UNIVERSITY OF CAPE COAST

CHANGING BEACH DYNAMICS OF CAPE COAST-ELMINA COASTLINE IN GHANA

KINGSLEY NANA OSEI

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BY

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Thesis submitted to the Department of Geography and Regional Planning of the Faculty of Social Sciences, College of Humanities and Legal Studies, University of Cape Coast, in partial fulfilment of the requirements for the award of Doctor of Philosophy degree in Geography and Regional Planning

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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: ....

Name: Kingsley Nana Osei

Supervisors' Declaration

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

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

Name: Prof. Laud Alfred Dei

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Name: Prof. Kwabena Barima Antwi

ABSTRACT

This study investigates the changes in beach dynamics along the Cape Coast-Elmina coastline in Ghana from 1991 to 2020 and their impacts on local communities. The research uses a mixed-methods approach, combining remote sensing, fieldwork, community surveys, and policy analysis to understand beach erosion and its causes. Satellite imagery is used to track changes in shoreline position and beach extent, while sediment grain size measurements provide insight into alterations in beach characteristics. Community surveys, particularly among residents and fisherfolk, reveal the disruptive effects of these changes on livelihoods, including impacts on fishing operations, tourism infrastructure, and increased exposure to coastal hazards. The study attributes shoreline recession and beach erosion to a combination of natural factors such as sea level rise and wave action, as well as human activities including sand mining and coastal development. An evaluation of national coastal management policies reveals shortcomings in their implementation and enforcement, particularly in addressing these complex, interrelated issues. The research emphasizes the need for more inclusive, community-driven coastal management strategies that incorporate indigenous knowledge and local involvement. It advocates for more comprehensive, context-specific policies to promote coastal adaptation and resilience, thereby addressing the region's multifaceted challenges posed by beach dynamics. This study provides valuable evidence for improving coastal governance and safeguarding both the environment and local livelihoods.

KEYWORDS:

Spatio-Temporal

Integrated Coastal Zone Management

Coastline

Beach Dynamics

Granulometric characteristics

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DEDICATION

To my wife Esther Osei and my three children Emmanuel Osei-Boateng, Edward Gyapong Osei and Emmanuella Yaa Serwaa Osei.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
CCMA	Cape Coast Metropolitan Assembly
CODA	Coastal Development Authority
DPSIR	Driver-Pressure-State-Impact-Response framework
DPSWR	Driver-Pressure-State-Welfare-Response
DSAS	Digital Shoreline Analysis System
EPA	Environmental Protection Authority
EPR	End Point Rate
ERP	Erosion Potential Rate
GIS	Geographic Information Systems
GPS	Global Positioning System
ICUD	Index of Coastline Utilization Degree
ICZM	Integrated Coastal Zone Management
IWRM	Integrated Water Resources Management
KEEA	Komenda Edina Eguafo Abirem Municipal Assembly
LULC	Land Use Land Cover
LZs	Littoral Zones
NSM	Net Shoreline Movement
RS	Remote Sensing
SESs	Social-Ecological Systems
USGS	United States Geological Survey
WLR	Weighted Linear Regression

CHAPTER ONE

INTRODUCTION

Introduction

Coastal environments are among the most dynamic and ecologically significant landscapes, continually shaped by natural forces and human activities. However, in many parts of the world, coastal erosion, sea-level rise, and human interventions have significantly altered beach dynamics, leading to shoreline retreat, habitat loss, and socio-economic vulnerabilities (Bird, 2010). These challenges are particularly pronounced in West Africa, where rapid urbanization, climate change, and unsustainable coastal management practices have intensified the rate of coastal transformation (Appeaning Addo et al., 2011). The Cape Coast-Elmina coastline in Ghana is a critical segment of the country's high-energy littoral zone, experiencing significant shoreline changes due to natural and anthropogenic factors**.** However, the region is increasingly threatened by coastal erosion, sedimentation imbalances, and human modifications, including sea defence structures, sand mining, and harbour developments.

While various studies have examined coastal erosion and sediment transport along Ghana's shores, limited research has focused on the spatiotemporal dynamics of Sea beach changes along the Cape Coast-Elmina stretch. This study, therefore, investigates the changing beach dynamics of the Cape Coast-Elmina coastline**,** analyzing shoreline movements, beach morphology variations, and the drivers of coastal change over time. The findings will contribute to sustainable coastal management practices, climate adaptation policies, and long-term shoreline monitoring efforts in Ghana and beyond.

Background to the Study

The coastal zone is considered one of the most dynamic environments globally, as it is the interface where different geospheres interact (Dora et al., 2012 as cited in Olali, 2015; Mwakumanya, Munyao, & Ucakuwun, 2009). These interactions, occurring over various timescales, lead to the continuous reshaping of the coastline, a process known as coastal morphodynamics, which results in the formation of beaches (Labuz, 2015).

Beaches are gently sloping landforms located along the edge of large water bodies, primarily composed of unconsolidated materials such as sand, gravel, pebbles, cobbles, rock, or shells (Morang et al., 2003). These areas are known for their constant and sometimes catastrophic changes, which can have significant economic and human consequences (Dolan, 2020). Beaches are characterized by the continuous shifting and orientation of particle groups in response to changing waves and currents (Pethick, 1984). Interestingly, beaches are unlikely to be found directly facing the open sea, as their survival depends on the loose nature of the sand and shingle that allows them to remain intact along the coastline (Pethick, 1984).

The importance of beaches to both ecosystems and human environments is profound. Coastal ecosystems, including estuaries, wetlands, and deltas, provide essential goods and services such as recreation, cultural heritage, natural protection, flood control, shoreline stabilization, sediment retention, and nutrient cycling (Brown et al., 2013; Bayed, 2008). These ecosystems also nurture marine life and biodiversity, acting as critical nesting grounds for sea fish and turtles. Economically, beaches are crucial for local eco-tourism, significantly influencing the local economy through tourism and coastal development (Dipo et al., 2011). The exploitation of coastal areas has surged in the 20th century, a trend expected to continue into the 21st century (Nicholls et al., 2007). As a result, coastal regions support large populations and facilitate key socio-economic activities worldwide (Birkmann, 2010). It is anticipated that by 2030, half of the global population will live within 100 kilometers of the coast (Small & Nicholls, 2003).

Natural and human-induced factors have historically threatened coastlines, resulting in shifting beach dynamics. These dynamics encompass sediment deposits, energy dissipation from waves, and changes in tidal levels, all of which affect the sedimentary deposits on beaches (Nehra, 2016). Beaches are increasingly affected by both natural and human-induced disturbances, resulting in shoreline changes that occur across various timescales. These changes can stem from smaller-scale (short-term) events like storms, regular wave action, tides, and winds, as well as larger-scale (long-term) phenomena (Olali, 2015). Natural forces such as wind, waves, and currents can readily move unconsolidated sand and soil in coastal areas, causing rapid alterations in shoreline positions. Additionally, factors like sea-level rise, coastal erosion and deposition, resource over-exploitation, and other threats play a role in shaping beach dynamics (Anim, 2012). The overall dynamics of beaches are influenced by both natural elements, including sea-level rise and winter storms, and human activities such as beach sand mining and coastal development.

In West Africa, including Ghana, beaches have faced risks since the 1960s due to several factors, such as dam construction, harbor development, dredging, and coastal defense systems (Addo et al., 2011; Angnuureng et al., 2013; Laïbi et al., 2014). These human activities have disrupted the sediment balance, leading to a decrease in natural sediment supply to the beaches. Beaches are dynamic and geomorphologically complex systems that respond in various ways to extreme weather events (Balica et al., 2013). Additionally, contrasting beach forms and dynamics are often observed within the same coastal cell, raising questions about the other factors influencing beach morphodynamics (Silveira, 2017). The coastline has also faced significant exploitation aimed at providing increasingly demanding tourist services (Rodríguez et al., 2009).

Much of the West African coast, especially the Gulf of Guinea region—including the Niger Delta and the coastline stretching westward to Ghana—is facing threats from changes in beach dynamics (Kearney, 2012; Jayson-Quashigah, Appeaning, Amisigo, & Wiafe, 2019). These threats are intensified by rising sea levels, increasing coastal populations, and growing pressures on socio-economic systems. Therefore, it is essential to evaluate beach dynamics and their implications for human activities in the coastal environment. Currently, the coastal populations in this region are primarily rural; however, this is anticipated to change, as each delta is connected to at least one large and rapidly growing megacity (Brooks, Nicholls & Hall, 2006). While the growing coastal population has significantly contributed to socio-economic development, it has also resulted in the degradation of the ecosystems that support these economic benefits. The deterioration of beaches has become an increasing concern in recent years (Payet et al., 2009; Ramsay & Cooper, 2002). The economic and social impacts of beach dynamics can be significant and may threaten the sustainable development of coastal communities. Therefore, it is essential to understand and tackle the challenges posed by these dynamic coastal environments to ensure the long-term resilience and growth of the region.

The coastline of Ghana, like many others in the sub-region, across the continent, and globally, has experienced changes over the years due to modifications in the natural environment. These changes have occurred at various temporal and spatial scales, influenced by factors such as tectonic activity, sea-level variations, and climate changes (Oteng-Ababio, Owusu & Addo, 2011; Jayson-Quashigah et al., 2019; Jonah, Mensah, Edziyie, Agbo & Adjei-Boateng, 2016). In Ghana, lateral shifts in the coastline have resulted in coastal erosion, which has severely affected the coastal environment, altered the socio-economic conditions of local communities, threatened cultural heritage, and hindered the development of coastal tourism (Addo, 2009; Jonah et al., 2016). Understanding beach dynamics and their influence on socio-economic development in vulnerable coastal communities is crucial, especially where adaptation options are limited (Olympio & Amos-Abanyie, 2013). These changes in the coastal environment present significant challenges for communities along the Ghanaian coastline, underscoring the need for a comprehensive understanding and effective management strategies to promote resilience and sustainable development in these at-risk coastal areas.

