erosion mitigation strategy.

Continued commitment to maintaining a longitudinal monitoring programme is of critical importance for expanding the value of the data to support hazard management and medium-term and long-term coastal change analysis.

The study gathered valuable data was gathered through the survey. This needs to be extended to a monitoring momentum which should be maintained through continued longitudinal surveys. However, critical thought must be given to the purpose and structure of these activities to ensure the most effective use of data to aid future decision-making.

According to Pilkey and Wright (1988), the selection and type of mitigation to offset land loss depend on understanding local causes of erosion and accretion. The most common response to erosion in the study sites were the usual structural methods. As these interventions may further lead to erosion it is important to look at the behaviour of these structures and design the appropriate structures. The impact of these structures was confirmed by the results of the BV analysis which showed a seasonal decline in beach sediment volume along CES. Silvester (1978) and Pilkey et al., (2009) that when groynes are high, erosion downdrift occurs due to much sediment being held.

Longshore sediment transport also prevails and longshore sediment is concentrated in the surf zone. This builds up beaches due to retention of sediment. Therefore, the height of these groynes must be taken into consideration. The Government, EPA and the CZM must carry out maintenance checks on groyne height that has been reduced by accretion in the study sites.

It was observed from the study that CES at certain locations could not serve the purpose for which it was constructed due to the fact that it could not meet engineering standards (as it was the case at Anomabo Beach Resort). Beach monitoring helps with the understanding of beach behaviour in order to design fitting structures. The CZM, EPA must ensure that CES meets engineering standards. It is therefore recommended that beach monitoring forms a large component of coastal management. This will help understand the morphology of individual beaches and to design the required engineering structure in coastal fortification.

Of relevance to beach monitoring are wave records in close proximity to beaches of interest. Currently, wave records from such sites have not been collected. There should be a number of short duration records to be collected as part of university research and consulting projects. This must be generally of insufficient length for interpretation of beach monitoring datasets.

Sea level and changes in sea level are also an important control on beach behaviour. Important aspects of sea level of interest to the beach monitoring programme are; periods of extreme sea level associated with storms, interannual and decadal variations in sea level driven by broad climatic oscillations and long-term changes in sea level. The CZM, EPA in conjunction with the Maritime Academy should collect data on long-term and short-term sea-level changes by putting in place a sea level recorder which will be operational along the coast of Ghana to record short-term and long-term records. There is the need to take note of sea level record of significant decadal scale variation and a long-term increase. Such variations require careful and detailed interpretation in the context of beach monitoring records. Currently, there are no beach monitoring sites records of sufficient length to allow such analysis to occur. This hinders the development of multi-decadal coastal monitoring datasets to evaluate cause and effect relationships between wave climate, sea level and observed coastal change.

Beach nourishment may be a good choice where there is high cross-shore sediment transport on gentle sloping beaches with no submarine canyons or trenches where sediments will not be recoverable. However, sediment transport rates may help in decision making of what kind of shore management system to put in place with regards to erosion, either soft or hard. Therefore, the CZM and the government might have to have a second look at the soft options in mitigating erosion.

On a more generic basis, it is important to note that it is extremely difficult to identify causes of erosion or accretion on coastal systems from survey data alone. There are a number of causes of coastal change that are natural (change in wave climate, sediment supply and sea-level rise) and human-induced (e.g. sand extraction, shoreline modification). Accurate detection of the causes of shoreline change require complementary monitoring of key environmental variables (wave climate being of highest priority) and field investigation of human activities and modifications at the coast. This should form part of a comprehensive mitigation strategy by the government *and policy makers.*

No systematic measurement of environmental variables has occurred to support interpretation of coastal survey or monitoring records. Wave climate is the most important parameter to measure. Wave energy and changes in both the direction and height of waves have been identified as a major contributor to short and medium-term coastal change. These environmental variables should be considered and given critical attention in monitoring coastal environments.

In areas where rivers or estuaries meet the sea deposition often occurs. The sediment which is deposited usually builds up over the years to form a long ridge of material (usually sand or shingle), a spit. Such is the case at Kedzi and Keta which build an extensive sand bar, probably of geological age, on which the entire Keta and Kedzi townships are built. As it has been the usual behavior of sandbars, eroding and redepositing due to their temporal nature, the sand supra sandbar is eroding in response to sea level rise. It is therefore advisable to relocate these communities or construct a harbor to accommodate the erosion problem.

Suggestions for Further Research

I am delighted to have conducted this research. However, if given the opportunity again, the research would be conducted over a longer period of time (5years) which will involve monitoring instead of a survey.

The issue of erosion is dynamic and multi-dimensional. Nevertheless, due to some constraints, certain variables and concepts were held constant. The following are recommended for further research that will help with the mitigation of coastal erosion; sediment transport rate, site specific data on wave, wind, beach profile etc., fall velocity of sediments, influence of subaerial processes on erosion, evaluation of the CES and the evolution of site-specific coastlines

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APPENDIX A

IMAGES OF THE STUDY AREA SHOWING THE CONDITION OF BEACHES

Figure showing building that has been abandoned due to deposition of beach sediment from the seas.

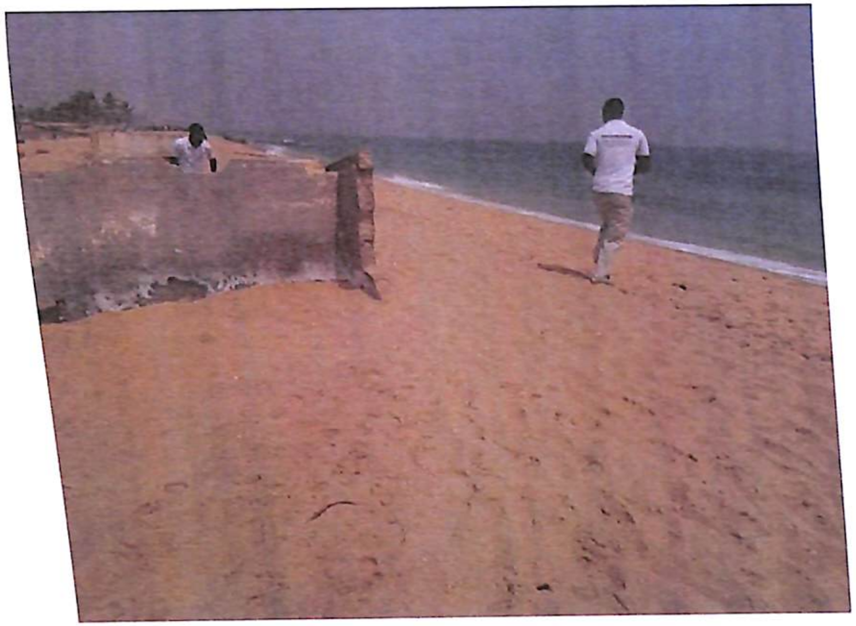

Figure showing buildings that were farther away from the beach with several others that used to be several meters into the sea that has been eroded.

Figure showing beach sediment up to the window level of buildings at Blekuso, downdrift of Keta

Figure showing the major road connecting Keta and nearby communities eroded by the seas

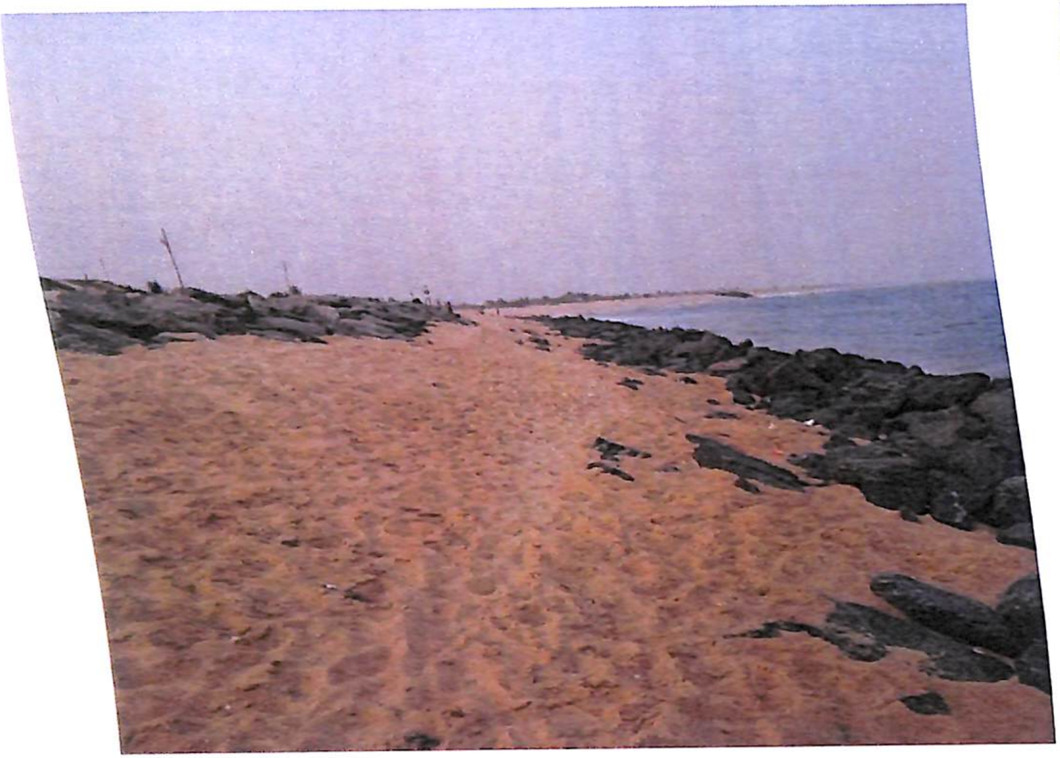

Figure showing a section of the beach at Keta

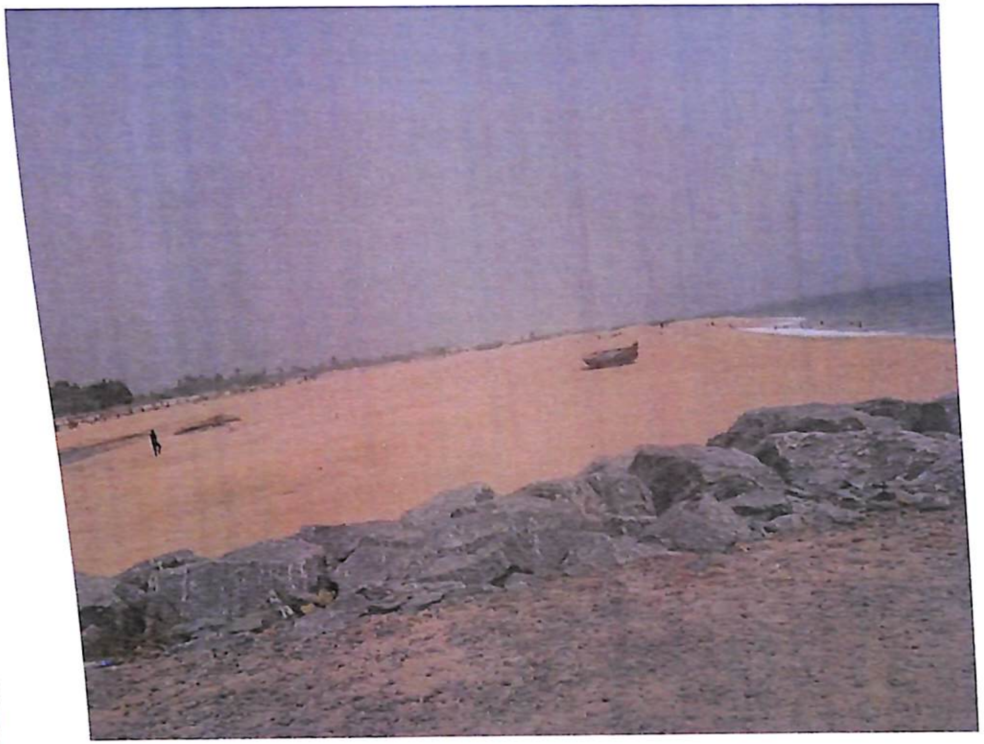

Figure showing the beach and groyne surface at Kedzi

Figure showing the construction of newer buildings close to the sea at Ada

Figure showing human interference on the beach at Kedzi

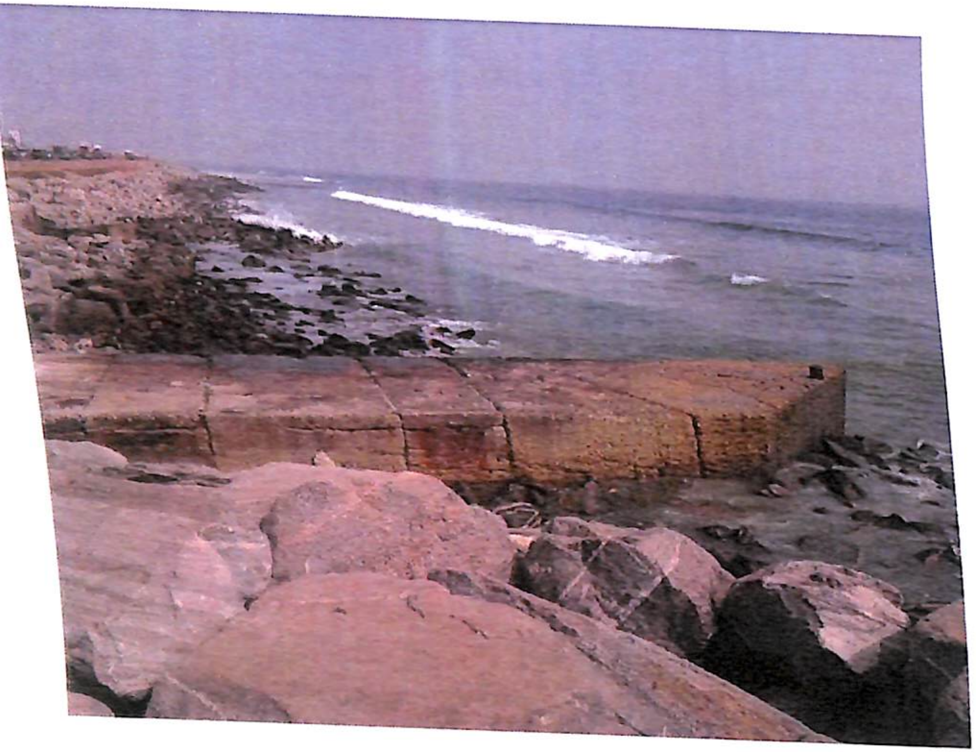

Figure showing the CES (stone revetment) at Sakumono in Accra

Figure showing the CES (gravity wall) at Sakumono in Accra

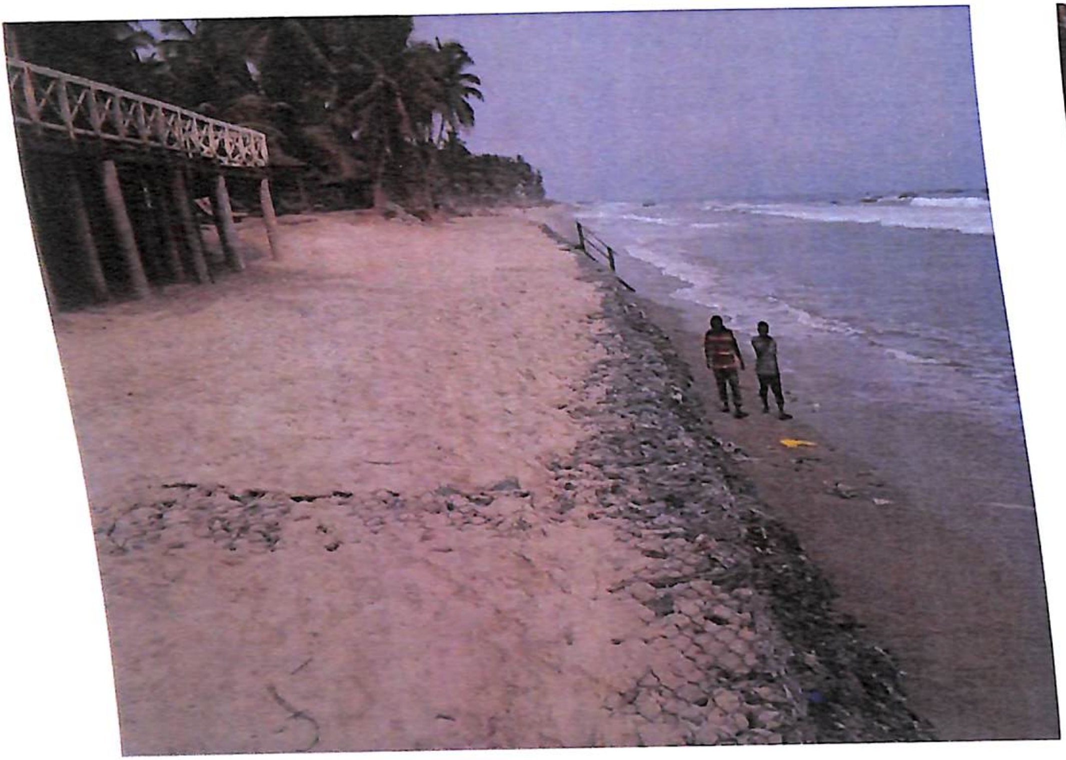

Figure showing a privately owned CES at Anomabo Beach Resort

Figure showing a privately owned CES (defence wall) at Anomabo Beach Resort. In a year construction the defence wall was destroyed by wave action.