The Cape Coast-Elmina coastline is one of Ghana's prominent coastlines that has experienced and continues to experience changing dynamics. The interplay between beach dynamics and the socio-economic development of coastal communities is a critical area for policy planning (Kearney, 2012; Klemas, 2013). This relationship is significant because beach dynamics affect the socio-economic conditions of these communities, and vice versa. For effective planning, policy formulation, and implementation regarding beach dynamics, decision-makers must grasp the key factors that explain the current situation and future coastal development. In assessing beach dynamics, archival data provide insights into historical shoreline positions, while current data reflect the present shoreline position (Appeaning-Addo & Lamptey, 2012). Combining shoreline data from these two sources provides a valuable opportunity to monitor shoreline evolution over time and examine its patterns in both the short and long term. This approach also helps identify the factors influencing lateral morphological changes and allows for the estimation of historical shoreline change rates, which can be utilized to forecast future shoreline positions using various modeling techniques. This foundational information is crucial for creating effective strategies to manage the dynamic coastal environment and promote the sustainable development of communities along the Cape Coast-Elmina coastline.

Assessing beach dynamics and their relationship to socio-economic development is crucial for managing coastal environments and the communities located along the coast (Anderson & Frazer, 2014). Various remote sensing techniques are commonly used to detect and monitor beach dynamics, with a particular emphasis on shoreline changes. These methods include aerial photography, visual interpretation, and on-screen digitization (Olali, 2015). The accuracy of these techniques is closely related to their spatial resolution. While vertical accuracy can vary significantly, horizontal accuracy—which determines the shoreline's position—generally corresponds with the spatial resolution of the source data (Gens, 2010 as cited in Olali, 2015). Information about the current shoreline location, its historical positions, and future predictions is essential for a wide range of studies conducted by coastal scientists, engineers, and managers (Boak & Turner, 2005). However, these methods are most effective when backed by reliable data on the dynamics that drive changes in the coastal area. A thorough understanding of the factors and processes that shape the coastal environment is vital for developing effective management strategies and ensuring the sustainable development of communities along the coastline.

Statement of the Problem

Ghana's coastline hosts a variety of vital infrastructure and assets, including key industries, major residential areas, tourism and conservation sites, and historical landmarks, all situated within 200 meters of the shore. Furthermore, many of the most densely populated coastal communities are located in low-lying plains that are susceptible to coastal flooding (Boateng, 2006). The observed spatial and temporal changes, both short-term and long-term, along with the human activities contributing to these changes, have attracted the attention of researchers in the field. Researchers are specifically interested in exploring the relationships between beach changes and human activities along the coastline, as well as evaluating the effectiveness of national coastal zone management policies in addressing these changes and activities along the Cape Coast-Elmina coastline. This heightened interest in understanding the complex dynamics and interactions among physical, environmental, and socio-economic factors shaping the coastal zone is essential for developing comprehensive strategies to manage and protect these valuable resources while ensuring the sustainable development of the communities that rely on them.

A study by Dei (1972), as cited in Jonah et al. (2016), reveals that during the 1970s, urbanization in Ghana's coastal zone coincided with a rise in the exploitation of coastal resources such as sand and stone for the construction industry. Armah (2011) examined the human activities contributing to changes in beaches, particularly focusing on shoreline erosion in Accra. Meanwhile, Olympio and Amos-Abanyie (2013) assessed the extent of shoreline recession and its impacts on buildings and infrastructure, using the Nkotompo coastline as a case study. Dogbey (2015) moved further from assessing coastal changes to analyzing the livelihoods strategies adopted by residents after the Keta Sea Defence and resettlement project was implemented. All these studies were geared towards the research orientation of the various researchers as well as the passion and quest for finding answers to pertinent questions regarding man-nature interactions along the coastal areas of Ghana.

The Cape Coast-Elmina coastline has been the focus of numerous studies. Researchers have employed various techniques to analyze changes along the beaches of Cape Coast, including aerial photography, satellite imagery, topographical maps, and Global Positioning System (GPS) data (Dadson, Owusu, & Adams, 2016; Jonah, Mensah, Edziyie, Agbo, & Adjei-Boateng, 2016). For example, Boateng (2012) conducted a comprehensive assessment of coastal recession along the coastline, emphasizing the importance of adopting sustainable management practices to tackle this issue. Additionally, Jonah, Adjei-Boateng, Agbo, Mensah, and Edziyie (2015) investigated various sediment mining activities along the Cape Coast and their contribution to coastal erosion. While these studies have offered valuable insights, they have largely overlooked other anthropogenic factors (beyond sand mining) that may be influencing changes in the beaches and the connections between these changes and human activities in the area. This underscores the need for a more thorough understanding of the complex interactions among the physical, environmental, and socio-economic factors shaping coastal dynamics in this region.

Some authors have researched changes in beaches and shorelines along the coastal areas of Ghana (Addo et al**.**, 2011; Oteng-Ababio, Owusu & Addo, 2011; Jayson-Quashigah et al., 2019; Jonah, Mensah, Edziyie, Agbo & Adjei-Boateng, 2016; Olympio & Amos-Abanyie, 2013; Appeaning- Addo & Lamptey, 2012). However, the literature on changes in beaches (erosion and deposition) in Ghana and Cape Coast specifically, barely extensively focused on the Spatial and temporal changes in beaches along Cape Coast - Elmina coastline in terms of assessing the long and short-term changes, the granulometric characteristics of beaches along the Cape Coast - Elmina coastline, the anthropogenic driving forces influencing changes in beaches along the Cape Coast - Elmina coastline, the linkages between changes in beaches and human activities along the Cape Coast - Elmina coastline. This study, therefore, seeks to accurately assess the changes in beaches between the Cape Coast and Elmina coastal zone.

Research Objectives

Main Objective

The main objective for this study is to assess the implications of changes in beaches on human activities along the Cape Coast - Elmina coastline.

Specifically, the study seeks to:

1. Assess the spatio-temporal changes (1991-2020) along the beaches of Cape Coast - Elmina coastline.
2. Assess the changes in granulometric characteristics of beaches along the Cape Coast - Elmina coastline
3. Explore the anthropogenic drivers of the changes in beaches along the Cape Coast - Elmina coastline; and
4. Assess the effects of the changes in beaches on human activities along the Cape Coast - Elmina coastline.

Research Questions

1. What spatio-temporal changes (1991-2020) have occurred along the beaches of Cape Coast - Elmina coastline?
2. What are the changes in granulometric characteristics of beaches along the Cape Coast - Elmina coastline?
3. What anthropogenic drivers have contributed to the changes in beaches along the Cape Coast - Elmina coastline; and
4. What are the effects of the changes in beaches on human activities along the Cape Coast - Elmina coastline?

Significance of the Study

Firstly, coastal zones are part of the most dynamic environments globally, as it represents the interaction of different geospheres over various timescales. Understanding coastal dynamics in terms of short and long term spatio-temporal changes, the anthropogenic drivers involved, and the connections between beach alterations and human activities along the coastline is essential. Sustainable Development Goal 14, which centers, on life below water, urges all nations to conserve and sustainably manage oceans, seas, and marine resources for the benefit of sustainable development. According to UNDP (2019), the current expansion of protected areas for marine biodiversity and existing policies promoting responsible ocean resource use remain insufficient to mitigate the adverse effects of both natural and human-induced factors. With billions of people depending on oceans for their livelihoods and food, there is a pressing need for enhanced efforts and interventions to conserve and sustainably manage ocean resources at all levels (UNDP, 2019). Consequently, the findings of this study offered valuable insights into the human-driven factors behind beach changes and the relationships between beach dynamics and human activities in coastal communities, which can guide local and national coastal zone management policies.

Secondly, the study highlighted the spatial and temporal changes along the Cape Coast-Elmina coastline, focusing on both short-term and long-term alterations in the beaches. This information will help community members, as well as the broader public, to comprehend the changes occurring at the beach and their connection to human activities in coastal communities, along with the policies that regulate these actions and inactions. This study, therefore, significantly enriches and broadens the knowledge and understanding of the study population and the general public on the relationship between changing beach dynamics, anthropogenic drivers of the changes and linkages with human activities as well as development of coastal communities and therefore, the relevance of ensuring sustainable development.

Thirdly, this study provided reliable data on the spatio-temporal changes in beaches, driving forces influencing the changes, the granulometric characteristics of the beaches along the Cape Coast - Elmina coastline, and how these changes are linked with human activities. Data as reliable as such will assist institutions responsible for coastal zone management and other stakeholders in terms of policy formulation and intervention on beach dynamics. In light of this, attention was drawn to drivers responsible for the changes in beaches, thus calling for effective policy interventions aimed at managing these drivers. Information regarding changes in beaches along the Cape Coast-Elmina coastal zone needs to be updated periodically to provide coastal managers and scientists with insights into ongoing changes. This will facilitate the planning and implementation of effective beach management strategies aimed at protecting vulnerable communities and infrastructure in the region. Furthermore, it will enhance the management and planning of the natural coastal environment and communities, particularly in response to rapid population growth, escalating economic activities, and subsequent urbanization.

Finally, the study would add to existing literature and knowledge on changes in beaches (erosion and deposition) between the Cape Coast and Elmina coastal zone using integrated remote sensing approaches in Ghana. It will also deliver current data on the spatial and temporal changes and the human-induced factors driving these changes, as well as the connections between alterations in beaches and human activities along the coast. This would assist scholars interested in studying similar topics as they can use findings from this investigation as entry point in understanding and explaining the Phenomena.

Scope of the Study

Geographically, this study covered the coastline of Cape Coast - Elmina in the Central Region of Ghana. The communities along the coastline of the Cape Coast Metropolis and Komenda Edina Eguafo Abirem Municipal constituted the study area with special emphasis on such communities as Duakor, Ahiaboeboe, Abakam, etc.

Thematically, this thesis focused on the changing beach dynamics of Cape Coast – Elmina Coastline, Ghana. Specifically, it documented the spatial and temporal changes in beaches along the Cape Coast-Elmina coastline from 1990 to 2020, examined the granulometric characteristics of these beaches, identifies the human-driven forces affecting beach changes and explored the connections between beach alterations and human activities along the Cape Coast-Elmina coastline.

Organization of the Study

The study was structured into eight chapters. Chapter One included the Introduction, outlining the background, statement of the problem, research objectives, research questions, significance of the study, delimitations, and the overall organization of the study. Chapter Two concentrated on theoretical and conceptual reviews, while Chapter Three provided an empirical review of relevant literature pertaining to the study. Chapter Four detailed the research methodology, including descriptions of the study area, research design, data sources, target population, sample size, sampling techniques, data collection tools, data processing and analysis, and ethical considerations. Chapter Five focused on the spatial and temporal changes in beaches along the Cape Coast-Elmina coastline from 1990 to 2020.

Chapter Six assessed the granulometric characteristics of beaches along the Cape Coast - Elmina coastline, while Chapter Seven explored the linkages between changes in beaches and human activities along the Cape Coast - Elmina coastline. Finally, Chapter Eight summarized, concluded and recommended appropriately depending on the key findings of the study.

CHAPTER TWO

CONCEPTUAL OVERVIEW AND THEORETICAL PERSPECTIVES

Introduction

This chapter centers on reviewing pertinent literature for the study and is primarily divided into two sections. The first section addresses relevant concepts and theoretical perspectives. The chapter concludes with a summary that provides an overview of the topics discussed.

Conceptualizing Coastal Zone

As noted by Olali (2015), the coastal zone is a dynamic environment encompassing beaches, coral reefs, dunes, coastal floodplains, marshes, tidal flats, and marine fisheries. This area represents a broader environment characterized by ongoing interactions between land and sea, influenced by both natural and human activities across various spatial and temporal scales (Okorobia & Olali, 2018). The coastal zone operates as a morphodynamics system, comprising an energy component (including wind, tides, and waves) and a material component (such as rock and sediment). These components interact to shape the coastline and drive morphological changes (Olali, 2015). The processes involving coastal materials and forces—such as waves, tides, currents, and wind—are interrelated. Consequently, any alterations in the inputs and outputs of coastal materials can significantly impact the forces shaping the coastline, and vice versa (Wiafe et al., 2013). Coastal zone resources and facilities are vital for fulfilling societal needs and cover approximately 12 percent of the Earth's surface (Costanza et al., 1997; Luisetti et al., 2011).

As coastal populations continue to expand, their impact on the development and use of coastal habitats is expected to increase (Burke et al., 2001). The combined impacts of population growth, economic development, and technological advancements threaten ecosystems that provide vital economic benefits. Shoreline changes resulting from erosion and accretion are natural processes that occur over different time scales. These changes can be initiated by smaller-scale (short-term) events such as storms, regular wave action, tides, and winds, or by larger-scale (long-term) events like glaciation, orogenic cycles that significantly influence sea levels (either rising or falling), and tectonic activities that cause coastal land subsidence or emergence (Taguchi et al., 2013). As a result, most coastlines are inherently dynamic, with erosion cycles being a fundamental characteristic of their ecological nature. Natural forces such as wind, waves, and currents easily transport unconsolidated sand and soil in coastal regions, leading to rapid changes in shoreline positions. While these dynamic processes shape the coastal environment, escalating human activities and development in coastal areas can significantly disrupt this natural balance, often resulting in considerable environmental, social, and economic consequences.

To promote sustainable coastal development and implement effective strategies for controlling beach erosion, delineating flood zones, and protecting ecosystems, coastal managers and scientists require comprehensive data on both long-term and short-term changes along the coastline, including shifts in beach profiles resulting from erosion and deposition processes (Klemas, 2013; Olali, 2015). Building this essential information base and understanding the complex interactions among various environmental, social, and economic factors affecting the coastal zone will require close collaboration among scientists, coastal engineers, managers, and practitioners in monitoring and information technology (Burke et al., 2001). This interdisciplinary approach is essential for evaluating the current state of coastal environments and developing integrated management strategies that address the diverse needs and interests of coastal communities, ecosystems, and economic activities. By fostering this collaborative approach, coastal decision-makers can make informed decisions that enhance the sustainable use and conservation of these dynamic and valuable coastal resources.

Beach Dynamics

Coastal environments are undergoing physical transformations at both local and global levels due to a combination of natural processes and human-induced degradation (Sertel & Seker, 2012). The threats to coastal ecosystems have reached alarming levels, with about 38% of Africa's coastal ecosystems being significantly endangered (Food and Agriculture Organisation [FAO], 1998). Acknowledging the economic value of nature and its services to humanity has become increasingly vital in the realm of coastal zone management (Luisetti et al., 2011). Given that the coastal zone is a crucial economic, social, and environmental resource, one of the primary challenges faced by coastal managers is shoreline erosion (Archetti & Lamberti, 2009). As the erosion front advances, the volume of beach sand decreases, leading to a landward retreat of the shoreline, which poses threats to coastal infrastructure (Finkl & Makowski, 2013). This ongoing coastal erosion presents significant challenges for coastal communities, infrastructure, and the overall sustainability of coastal ecosystems. Addressing these issues requires a comprehensive understanding of the complex interactions between natural and human factors driving coastal changes, as well as the establishment of integrated management strategies that balance the various economic, social, and environmental needs within the coastal zone.

Coastal areas have long relied on the exploitation of coastal resources for commercial and industrial activities. Given the significant economic opportunities presented by coastal regions, the emerging threats posed by coastal erosion are of great concern (Sertel & Seker, 2012). These coastal ecosystems are under immense pressure due to the rapid increase in population size, which has not been matched by a corresponding growth in the natural resource base (FAO, 1998). The social, economic, and ecological effects of coastal erosion are extensive and severe. They include the loss of pristine white sand beaches, valuable agricultural land leading to decreased productivity, damage or destruction of coastal properties and infrastructure—such as hotels, roads, and fish landing sites—as well as the loss of indigenous coastal forests and critical ecosystems like coral reefs and mangroves, along with the genetic diversity and species they sustain (Luisetti et al., 2011). Additionally, ongoing coastal erosion results in the loss of employment opportunities in coastal communities (Archetti & Lamberti, 2009). These complex impacts underscore the urgent need for comprehensive and proactive management strategies to tackle the challenges faced by coastal areas and ensure the sustainable use and conservation of these essential resources (Finkl & Makowski, 2013).

The increasing development in coastal areas has heightened interest in addressing erosion issues, leading to substantial efforts to manage coastal erosion and improve the resilience of these regions against both short- and long-term changes resulting from human activities, extreme events, and rising sea levels (Tolhurst et al., 1999). However, erosion problems can be exacerbated when countermeasures, whether hard or soft structural solutions—are inappropriate, poorly designed, inadequately constructed, or insufficiently maintained, particularly if the effects on adjacent shores are not thoroughly evaluated. Typically, erosion is managed at specific local sites or within certain regional or jurisdictional boundaries, rather than taking into account system boundaries that reflect the natural processes at play (Bray et al., 1997; Van der Weide et al., 2001). This narrow approach is often due to a lack of understanding of coastal processes and the protective functions of coastal systems. Effective management of coastal erosion requires a more comprehensive grasp of the complex interactions between natural and human factors affecting the coastal environment (Van der Weide et al., 2001). Embracing a systems-based approach that recognizes the interconnected nature of coastal processes and the potential impacts of interventions on the wider coastal ecosystem is crucial for developing sustainable solutions to the erosion challenges faced by coastal communities (Bray et al., 1997; Tolhurst et al., 1999).

In Africa, the coastal zone is typically narrow and low-lying, rendering it especially susceptible to various impacts, including sea-level rise, storm surges, increased flooding, climate change, and human activities (Goussard & Ducrocq, 2014). These physical, ecological, and socio-economic pressures have significantly heightened the challenges faced by coastal regions. Coastal nations in Africa, such as Egypt, South Africa, Nigeria, and Ghana, feature low-lying lagoon coasts that are vulnerable to erosion and threatened by rising sea levels, a situation further exacerbated by urban growth in these areas (IPCC, 2007). Human activities along the coast—such as land reclamation, port development, agriculture, river damming and diversion, as well as offshore activities like dredging and sand mining—often interact with natural forces, aggravating coastal erosion in many locations (Warne & Stanley, 1993). These human impacts, combined with natural factors, jeopardize the long-term capacity of coastlines to fulfill their socio-economic and ecological functions at a sustainable cost. For instance, studies examining the impacts of sea-level rise on the Egyptian coast have reported substantial loss in the northern region of the Nile Delta due to flooding and erosion (Warne & Stanley, 1993). Likewise, research on the Eastern Coast of South Africa has associated coastline retreat with a combination of waves, tides, rising sea levels, wind, and human activities (Corbella & Stretch, 2012).