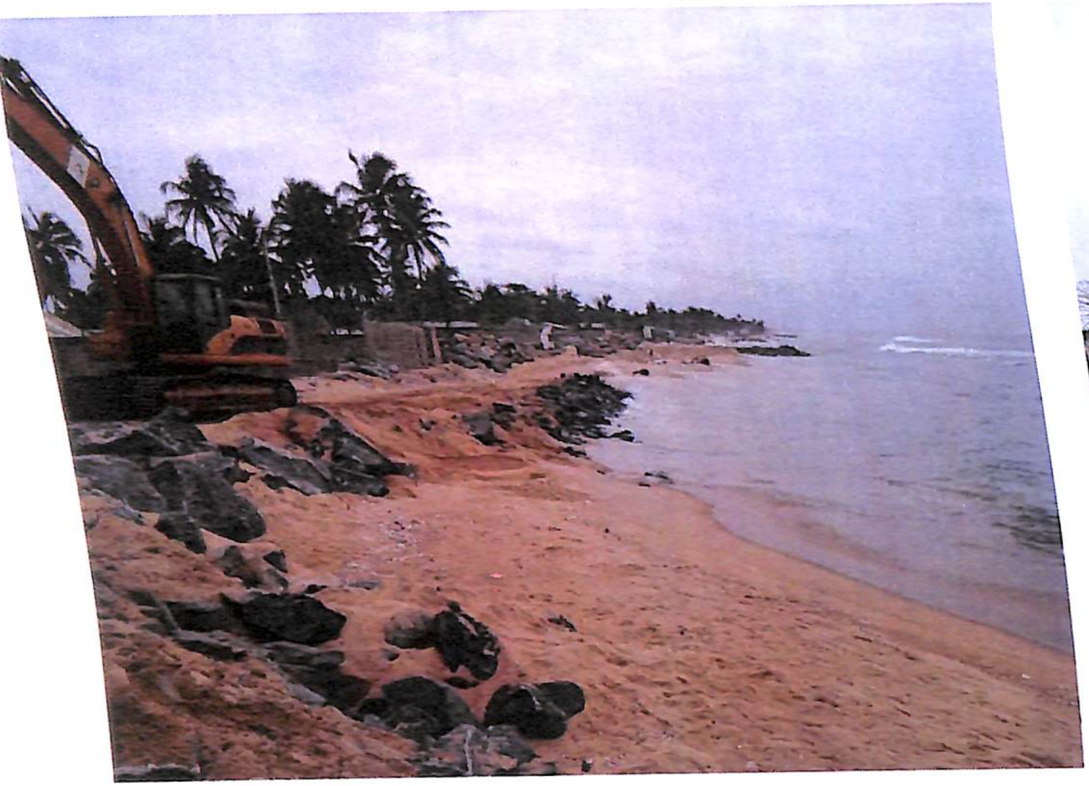

Figure showing the construction of new CES at Blekuso due to erosion being caused at downdrift side of the Kedzi-Keta structures

Figure showing the construction of new CES at Blekuso due to erosion being caused at downdrift side of the Kedzi-Keta structures by AMANDI

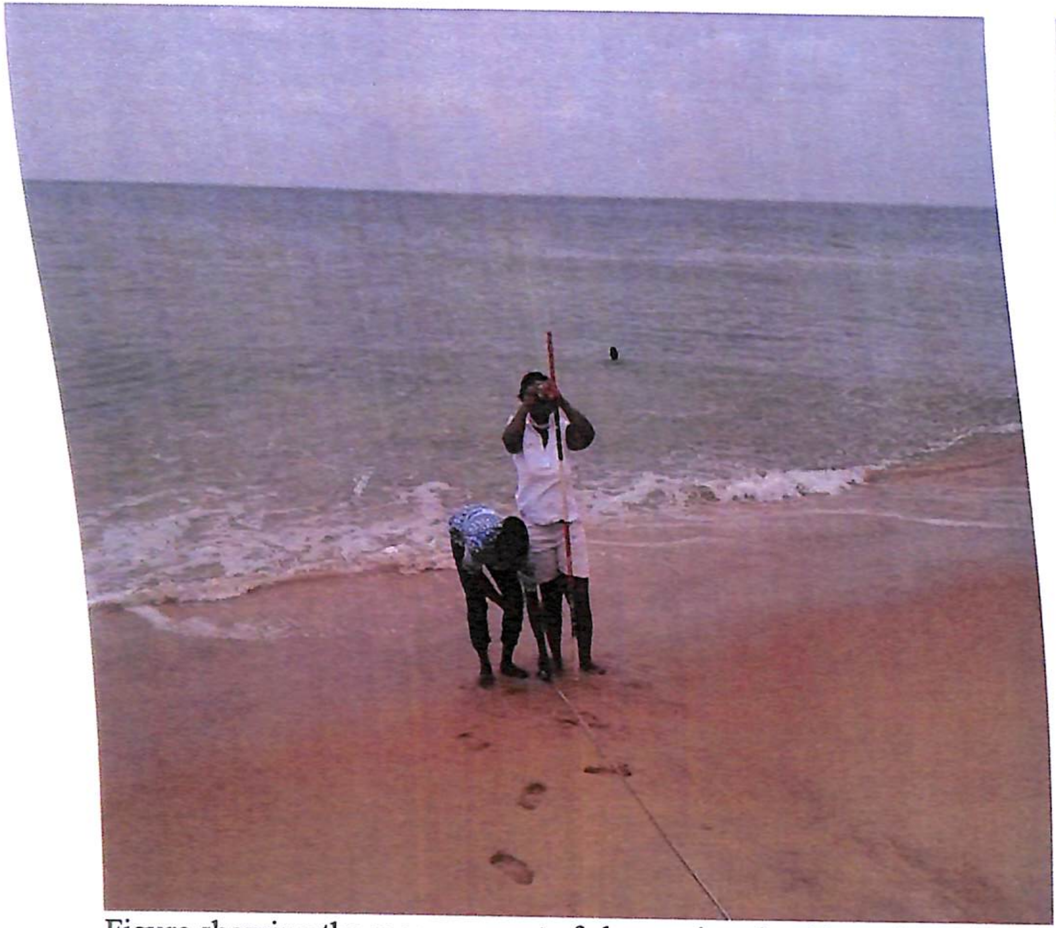

Figure showing the measurement of slope using the Abney level

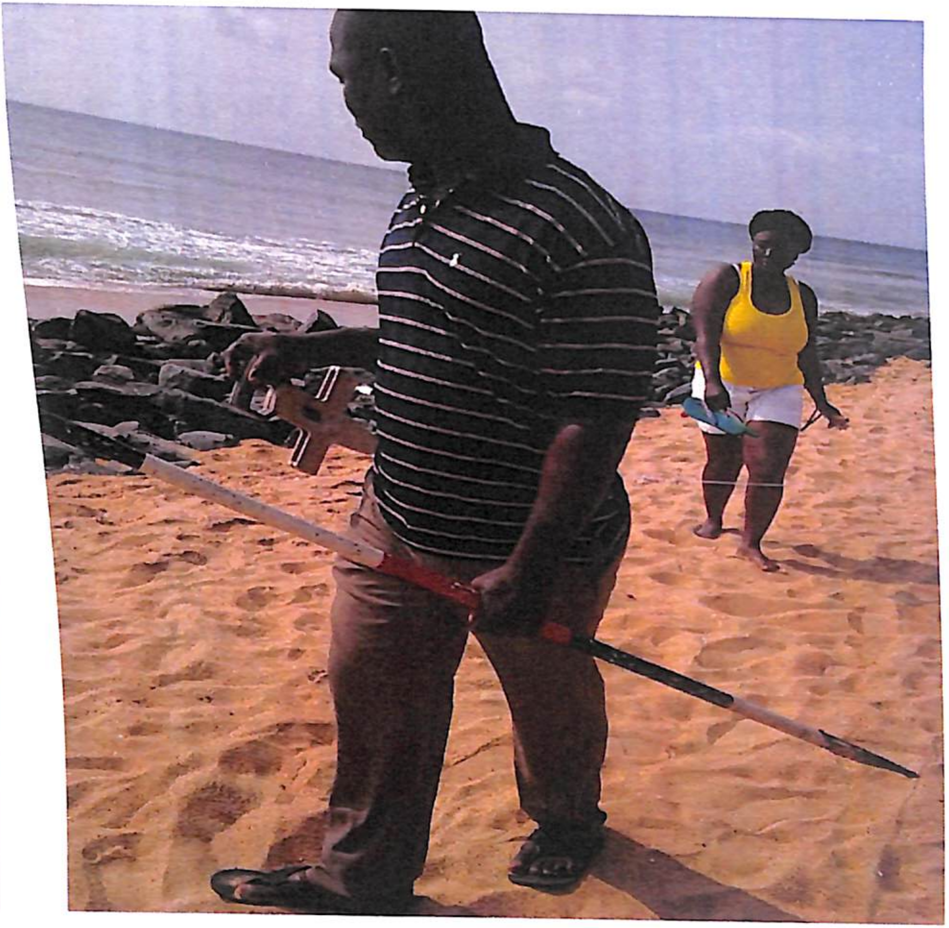

Figure showing the measurement of beach profile

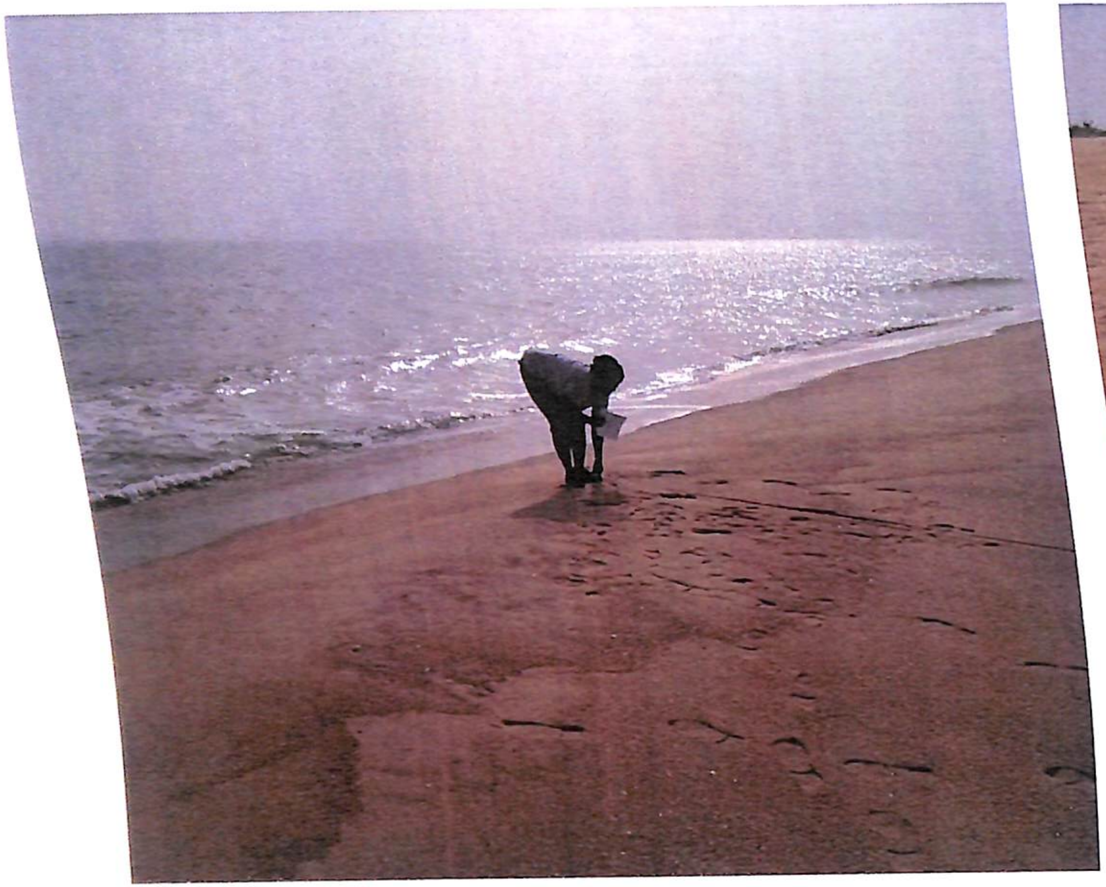

Figure showing the measurement of beach profile

Figure showing a section of the beach at Kedzi

Figure showing a quadrant used in taking sand samples

Figure showing the measuring of angles

Figure showing the reading of the Abney level with a magnifying glass. Hanging on the researcher was the GPS used in taking and tracking positions of profile lines

Figure showing the researcher with her team of field assistants

ving the researcher with her team of field assistants

Figure showing a section of the keta beach

Figure showing the researcher with her team of field assistants

Figure showing a section of the keta beach

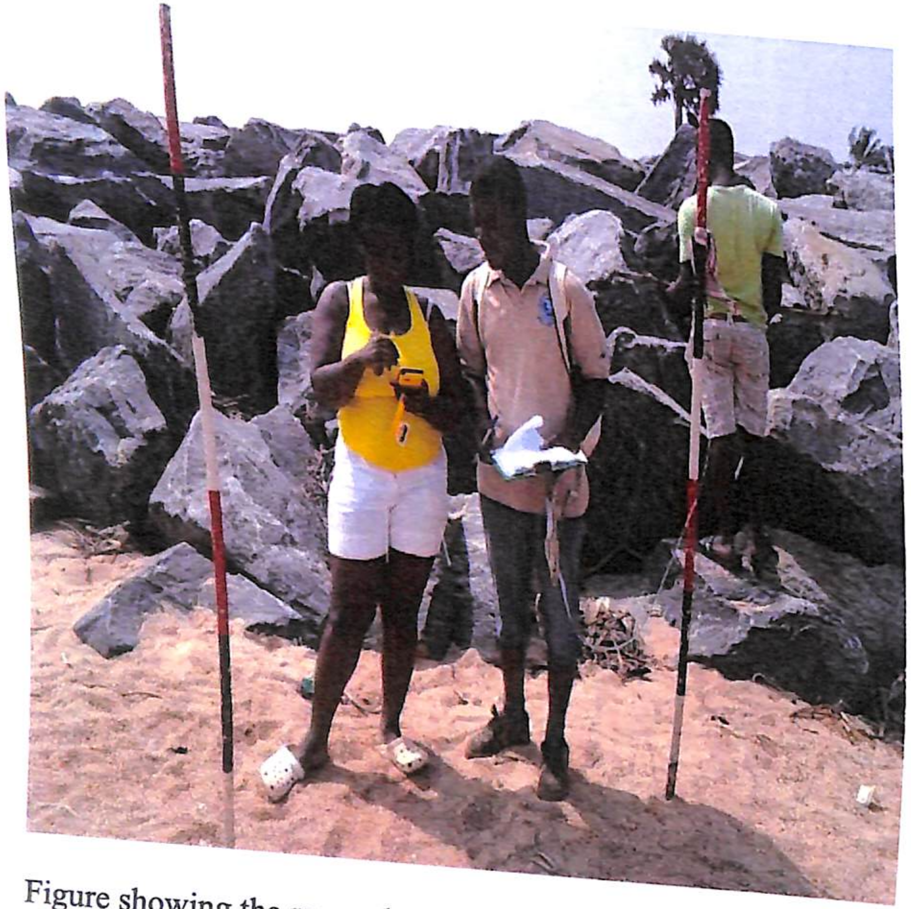

Figure showing the researcher with her team of field assistants at Atorkor beach

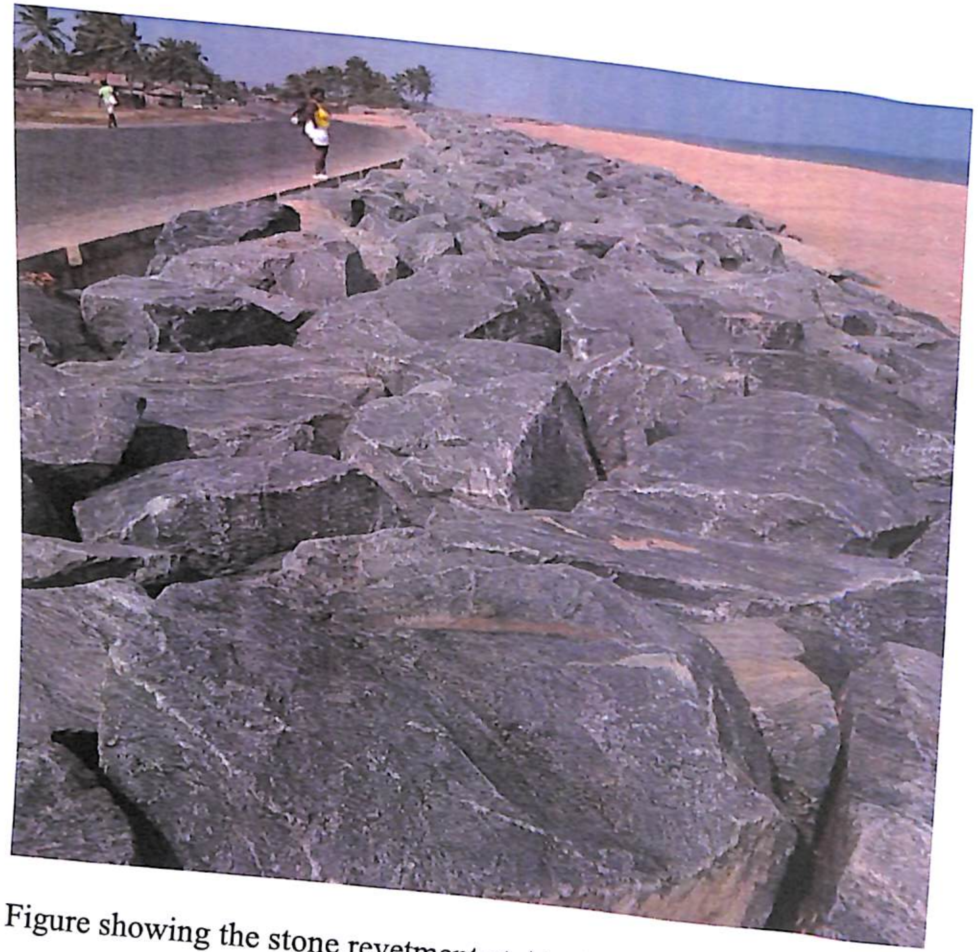

Figure showing the stone revetment at Atorkor. Beside it is the major road linking nearby villages up to the estuary at Ada.