Coastal Erosion

Coastal erosion and sediment deposition are intricate processes that must be analyzed from various angles, including the movement of sediment driven by wind, waves, and tidal currents, as well as beach dynamics related to sediment and human activities along the coast, within river catchments, and offshore. In terms of temporal scales, the issue of sea-level rise is particularly complex, leading to a range of environmental challenges. As sea levels increase, water depth rises, and the wave base becomes deeper, resulting in waves reaching the shore with greater energy, which can erode and transport larger quantities of sediment (IPCC, 2007; Davidson-Arnott et al., 2019). This initiates a process of coastal adjustment aimed at maintaining a dynamic equilibrium. Human activities, including dam construction, unsustainable coastal resource utilization (such as bush burning, sand mining, deforestation, and certain agricultural practices), as well as the building of artificial structures, also influence changes in beach dynamics (Rahman et al., 2019). These human-induced modifications, coupled with natural processes, create a complex and dynamic coastal environment that necessitates a comprehensive understanding for the development of effective management strategies.

Globally, coastal erosion has emerged as one of the most critical environmental challenges affecting coastal zones, with significant implications for the development of various economies (Anim, 2012). Although coastal erosion and deposition are natural phenomena, they have become increasingly erratic and widespread in many countries due to a mix of natural forces, population growth, and unregulated economic activities along the coast, within river catchments, and offshore (French et al., 2016). The Earth's dynamic state and its inherent fluctuations result in rapid changes in oceans as they seek equilibrium (Addo, 2009). Given the fluid characteristics of coastal zones, both human actions and natural processes can have substantial impacts. Depositional processes can introduce sediments to beaches, thereby increasing the volume of existing beach sand (Zhang, 2011). In contrast, coastal erosion has led to heightened flooding, damage to protective infrastructure, loss of renewable and subsistence resources, property damage, loss of coastal habitats, and even fatalities (Anthony, 2005). These consequences underscore the urgent need for effective management and mitigation strategies to address the complex interactions between natural and human-induced factors affecting the coastal environment.

Research indicates that coastal erosion is a significant issue in various regions worldwide. Bilan (1993) noted alarming erosion rates in different parts of China, with the northern region of Jiangsu Province experiencing erosion rates as high as 85 meters per year, Hangzhou Bay at 40 meters per year, and Tianjin ranging from 16 to 56 meters per year. Notably, even areas equipped with protective measures like sea dykes are not exempt from this problem, as beach scour has been observed along coastlines with such structures. The causes of ongoing coastal erosion are multifaceted. River damming and diversion have reduced sediment supply to the coast, while the clearance of mangrove forests has heightened the vulnerability of coastal areas to erosion (Bilan, 1993). Additionally, the rising frequency and intensity of storm events have resulted in substantial amounts of sediment being washed offshore, with only a small fraction returning to the coast under normal circumstances. In Malaysia, Othman (1994) noted that nearly 30 percent of the country's coastline is facing erosion.

Similarly, the rapid erosion of Sagar Island's coastline in West Bengal, India, is caused by a combination of natural processes, such as cyclones, waves, and tides reaching heights of up to six meters, along with human activities like settlement and aquaculture, which have led to the removal of mangroves and other coastal vegetation (Gopinath & Seralathan, 2005). Additionally, the Godavari Delta region in India has experienced coastal erosion and habitat loss due to dam construction on the Godavari River and its tributaries, which has decreased sediment supply to the coast, coupled with ongoing coastal land subsidence (Malini & Rao, 2004). These examples from various regions highlight the widespread and complex nature of coastal erosion, underscoring the necessity for comprehensive and sustainable management strategies that address both natural and human-induced factors contributing to this environmental issue.

Romine et al. (2013) studied coastline retreat in Hawaii and found rising ocean levels as the primary cause of this phenomenon. The increase in ocean levels along the Hawaiian coast was specifically associated with changes in island subsidence. Additionally, factors such as sediment supply, wave action, human activities, and littoral processes were also found to affect coastal erosion in Hawaii. In the United Kingdom, coastlines experience varying erosion rates due to the diverse geography and geomorphic characteristics of different coastal regions. This underscores the heterogeneous nature of coastal erosion processes across various geographic contexts. It is a well-documented trend that major cities in both developed and developing nations are often situated along coastlines or major river systems worldwide. This trend has important implications for managing coastal erosion, especially for Asia, where coastal erosion presents a significant challenge due to the strong socio-economic ties to coastal cities.

For instance, Shandong Peninsula in China, which is facing coastal erosion, is particularly vulnerable due to its low-lying topography. Cai et al. (2009) reported a coastal retreat of 300 meters per year at the mouth of the Luanhe River, resulting in an erosion rate of 25 meters annually for the offshore sandbars. This erosion has been associated with rising ocean levels and the negative impacts of human activities. These findings underscore the complex and multifaceted nature of coastal erosion, shaped by a combination of natural and human factors, including sea level rise, sediment dynamics, geographic characteristics, and human interventions. The significant presence of major cities in coastal areas highlights the urgent need for comprehensive and context-specific strategies to address the challenges of coastal erosion and improve the resilience of these crucial regions.

Coastal Deposition

Coastal deposition is a process driven by wave action, which results in the accumulation of various sediments, including sand, rock, and pebbles (Turner, Subak & Adger, 1996). Key factors in the transport and deposition of these materials include gravity and friction, which act as the primary forces encountered by the waves. Sediments are moved by waves through several mechanisms, such as suspension, saltation, solution, and traction. The coastal deposition process is essential as it facilitates the movement of different materials (Meng, Yang, Yao & Liu, 2013; Pender & Karunarathna, 2013). This movement is usually the primary cause of the formation of various depositional landforms, such as beaches, lagoons, spits, and tombolos. Coastal deposition also accounts for the significant differences in materials found around shorelines and beaches compared to the surrounding environment (Horn & Mason, 1994). These sediments and materials often originate from various areas of the ocean floor and are transported by wave action.

Geological deposition is the process by which soil, rocks, sand, and other sediments are added to an existing landscape. During sediment transport, waves may occasionally lose energy, causing sediments to be released and settle (Turner & Nielsen, 1997; Turner & Masselink, 1998; Masselink & Li, 2001). Deposition occurs when the forces of waves and wind are unable to overcome the effects of gravity. This interaction of forces generates friction that aids in transportation, ultimately leading to deposition. Coastal deposition typically occurs when the swash—the forward movement of waves—exceeds the backwash—the backward movement of waves (Fredsøe & Deigaard, 1992; Butt & Russell, 1999; Pritchard & Hogg, 2005). As a result, coastal deposition usually arises from constructive waves, where the swash dominates over the backwash. However, it is important to note that destructive waves can also contribute to coastal deposition. The sediments and materials that are moved and deposited can vary in grain size depending on wave energy (Pritchard & Hogg, 2005). For instance, higher wave energy typically transports and deposits larger sediments, while lower wave energy is more likely to carry and deposit smaller sediments, such as fine-grained particles.

In addition to the previously mentioned factors, several other elements are essential to the coastal deposition process, including the rate of sediment transport, climate change, weather patterns, storm surges, and various geological processes (Turner & Masselink, 1998; Masselink & Li, 2001). These factors can significantly influence the dynamics and results of coastal deposition. Furthermore, coastal deposition is crucial for the biodiversity found in beach areas, as the accumulation of sediments and materials can alter local ecosystems and habitat structures. Coastal deposition is more likely to occur in regions with low wind, an ample supply of sediments, and where waves enter shallow or sheltered waters (Turner & Nielsen, 1997; Masselink & Li, 2001). The movement of waves and the subsequent deposition of materials often contribute to the formation of various geological structures and landforms along coastlines.

Particle Size Distribution of Beach Sediment

Particle size distribution or grain size distribution as it may sometimes be referred to; is a fundamental characteristic of beach sediments, influencing various sedimentary properties and coastal processes. Over the years, various methods have been created to measure and analyze sediment grain sizes, reflecting the advancing knowledge of coastal geomorphology.

Early methodologies for determining grain size frequency distribution, such as those outlined by Krumbein (1934); and Herdan and Smith (1960), paved the way for comprehensive studies by Folk (1966) and others. Sieving emerged as a predominant technique, notably championed by Udden (1914) and later refined by Folk (1966) for its effectiveness in distinguishing sand environments.

Contemporary advancements in sediment analysis encompass a range of methods including Sieve/Hydrometer, X-ray Attenuation, Scanning Electron

Microscopy (SEM), Sedimentation, and Laser Diffraction techniques (Switzer, 2013). Each method offers unique advantages and applications, contributing to a nuanced understanding of sediment characteristics.

Grain-size studies have served as invaluable tools for elucidating sedimentary processes and depositional environments in coastal zones (Kulkarni et al., 2015). By analyzing particle size distributions, sedimentologists can infer source materials, weathering processes, transportation mechanisms, and depositional histories, thereby facilitating comprehensive coastal management strategies.

Sedimentologists emphasize three key aspects of particle size analysis: measurement techniques, data quantification, and genetic interpretation (Bramha et al., 2017; Kulkarni et al., 2015). The distribution of sediment particle sizes exhibits discernible spatial and temporal patterns, reflective of specific depositional environments and processes (Knight et al., 2002). Muddy sediments, characterized by biological patchiness, demonstrate notable variation at both small and short scales (Wheatcroft & Butman, 1997). For example, studies by Hakro and Baig (2014) and Bramha et al. (2017) underscore the diverse nature of sediment compositions and grain sizes along coastal regions. Variations in grain size distribution, particularly between foreshore and mid-shore regions, highlight the dynamic nature of sandy beach environments. Understanding spatial and temporal variations in particle size distribution is integral to effective coastal management strategies.