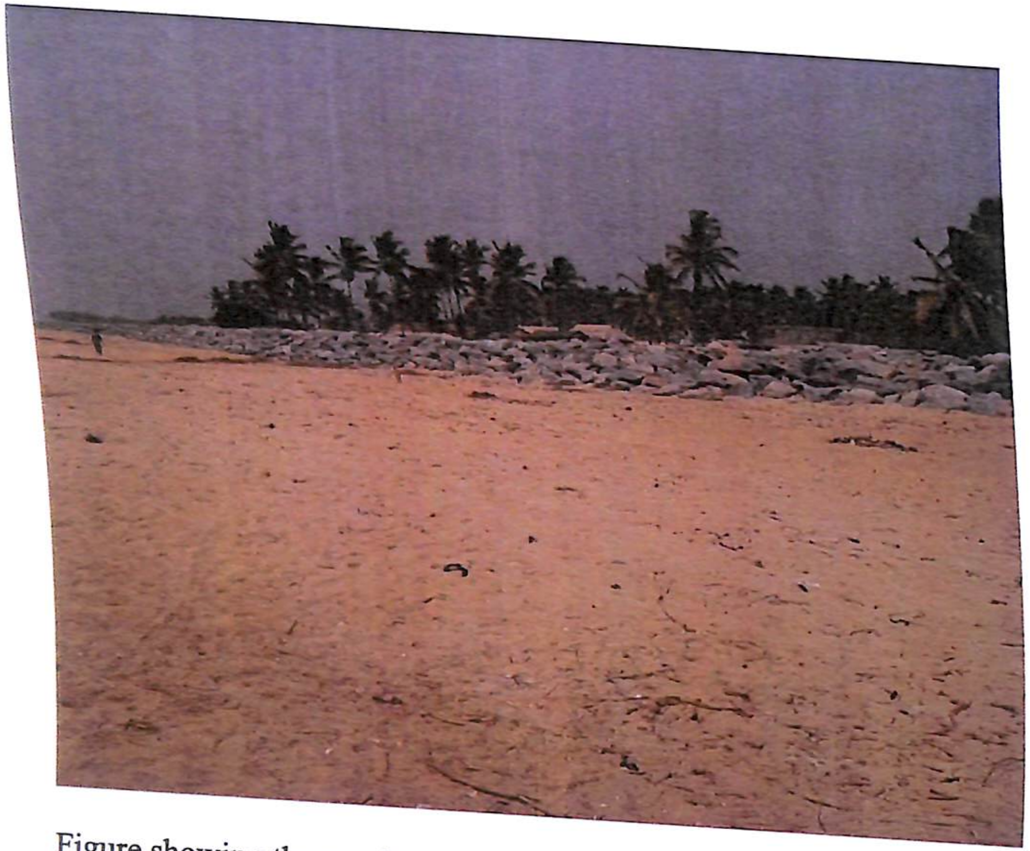

Figure showing the sea defence wall at Atorkor

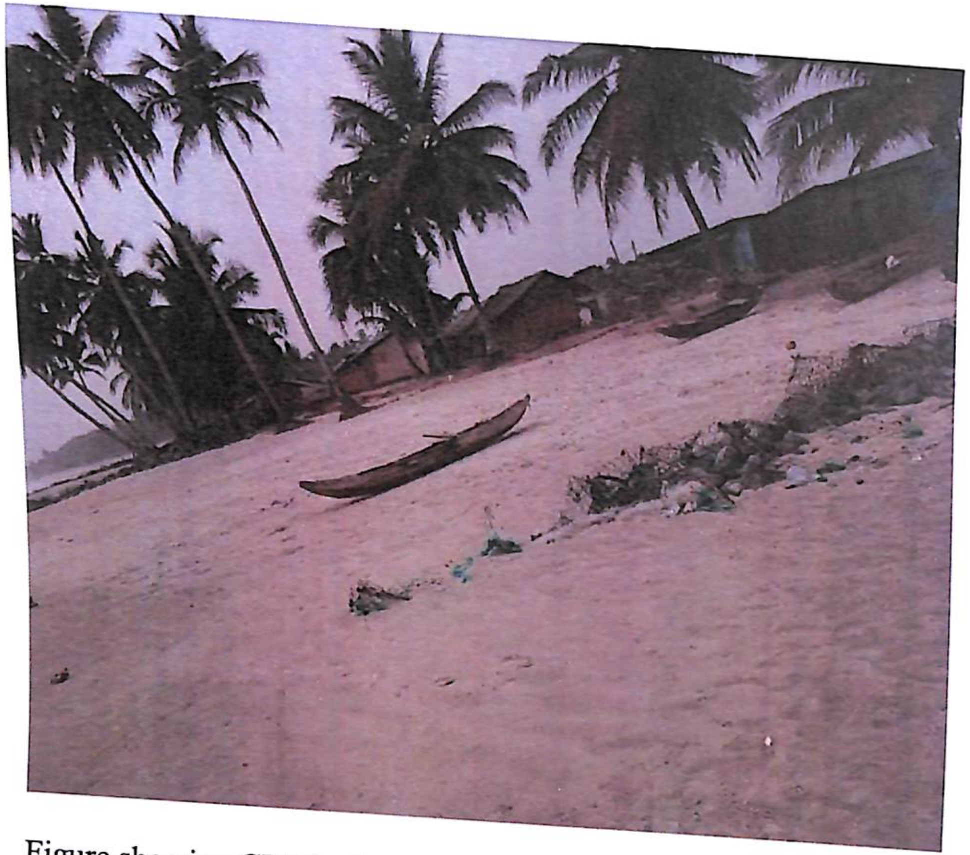

Figure showing CES buried at Princess Town

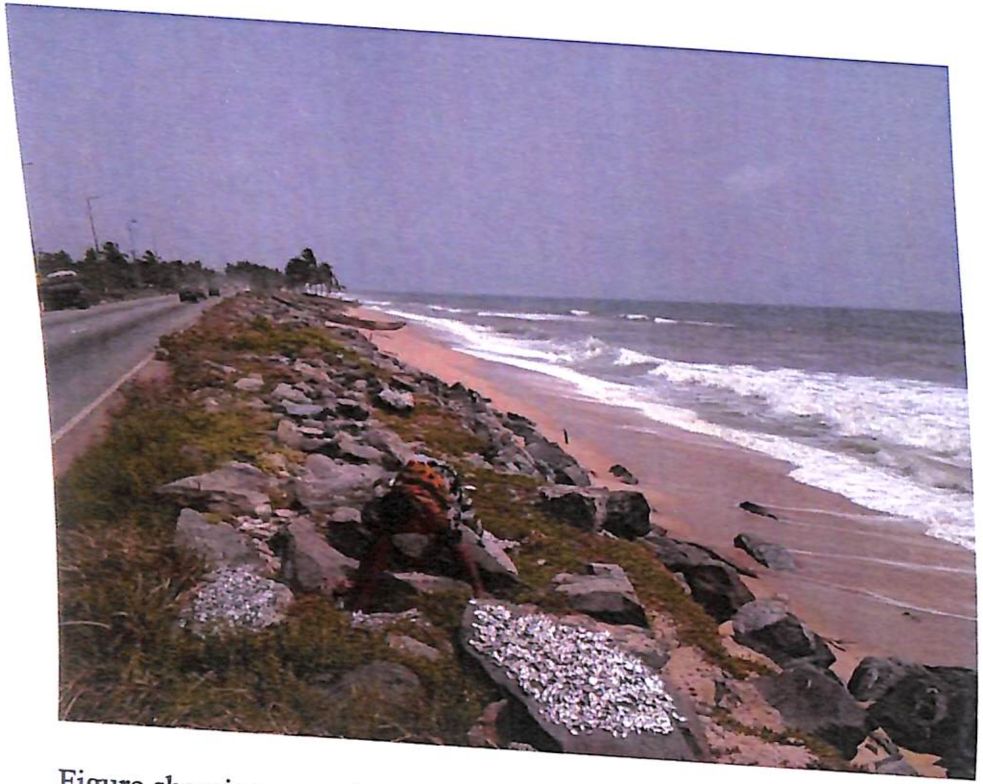

Figure showing a section of the beach at Abakam

Figure showing CES under construction at Amanful Kumah

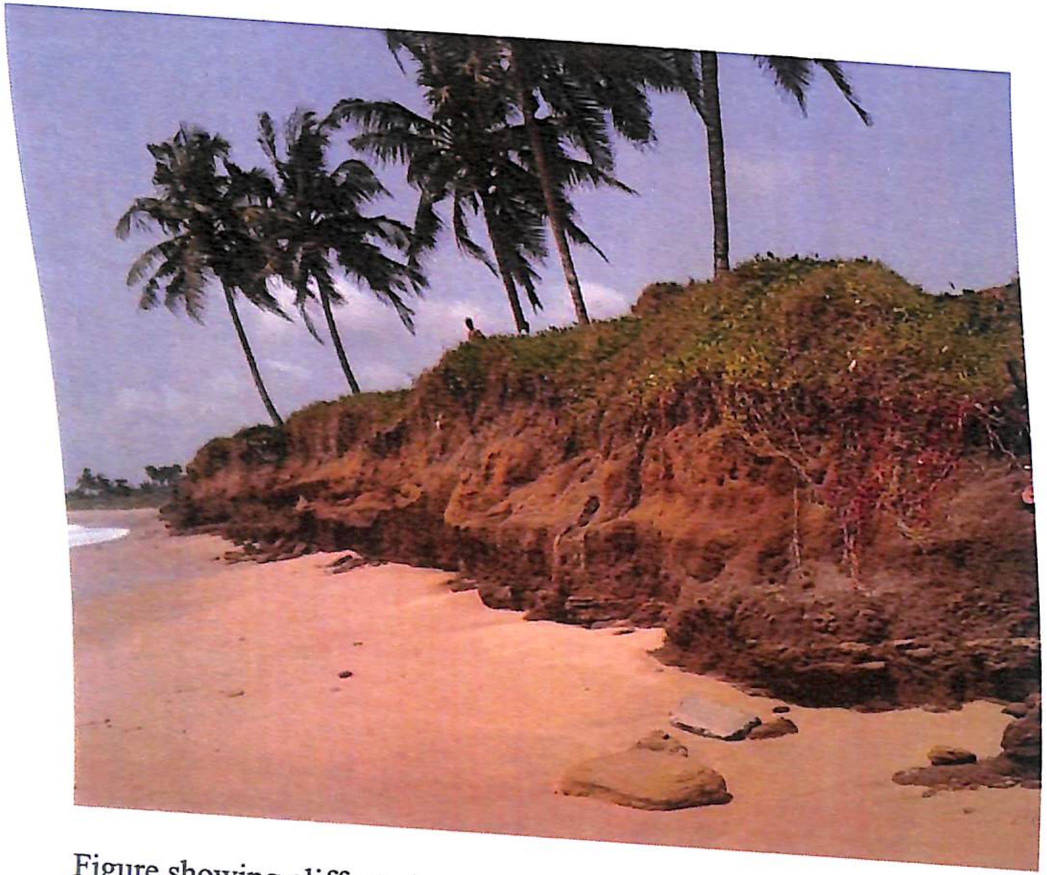

Figure showing cliff erosion at Amanful Kumah

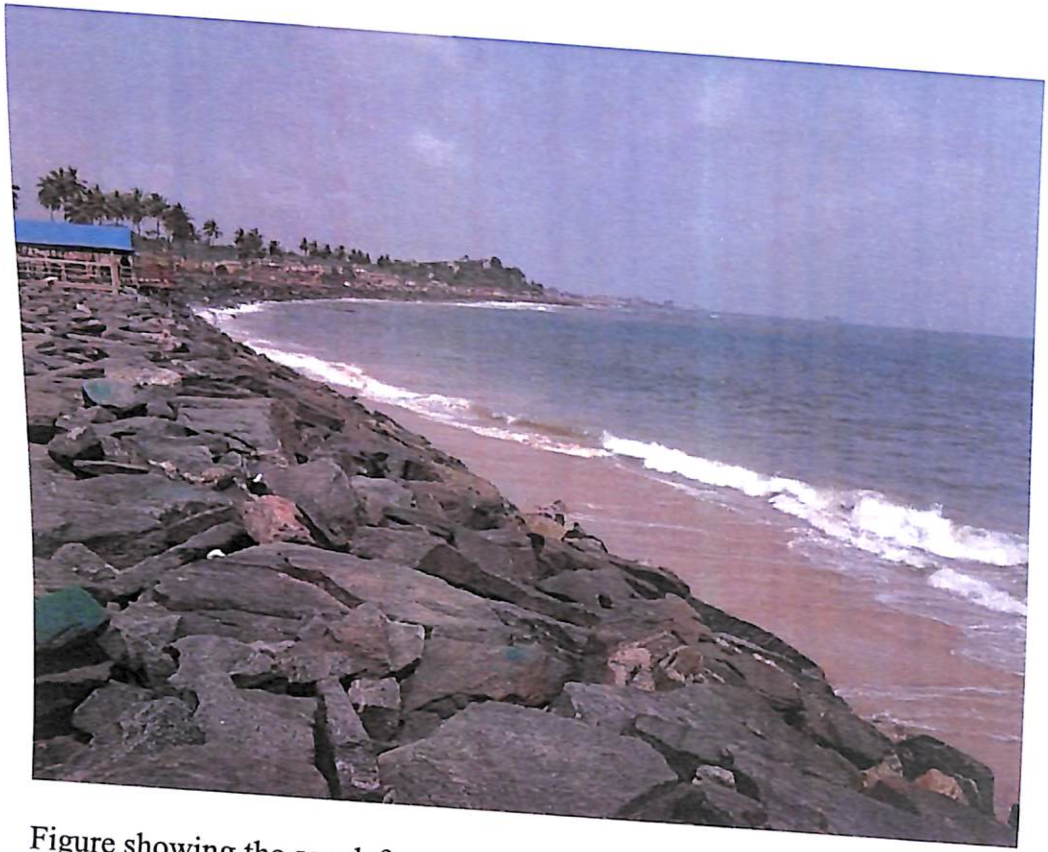

Figure showing the sea defence wall at Nkontompo

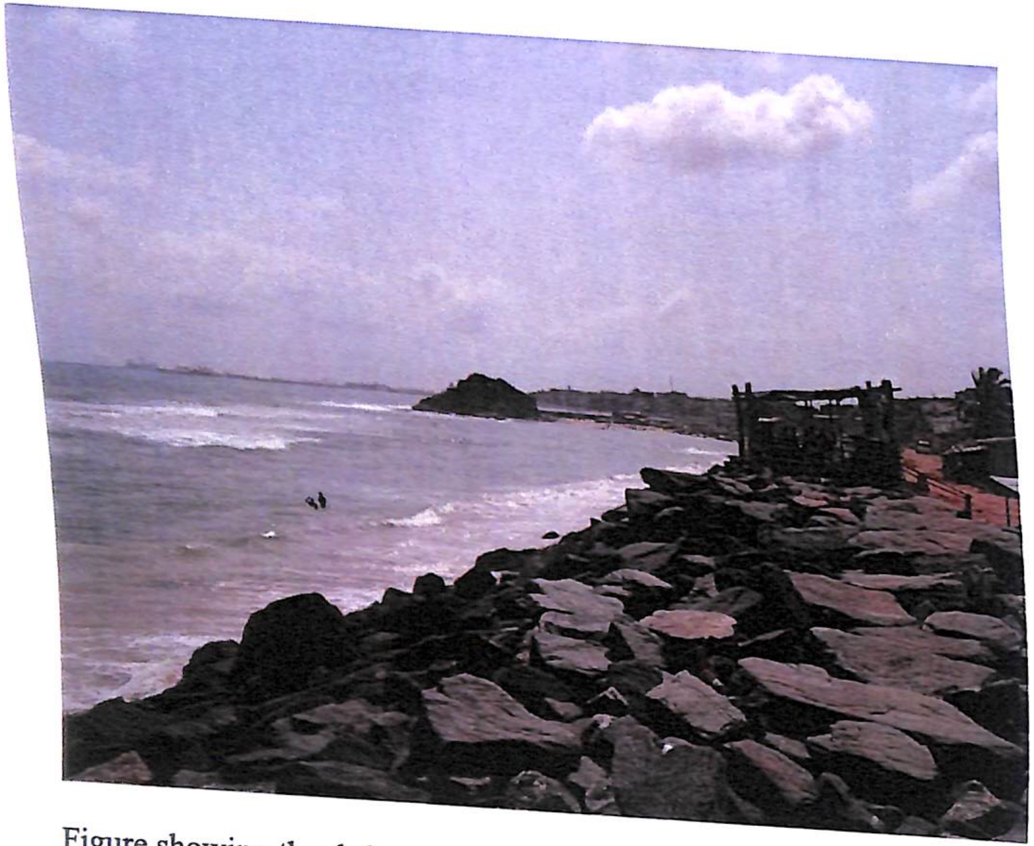

Figure showing the defence wall at Nkontompo with the famous

Nkontompo stack

Figure showing a crucible and crusher used in sand weighting at the laboratory

Figure showing the oven used in drying beach sediment samples at the laboratory

Figure showing an electric balance used in weighting beach sediments

Figure showing the mechanical shaker and sieve sizes used in weighting beach sediment at the laboratory

APPENDIX B

DATA ON BEACH PROFILES FOR DRY SEASON

bakam

	P1	p1	P2	P2	p2	P3	P3	p3	P4	P4		P5	P5		P6	P6	
0	1.4		0	1.4		0	1.4		0	1.4		0	1.4		0	1.4	
12	0.6	0.05	13.54	0.59	0.04	11.6	0.62	0.05	15.6	0.56	0.04	6.21	0.54	0.09	6.93	0.62	0.09
20	0.4	0.02	28.77	0.46	0.01	28.9	0.45	0.02	31.9	0.41	0.013	11.55	0.43	0.04	17.53	0.44	0.03
25.3	-0.12	-0.004	35.98	0.3	0.008	43.9	0.38	0.01	46.9	0.33	0.007	25.55	0.4	0.02	32.53	0.35	0.011
31.4	-0.22	-0.007	48.21	-0.18	-0.004	49.5	-0.23	-0.005	52.5	-0.13	-0.002	32.15	-0.2	-0.006	45.73	-0.12	-0.003
		0.059			0.054			0.075			0.058			0.144			0.128

P1	P2		P3	P4		P5	P6		P7	P8		P9	P10		P11		
0	0		0	0		0	0		0	0		0	0		0		
12	13.54		11.6	15.6		6.21	6.93		19.57	10.1		11.61	8.5		11.566		
20	28.77		28.9	31.9		11.55	17.53		24.57	20.1		26.61	26.5		23.643		
25.3	35.98		43.9	46.9		25.55	32.53		34.85	33.1		40.81	35.3		35.422		
31.4	48.21		49.5	52.5		32.15	45.73		42.46	38.1		46.61	49.1		43.576		

43.576																	
ABW =	43.576																
	360			399.43			359.6			436.8			167.67			214.83	
	400			661.71			650.25			653.95			248.325			385.66	
	-151.8			539.7			834.1			773.85			511			569.275	
	-345.4			-433.89			- 569.25			-341.25			-321.5			-274.38	
	262.8			1166.95			1274.7			1523.35			605.495			895.385	
P7	P7		P8	P8		P9	P9			P10		P10			P11	p11	
0	1.4		0	1.4		0	1.4			0		1.4			0	1.4	
19.57	0.62	0.032	10.1	0.71	0.07	11.61	0.57	0.05		8.5		0.68		0.08	11.566	0.611	
24.57	0.56	0.023	20.1	0.65	0.03	26.61	0.55	0.021		26.5		0.54		0.02	23.643	0.489	
34.85	0.44	0.013	33.1	0.5	0.015	40.81	0.43	0.011		35.3		0.43		0.012	35.422	0.344	
42.46	-0.24	0.006	38.1	-0.13	0.003	46.61	-0.17	-0.004		49.1		-0.23		-0.005	43.576	-0.185	
		0.074			0.118			0.078						0.107	ME	0.31475	
										mean slope =				0.0895			
P1	P2		P3	P4		P5	P6			P7		P8			P9	P10	p11
1.4	1.4		1.4	1.4		1.4	1.4			1.4		1.4			1.4	1.4	1.4
0.6	0.59		0.62	0.56		0.54	0.62			0.62		0.71			0.57	0.68	0.611
0.4	0.46		0.45	0.41		0.43	0.44			0.56		0.65			0.55	0.54	0.489
-0.12	0.3		0.38	0.33		0.4	0.35			0.44		0.5			0.43	0.43	0.344

-0.22	-0.18		-0.23	-0.13		-0.2	-0.12		-0.24	-0.13		-0.17	-0.23	-0.185
													MS	2.659
													0.603	
	606.67			358.55			330.885			289			353.341	
	687.96			653.25			731.775			715.5				
	766.7			827.5			877.415			758.95				
	-509.52			-247.65			-396.19			-564.65				
												TBV	ABV	
	1294.63			1591.65			1062.66			1004.5		10682.1	1068.21	

P1	P1		P2	P2		P3	P3		P4	P4		P5	P5		P6	P6
0	2.2		0	2.2		0	2.2		0	2.2		0	2.2		0	2.2
68.9	0.58	0.008	11.8	0.51	0.043	13.1	0.79	0.06	57.8	0.61	0.011	47.14	0.71	0.015	48	0.8
90.63	0.4	0.004	17.24	0.34	0.02	19.18	0.59	0.031	63.77	0.42	0.007	56.64	0.53	0.009	51.94	0.62
106.5	-0.14	-0	23.52	-0.18	-0.01	28.23	0.4	0.014	75.12	0.3	0.004	73.73	0.33	0.004	66.91	0.32
125.3	-0.39	-0	40.82	-0.32	-0.01	45.13	-0.25	-0.01	87.78	-0.31	-0	80.33	-0.21	-0	73.51	-0.2
		0.008			0.047			0.1			0.018			0.026		
1998			300.9			517.5			1763			1673			1920	
1813			293.1			565.8			1339			1501			1610	
-746			-212			564.6			1127			1217			1071	
-2444			-653			-564			-1361			-843			-735	
621.1			-271			1084			2868			3548			3866	

P7	*P7*		*P8*	*P8*		*P9*	*P9*		*P10*	*P10*		*P11*	*P11*
0	*2.2*		*0*	*2.2*		*0*	*2.2*		*0*	*2.2*		*0*	*2.2*
45.6	0.7	0.015	50.14	0.71	0.014	47.17	0.61	0.013	47.17	0.83	0.018	43.68	1.149
53.3	0.64	0.012	61.44	0.6	0.01	53.54	0.42	0.008	58.54	0.52	0.009	52.62	0.871
64.3	0.45	0.007	80.84	0.5	0.006	61.74	0.31	0.005	61.74	0.5	0.008	64.27	0.556
69.7	-0.23	-0	101	-0.27	-0	74.74	-0.13	-0	69.74	-0.22	-0	76.81	-0.4
		0.031			0.027			0.024			0.031		
							MS	0.034				ME	0.543
1596			1780			1439			1958				
1706			1843			1124			1522				
1447			2021			957			1544				
-802			-1364			-486			-767			TBV	ABV
3947			4280			3034			4256			27232	2723

P1	P1		P2	P2		P3	P3		P4	P4		P5	P5		P6	P6	
0	1.3		0	1.3		0	1.3		0	1.3		0	1.3		0	1.3	
62.6	0.53	0.00847	48.4	0.49	0.01012	28.62	0.75	0.02621	23.6	0.74	0.03136	26.8	0.87	0.03246	21.39	0.87	0.04067
79.2	0.44	0.00556	73.63	0.37	0.00503	47.25	0.51	0.01079	42	0.55	0.0131	34.66	0.57	0.01645	26.49	0.54	0.02039
81.9	0.23	0.00281	80.06	0.25	0.00312	53.97	0.43	0.00797	49.05	0.45	0.00917	46.52	0.2	0.0043	37.38	0.2	0.00535
88.5	-0.11	-0.0012	90.06	-0.16	-0.0018	76.37	-0.31	-0.0041	60.85	-0.25	-0.0041	63.92	-0.1	-0.0016	45.78	-0.1	-0.0022
		0.01559			0.0165			0.04091			0.04952			0.05164			0.06422
	1658.9			1185.8			1073.25			873.2			1165.8			930.465	
	1742.4			1362.16			1204.88			1155			987.81			715.23	
	941.85			1000.75			1160.36			1103.63			465.2			373.8	
	-486.7			-720.4			-1183.			-760.6			-319.6			-228.9	

Atorkor

P1	P1		P2	P2		P3	P3		P4	P4		P5	P5		P6	P6	
0	1.3		0	1.3		0	1.3		0	1.3		0	1.3		0	1.3	
62.6	0.53	0.00847	48.4	0.49	0.01012	28.62	0.75	0.02621	23.6	0.74	0.03136	26.8	0.87	0.03246	21.39	0.87	0.04067
79.2	0.44	0.00556	73.63	0.37	0.00503	47.25	0.51	0.01079	42	0.55	0.0131	34.66	0.57	0.01645	26.49	0.54	0.02039
81.9	0.23	0.00281	80.06	0.25	0.00312	53.97	0.43	0.00797	49.05	0.45	0.00917	46.52	0.2	0.0043	37.38	0.2	0.00535
88.5	-0.11	-0.0012	90.06	-0.16	-0.0018	76.37	-0.31	-0.0041	60.85	-0.25	-0.0041	63.92	-0.1	-0.0016	45.78	-0.1	-0.0022
		0.01559			0.0165			0.04091			0.04952			0.05164			0.06422
	1658.9			1185.8			1073.25			873.2			1165.8			930.465	
	1742.4			1362.16			1204.88			1155			987.81			715.23	
	941.85			1000.75			1160.36			1103.63			465.2			373.8	
	-486.7			-720.4			-1183.			-760.6			-319.6			-228.9	

	5				8				7				3								
	3856.4				2828.23				2254.75				2371.2				2299.21			1790.6	
p1	p2			p3	p4			p5	p6			p7	p8			p9	p10				
0	0			0	0			0	0			0	0			0	0			0	
66.6	62			28.62	23.6			26.8	21.39			15.72	26.85			14.83	21.02			30.743	
76.2	73.63			47.25	42			34.66	26.49			21.76	40.1			23.95	29.54			41.558	
81.9	80.06			53.97	49.05			46.52	37.38			33.26	49.66			38.38	39.64			50.982	
88.5	90.06			59.37	60.85			63.92	45.78			57.06	67.26			43.78	43.84		62.042	62.042	
120	120			120	120			120	120			120	120			120	120			120	

P7	P7		P8	P8		P9	P9		P10	P10		P11	P11	
0	1.3		0	1.3		0	1.3		0	1.3		0	1.3	
15.72	0.92	0.05852	26.85	0.94	0.03501	14.83	0.52	0.03506	21.02	0.88	0.04186	30.743	0.791	
21.76	0.57	0.02619	40.1	0.66	0.01646	23.95	0.33	0.01378	29.54	0.62	0.02099	41.558	0.556	
33.26	0.3	0.00902	49.66	0.32	0.00644	38.38	0.15	0.00391	39.64	0.41	0.01034	50.982	0.309	
57.06	-0.1	-0.0018	67.26	-0.21	-0.0031	53.78	-0.26	-0.0048	53.84	-0.2	-0.0037	62.042	-0.175	
		0.09199			0.05479			0.04792			0.06948	ME=	0.37025	
									MS	0.05025				
	723.12			1261.95			385.58			924.88			1215.89	
	620.16			1323.3			395.175			915.74				
	498.9			794.56			287.85			812.62				
	-285.3			-706.23			-699.14			-538.4				
												TBV	ABV	
	1556.88			2673.58			369.465			2114.84		22115.1	2211.51	
	p1		p2	p3		p4	p5		p6	p7		p8	p9	p10
	1.3		1.3	1.3		1.3	1.3		1.3	1.3		1.3	1.3	1.3
	0.53		0.59	0.75		0.88	0.97		0.87	0.92		0.94	0.92	0.88
	0.44		0.47	0.51		0.74	0.77		0.54	0.57		0.66	0.73	0.82
	0.23		0.25	0.43		0.45	0.2		0.1	0.1		0.32	0.3	0.61
	-0.11		-0.16	-0.4		0.45	0.2		0.2	0.1		0.32	0.3	0.61
	0.26		0.43	0.43		0.45	0.2		0.1	0.1		0.32	0.3	0.61
	0.26		0.24	0.12		0.45	0.2		0.1	0.1		0.32	0.3	0.61
	0.01		0.01	0.01		0.01	0.01		0.01	0.01		0.01	0.01	0.01

Kedzi

P1	P1		P2	P2		P3	P3		P4	P4		P5	P5		P6	P6	
0	0.82		0	0.82		0	0.82		0	0.82		0	0.82		0	0.82	
79.2	0.51	0.00644	41.3	0.65	0.01574	49.54	0.52	0.0105	42.65	0.52	0.01219	46.26	0.64	0.01383	65	0.61	0.00938
101.4	0	0	64.7	0.5	0.00773	60.06	0	0	52.65	0	0	56.21	0.58	0.01032	75.1	0.52	0.00692
118.2	-0.11	-0.0009	93.5	0	0	70.06	-0.1	-0.0014	60.58	-0.23	-0.0038	85.61	0.54	0.00631	94.28	0	0
127.59	-0.28	-0.0022	125.03	-0.22	-0.0018	78.55	-0.21	-0.0027	75.98	-0.3	-0.0039	104.01	0	0	106.68	-0.23	-0.0022
135.19	-0.33	-0.0024	125.03	-0.22	-0.0018	90.35	-0.25	-0.0028	88.78	-0.31	-0.0035	108.01	-0.47	-0.0044	123.28	-0.35	-0.0028
		0.00087			0.01995			0.00363			0.00096			0.02611			0.01131
TOTAL AND AVERAGE BEACH VOLUME																	
	2019.6			1342.25			1288.04			1108.9			1480.32			1982.5	
	0			1617.5			0			0			1630.09			1952.6	
	-650.1			0			-350.3			-696.67			2311.47			0	
	-1786.3			-1375.3			-824.78			-1139.7			0			-1226.8	
	-2230.6						-1129.4			-1376.1			-2538.2			-2157.4	
	-2647.4			1584.42			-1016.4			-2103.6			2883.65			550.88	

P7	*P7*		*P8*	*P8*		*P9*	*P9*		*P10*	*P10*		*P11*	*P11*
0	*0.82*		*0*	*0.82*		*0*	*0.82*		*0*	*0.82*		0	0.82
15.17	0.66	0.04351	40.8	0.66	0.01618	22.74	0.57	0.02507	52.47	0.58	0.01105	45.513	0.592
20.27	0.62	0.03059	47.17	0.55	0.01166	55.94	0.51	0.00912	90.62	0.55	0.00607	62.412	0.383
45.99	0	0	55.37	0.5	0.00903	84.54	0	0	103.42	0	0	81.155	0.06
57.73	-0.3	-0.0052	68.37	0	0	103.24	-0.12	-0.0012	128.22	-0.13	-0.001	97.54	-0.179
57.73	-0.3	-0.0052	74.37	-0.32	-0.0043	117.84	-0.17	-0.0014	154.17	-0.4	-0.0026	106.475	-0.312
		0.0637			0.03256			0.03158			0.01351	ME=	0.1088
									MS	0.02042			
	500.61			1346.4			648.09			1521.63			1347.18
	628.37			1297.18			1426.47			2492.05			
	0			1384.25			0			0			
	- 865.95			0			-619.44			-833.43			
				-1189.9			-1001.6			-3083.4			
												TBV	ABV
	263.03			2837.91			453.48			96.85		2902.85	290.285