Sediment Transport

According to Splinter et al. (2010), alterations in wave climate and sediment supply have resulted in sandy shorelines along most of the world's coasts, characterized by spatial variability and notable temporal changes. Various factors, including runoff, tides, and other hydrodynamic forces, work together to mobilize, transport, and deposit marine sediments (Do Carmo & Seabra-Santos, 2002). The processes affecting the spatial distribution of sediment and coastal geomorphology indicate that the composition and arrangement of sediment offer valuable insights into sediment source-sink dynamics and environmental changes (Balsam & Beeson, 2003; Murraya et al., 2002). This information can reveal spatial variability, sediment migration patterns, and sediment dynamics.

The transport of beach sediments is shaped by various mechanisms. Wind primarily transports sediments at the upper sections of the beach, while oceanographic conditions, including tides, currents, and waves, enable ongoing sediment movement in the swash zone and nearshore areas, extending to the continental shelf (Pradhan et al., 2020). According to Splinter et al. (2010), both onshore-offshore sand transport and gradients in longshore sand transport influence the temporal variability of the shoreline. Longshore transport is driven by longshore currents and oblique wave action, whereas cross-shore transport is influenced by changes in wave height, as well as contributions from cross-shore currents and wave breaking processes. The short-wave orbital velocities and turbulent energy generated by breaking waves mobilize sand grains, which are then carried along the coast by these currents (Splinter et al., 2010). Additionally, Cowell et al. (1995) found that a 1 percent decrease in longshore sand transport could lead to shoreline retreat comparable to that resulting from a 0.5 m rise in sea level. This consideration is essential for future climate change scenarios.

Brambilla, Papini, and Longoni (2018) emphasize the need for a deeper understanding of sediment sources to effectively predict and manage risks, comprehend the underlying physics, and mitigate associated dangers. When planning and constructing a coastal structure, such as a breakwater or jetty, for example, it is critical to estimate the total amount of sediments that will be blocked by the structure over time. However, because the sea waves that cause this transport are random, the amount of sediments transported varies over time. Seymour and Castel (1985), explained the variance in transportation over a year.

The major sediment types have been classified as "relict," "modern," or "palimpsest" based on their ages" (Hastie, 1983). Relict sediments are sediments that are left over from a previous climate (Emery, 1952). They are uncoordinated with their present environment. The term "modern sediments" refers to sediments that are currently being delivered to the shelf (Curray, 1965). They are in a state of equilibrium with their surroundings. Palimpsest sediments are sediments that have characteristics of an earlier depositional environment as well as characteristics of a later environment as a result of reworking (Swift, Stanley & Curray, 1971).

According to Swift (1970), modern sediments can be categorized into two distinct facies based on their transport mechanisms. The first component is the "nearshore modern sand prism," which includes mainland beaches, spits, or barrier islands, along with a seaward-thinning and fine-grained wedge of hydraulically concentrated nearshore sand. The second component is the "shelf modern mud blanket," which is designated for depositing suspended loads at greater offshore distances (Swift, 1970). The term "inner continental shelf" refers to the underwater surface of the nearshore modern sand prism. This inner shelf can be subdivided into two morphological components on unconsolidated coasts: the "shoreface" and the "inner shelf floor". The shoreface extends from the shoreline to depths of 12 to 20 meters, where the inner shelf floor is located. The term "nearshore" pertains to the upper section of the shoreface.

Sediments Sorting

The sorting of sediments in beach environments is a dynamic process determined by various factors, including wave dynamics, grain size distribution, and beach morphology. Sorting, as defined by Shu and Collins (2001), refers to the uniformity of particle sizes within sediment samples. Inman and Chamberlain (1955) further elaborate on sorting as a measure of the distribution of sediment particle sizes, indicating either well-sorted or poorly-sorted conditions.

The sorting of beach sediments primarily stems from the differential velocities of water movements, leading to the accumulation of finer sediments near the swash line and coarser sediments at the plunge line. This process, as highlighted by Evan (1939), significantly contributes to the formation of various beach structures such as spits, bars, and barriers.

Various sorting coefficients have been developed over time to quantify the degree of sediment sorting. These include Udden's index, Baker's grading factor, Trask's measure, Niggli's index, and the Inclusive Graphic Deviation (Folk & Ward, 1957). However, the efficacy of these coefficients has been questioned, particularly regarding their ability to accurately represent sorting beyond simple grain-size distribution spreads (Krumbein, 1938).

In contemporary literature, emphasis is placed on refining measurement techniques to capture the intricacies of sediment sorting. Notably, Inman's Phi Deviation Measure and Folk and Ward's Inclusive Graphic Standard Deviation have emerged as prominent methods for characterizing sediment sorting characteristics. These approaches utilize percentile-based measurements to provide a more nuanced understanding of sorting patterns, moving beyond traditional quartile-based assessments (Inman, 1952; Friedman, 1962). (Inman, 1952; Friedman, 1962).

Inman (1952) advocated for the use of percentile measures, specifically the 16th and 84th percentiles, over quartiles, as a more accurate representation of sediment sorting characteristics. This recommendation, supported by Friedman (1962), aimed to enhance the precision of sorting coefficient calculations and provide a better understanding of coastal sediment dynamics.

Sharp and Fan (1963) elucidate the qualitative aspects of sorting, emphasizing both the uniformity of sediment distribution among classes and the spread of grain-size distribution.

Remote Sensing (RS) and Geographic Information System (GIS)

Remote sensing is the science and art of gathering information about an area, object, or phenomenon without direct physical contact (Lillesand et al., 2015). Remote sensing systems employ sensors mounted on aircraft or spacecraft to measure the energy that is either reflected or emitted from the Earth's surface. When integrated with Geographic Information Systems (GIS) and field surveys, remote sensing offers valuable spatial data for assessing environmental changes in water bodies and their surrounding areas at local, regional, and global levels (Myint et al., 2011). This data is crucial for tracking changes in surface phenomena over time, which is vital for environmental monitoring programs (Howarth & Wickware, 1981, cited in Temiz & Durduran, 2016). Digital spatial data analysis, mapping, remote sensing, and GIS are widely utilized for monitoring environmental and natural resources (Giardino & Haley, 2006). Remote sensing, along with other geospatial tools, facilitates a comprehensive assessment and monitoring of environmental changes without requiring direct physical interaction with the study area.

A Geographic Information System (GIS) is an integrated system that combines hardware, software, and data for capturing, managing, analyzing, and displaying geographically referenced information (Temiz & Durduran, 2016). GIS allows users to view, analyze, question, interpret, and visualize data in ways that reveal relationships, patterns, and trends, which can be depicted through maps, globes, reports, and charts (Durduran, 2010; GIS.com, 2011). Variations in spatial and temporal parameters provide data for GIS and other modeling tools, making GIS a crucial resource across multiple disciplines that rely on spatial data (Şeker, Tanık, & Öztürk, 2009). The outputs generated by GIS can be used as input for modeling studies and are frequently employed to visualize the results obtained from these models (Ertürk, Ekdal, Gurel, Yuceil, & Tanik, 2004). In summary, GIS integrates various components to capture, store, retrieve, analyze, and display spatial data, facilitating the exploration of relationships, patterns, and trends while aiding data-driven decision-making in diverse fields.

In recent years, remote sensing and Geographic Information Systems (GIS) have become essential tools for monitoring changes in coastal area management and usage (Sesli & Karslı, 2003). By comparing historical and contemporary satellite images of a region, it is possible to evaluate changes along the coastline, which is often more efficient than relying solely on topographic measurements (Sesli & Karslı, 2003). These remote sensing and GIS-based methods facilitate a systematic observation of the developmental history of environmental issues in coastal regions (Sesli & Karslı, 2003). Additionally, they allow for the quantification of the dimensions and impacts of the observed changes (Tran Thi, Tien Thi Xuan, Phan Nguyen, Dahdouh-Guebas & Koedam, 2014; Kuleli, 2010).

Coastlines are recognized as unique features on the Earth's surface (Li, Di & Ma, 2003). A coastline is defined as the boundary line where land meets a body of water (Alesheikh, Ghorbanali & Talebzadeh, 2004). Understanding coastlines is essential for addressing coastal challenges and for evaluating and characterizing land and water resources, including land area and coastline perimeter (Klein & Lichter, 2006). Monitoring the evolution of coastlines is crucial for various purposes, such as cartography and the environmental management of the entire coastal zone (Dellepiane, De Laurentiis, & Giordano, 2004). Accurate knowledge of coastline dynamics is essential for effectively managing and addressing the challenges faced by coastal environments.

Changes in coastlines and sea levels are sensitive indicators of both past and current climate variations and human activities at local and regional scales (Chopra, Verma & Sharma, 2001). These alterations primarily reflect variations in precipitation, evaporation, runoff, and human interventions in coastal areas. The availability of multispectral, multitemporal, and multi-sensor satellite imagery, along with advancements in digital processing and analysis, has enabled researchers to gather data on the spatial and temporal evolution and sensitivities of changes caused by both natural and human-induced events (Kalivas, Kollias & Karantounias, 2003; Ma, Wang, Veroustraetes & Dong, 2007). While lakes represent a relatively small fraction of the Earth's water, they play a crucial role in the global hydrological system, and hold significant importance for humanity, providing water supply, serving as habitats for food, generating power, and offering recreational and aesthetic value. In summary, remotely sensed data from satellites have become a valuable tool for monitoring and understanding the changes in coastlines and water bodies, which can serve as sensitive indicators of broader climate and human-induced changes at regional and global scales.