Keta

P1	P1		P2	P2		P3	P3		P4	P4		P5	P5		P6	P6	
0	1.2		0	1.2		0	1.2		0	1.2		0	1.2		0	1.2	
75	0.54	0.0072	50	0.44	0.0088	12.8	0.63	0.04922	16.8	0.84	0.05	19.3	0.69	0.03575	20.4	0.84	0.04118
80.5	0.35	0.00435	79	0	0	50.36	0.33	0.00655	19.9	0.63	0.0317	30	0.47	0.01567	53.2	0.63	0.01184
91.6	0	0	84.6	-0.1	-0.0012	61.9	0.23	0.00372	53.5	0	0	44.37	0	0	78.6	0.55	0.007
106.96	-0.23	-0.0022	91.6	-0.11	-0.0012	79.9	0	0	72.1	-0.1	-0.0014	51.4	-0.34	-0.0066	88.7	0	0
106.96	-0.23	-0.0022	109	-0.11	-0.001	100.9	-0.13	-0.0013	78.4	-0.1	-0.0013	51.4	-0.34	-0.0066	97.3	-0.12	-0.0012
106.96	-0.23	-0.0022	113.2	-0.3	-0.0027	108.9	-0.31	-0.0028	84.4	-0.22	-0.0026	51.4	-0.34	-0.0066	97.3	-0.12	-0.0012
		0.0051			0.00276			0.05535			0.0764			0.03157			0.05755
	0.0286			-0.0257			0.1071			0.15			0.02			0.25429	
	2025			1100			403.2			705.6			665.85			856.8	
	1408.8			0			830.94			626.85			705			1675.8	
	0			-423			711.85			0			0			2161.5	
	-1230			-503.8			0			-360.5			-873.8			0	
				-599.5			-655.85			-392						-583.8	
				-1698			-1688										
	2203.7			173.2			1945.9			971.95			497.1			4694.1	

Keta

P1	P1		P2	P2		P3	P3		P4	P4		P5	P5		P6	P6	
0	1.2		0	1.2		0	1.2		0	1.2		0	1.2		0	1.2	
75	0.54	0.0072	50	0.44	0.0088	12.8	0.63	0.04922	16.8	0.84	0.05	19.3	0.69	0.03575	20.4	0.84	0.04118
80.5	0.35	0.00435	79	0	0	50.36	0.33	0.00655	19.9	0.63	0.0317	30	0.47	0.01567	53.2	0.63	0.01184
91.6	0	0	84.6	-0.1	-0.0012	61.9	0.23	0.00372	53.5	0	0	44.37	0	0	78.6	0.55	0.007
106.96	-0.23	-0.0022	91.6	-0.11	-0.0012	79.9	0	0	72.1	-0.1	-0.0014	51.4	-0.34	-0.0066	88.7	0	0
106.96	-0.23	-0.0022	109	-0.11	-0.001	100.9	-0.13	-0.0013	78.4	-0.1	-0.0013	51.4	-0.34	-0.0066	97.3	-0.12	-0.0012
106.96	-0.23	-0.0022	113.2	-0.3	-0.0027	108.9	-0.31	-0.0028	84.4	-0.22	-0.0026	51.4	-0.34	-0.0066	97.3	-0.12	-0.0012
		0.0051			0.00276			0.05535			0.0764			0.03157			0.05755
	0.0286			-0.0257			0.1071			0.15			0.02			0.25429	
	2025			1100			403.2			705.6			665.85			856.8	
	1408.8			0			830.94			626.85			705			1675.8	
	0			-423			711.85			0			0			2161.5	
	-1230			-503.8			0			-360.5			-873.8			0	
				-599.5			-655.85			-392						-583.8	
				-1698			-1688										
	2203.7			173.2			1945.9			971.95			497.1			4694.1	

P7	*P7*		*P8*	*P8*		*P9*	*P9*		*P10*	*P10*		*P11*	*P11*
0	1.2		0	1.2		0	1.2		0	1.2		0	1.2
7.3	0.65	0.08904	30.6	0.61	0.01993	49.6	0.53	0.01069	49.6	0.63	0.0127	33.14	0.76
33.7	0.43	0.01276	56	0.49	0.00875	70.4	0.32	0.00455	72.4	0	0	54.546	0.555
49.1	0.35	0.00713	74.8	0.13	0.00174	89.6	0	0	93.8	-0.1	-0.0011	72.187	0.225
62.3	0.16	0.00257	84.4	0	0	102	-0.11	-0.0011	99.4	-0.1	-0.001	83.876	-0.016
71.85	0	0	94.4	-0.14	-0.0015	107.2	-0.34	-0.0032	99.4	-0.1	-0.001	90.681	-0.189
76.85	-0.1	-0.0013	104.4	-0.29	-0.0028	107.2	-0.34	-0.0032	99.4	-0.1	-0.001	91.901	-0.233
		0.1102			0.02616			0.00781			0.00862		
												ME	0.18367
	0.21286			0.11429			0.00857			0.03286			
												MS	0.03815
	237.25			933.3			1314.4			1562.4			1259.32
	724.55			1372			1126.4			0			
	859.25			486.2			0			-469			
	498.4			0			-561			-497			
	0			-660.8			-1822.4						
	-384.25			-1513.8									
												TBV	ABV
	1935.2			616.9			57.4			596.4		13691.9	1369.19

Abakam

DATA ON BEACH PROFILES FOR WET SEASON

	P1		P2	P2		P3	P3		P4	P4		P5	P5		P6	P6	
0	1.4		0	1.4		0	1.4		0	1.4		0	1.4		0	1.4	
.7	0.64	0.073563	9.96	0.6	0.060241	7.3	1.22	0.167123	11.8	0.8	0.017474	8.9	0.91	0.102247	9.54	0.88	0.09224
.57	-0.22	-0.0107	19.36	0.32	0.016529	15.8	0.6	0.037975	29.4	-0.12	-0.00408	23.35	-0.12	-0.00514	20.34	-0.11	-0.0054
.57	-0.22		31.76	-0.31	-0.00976	27.2	-0.29	-0.01066	29.4		0	28.35	-0.32	-0.01129	23.34	-0.41	-0.0175
		0.062868			0.067009			0.194436			0.013392			0.085821			0.06926
	TBV in each cell																
	278.4			298.8			445.3			472			404.95			419.76	
	-226.27			309.76			474			-176.4			-140.1			-111.87	
				-492.28			-394.4										
	52.13			116.28			524.9			295.6			264.85			307.89	

P7	*P7*		*P8*	*P8*		*P9*	*P9*		*P10*	*P10*		*P11*	*P11*
0	*1.4*		*0*	*1.4*		*0*	*1.4*		*0*	*1.4*		0	1.4
8.4	0.78	0.092857	15.24	0.7	0.045932	14.4	0.86	0.059722	9.1	0.87	0.095604	10.334	0.826
19.2	-0.12	-0.00625	28.34	-0.25	-0.00882	26.95	-0.23	-0.00853	21.75	-0.16	-0.00736	22.506	-0.041
19.2	-0.12		28.34	-0.25		26.95	-0.23		21.75	-0.16		24.886	-0.253
		0.086607			0.03711			0.051188			0.088248	ME	0.177333
												MS	0.075595
	327.6			533.4			619.2			395.85			426.7942
	-115.2			-354.25			-309.925			-174			
												TBV	ABV
	212.4			179.15			309.275			221.85		2484.325	248.4325

Ada

P1		P2	P2		P3	P3		P4	P4		P5	P5		P6	P6	
2.2		0	2.2		0	2.2		0	2.2		0	2.2		0	2.2	
0.72	0.010811	62	0.66	0.010645	56	0.68	0.012143	49	0.76	0.01551	64	0.85	0.013281	58	0.84	0.0144
0.44	0.005774	73.63	0.35	0.004753	84	0.33	0.003929	67.4	0.44	0.006528	91	0.41	0.004505	91	0.2	0.0021
-0.13	-0.00159	80.06	-0.14	-0.00175	90.72	-0.12	-0.00132	74.45	-0.1	-0.00134	102.86	-0.25	-0.00243	101.89	-0.1	-0.000
	0.014998			0.01365			0.014749			0.020695			0.015356			0.0156
2397.6			2046			1904			1862			2720			2436	
1676.4			1288.525			1386			1482.8			1865.5			910	
-532.35			-560.42			-544.32			-372.25			- 1285.75			-509.45	
3541.65			2774.105			2745.68			2972.55			3299.75			2836.55	

p7	*P7*		*P8*	*P8*		*P9*	*P9*		*P10*	*P10*		*P11*	*P11*
0	*2.2*		*0*	*2.2*		*0*	*2.2*		*0*	*2.2*		0	2.2
46	0.81	0.017609	71	0.48	0.006761	45.21	0.62	0.013714	44.54	0.61	0.013696	56.235	0.703
79	0.66	0.008354	113.13	0.32	0.002829	73.34	0.3	0.004091	77.06	0.62	0.008046	82.576	0.407
90.5	-0.19	-0.0021	128.49	-0.13	-0.00101	87.77	-0.22	-0.00251	87.16	-0.2	-0.00229	92.58	-0.158
		0.023864			0.008577			0.015298			0.019447	ME	0.317333
												MS	0.016233
	1863			1704			1401.51			1358.47			
	2607			1810.08			1100.1			2388.86			
	-859.75			-835.185			-965.47			-871.6			
												TBV	ABV
	3610.25			2678.895			1536.14			2875.73		28871.3	2887.13

Atorkor

P1	p1		P2	p2		P3	p3		P4	p4		P5	p5		P6	p6	
0	1.3		0	1.3		0	1.3		0	1.3		0	1.3		0	1.3	
47.5	0.83	0.017474	37.4	0.61	0.01631	24.4	0.92	0.037705	29.2	0.8	0.027397	24.4	1.1	0.045082	20.2	1.1	0.054455
50.4	0.72	0.014286	58.8	0.5	0.008503	36.5	0.64	0.017534	41	0.79	0.019268	35.8	0.72	0.020112	31.9	0.72	0.022571
63.2	0.55	0.008703	69.7	0.41	0.005882	42.3	-0.24	-0.00567	72	-0.12	-0.00167	40.8	-0.11	-0.0027	44.9	-0.11	-0.00245
71.8	-0.21	-0.00292	78.1	-0.23	-0.00294	42.3	-0.24		72	-0.12		40.8	-0.11		64.9	-0.31	-0.00478
		0.037537			0.027751			0.049565			0.044999			0.062498			0.0698
	1971.25			1140.7			1122.4			1168			1342			1111	
	1814.4			1470			1168			1619.5			1288.8			1148.4	
	1738			1428.85			-507.6			-432			-224.4			-246.95	
	-753.9			-898.15													
	4769.75			3141.4			1782.8			2355.5			2406.4			2012.45	

Atorkor

P1	p1		P2	p2		P3	p3		P4	p4		P5	p5		P6	p6	
0	1.3		0	1.3		0	1.3		0	1.3		0	1.3		0	1.3	
47.5	0.83	0.017474	37.4	0.61	0.01631	24.4	0.92	0.037705	29.2	0.8	0.027397	24.4	1.1	0.045082	20.2	1.1	0.054455
50.4	0.72	0.014286	58.8	0.5	0.008503	36.5	0.64	0.017534	41	0.79	0.019268	35.8	0.72	0.020112	31.9	0.72	0.022571
63.2	0.55	0.008703	69.7	0.41	0.005882	42.3	-0.24	-0.00567	72	-0.12	-0.00167	40.8	-0.11	-0.0027	44.9	-0.11	-0.00245
71.8	-0.21	-0.00292	78.1	-0.23	-0.00294	42.3	-0.24		72	-0.12		40.8	-0.11		64.9	-0.31	-0.00478
		0.037537			0.027751			0.049565			0.044999			0.062498			0.0698
	1971.25			1140.7			1122.4			1168			1342			1111	
	1814.4			1470			1168			1619.5			1288.8			1148.4	
	1738			1428.85			-507.6			-432			-224.4			-246.95	
	-753.9			-898.15													
	4769.75			3141.4			1782.8			2355.5			2406.4			2012.45	

P7	p7		P8	p8		P9	p9		P10	p10		p11	p11
0	1.3		0	1.3		0	1.3		0	1.3		0	1.3
23.1	0.82	0.035498	22.2	0.7	0.031532	23.5	0.84	0.035745	27.73	0.71	0.025604	27.963	0.843
34.2	-0.31	-0.00906	32.6	-0.21	-0.00644	46	0.35	0.007609	39.39	0.13	0.0033	40.659	0.405
34.2	-0.31		32.6	-0.21		54.1	-0.24	-0.00444	43.44	-0.13	-0.00299	49.724	-0.051
34.2	-0.31		32.6	-0.21		62.1	-0.34	-0.00548	43.44	-0.13		53.824	-0.221
		0.026434			0.02509			0.033442			0.025912	ME	0.244
												MS	0.040303
	947.1			777			987			984.415			
	-530.1			-342.3			805			256.035			
										-282.36			
												TBV	ABV
	417			434.7			1792			958.09		20070.09	2007.009

P7	p7		P8	p8		P9	p9		P10	p10		p11	p11
0	1.3		0	1.3		0	1.3		0	1.3		0	1.3
23.1	0.82	0.035498	22.2	0.7	0.031532	23.5	0.84	0.035745	27.73	0.71	0.025604	27.963	0.843
34.2	-0.31	-0.00906	32.6	-0.21	-0.00644	46	0.35	0.007609	39.39	0.13	0.0033	40.659	0.405
34.2	-0.31		32.6	-0.21		54.1	-0.24	-0.00444	43.44	-0.13	-0.00299	49.724	-0.051
34.2	-0.31		32.6	-0.21		62.1	-0.34	-0.00548	43.44	-0.13		53.824	-0.221
		0.026434			0.02509			0.033442			0.025912	ME	0.244
												MS	0.040303
	947.1			777			987			984.415			
	-530.1			-342.3			805			256.035			
										-282.36			
												TBV	ABV
	417			434.7			1792			958.09		20070.09	2007.009

Kedzi

p1		P2	p2		P3	p3		P4	p4		P5	p5		P6	p6	
0.82		0	0.82		0	0.82		0	0.82		0	0.82		0	0.82	
0.5	0.025	18.8	0.61	0.032447	17	0.51	0.03	28.62	0.46	0.016073	23.6	0.59	0.025	65	0.38	0.005846
0.45	0.01590	39.4	0.51	0.012944	54.3	0.31	0.005709	47.25	0	0	42	0	0	75.1	0	0
0.41	0.01099	47.8	0.4	0.008368	60.1	0	0	53.97	-0.21	-0.00389	49.05	-0.1	-0.00204	94.28	-0.1	-0.00106
0	0	76.4	0	0	85.5	-0.1	-0.00117	53.97	-0.21		49.05	-0.1		106.68	-0.3	-0.00281
-0.21	-0.00278	83.8	-0.25	-0.00298	98.3	-0.33	-0.00336	53.97	-0.21		49.05	-0.1		123.28	-0.35	-0.00284
	0.04911			0.050776			0.031182			0.012182			0.022961			-0.00087
500			573.4			433.5			658.26			696.2			1235	
636.75			1004.7			841.65			0			0			0	
764.65			956			0			-566.69			-245.25			-471.4	
0			0			-427.5									-1600.2	
-792.75			-1047.5			-1621.9									-2157.4	
1108.7			1486.6			-774.3			91.575			450.9			-2994	

P7	*p7*		*P8*	*p8*		*P9*	*p9*		*P10*	*p10*		*P11*	*p11*
0	0.82		0	0.82		0	0.82		0	0.82		0	0.82
15.17	0.44	0.029005	40.8	0.47	0.01152	13.6	0.51	0.0375	14.83	0.53	0.035738	25.742	0.644
20.27	0	0	47.17	0	0	26.85	0.51	0.018994	23.96	0	0	40.46	0.223
45.99	-0.1	-0.00217	55.37	-0.22	-0.00397	36.41	0	0	38.39	-0.22	-0.00573	51.866	-0.095
57.73	-0.1	-0.00173	68.37	-0.22	-0.00322	59.91	-0.1	-0.00167	38.39	-0.22		66.55	-0.212
77.73	-0.3	-0.00386	68.37	-0.3	-0.00439	72.41	-0.3	-0.00414	38.39	-0.22		72.08	-0.297
		0.021239			-5.9E-05			0.050682			0.030008	ME=	0.0526
												MS	0.026722
	333.74			958.8			346.8			392.995			
	0			0			684.675			0			
	-229.95			-609.07			0			-422.29			
	-288.65			-752.07			-299.55						
							-1086.15					TBV	ABV
	-184.86			-402.34			-354.225			-29.295		-1601.25	-160.125

Keta

p1	p1		P2	p2		P3	p3		P4	p4		P5	p5		P6	p6	
0	1.2		0	1.2		0	1.2		0	1.2		0	1.2		0	1.2	
15.8	0.65	0.041139	10.7	0.54	0.050467	15.5	0.6	0.03871	10	0.9	0.09	3.7	0.88	0.237838	40	0.42	0.0105
26.6	0.5	0.018797	24.9	0.37	0.014859	59.4	0	0	14.7	0	0	6	0.6	0.1	62.4	0	0
36.8	0	0	47.8	0.22	0.004603	82.4	-0.32	-0.00388	23.7	-0.1	-0.00422	11	0.48	0.043636	69.6	-0.22	-0.00316
44.9	-0.2	-0.00445	77.9	0	0	99.52	-0.32	-0.00322	23.7	-0.1		20	0.34	0.017	69.6	-0.22	
65.8	-0.23	-0.0035	89.2	-0.2	-0.00224	108.02	-0.32	-0.00296	23.7	-0.1		20	0	0	69.6	-0.22	
		0.051986			0.067687			0.028648			0.085781			0.398474			0.007339
	513.5			288.9			465			450			162.8			840	
	665			460.65			0			0			180			0	
	0			525.8			-1318.4			-118.5			264			-765.6	
	-449			0			-1592.32						340				
	-756.7			-892			-1728.32						0				
	-27.2			383.35			-4174.04			331.5			946.8			74.4	

Keta

p1	p1		P2	p2		P3	p3		P4	p4		P5	p5		P6	p6	
0	1.2		0	1.2		0	1.2		0	1.2		0	1.2		0	1.2	
15.8	0.65	0.041139	10.7	0.54	0.050467	15.5	0.6	0.03871	10	0.9	0.09	3.7	0.88	0.237838	40	0.42	0.0105
26.6	0.5	0.018797	24.9	0.37	0.014859	59.4	0	0	14.7	0	0	6	0.6	0.1	62.4	0	0
36.8	0	0	47.8	0.22	0.004603	82.4	-0.32	-0.00388	23.7	-0.1	-0.00422	11	0.48	0.043636	69.6	-0.22	-0.00316
44.9	-0.2	-0.00445	77.9	0	0	99.52	-0.32	-0.00322	23.7	-0.1		20	0.34	0.017	69.6	-0.22	
65.8	-0.23	-0.0035	89.2	-0.2	-0.00224	108.02	-0.32	-0.00296	23.7	-0.1		20	0	0	69.6	-0.22	
		0.051986			0.067687			0.028648			0.085781			0.398474			0.007339
	513.5			288.9			465			450			162.8			840	
	665			460.65			0			0			180			0	
	0			525.8			-1318.4			-118.5			264			-765.6	
	-449			0			-1592.32						340				
	-756.7			-892			-1728.32						0				
	-27.2			383.35			-4174.04			331.5			946.8			74.4	

P7	p7		P8	p8		P9	p9		P10	p10		P11	p11
0	1.2		0	1.2		0	1.2		0	1.2		0	1.2
37.5	0.63	0.0168	10	0.83	0.083	2.5	0.74	0.296	5	0	0	15.07	0.673
53.4	0	0	14.7	0	0	6.8	0	0	5	-0.38	-0.076	27.39	-0.123
59.4	-0.2	-0.00337	23.7	-0.33	-0.01392	10.8	-0.46	-0.04259	5	-0.38		36.62	-0.191
59.4	-0.2		23.7	-0.33		10.8	-0.46		5	-0.38		43.052	-0.261
59.4	-0.2		23.7	-0.33		10.8	-0.46		5	-0.38		47.122	-0.305
		0.013433			0.069076			0.253407			-0.076	ME =	-0.0414
												MS	0.089983
	1181.25			415			92.5			0			507.1055
	0			0			0						
	-594			- 391.05									
												TBV	ABV
	587.25			23.95			92.5			0		- 1761.49	-176.149

P7	*p7*		*P8*	*p8*		*P9*	*p9*		*P10*	*p10*		*P11*	*p11*
0	1.2		0	1.2		0	1.2		0	1.2		0	1.2
37.5	0.63	0.0168	10	0.83	0.083	2.5	0.74	0.296	5	0	0	15.07	0.673
53.4	0	0	14.7	0	0	6.8	0	0	5	-0.38	-0.076	27.39	-0.123
59.4	-0.2	-0.00337	23.7	-0.33	-0.01392	10.8	-0.46	-0.04259	5	-0.38		36.62	-0.191
59.4	-0.2		23.7	-0.33		10.8	-0.46		5	-0.38		43.052	-0.261
59.4	-0.2		23.7	-0.33		10.8	-0.46		5	-0.38		47.122	-0.305
		0.013433			0.069076			0.253407			-0.076	ME =	-0.0414
												MS	0.089983
	1181.25			415			92.5			0			507.1055
	0			0			0						
	-594			- 391.05									
												TBV	ABV
	587.25			23.95			92.5			0		- 1761.49	-176.149

Mean profile in dry season

Abakam	Abakam	Ada	Ada	Atorkor	Atorkor	Kedzi	Kedzi	Keta	Keta
0	1.4	0	2.2	0	1.3	0	0.82	0	1.2
11.566	0.611	43.682	1.149	30.743	0.791	45.513	0.592	33.14	0.76
23.643	0.489	52.622	0.871	41.558	0.556	62.412	0.383	54.546	0.555
35.422	0.344	64.266	0.556	50.982	0.309	81.155	0.06	72.187	0.225
43.576	-0.185	76.812	-0.403	62.042	-0.175	97.54	-0.179	83.876	-0.016
						106.475	-0.312	90.681	-0.189
								91.901	-0.233

Mean profile in dry season

Abakam	Abakam	Ada	Ada	Atorkor	Atorkor	Kedzi	Kedzi	Keta	Keta
0	1.4	0	2.2	0	1.3	0	0.82	0	1.2
11.566	0.611	43.682	1.149	30.743	0.791	45.513	0.592	33.14	0.76
23.643	0.489	52.622	0.871	41.558	0.556	62.412	0.383	54.546	0.555
35.422	0.344	64.266	0.556	50.982	0.309	81.155	0.06	72.187	0.225
43.576	-0.185	76.812	-0.403	62.042	-0.175	97.54	-0.179	83.876	-0.016
						106.475	-0.312	90.681	-0.189
								91.901	-0.233

Mean profile in wet season

	Abakam	Abakam	Ada	Ada	Atorkor	Atorkor	Kedzi	Kedzi	Keta	Keta
	0	1.4	0	2.2	0	1.3	0	0.82	0	1.2
	10.334	0.826	56.235	0.879	27.963	0.843	25.742	0.644	15.07	0.673
	22.506	-0.041	82.576	0.537	40.659	0.405	40.46	0.223	27.39	-0.123
	24.886	-0.253	92.58	-0.158	49.724	-0.051	51.866	-0.095	36.62	-0.191
					53.824	-0.221	66.55	-0.212	43.052	-0.261
							72.08	-0.297	47.122	-0.305

Mean profile in wet season

	Abakam	Abakam	Ada	Ada	Atorkor	Atorkor	Kedzi	Kedzi	Keta	Keta
	0	1.4	0	2.2	0	1.3	0	0.82	0	1.2
	10.334	0.826	56.235	0.879	27.963	0.843	25.742	0.644	15.07	0.673
	22.506	-0.041	82.576	0.537	40.659	0.405	40.46	0.223	27.39	-0.123
	24.886	-0.253	92.58	-0.158	49.724	-0.051	51.866	-0.095	36.62	-0.191
					53.824	-0.221	66.55	-0.212	43.052	-0.261
							72.08	-0.297	47.122	-0.305

APPENDIX C

DATA ON WEIGHTED GRAIN SIZES IN DRY SEASON

Abakam

	Sieve size in microns												
	4000	**2000**	**500**	**250**	**125**	**63**			**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
	0	2.6	35.4	9.6	1.9	0	49.5		4	0	0	0	0
	0	0	49.6	0	0	0	49.6		2	14	14	0.83	0.83
	0	0	27.2	22	0.4	0	49.6		0.5	676	690	40.10	40.94
	0	0	26.8	22.4	0.6	0	49.8		0.25	839	1529	49.80	90.74
	0	0	9	31.8	8.4	0.8	50		0.125	152	1680	9.01	99.74
	0	0.6	1.8	32.2	14	0.4	49		0.063	4	1685	0.26	100.00
	0	0.1	14.4	31	3.6	0.4	49.5			1684.6			
	0	2.2	16	30.4	1.6	0.1	50.3						
	0	1.8	19.6	18.8	9.4	0	49.6						
	0	0.2	29	19.2	1.2	0	49.6						
	0	0	18.2	26	5.2	0	49.4						
	0	0	14.2	28.8	6.8	0.2	50						
	0	0	9	33.2	4.4	0.4	47						
	0	0.6	26.4	20.6	2.2	0	49.8						
	0	0	13.6	29.6	5.8	0	49						
	0	0	5.4	23.2	19.6	0.6	48.8						
	0	0	4.2	38.4	6.4	0.2	49.2						
	0	0.6	21.2	25.6	2.2	0	49.6						
	0	0.2	21.4	25.6	2.8	0	50						

Abakam

APPENDIX C

DATA ON WEIGHTED GRAIN SIZES IN DRY SEASON

	Sieve size in microns												
	4000	2000	500	250	125	63			Data	Frequency	Cum. Freq	Percentage	Cum. %
	0	2.6	35.4	9.6	1.9	0	49.5		4	0	0	0	0
	0	0	49.6	0	0	0	49.6		2	14	14	0.83	0.83
	0	0	27.2	22	0.4	0	49.6		0.5	676	690	40.10	40.94
	0	0	26.8	22.4	0.6	0	49.8		0.25	839	1529	49.80	90.74
	0	0	9	31.8	8.4	0.8	50		0.125	152	1680	9.01	99.74
	0	0.6	1.8	32.2	14	0.4	49		0.063	4	1685	0.26	100.00
	0	0.1	14.4	31	3.6	0.4	49.5			1684.6			
	0	2.2	16	30.4	1.6	0.1	50.3						
	0	1.8	19.6	18.8	9.4	0	49.6						
	0	0.2	29	19.2	1.2	0	49.6						
	0	0	18.2	26	5.2	0	49.4						
	0	0	14.2	28.8	6.8	0.2	50						
	0	0	9	33.2	4.4	0.4	47						
	0	0.6	26.4	20.6	2.2	0	49.8						
	0	0	13.6	29.6	5.8	0	49						
	0	0	5.4	23.2	19.6	0.6	48.8						
	0	0	4.2	38.4	6.4	0.2	49.2						
	0	0.6	21.2	25.6	2.2	0	49.6						
	0	0.2	21.4	25.6	2.8	0	50						

	0	*0*	*18.6*	*26*	*4.8*	*0.6*	*50*					
	0	*0*	*8.8*	*31.2*	*8.6*	*0.4*	*49*					
	0	1	31.6	15.4	0.6	0	48.6					
	0	1	26.2	19.8	2.4	0	49.4					
	0	0	25.2	22.8	1.6	0	49.6			sieve size			
	0	0.2	21	26	2.6	0.2	50			4	0	99.97	4
	0	0	8.4	36.6	5	0	50			2	0.83	99.71	2
	0	1	35.6	11.8	1.4	0	49.8			0.5	40.1	90.7	0.5
	0	0.2	18.6	27.2	4	0	50			0.25	49.8	40.9	0.25
	0	0.8	19	27	3.2	0	50			0.125	9.01	0.83	0.125
	0	0.6	26.4	20.8	1.4	0	49.2			0.063	0.26	0	0.063
	0	0.2	24.6	18.8	6.2	0	49.8						
	0	0.1	22.6	23.4	3.8	0	49.9			4000	99.97		
	0	0	13.4	34.6	2	0	50			2000	99.71		
	0	0	13.2	29.2	7.6	0	50			500	90.7		
Total	**0**	**14**	**675.6**	**839**	**151.7**	**4.3**	1684.6			250	40.9		
G.Total	**1684.6**									125	0.83		
Percentage	**0.00**	**0.83**	**40.10**	**49.80**	**9.01**	**0.26**				63	0		

	0	*0*	*18.6*	*26*	*4.8*	*0.6*	*50*						
	0	0	8.8	31.2	8.6	0.4	49						
	0	1	31.6	15.4	0.6	0	48.6						
	0	1	26.2	19.8	2.4	0	49.4						
	0	0	25.2	22.8	1.6	0	49.6			sieve size			
	0	0.2	21	26	2.6	0.2	50			4	0	99.97	4
	0	0	8.4	36.6	5	0	50			2	0.83	99.71	2
	0	1	35.6	11.8	1.4	0	49.8			0.5	40.1	90.7	0.5
	0	0.2	18.6	27.2	4	0	50			0.25	49.8	40.9	0.25
	0	0.8	19	27	3.2	0	50			0.125	9.01	0.83	0.125
	0	0.6	26.4	20.8	1.4	0	49.2			0.063	0.26	0	0.063
	0	0.2	24.6	18.8	6.2	0	49.8						
	0	0.1	22.6	23.4	3.8	0	49.9			4000	99.97		
	0	0	13.4	34.6	2	0	50			2000	99.71		
	0	0	13.2	29.2	7.6	0	50			500	90.7		
Total	**0**	**14**	**675.6**	**839**	**151.7**	**4.3**	1684.6			250	40.9		
G.Total	**1684.6**									125	0.83		
Percentage	**0.00**	**0.83**	**40.10**	**49.80**	**9.01**	**0.26**				63	0		

da

	Grain size in microns											
	4000	**2000**	**500**	**250**	**125**	**63**		**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
	1.2	1.8	18.8	20.4	6.6	0.8		4	4.02	4.02	0.19	0.19
			6.6	29.8	11.8	0.8		2	41.11	45.13	1.93	2.12
			7	29.8	11.2	0.8		0.5	663.2	708.33	31.09	33.21
			21.4	19.4	8.6	0.4		0.25	1110.2	1818.53	52.05	85.26
			3.6	22.8	18.4	4.6		0.125	298.8	2117.33	14.01	99.26
			9	30.2	10.8	0.2		0.063	15.71	2133.04	0.74	100.00
			14.8	29.6	4.6				2133.04			
		22.8	23	4.2								
			13.4	25.2	10	0.4						
	1.6	3.8	21.4	19.6	3							
		0.8	6.4	31.8	9.4	0.6						
		1	1.8	44.4	2.8							
			14.8	29.4	5.4							
			19.4	25.8	5.2	0.4						
	0.6	1	20.2	26	2							
		1.6	17.4	22.8	8.4							
		0.8	18.6	22.6	6.4	0.6						
		0.2	20.6	23.2	5.2	0.6						
		0.1	22	22	5.6	0.2						
		0.2	19.4	26.6	3.8							
		0.1	20.8	25.2	3.8	0.1						

Ada

	Grain size in microns							Data	Frequency	Cum. Freq	Percentage	Cum. %
	4000	**2000**	**500**	**250**	**125**	**63**						
	1.2	1.8	18.8	20.4	6.6	0.8		4	4.02	4.02	0.19	0.19
			6.6	29.8	11.8	0.8		2	41.11	45.13	1.93	2.12
			7	29.8	11.2	0.8		0.5	663.2	708.33	31.09	33.21
			21.4	19.4	8.6	0.4		0.25	1110.2	1818.53	52.05	85.26
			3.6	22.8	18.4	4.6		0.125	298.8	2117.33	14.01	99.26
			9	30.2	10.8	0.2		0.063	15.71	2133.04	0.74	100.00
			14.8	29.6	4.6				2133.04			
		22.8	23	4.2								
			13.4	25.2	10	0.4						
	1.6	3.8	21.4	19.6	3							
		0.8	6.4	31.8	9.4	0.6						
		1	1.8	44.4	2.8							
			14.8	29.4	5.4							
			19.4	25.8	5.2	0.4						
	0.6	1	20.2	26	2							
		1.6	17.4	22.8	8.4							
		0.8	18.6	22.6	6.4	0.6						
		0.2	20.6	23.2	5.2	0.6						
		0.1	22	22	5.6	0.2						
		0.2	19.4	26.6	3.8							
		0.1	20.8	25.2	3.8	0.1						

Ada

	Grain size in microns											
	4000	**2000**	**500**	**250**	**125**	**63**		**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
	1.2	1.8	18.8	20.4	6.6	0.8		4	4.02	4.02	0.19	0.19
			6.6	29.8	11.8	0.8		2	41.11	45.13	1.93	2.12
			7	29.8	11.2	0.8		0.5	663.2	708.33	31.09	33.21
			21.4	19.4	8.6	0.4		0.25	1110.2	1818.53	52.05	85.26
			3.6	22.8	18.4	4.6		0.125	298.8	2117.33	14.01	99.26
			9	30.2	10.8	0.2		0.063	15.71	2133.04	0.74	100.00
			14.8	29.6	4.6				2133.04			
		22.8	23	4.2								
			13.4	25.2	10	0.4						
	1.6	3.8	21.4	19.6	3							
		0.8	6.4	31.8	9.4	0.6						
		1	1.8	44.4	2.8							
			14.8	29.4	5.4							
			19.4	25.8	5.2	0.4						
	0.6	1	20.2	26	2							
		1.6	17.4	22.8	8.4							
		0.8	18.6	22.6	6.4	0.6						
		0.2	20.6	23.2	5.2	0.6						
		0.1	22	22	5.6	0.2						
		0.2	19.4	26.6	3.8							
		0.1	20.8	25.2	3.8	0.1						