Public Policy Responses

Researchers have sought to clarify the concept of policy. Marfo and Wiggins (2002) define policy as the intended actions and actual measures implemented by the state to tackle a specific issue. They contend that policies encompass both objectives (such as ends, targets, goals, and aims) and instruments (means and activities) used to achieve those objectives. Conversely, Anderson (1997), as cited in Anyebe (2018) offers a broader definition, describing policy as a relatively stable and purposeful course of action taken by an individual or group of individuals to address a problem or a matter of concern. This definition is not restricted to the state or government as the exclusive source of policy. This study aligns with Anderson's definition, focusing specifically on government policies intended to mitigate the challenges associated with the dynamics along coastlines. Policies, in this context, refer to the intended course of action or documented plans by governments to address perceived public demands and enhance development in coastal areas.

A policy can be defined as a specific course of action or method selected from available alternatives, in light of a given situation, to guide and inform present and future decision-making (Anyebe, 2018). Policies can also be viewed as the general principles that govern a government or governmental body's management of affairs to achieve rational outcomes (Anyebe, 2018). Policies are typically established when a problem arises that needs to be addressed, with the aim of preventing the problem from escalating (Anyebe, 2018). These policies are typically adopted by a governing body, which pertains to the effectiveness of an institution in formulating, implementing, and enforcing sound policies efficiently, effectively, equitably, and inclusively (Anyebe, 2018). In summary, policies are intentional courses of action implemented by governing bodies to tackle specific issues and inform future decision-making, aiming to achieve rational and favorable outcomes through effective and inclusive governance.

Theoretical Perspective

Catastrophe Theory

Two theories have become prominent in the social sciences literature for the study of changes in complex, dynamic phenomena. These are the chaos theory and catastrophe theory. Chaos theorists advance the argument that change in a phenomenon appears random and in a chaotic manner (Mason, 2008). Catastrophe advances the opposite argument that changes are a result of steady internal and external effects on the phenomena. This study is particularly interested in landscape changes that are not chaotic and as such align with the catastrophe theory.

Catastrophe theory was postulated by French Mathematician Rene Thom in the 1960s. Even though Thom used the word “catastrophe” in his book, Christopher Zeeman is credited with suggesting that the theory advanced by Thom should be called Catastrophe Theory. Due to the controversies on the understanding of the word catastrophe, it is significant to clarify what is meant by catastrophe as used in the theory. Typically, a catastrophe evokes images of a sudden and dramatic occurrence, such as disasters that are often viewed as harmful or malevolent However, catastrophes also have a specific mathematical definition. In this context, a catastrophe refers to a situation where a continuous change in causes leads to a sudden change in effects.

Thom aimed to "apply ideas from differential topology and topological dynamics to natural phenomena that exhibited sudden and dramatic (catastrophic) discontinuities of behavior" (Stewart, 1983). According to Mathews, White, and

Long (1999), catastrophe theory serves as a mathematical modeling methodology for situations where gradual and continuous pressures result in abrupt discontinuities or divergent changes. Moving beyond mathematical modeling, Mason (2008) explained that catastrophe theory generally helps to understand how sudden societal changes can arise from minor effects. In relation to systems, it is argued that catastrophe theory studies systems whose steady equilibrium state can change suddenly due to slight variations in input variables (Schreiber et al., 1997). Events that undergo catastrophic changes result from dynamic processes that cause abrupt shifts in at least one variable, often due to relatively minor changes in other variables or parameters (Manning, 1975).

At the core of catastrophe theory is the idea that any living or non-living form can be linked to the collapse of a structurally stable attractor state within a system as a result of changes in the influencing factors. Thom (1975) noted that morphogenesis displays its characteristics through environmental discontinuities. Woodcock (1978) clarified that these discontinuities, or bifurcations, can trigger catastrophic changes that destabilize the existing states of a system, leading to the formation of new stable states, which may be evident as morphological transformations.

Zeeman not only coined the term for the theory but also significantly contributed to its development and popularization. He applied catastrophe theory to examine changes across various fields, including sociology, political science, animal behavior, psychology, biology, physics, and engineering (Zeeman, 1977). Zeeman (1977) argued that the theory has significant generality and can illustrate the evolution of forms in all areas of nature, particularly in situations where gradually varying forces or motivations lead to abrupt changes in behavior. Building on Zeeman's work, scholars in multiple disciplines have utilized catastrophe theory to investigate changes in various phenomena, including alterations in landforms. This led Stewart (1983) to assert that a key feature of catastrophe theory is its applicability across a wide range of scientific fields.

Specifically, Jones (1977) and Loehle (1989) applied catastrophe theory to investigate ecological systems, while Lockwood and Lockwood (1993) used it to examine rangeland ecosystem dynamics. Su et al. (2012) proposed and utilized catastrophe theory to characterize the spatial variations in agroecosystem health. Zeeman developed catastrophic models to explain a range of events, including riots in jails, stock market crashes, and the propagation of nerve impulses. Relevantly, Chappell (1978) applied the theory to provide a detailed account of the accretion-degradation discontinuity in the landforms of Papua New Guinea. This application by Chappell demonstrates that changes in coastal landforms can indeed be analyzed using catastrophe theory.

The theory has faced significant criticism, particularly in the field of mathematics where it was first applied. Critics contended that the theory was overstated and that its contributions to the biological and social sciences were minimal (Zahler and Sussmann, 1977, cited in Boutot, 1993). Others criticized the application of the theory in fields like sociology where quantification is impossible. It was also argued that catastrophe theory’s applicability is limited and has no predictive powers. In defense of catastrophe theory against the onslaught of criticisms on its limited predictive power, Boutot (1993) contended that theories should not be judged on their ability to predict. Also, Thom cited in Boutot (1993) pointed out that only a rigorous quantitative model allows predictions and this seems to be limited to physics and mechanics.

Despite the criticisms, the theory offers a plausible explanation to changes in phenomena like landforms which are nonlinear and are of which changes are as a result of gradual continuous changes. The catastrophe theory is, therefore, the appropriate theory to study the beach dynamics of Cape Coast –Elmina Coastline.

The Driver-Pressure-State-Impact-Response (DPSIR) Framework

The Driver-Pressure-State-Impact-Response (DPSIR) framework is an essential tool developed by the Organization of Economic Cooperation and Development (OECD, 1993) and the European Environment Agency (EEA, 1995) for managing Social-Ecological Systems (SESs). This systems-thinking framework demonstrates the cause-and-effect relationships among the interacting components of social, economic, and environmental systems. The DPSIR framework has been utilized in various contexts related to environmental resources, including agricultural system management (Kuldna et al., 2009; Binimelis et al., 2009), water resources (Mysiak et al., 2005; Borja et al., 2006), biodiversity (Maxim et al., 2009; Omann et al., 2009), and marine resources (Mangi et al., 2007; Ojeda-Martinez et al., 2009; Nuttle & Fletcher, 2013). Furthermore, it can integrate social, cultural, and economic aspects of environmental and human health into a cohesive model (Yee et al., 2012). The framework is primarily employed in environmental management to connect ecological and socioeconomic factors.

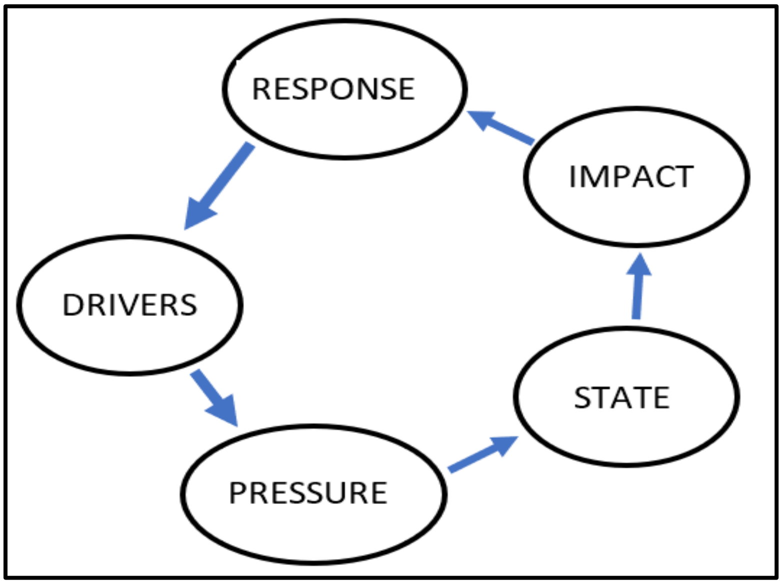

Figure 1: The DPSIR Framework

Source: OECD (1993)

Patrício et al. (2016) view the DPSIR framework as an effective and straightforward tool for addressing major environmental issues, thereby facilitating the decision-making process in policy and regulatory implementation. Insights gained from DPSIR analyses have been instrumental in the development of Integrated Coastal Zone Management (ICZM) (Pacheco et al., 2006) and Integrated Water Resources Management (IWRM) systems (Kagalou et al., 2012). Although the DPSIR framework is acknowledged as a valuable resource (Bidone and Lacerda, 2004; Caeiro et al., 2004; Karageorgis et al., 2006, cited in Bradley & Yee, 2015), it has been proposed that its effectiveness could be enhanced by combining it with other methodologies (Pacheco et al., 2006; Maxim et al., 2009;

Bell, 2012). This review primarily focuses on the use of DPSIR for environmental assessment, especially within coastal social-ecological systems (SESs), along with a critique and analysis of the ongoing improvements to the framework.

According to the DPSIR framework, there is a sequence of causal links that begins with "driving forces" (economic sectors, human activities) and progresses through "pressures" (emissions, waste) to "states" (physical, chemical, and biological conditions), leading to their "impacts" on ecosystems, human health, and functions, and ultimately resulting in political "responses" (prioritization, target setting, indicators) (Kristensen, 2004, cited in Bradley & Yee, 2015). Describing this causal chain from driving forces to impacts and responses is a complex endeavor and is often broken down into sub-tasks, such as examining the pressure-state relationship.

Driving Forces

Driving Forces are the factors that motivate human activities and satisfy fundamental human needs, consistently recognized as vital conditions and resources for well-being, health, social relationships, security, and freedom (Maxim et al., 2009; MEA, 2005; EEA, 2005; Narayan, 2000). The spatial distribution and intensity of these Driving Forces can vary, operating at global, regional, or local levels. They reflect "the social, demographic, and economic developments in societies" (Gabrielsen & Bosch, 2003, cited in Bradley & Yee, 2015). Many studies highlight economic sectors as primary drivers, while social factors that shape the structure, characteristics, and functioning of these sectors are less frequently analyzed (Maxim et al., 2009). Social determinants also significantly influence human health (U.S. Department of Health and Human Services, 2008, cited in Bradley & Yee, 2015). Key Driving Forces include population factors (such as size, age structure, and education levels), transportation (for individuals and goods via road, water, air, or off-road), energy consumption (including types of energy used by activity and fuel), power plants (types, age, and fuel sources), industry (types of facilities, age structures, and resources), refineries/mining (types and age of operations), sewage systems (types), non-industrial sectors, and land use (Kristensen, 2004).

Pressures

Pressures are defined as human activities that emerge from the functioning of social and economic Driving Forces, leading to environmental changes (Maxim et al., 2009; EEA, 2005), or as human behaviors that can impact health. It is crucial to distinguish pressures from stressors; stressors refer to the environmental elements altered by these pressures. For example, land development (the pressure) can increase sediment levels (the stressor) in coastal areas, which may negatively affect the ecological components of reefs. Pressures can be categorized into two types: Environmental Pressures and Human Behavior Pressures. Driving forces result in human activities such as transportation or food production to meet various needs. These activities generate "pressures" on the environment due to production or consumption processes. Such pressures can be further classified into excessive use of environmental resources, changes in land use, and emissions (including chemicals, waste, radiation, and noise) into air, water, and soil.

State

The term "state" refers to the condition of both natural and built environments, encompassing the quantity and quality of physical, chemical, and biological components (Gabrielsen & Bosch, 2003), as well as human systems, which include characteristics at both the population and individual levels (Yee et al., 2012). Various chemical, physical, and biological processes interact to influence different components of ecosystems, such as chemical substances and biological species, which can be assessed using specific metrics related to their quantity or quality. All biota include community and population characteristics, while the human condition involves attributes of individuals and sub-populations.

Consequently, the "state" of the environment is shaped by pressures that impact the quality of various environmental compartments, such as air, water, and soil, in relation to their functions. Thus, the "state of the environment" reflects a combination of physical, chemical, and biological conditions. Examples of this state include water quality in rivers, lakes, seas, coastal areas, and groundwater; soil quality in national, local, natural, and agricultural regions; and ecosystems, which encompass biodiversity, vegetation, soil organisms, and aquatic life (Kristensen, 2004, cited in Bradley & Yee, 2015).

Impacts

Changes in ecosystem quality and functioning significantly affect human welfare, including the provision of ecosystem goods and services, which ultimately influence human well-being (Gabrielsen & Bosch, 2003). Ecosystem goods and services can be defined in various ways, including as the processes of ecosystems or the products derived from these processes that provide direct or indirect benefits to humans (Munns et al., 2015, cited in Temiz & Durduran, 2016; MEA, 2005, 2003; Costanza et al., 1997). The Millennium Ecosystem Assessment (2005) categorizes ecosystem goods and services into four types: Provisioning services (the biological, chemical, or physical products obtained from ecosystems for human use), Regulating services (the biophysical processes that help maintain ecosystem regulation), Cultural services (the non-material benefits derived from the ecological integrity of ecosystems, including spiritual enrichment, recreation, and aesthetic experiences), and Supporting processes (the biophysical processes that sustain ecosystem function and are essential for the production of other ecosystem services, even if they do not directly affect humans).

Changes in the physical, chemical, or biological state of the environment affect the quality of ecosystems, which subsequently impacts human welfare. In other words, alterations in the state of ecosystems can result in environmental or economic "impacts" on their functioning, life-support capabilities, and ultimately on human health and the social and economic performance of society (Summers et al., 2012, cited in Bradley & Yee, 2015; Clark & McGillivray, 2007; MEA, 2005; Diener & Seligman, 2004).

Responses

One of the key benefits of the DPSIR framework is its explicit inclusion of an Action or Response component that can be applied at any level within the causal network (Yee et al., 2011, cited in Bradley and Yee, 2015; Waheed et al., 2009). In this framework, responses refer to actions taken by individuals or groups in society and government to prevent, mitigate, adapt to, or compensate for changes in the environmental state. These responses may also seek to alter human behaviors that contribute to health risks, improve health through medical interventions, or address the social and economic impacts of human conditions on well-being (Yee et al., 2012). A societal or policymaker "response" is triggered by an undesirable impact and can influence any segment of the causal chain connecting driving forces to impacts (Kristensen, 2004).

Despite its widespread application, the DPSIR framework has received significant criticism for its failure to account for feedback processes and multiple pressures, for lacking clear connections to human welfare, for not addressing trade-offs between resource use, conservation, and enhancement, and for being more reactive than proactive (Gomez et al., 2016). In response, Elliott et al. (2017) proposed enhancements to the DPSIR framework to include elements that capture the intricate interactions between ecological structure and functioning, physico-chemical processes, and socio-economic systems. Recent advancements in the framework have started to tackle some of these criticisms (Borja et al., 2016; Cooper, 2013), allowing for a more comprehensive application of the concept. Furthermore, the DPSIR framework is a well-established method that is recognized across various disciplines, promoting effective communication among them. It can also be integrated into a broader conceptual framework to capture feedbacks and multiple pressures.

As the DPSIR conceptual framework has developed, various groups have focused on clarifying specific aspects. For instance, Cooper (2013) emphasized that impacts should be viewed as changes in societal welfare, suggesting that the element 'Impact' be replaced with 'Welfare.' The revised framework, DPSWR (Driver-Pressure-State-Welfare-Response), stresses that impacts should be framed in terms of their effects on human welfare. Following this, Borja et al. (2016) highlighted the importance of distinguishing drivers from activities, noting that drivers represent societal demands on nature (such as the need for building aggregates), while activities refer to sectoral actions taken to meet those demands (like dredging for aggregates). Most iterations indicate that human responses can directly influence both drivers (and activities) and pressures. However, Cooper (2013) also acknowledged that responses can directly affect State variables, for example, through restoration efforts.

After examining two decades of insights from the application of the DPSIR framework, Patrício et al. (2016) determined that it serves as a valuable unifying tool for evaluating the relationships between human pressures and coastal and marine ecosystems. In this regard, the DPSIR framework is especially effective in pinpointing key drivers, pressures, and the state of interactions between coastal and human systems. However, despite its long-standing application, the framework has been less frequently utilized in assessing coastal and human interactions (Patrício et al., 2016). This is especially noticeable in Ghana, where the DPSIR framework has rarely been utilized in research concerning human and environmental interactions. Consequently, this study seeks to apply the DPSIR framework to assess the relationship between the environment and human activities, concentrating on beach dynamics and their socio-economic effects on coastal communities. The goal is to analyze how the various components of the DPSIR framework can be utilized in this context and to assess its effectiveness as a tool for managing the coastal zone.

Link between the Theory and the Framework

The Catastrophe Theory and the Driver-Pressure-State-Impact-Response (DPSIR) Framework provide a complementary approach to understanding the changing beach dynamics of the Cape Coast-Elmina coastline in Ghana. The Catastrophe Theory, which explains sudden shifts in systems due to small, gradual changes in external conditions, is highly relevant to coastal morphodynamics, where incremental alterations in wave energy, sediment transport, and human activities can trigger abrupt and often irreversible changes in beach stability. These shifts can manifest rapid coastal erosion, beach accretion, or sudden geomorphic transformations, leading to severe implications for coastal ecosystems, settlements, and infrastructure. However, these abrupt changes do not occur in isolation, but rather are driven by complex socio-environmental interactions, which the DPSIR framework effectively categorizes into drivers (e.g., climate change, urbanization), pressures (e.g., rising sea levels, sand mining), state changes (e.g., beach erosion, shoreline retreat), impacts (e.g., loss of livelihoods, habitat destruction), and responses (e.g., sea defence structures, policy interventions).

By integrating the Catastrophe Theory with the DPSIR framework, the conceptual framework developed for this study provides a holistic perspective on the dynamic interactions shaping the Cape Coast-Elmina coastline. The DPSIR model helps systematically track the environmental and anthropogenic forces influencing coastal change, while the Catastrophe Theory explains the nonlinear thresholds that lead to sudden disruptions in beach equilibrium. This integration is crucial for identifying critical tipping points, predicting potential coastal hazards, and informing sustainable coastal management strategies. The combined framework not only enhances the scientific understanding of coastal transformations but also provides a decision-making tool for policymakers, urban planners, and environmental managers, ensuring proactive and adaptive responses to the escalating challenges of coastal erosion and shoreline instability in Ghana.