			17.6	26.4	5.4	0.1						
		0.1	13.2	25.4	10.4	0.6						
		1.6	13.2	29	5.4	0.2						
		0.2	10	31	8.2	0.2						
		0.2	18.8	26.8	4.2							
	0.2	0.4	24.2	20.8	4.4				4000	100		
			8	27	14.2	0.8			2000	99.2634925		
		0.2	16	28.6	4.8				500	85.2553164		
			7.6	28.2	13.6	0.4			250	33.2075348		
		0.6	20.2	24.8	3.8				125	2.11575967		
	0.02	0.6	17.8	25.8	5.2	0.01			63	0.18846341		
		0.8	9.8	29.2	8.4	0.8						
			11.6	23.8	13.6	0.4						
		0.6	34.8	10.8	2.8	0.1						
		0.2	19.2	25.6	4.8	0.2						
	0.4	1.2	23.2	22.4	2.4	0.2						
			15.2	28.4	6							
			7.8	26.6	13.6	0.4						
			13.8	27.8	7.8	0.4						
			12.6	27.2	9.8	0.4						
		0.01	18.4	28.4	2.4							
		0.2	9.8	35.4	4.6							
Total	**4.02**	**41.11**	**663.2**	**1110.2**	**298.8**	**15.71**						
G.Total	**2133.04**											

Atorkor

	Grain size in microns											
	4000	**2000**	**500**	**250**	**125**	**63**		**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
		0.2	45.4	4.4				4	2.4	2.4	0.12	0.12
		0.4	21.2	26	2.4			2	17.1	19.5	0.86	0.98
	0.8	1.4	12.6	29.4	5.4			0.5	890.8	910.3	44.65	45.63
			21.2	24.8	3.6			0.25	945.6	1855.9	47.40	93.02
		1.4	37.6	10.8	0.2			0.13	138.4	1994.3	6.94	99.96
		0.1	14.6	30	5.2			0.06	0.8	1995.1	0.04	100.00
		0.2	15.6	29	5.2				1995.1			
		0.2	16.6	29	4	0.2						
		0.2	35	13.8	0.8							
		0.2	16.2	29	4.6				4000	100		
		0.1	15.4	28.6	5.8				2000	99.9599018		
	0.2	1.4	24.8	20.2	3				500	93.0229061.		
		0.6	33.6	14.8	1				250	45.6267856		
			13.2	28.8	7.8				125	0.97739462		
		0.6	25	22.8	1.6				63	0.12029472		
		0.6	15.4	27.2	6.6							
		0.2	29.4	18	2.4							
		0.2	19.4	26.6	3.6							
		0.4	15.2	28	6.4							
		0.1	15.6	30.6	3.4	0.2						

Atorkor

	Grain size in microns											
	4000	**2000**	**500**	**250**	**125**	**63**		**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
		0.2	45.4	4.4				4	2.4	2.4	0.12	0.12
		0.4	21.2	26	2.4			2	17.1	19.5	0.86	0.98
	0.8	1.4	12.6	29.4	5.4			0.5	890.8	910.3	44.65	45.63
			21.2	24.8	3.6			0.25	945.6	1855.9	47.40	93.02
		1.4	37.6	10.8	0.2			0.13	138.4	1994.3	6.94	99.96
		0.1	14.6	30	5.2			0.06	0.8	1995.1	0.04	100.00
		0.2	15.6	29	5.2				1995.1			
		0.2	16.6	29	4	0.2						
		0.2	35	13.8	0.8							
		0.2	16.2	29	4.6				4000	100		
		0.1	15.4	28.6	5.8				2000	99.9599018		
	0.2	1.4	24.8	20.2	3				500	93.0229061.		
		0.6	33.6	14.8	1				250	45.6267856		
			13.2	28.8	7.8				125	0.97739462		
		0.6	25	22.8	1.6				63	0.12029472		
		0.6	15.4	27.2	6.6							
		0.2	29.4	18	2.4							
		0.2	19.4	26.6	3.6							
		0.4	15.2	28	6.4							
		0.1	15.6	30.6	3.4	0.2						

		0.2	*30.2*	*16.6*	*2.8*							
		0.4	20.4	26.4	2.8							
	0.2	0.4	12.2	29	8.2							
		0.2	27.6	19	3							
		0.4	36.2	12.4	0.8							
		0.2	20	27.6	2.2							
			15.6	29	5.4							
		0.4	22.2	25	2.4							
		0.4	27.4	19.2	3.2							
	0.2	1	22.8	22.8	2.8	0.2						
		0.2	16.8	30	3							
	0.2	2.4	29.6	15.2	1.6							
		0.2	30.4	18.2	1.2							
		0.2	16.2	29.4	3.8							
	0.2	1	23.4	23.4	2							
	0.2	0.2	22.2	24.8	2.6							
		0.2	25	22.8	2							
		0.2	19.4	27.6	2.6	0.2						
		0.2	12.8	28.4	8.6							
	0.4	0.2	17.4	27	4.4							
Total	**2.4**	**17.1**	**890.8**	**945.6**	**138**	**0.8**						
G.Total	**1995.1**											
Percentage	**0.12**	**0.86**	**44.65**	**47.40**	**6.94**	**0.04**						

		0.2	30.2	16.6	2.8								
		0.4	20.4	26.4	2.8								
	0.2	0.4	12.2	29	8.2								
		0.2	27.6	19	3								
		0.4	36.2	12.4	0.8								
		0.2	20	27.6	2.2								
			15.6	29	5.4								
		0.4	22.2	25	2.4								
		0.4	27.4	19.2	3.2								
	0.2	1	22.8	22.8	2.8	0.2							
		0.2	16.8	30	3								
	0.2	2.4	29.6	15.2	1.6								
		0.2	30.4	18.2	1.2								
		0.2	16.2	29.4	3.8								
	0.2	1	23.4	23.4	2								
	0.2	0.2	22.2	24.8	2.6								
		0.2	25	22.8	2								
		0.2	19.4	27.6	2.6	0.2							
		0.2	12.8	28.4	8.6								
	0.4	0.2	17.4	27	4.4								
Total	**2.4**	**17.1**	**890.8**	**945.6**	**138**	**0.8**							
G.Total	**1995.1**												
Percentage	**0.12**	**0.86**	**44.65**	**47.40**	**6.94**	**0.04**							

Kedzi

	Grain size in microns											
	4000	**2000**	**500**	**250**	**125**	**63**		**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
		0.2	35.4	13.2	1	0		4	0.2	0.2	0.01	0.01
			14	35.4	0.6	0		2	6.74	6.94	0.35	0.36
		0.2	24.8	23.4	1.6	0		0.5	803.8	810.74	41.49	41.85
			24.2	23.6	1.4	0		0.25	1022.4	1833.14	52.78	94.63
		0.6	18.6	27.2	3	0.1		0.125	103.2	1936.34	5.33	99.96
		0.2	24	22.6	2.6	0		0.063	0.8	1937.14	0.04	100.00
	0.2	0.1	25.6	21.4	2.4	0			1937.14			
		0.6	26.6	22.8	0	0						
			15.4	29.6	4.2	0						
		0.1	16.2	31.6	2	0						
			18	28	2.6	0			4000	100		
			15.6	33	1.4	0			2000	99.958702		
		0.2	22.8	25	2	0			500	94.6312605		
			16.6	30	3.4	0			250	41.8524216		
			10.2	33.8	5	0			125	0.35826012		
			18.2	29.6	2	0			63	0.0103245		
		0.02	26.6	20.8	2.4	0						
		0.2	26.2	22.6	1	0						
			23.8	24	2.2	0						
			18	27.4	4.4	0.2						
			16.8	29.4	3.4	0						

Kedzi

	Grain size in microns											
	4000	**2000**	**500**	**250**	**125**	**63**		**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
		0.2	35.4	13.2	1	0		4	0.2	0.2	0.01	0.01
			14	35.4	0.6	0		2	6.74	6.94	0.35	0.36
		0.2	24.8	23.4	1.6	0		0.5	803.8	810.74	41.49	41.85
			24.2	23.6	1.4	0		0.25	1022.4	1833.14	52.78	94.63
		0.6	18.6	27.2	3	0.1		0.125	103.2	1936.34	5.33	99.96
		0.2	24	22.6	2.6	0		0.063	0.8	1937.14	0.04	100.00
	0.2	0.1	25.6	21.4	2.4	0			1937.14			
		0.6	26.6	22.8	0	0						
			15.4	29.6	4.2	0						
		0.1	16.2	31.6	2	0						
			18	28	2.6	0			4000	100		
			15.6	33	1.4	0			2000	99.958702		
		0.2	22.8	25	2	0			500	94.6312605		
			16.6	30	3.4	0			250	41.8524216		
			10.2	33.8	5	0			125	0.35826012		
			18.2	29.6	2	0			63	0.0103245		
		0.02	26.6	20.8	2.4	0						
		0.2	26.2	22.6	1	0						
			23.8	24	2.2	0						
			18	27.4	4.4	0.2						
			16.8	29.4	3.4	0						

			20.2	25.2	4.2	0							
			12.4	31.4	5.6	0							
		0.2	19.2	26.6	3.8	0							
			18.6	28.2	3	0.1							
			13.2	31.6	4.8	0							
		0.4	49.6	0	0	0							
		0.2	22.8	3.6	0	0							
		0.2	21.4	25.4	2.8	0							
			24.2	22.6	2.4	0.2							
		1	25	22.8	0.6	0							
		0.1	18.6	27.4	3.6	0							
			13	32.8	3.2	0							
		0.02	20.6	25.4	2.2	0							
			0	25.4	0.6	0							
		0.6	26.4	20.4	1.2	0							
		0.4	21.2	25.4	2.6	0							
		0.2	14.2	30.8	4.6	0							
		0.2	8	36.6	4.2	0.2							
		0.8	17.6	26.4	5.2	0							
Total	**0.2**	**6.74**	**803.8**	**1022.4**	**103.2**	**0.8**							
G.Total	**1937.14**												
Percentage	**0.01**	**0.35**	**41.49**	**52.78**	**5.33**	**0.04**							

			20.2	25.2	4.2	0						
			12.4	31.4	5.6	0						
		0.2	19.2	26.6	3.8	0						
			18.6	28.2	3	0.1						
			13.2	31.6	4.8	0						
		0.4	49.6	0	0	0						
		0.2	22.8	3.6	0	0						
		0.2	21.4	25.4	2.8	0						
			24.2	22.6	2.4	0.2						
		1	25	22.8	0.6	0						
		0.1	18.6	27.4	3.6	0						
			13	32.8	3.2	0						
		0.02	20.6	25.4	2.2	0						
			0	25.4	0.6	0						
		0.6	26.4	20.4	1.2	0						
		0.4	21.2	25.4	2.6	0						
		0.2	14.2	30.8	4.6	0						
		0.2	8	36.6	4.2	0.2						
		0.8	17.6	26.4	5.2	0						
Total	**0.2**	**6.74**	**803.8**	**1022.4**	**103.2**	**0.8**						
G.Total	**1937.14**											
Percentage	**0.01**	**0.35**	**41.49**	**52.78**	**5.33**	**0.04**						

Keta

	Grain size in microns							Data	Frequency	Cum. Freq	Percentage	Cum. %
	4000	2000	500	250	125	63						
	0	1.6	22.8	15.6	5	0		4	0.83	0.83	0.04	0.04
	0	0.6	34.6	14.4	0.4	0		2	64.40	65.23	3.09	3.13
	0	0.1	15.8	26.6	7.4	0		0.5	829.20	894.43	39.75	42.88
	0	0.4	9	26.8	13.8	0		0.25	1013.20	1907.63	48.57	91.45
	0	1.4	25.6	17.6	5.4	0		0.125	177.82	2085.45	8.52	99.98
	0	0	22.8	25.4	1.8	0		0.063	0.43	2085.88	0.02	100.00
	0	0.2	31.8	17.4	0.4	0			2085.88			
	0.2	0.2	22.8	24.6	1.8	0						
	0	0.4	20.8	20.2	8.2	0.2						
	0	0	10.4	33.2	6.4	0						
	0.02	0	15.8	30.4	3.2	0			4000	100		
	0	0.4	20.4	24	5.2	0			2000	99.9793852		
	0	0.4	34.2	14.8	0.6	0			500	91.4544461		
	0.2	0.2	16.6	27.2	5.4	0			250	42.8802232		
	0	0.2	18.4	25.8	5.6	0			125	3.12721729		
	0	0.3	7.4	37	5.2	0			63	0.03979136		
	0	0	17.6	29.4	1.8	0						
	0	0.4	14.8	28.8	5.8	0.2						
	0	0	31	17.8	1	0						
	0	49.8	0.2	0	0	0						
	0	1.8	41.2	6.8	0.02	0						

Keta

Grain size in microns					
4000	**2000**	**500**	**250**	**125**	**63**
0	1.6	22.8	15.6	5	0
0	0.6	34.6	14.4	0.4	0
0	0.1	15.8	26.6	7.4	0
0	0.4	9	26.8	13.8	0
0	1.4	25.6	17.6	5.4	0
0	0	22.8	25.4	1.8	0
0	0.2	31.8	17.4	0.4	0
0.2	0.2	22.8	24.6	1.8	0
0	0.4	20.8	20.2	8.2	0.2
0	0	10.4	33.2	6.4	0
0.02	0	15.8	30.4	3.2	0
0	0.4	20.4	24	5.2	0
0	0.4	34.2	14.8	0.6	0
0.2	0.2	16.6	27.2	5.4	0
0	0.2	18.4	25.8	5.6	0
0	0.3	7.4	37	5.2	0
0	0	17.6	29.4	1.8	0
0	0.4	14.8	28.8	5.8	0.2
0	0	31	17.8	1	0
0	49.8	0.2	0	0	0
0	1.8	41.2	6.8	0.02	0

Data	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
4	0.83	0.83	0.04	0.04
2	64.40	65.23	3.09	3.13
0.5	829.20	894.43	39.75	42.88
0.25	1013.20	1907.63	48.57	91.45
0.125	177.82	2085.45	8.52	99.98
0.063	0.43	2085.88	0.02	100.00
	2085.88			
	4000	100		
	2000	99.9793852		
	500	91.4544461		
	250	42.8802232		
	125	3.12721729		
	63	0.03979136		

Keta

	Grain size in microns											
	4000	**2000**	**500**	**250**	**125**	**63**		**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
	0	1.6	22.8	15.6	5	0		4	0.83	0.83	0.04	0.04
	0	0.6	34.6	14.4	0.4	0		2	64.40	65.23	3.09	3.13
	0	0.1	15.8	26.6	7.4	0		0.5	829.20	894.43	39.75	42.88
	0	0.4	9	26.8	13.8	0		0.25	1013.20	1907.63	48.57	91.45
	0	1.4	25.6	17.6	5.4	0		0.125	177.82	2085.45	8.52	99.98
	0	0	22.8	25.4	1.8	0		0.063	0.43	2085.88	0.02	100.00
	0	0.2	31.8	17.4	0.4	0			2085.88			
	0.2	0.2	22.8	24.6	1.8	0						
	0	0.4	20.8	20.2	8.2	0.2						
	0	0	10.4	33.2	6.4	0						
	0.02	0	15.8	30.4	3.2	0			4000	100		
	0	0.4	20.4	24	5.2	0			2000	99.9793852		
	0	0.4	34.2	14.8	0.6	0			500	91.4544461		
	0.2	0.2	16.6	27.2	5.4	0			250	42.8802232		
	0	0.2	18.4	25.8	5.6	0			125	3.12721729		
	0	0.3	7.4	37	5.2	0			63	0.03979136		
	0	0	17.6	29.4	1.8	0						
	0	0.4	14.8	28.8	5.8	0.2						
	0	0	31	17.8	1	0						
	0	49.8	0.2	0	0	0						
	0	1.8	41.2	6.8	0.02	0						

	0	0.2	13.8	29.8	6.2	0						
	0	0	10.6	31.8	7	0						
	0	0.2	24.2	23.2	2.4	0						
	0	0.2	22	24.2	3.6	0						
	0	0	15.4	30	4.6	0						
	0.4	2.6	32	14.4	0.6	0						
	0	0.2	29.2	19	1.2	0						
	0	0.6	29.6	18.6	1.2	0						
	0	0.4	24	22.2	3.2	0						
	0	0	18	28.2	3.8	0						
	0	0	13	33.8	3.2	0						
	0	0	11	35	4	0						
	0	0	12.6	31.2	5.8	0						
	0	0	10.6	32.6	5.4	0						
	0	1	21.2	21.8	6	0						
	0	0	14.8	27.4	7.8	0						
	0.01	0.2	21.2	19.6	8.2	0.02						
	0	0	12.6	29	7.6	0.01						
	0	0.2	29.6	18.8	0.6	0						
	0	0.2	22.2	24.8	2.8	0						
	0	0	7.6	34	8.2	0						
Total	**0.83**	**64.4**	**829.2**	**1013.2**	**177.82**	**0.43**						
G.Total	**2085.88**											
Percentage	**0.04**	**3.09**	**39.75**	**48.57**	**8.52**	**0.02**						

Abakam

DATA ON WEIGHTED GRAIN SIZES IN WET SEASON

	Sieve size in microns												
	4000	**2000**	**500**	**250**	**125**	**63**			**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
	0	1.2	41.2	7.2	0	0	49.6		4	0.21	0.21	0.02	0.02
	0	2.98	47.01	0.00	0	0	49.99		2	14.51	14.72	1.33	1.35
	0	1	44.4	1.4	2.8	0.6	50.2		0.5	660.15	674.87	60.57	61.92
	0	0	28.8	20.4	0.6	0	49.8		0.25	350.41	1025.28	32.15	94.07
	0	0.72	31.73	16.53	0.94	0	49.92		0.125	62.54	1087.82	5.74	99.81
	0	0.6	38	9.6	1.2	0.04	49.44		0.063	2.12	1089.94	0.19	100.00
	0	0	30.4	17.4	1	0	48.8			1089.94			
	0	0	22.8	24.2	2.2	0	49.2						
	0	1.45	34.88	12.44	0.72	0.06	49.55						
	0	0.4	35	12.8	1.6	0	49.8						
	0	0.2	21	24.8	2.8	0	48.8						
	0	0.6	30.6	15.6	2	0.6	49.4						
	0	0.8	19.2	22.6	7	0	49.6						

Abakam

DATA ON WEIGHTED GRAIN SIZES IN WET SEASON

	Sieve size in microns												
	4000	2000	500	250	125	63			Data	Frequency	Cum. Freq	Percentage	Cum. %
	0	1.2	41.2	7.2	0	0	49.6		4	0.21	0.21	0.02	0.02
	0	2.98	47.01	0.00	0	0	49.99		2	14.51	14.72	1.33	1.35
	0	1	44.4	1.4	2.8	0.6	50.2		0.5	660.15	674.87	60.57	61.92
	0	0	28.8	20.4	0.6	0	49.8		0.25	350.41	1025.28	32.15	94.07
	0	0.72	31.73	16.53	0.94	0	49.92		0.125	62.54	1087.82	5.74	99.81
	0	0.6	38	9.6	1.2	0.04	49.44		0.063	2.12	1089.94	0.19	100.00
	0	0	30.4	17.4	1	0	48.8			1089.94			
	0	0	22.8	24.2	2.2	0	49.2						
	0	1.45	34.88	12.44	0.72	0.06	49.55						
	0	0.4	35	12.8	1.6	0	49.8						
	0	0.2	21	24.8	2.8	0	48.8						
	0	0.6	30.6	15.6	2	0.6	49.4						
	0	0.8	19.2	22.6	7	0	49.6						

	0.21	*0.14*	*11.53*	*32.64*	*5.28*	*0.18*	*49.98*						
	0	0	21.2	24	4	0	49.2			4	0.01926712	4	0.019267116
	0	0.4	22.4	24	3	0	49.8			2	1.33126594	2	1.350533057
	0	0.02	19.4	18	10.8	0.4	48.62			0.5	60.5675542	0.5	61.91808723
	0	0.4	23.4	18.8	6.4	0.2	49.2			0.25	32.1494761	0.25	94.06756335
	0	1.8	29.8	12.6	5.6	0.04	49.84			0.125	5.73793053	0.125	99.80549388
	0	0.4	27.2	17.6	4.4	0	49.6			0.063	0.19450612	0.063	100
	0	0.2	39	10.6	0.2	0	50						
	0	1.2	41.2	7.2	0	0	49.6			4000	100		
Total	**0.21**	**14.51**	**660.15**	**350.41**	**62.54**	**2.12**	1089.94			2000	99.8054939		
G.Total	**1089.94**									500	94.0675634		
Percentage		**1.33127**	**60.5676**	**32.1495**	**5.73793**	**0.19451**		99.98		250	61.9180872		
										125	1.35053306		
										63	0.01926712		

Ada

	sieve size in microns									
	4000	**2000**	**500**	**250**	**125**	**63**	**Data**	**Frequency**	**Cum. Freq**	**Percentage**
	0.2	2.34	34.57	11.53	1.6	0	4	1.8	1.8	0.12
	0	0.02	37.2	11.2	0.6	0	2	59.79	61.59	4.03
	0.78	5.86	26.58	14.79	1.16	0.04	0.5	633.43	695.02	42.65
	0.14	3.25	31.84	13.04	0.94	0	0.25	618.59	1313.61	41.65
	0.28	1.66	37.25	10.23	0.7	0	0.125	157.72	1471.33	10.62
	0.2	1.4	28.6	17.2	2.2	0	0.063	13.97	1485.3	0.94
	0	0.6	24.6	21.6	2.2	0		1485.3		
	0	19.8	25.8	3.6	0.02	0				
	0.2	22.19	27.62	3.23	0.17	0				
	0	0.02	20.68	25.36	3.92	0.23				
	0	0	19.8	25.8	3.6	0.02		4000	100	
	0	0	0	21.2	25.2	3.2		2000	99.0594493	
	0	0.2	22	25	2.6	0		500	88.440719	
	0	0.6	22.2	23.4	3.2	0		250	46.7932404	
	0	0	16.8	28.8	4	0.02		125	4.14663704	
	0	0	7.6	29.6	11.8	0.2		63	0.12118764	

Ada

	sieve size in microns									
	4000	**2000**	**500**	**250**	**125**	**63**	**Data**	**Frequency**	**Cum. Freq**	**Percentage**
	0.2	2.34	34.57	11.53	1.6	0	4	1.8	1.8	0.12
	0	0.02	37.2	11.2	0.6	0	2	59.79	61.59	4.03
	0.78	5.86	26.58	14.79	1.16	0.04	0.5	633.43	695.02	42.65
	0.14	3.25	31.84	13.04	0.94	0	0.25	618.59	1313.61	41.65
	0.28	1.66	37.25	10.23	0.7	0	0.125	157.72	1471.33	10.62
	0.2	1.4	28.6	17.2	2.2	0	0.063	13.97	1485.3	0.94
	0	0.6	24.6	21.6	2.2	0		1485.3		
	0	19.8	25.8	3.6	0.02	0				
	0.2	22.19	27.62	3.23	0.17	0				
	0	0.02	20.68	25.36	3.92	0.23				
	0	0	19.8	25.8	3.6	0.02		4000	100	
	0	0	0	21.2	25.2	3.2		2000	99.0594493	
	0	0.2	22	25	2.6	0		500	88.440719	
	0	0.6	22.2	23.4	3.2	0		250	46.7932404	
	0	0	16.8	28.8	4	0.02		125	4.14663704	
	0	0	7.6	29.6	11.8	0.2		63	0.12118764	

	0	*0.02*	*8.69*	*29.17*	*11.49*	*0.57*				
	0	0	0.62	13.76	27.64	7.21				
	0	0	7.8	29.48	10.86	0.33				
	0	0.06	15.4	26.19	6.42	0.22				
	0	0	25.8	21.8	1.8	0				
	0	0	15.5	30.89	3.62	0				
	0	0	25.8	20.2	3	0.4				
	0	0.31	24.84	22.04	2.49	0.12				
	0	0.28	25.46	21.43	2.37	0.17				
	0	0.53	21.46	25.52	1.65	0.02				
	0	0.17	20.32	24.93	2.67	0.02				
	0	0.48	22.6	19.8	6.4	0.4				
	0	0	15.4	29.4	3.6	0				
	0	0	20.6	18.4	9.8	0.8				
Total	**1.8**	**59.79**	**633.43**	**618.59**	**157.72**	**13.97**				
G.Total	**1485.3**									
Percentage	**0.12**	**4.03**	**42.65**	**41.65**	**10.62**	**0.94**				

Atorkor

Grain size in microns										
4000	**2000**	**500**	**250**	**125**	**63**	**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
0.2	2.34	34.57	11.53	1.6	0	4	1.94	1.94	0.14	0.14
0	0.02	37.2	11.2	0.6	0	2	63.91	65.85	4.57	4.71
0.78	5.86	26.58	14.79	1.16	0.04	0.5	634.12	699.97	45.36	50.07
0	2.4	34.6	11.4	0.8	0	0.25	564.93	1264.9	40.41	90.48
0.14	3.25	31.84	13.04	0.94	0	0.125	127.24	1392.14	9.10	99.58
0.28	1.66	37.25	10.23	0.7	0	0.063	5.82	1397.96	0.42	100.00
0.2	1.4	28.6	17.2	2.2	0		1397.96			
0.14	2.07	30.38	15.75	11.27	0					
0	0.13	27.89	20.12	1.85	0					
0	0.6	24.6	21.6	2.2	0		4000	100		
0	19.8	25.8	3.6	0.02	0		2000	99.5836791		
0.2	22.19	27.62	3.23	0.17	0		500	90.481845		
0	0.02	20.68	25.36	3.92	0.23		250	50.0708175		
0	0	19.8	25.8	3.6	0.02		125	4.71043521		
0	0	0	21.2	25.2	3.2		63	0.13877364		
0	0.2	22	25	2.6	0					
0	0.6	22.2	23.4	3.2	0					

	0	*0*	*16.8*	*28.8*	*4*	*0.02*					
	0	0	7.6	29.6	11.8	0.2					
	0	0.02	8.69	29.17	11.49	0.57					
	0	0	7.8	29.48	10.86	0.33					
	0	0.06	15.4	26.19	6.42	0.22					
	0	0	15.5	30.89	3.62	0					
	0	0	25.8	20.2	3	0.4					
	0	0.28	25.46	21.43	2.37	0.17					
	0	0.53	21.46	25.52	1.65	0.02					
	0	0.48	22.6	19.8	6.4	0.4					
	0	0	15.4	29.4	3.6	0					
Total	**1.94**	**63.91**	**634.12**	**564.93**	**127.24**	**5.82**					
G.Total	**1397.96**										
Percentage	**0.14**	**4.57**	**45.36**	**40.41**	**9.10**	**0.42**					

	0	*0*	*16.8*	*28.8*	*4*	*0.02*					
	0	0	7.6	29.6	11.8	0.2					
	0	0.02	8.69	29.17	11.49	0.57					
	0	0	7.8	29.48	10.86	0.33					
	0	0.06	15.4	26.19	6.42	0.22					
	0	0	15.5	30.89	3.62	0					
	0	0	25.8	20.2	3	0.4					
	0	0.28	25.46	21.43	2.37	0.17					
	0	0.53	21.46	25.52	1.65	0.02					
	0	0.48	22.6	19.8	6.4	0.4					
	0	0	15.4	29.4	3.6	0					
Total	**1.94**	**63.91**	**634.12**	**564.93**	**127.24**	**5.82**					
G.Total	**1397.96**										
Percentage	**0.14**	**4.57**	**45.36**	**40.41**	**9.10**	**0.42**					

Kedzi

	Sieve size in microns										
	4000	**2000**	**500**	**250**	**125**	**63**	**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
	0	0.1	13.52	24.16	10.24	1.3	4	2.18	2.18	0.13	0.13
	0	0.29	15.96	29.49	4.36	0.09	2	9.46	11.64	0.56	0.69
	0.4	0.04	19.78	26.24	3.45	0.1	0.5	650.59	662.23	38.57	39.26
	0	0	20.04	24.94	5.3	0.16	0.25	827.39	1489.62	49.05	88.31
	0	0.21	8.8	26.03	13.15	1.69	0.125	180.54	1670.16	10.70	99.02
	0	0.01	25.13	23.46	1.2	0.06	0.063	16.57	1686.73	0.98	100.00
	0	0.3	28.11	20.28	1.34	0.06		1686.73			
	0	0.79	25.28	22.46	1.94	0.41					
	0	0.11	15.52	27.07	6.65	0.33					
	0	0.6	25.8	17	4	0.02					
	0	0.04	9.17	29.52	9.75	0.85		4000	100		
	0	0.12	16.13	26.39	6.65	0.91		2000	99.0176258		
	0.4	0.2	28.2	19.2	1.4	0		500	88.3140752		
	0.77	3	30.97	15.37	0.57	0.17		250	39.261174		
	0	0.01	22.38	24.88	2.1	0.01		125	0.69009266		
	0	0	11.71	32.4	5.72	0.31		63	0.12924416		

	0	*0.09*	*18.29*	*29.35*	*1.93*	*0*					
	0	0.04	19.15	26.7	3.47	0.14					
	0	0.01	14.2	28.29	7.36	0.38					
	0	0.1	18.66	24.85	5.71	0.21					
	0	0.18	20.49	24.01	2.48	0.08					
	0	0.2	28.4	18.6	2.2	0.01					
	0.4	2.2	29.2	16.4	1.6	0					
	0	0	20.6	18.4	9.8	0.8					
	0	0	15.8	25.8	8	0.4					
	0	0.17	20.32	24.93	2.67	0.02					
	0	0.31	24.84	22.04	2.49	0.12					
	0	0	25.8	21.8	1.8	0					
	0	0	0.62	13.76	27.64	7.21					
	0	0	9.39	31.53	8.49	0.35					
	0	0	12.2	30.8	6.2	0.2					
	0	0.2	24.4	22.6	2.2	0					
	0	0	20.2	26	3.4	0					
	0.21	0.14	11.53	32.64	5.28	0.18					
Total	**2.18**	**9.46**	**650.59**	**827.39**	**180.54**	**16.57**					
G.Total	**1686.73**										
Percentage	**0.13**	**0.56**	**38.57**	**49.05**	**10.70**	**0.98**					

	Sieve size in microns										
	4000	**2000**	**500**	**250**	**125**	**63**	**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
	0.87	1.06	19.18	22.74	4.85	0.08	4	4	4.00	0.22	0.23
	0	0	12.4	33.2	4.2	0.4	2	7	11.39	0.43	0.66
	0	0	16.6	28.6	3.8	0	0.5	817	828.35	47.53	48.19
	0	0.39	15.8	17.31	11.3	3.46	0.25	754	1582.32	43.86	92.05
	0	0.04	12.63	18.2	13.79	5.11	0.125	121	1703.74	7.06	99.11
	0.14	0.46	25.1	21.37	2.33	0.05	0.063	15	1719.04	0.89	100.00
	0	0.02	28.4	18.7	3.2	0.2		1719			
	1.8	0.4	32.2	14.6	1.2	0					
	0	0	31.4	16.6	1.6	0					
	0	0	15.65	26.75	7.28	0.14					
	0	0	23.95	22.43	3.42	0					
	0.17	0.68	36.28	12.64	0.43	0		4000	100		
	0	0	26.8	20.8	1.6	0		2000	99.1099684		
	0	0.2	26.4	21	0.6	0		500	92.0467238		
	0	0.12	24.25	21.13	4.35	0.15		250	48.1867787		
	0.04	0.17	27.32	20.3	2.16	0.01		125	0.66257911		
	0	0	13.4	32.6	3.2	0.2		63	0.23268801		
	0	0	28.02	19.95	1	0					

	Sieve size in microns										
	4000	**2000**	**500**	**250**	**125**	**63**	**Data**	**Frequency**	**Cum. Freq**	**Percentage**	**Cum. %**
	0.87	1.06	19.18	22.74	4.85	0.08	4	4	4.00	0.22	0.23
	0	0	12.4	33.2	4.2	0.4	2	7	11.39	0.43	0.66
	0	0	16.6	28.6	3.8	0	0.5	817	828.35	47.53	48.19
	0	0.39	15.8	17.31	11.3	3.46	0.25	754	1582.32	43.86	92.05
	0	0.04	12.63	18.2	13.79	5.11	0.125	121	1703.74	7.06	99.11
	0.14	0.46	25.1	21.37	2.33	0.05	0.063	15	1719.04	0.89	100.00
	0	0.02	28.4	18.7	3.2	0.2		1719			
	1.8	0.4	32.2	14.6	1.2	0					
	0	0	31.4	16.6	1.6	0					
	0	0	15.65	26.75	7.28	0.14					
	0	0	23.95	22.43	3.42	0					
	0.17	0.68	36.28	12.64	0.43	0			4000	100	
	0	0	26.8	20.8	1.6	0			2000	99.1099684	
	0	0.2	26.4	21	0.6	0			500	92.0467238	
	0	0.12	24.25	21.13	4.35	0.15			250	48.1867787	
	0.04	0.17	27.32	20.3	2.16	0.01			125	0.66257911	
	0	0	13.4	32.6	3.2	0.2			63	0.23268801	
	0	0	28.02	19.95	1	0					

	0	*0*	*31*	*17.2*	*0.4*	*0*					
	0	0	31.6	17	0.6	0					
	0.28	0.57	35.02	12.6	1.37	0.08					
	0	0	28.02	20.12	1.56	0					
	0	0	23.14	22.63	3.94	0.15					
	0	0	17.8	27	4.6	0.2					
	0	1.4	32	14.6	1.4	0					
	0	0.02	0	29.2	7.2	0.02					
	0	0	24.8	22	3	0.02					
	0	0.43	25.95	21.57	1.74	0.04					
	0	0.2	19.6	21.4	5.6	2.8					
	0	0	18.4	25	4.8	0.2					
	0	0.2	31.8	15.8	2	0					
	0.28	0.18	22.04	24.77	0.68	0.03					
	0	0	16.46	30.82	2.4	0					
	0.28	0.18	22.04	24.77	2.68	0.03					
	0	0.67	21.51	18.57	7.14	1.96					
Total	**3.86**	**7.39**	**817**	**754**	**121.4**	**15.3**					
G.Total	**1719**										
Percentage	**0.2**	**0.4**	**47.5**	**43.9**	**7.1**	**0.9**					