Wave Dynamics of the Coast

Wave dynamics is a fundamental driving mechanism influencing coastal geomorphology. Wind moving across the ocean's surface generates waves that significantly shape coastal landforms and drive coastal processes (Davidson-Arnott et al., 2019). The characteristics of waves, including their size and shape, are influenced by wind strength, the distance it travels, and the water depth

Waves can erode the coast in many ways. Firstly, they can crash against the shore, which can wear away the rocks and cliffs. Secondly, they can carry sediment along the shore, which can deposit in other areas (Pilkey, 2011). This process of erosion and deposition can create a variety of coastal landforms, such as beaches, barrier islands, and deltas (Pilkey et al., 2009).

Waves can also deposit sediment in the coastal zone. This sediment can be carried by the waves from the open ocean or from rivers and streams. The deposition of sediment can create a variety of coastal landforms, such as sandbars, spits, and shoals (Harris & Heap, 2003). The study of wave dynamics is important for understanding coastal geomorphology.

By understanding how waves move and behave, we can better understand how they shape the coast. This knowledge can be used to protect coastal communities from erosion and flooding. The following is an explanation of how wave dynamics affect coastal geomorphology and processes:

The wave period is the duration it takes for a wave to complete one full cycle, moving from trough to crest and back to trough. It is expressed in seconds (Brodtorb et al., 2000). The wave period is a critical factor in assessing the effects of waves on the coast. Waves with longer periods carry more energy than those with shorter periods (Mclvor et al., 2012). This is because a longer wave period allows the wave more time to accumulate energy as it moves through the water.

The wave period is also crucial in influencing the types of coastal landforms that develop. Waves with longer periods tend to form expansive sandy beaches, whereas those with shorter periods are more likely to create rocky shores (Ashton & Murray, 2006). The wave period is influenced by water depth and wind speed; deeper water results in longer wave periods, while stronger winds also lead to increased wave periods (Mariotti et al., 2013).

Wave breaking refers to collapse of waves as they reach the shore, which occurs due to the changing water depth as the wave approaches land. The energy of the wave becomes concentrated at the front, leading to its breaking (Mustapa et al., 2017). There are three primary types of wave breaking:

- Plunging breakers: These are the most common type of wave breaking. They occur when the wave steepens as it approaches the shore and then collapses, creating a turbulent splash.
- Surging breakers: These waves do not break completely. They simply rise up and then surge up the shore.
- Spilling breakers: These waves break slowly, with the wave front curling over and spilling onto the shore.

The type of wave breaking that occurs is determined by wave height, wave period, and the slope of the shore. Wave breaking is a crucial process in coastal geomorphology, contributing to the formation of various coastal landforms, including beaches, sandbars, and barrier islands. Additionally, it has a substantial bearing on coastal erosion and flooding (Masselink et al., 2006).

Wave shoaling refers to the increase in wave height as waves move into shallower water. This phenomenon occurs due to a change in wave speed as water depth decreases; as the depth diminishes, the wave speed also decreases. This results in the wave "piling up" at the front, causing a rise in height (Ward & Day, 2008). The extent of wave shoaling is caused by wave height, wave period, and the slope of the seabed. A steeper bottom slope results in greater wave shoaling (Eldrup et al., 2020).

Wave diffraction is the bending of waves around obstacles. This is caused by the fact that waves travel in a series of crests and troughs (Bryan & Power, 2020). As the waves encounter an obstacle, the crests and troughs are bent around the obstacle. The extent of wave diffraction is influenced by the size of the obstacle, the wavelength of the wave, and the depth of the water (Folley, 2017). The larger the obstacle, the more wave diffraction will occur. The shorter the wavelength, the more wave diffraction will occur. The deeper the water, the less wave diffraction will occur (Holthuijsen et al., 2003). Wave diffraction contributes to the creation of various coastal landforms, including headlands, bays, and spits.

Wave refraction is the bending of waves as they move through water of differing depths. This occurs because waves travel more quickly in shallow water compared to deep water (Gamito & Musgrave, 2002). When a wave enters shallow water, the portion nearest to the land moves slower than the part farther from the shore, causing the wave to bend and the crest to curl toward the beach (Short, 2007).

The extent of wave refraction is influenced by the difference in water depth, the wavelength of the wave, and the angle of incidence. A larger difference in water depth results in greater wave refraction, while shorter wavelengths also lead to increased refraction. Additionally, a steeper angle of incidence causes more wave refraction (Haditiar et al., 2018). This process causes the development of various coastal landforms, including headlands, bays, and spits.

Wave energy refers to the amount of energy transported by a wave. It is caused by wave height, wave period, and water density, and is measured in joules per square meter (J/m^2) (Purnata & Riyanto, 2022). Greater wave height, longer wave period, and denser water result in increased wave energy (Amrutha & Sanil Kumar, 2016). Wave energy plays a significant role in coastal geomorphology, acting as the driving force behind various coastal processes, including wave erosion, wave deposition, and wave breaking. Additionally, wave energy can be harnessed for electricity generation (Viles & Spencer, 2014).

Wavelength is the distance separating two consecutive crests of a wave. It is measured in meters. Wavelength is one of the most important parameters of a wave (Mohammed & Fritz. 2012). It determines the speed of the wave, the amount of energy it carries, and the way it interacts with other waves and objects.

The wavelength of a wave is influenced by water depth and wind speed (Babanin, 2009). Generally, deeper water results in longer wavelengths, while stronger winds also lead to increased wavelengths. Wavelength is a crucial concept in coastal geomorphology, as it helps determine the types of coastal landforms that form, the amount of available wave energy, and how waves interact with the coastline (Massalink et al., 2014).

Shoreline

As coastal populations increase and community infrastructures confront challenges from erosion, there is an escalating need for accurate information regarding historical and current trends and rates of shoreline movement. Furthermore, a comprehensive analysis of shoreline dynamics that is uniform across various coastal regions is essential (Hapke et al., 2011). A shoreline is described as the boundary where land meets water, indicating the transition between terrestrial areas and bodies of water such as oceans, lakes, or rivers (Durr et al., 2011).

Shorelines are dynamic features that continually evolve due to various factors, including wave action, tides, currents, and rising sea levels (Passeri et al., 2015). They could be categorized into different types depending on their shape and composition. Common types of shorelines around the world include rocky shorelines, sandy beaches, estuaries, and mudflats.

Rocky shorelines are typically located in regions with high wave energy, such as the California coast (Davis & Walther, 2002). The intense wave action continuously breaks down and reshapes the rocks, resulting in a diverse range of landforms. Common landforms on rocky shorelines include sea stacks, arches, riprap, and groins. These areas also provide habitats for various plants and animals, such as seaweed, lizards, and clams (Bourman et al., 2016).

Sand beaches consist of fine grains of sand that are continually shifted by waves and currents. The sand grains are typically made of quartz, which is a very hard mineral that is resistant to erosion. Sand beaches are often found in areas with lower wave energy, such as along the coast of Florida (Komar, 2007). This is because the lower wave energy allows the sand to accumulate and form beaches. Kindly paraphrase for me and maintain the in-text citations. Some common plants found on sand beaches include Sea Oats, Beach peas, and Sea rockets. Seagulls, Sand crabs, and Mollusks few animals that can be found at Sand beaches (Pilkey et al., 2004).

Estuaries are locations where rivers converge with the ocean, often characterized by a blend of sand, mud, and vegetation. The water in an estuary is brackish, containing a mixture of saltwater and freshwater (Day et al., 2012). Estuaries are significant for several reasons. They provide habitat for a diverse range of plants and animals, including fish, shellfish, and birds. Moreover, estuaries play a vital role in the cycling of nutrients and sediment. They are also vital for human activities, offering spaces for recreation, tourism, and transportation (Thrush et al., 2013). Common plants in estuaries include mangroves, salt marsh grasses, and seagrasses, while shellfish, fish, and various bird species inhabit these areas.

Mudflats are shorelines composed of mud and silt, usually found in regions with minimal wave energy, such as the Louisiana coast (Wells & Roberts, 1980). The mud and silt are carried and deposited by rivers and streams, and they are continually altered by tidal movements. Mudflats offer habitat for various plants and animals, with prevalent vegetation including Spartina, saltwort, and ferns (Sherr, 2015).

Shoreline Change

The term "shoreline changes" refers to changes in the position, form, and arrangement of coasts over time (Baig et al., 2020). Natural processes, human activity, or a combination of both can cause these changes. Scientists, legislators, and coastal communities are all interested in shoreline alterations because they can have a variety of environmental, social, and economic consequences (Sutherland et al., 2009). Changes in the shoreline can have an impact on coastal ecosystems, including plant, animal, and marine life habitats. The loss of coastal habitats can reduce biodiversity, affecting the entire food chain (Gilby et al., 2021). It can directly affect coastal communities by altering land availability, threatening property and infrastructure, and impacting tourism and recreation activities.

Factors Driving Shoreline Change

A combination of natural and man-made forces influences shoreline alteration. The importance of these forces varies based on the individual coastal environment and local conditions. Natural processes such as wave action, tides, currents, and rising sea levels can all lead to changes in shorelines.

The most important agent of shoreline modification is waves. They have the ability to erode the coast, deposit silt, and build a variety of coastal landforms. The wind speed and the distance covered by the waves define the force of the waves (Earlie et al., 2018). The way waves interact with the shore is also affected by the contour of the shoreline. Headlands, for example, are more resistant to erosion than bays. Waves are generated by wind blowing across the ocean's surface. This wind creates friction, causing the water to move (Bilham et al., 2001). The waves that reach the shore are known as swash. Typically, swash waves are small and weak, but they can become very powerful during storms (Yang et al., 2005). The strength of the waves is influenced by wind speed and the distance they have traveled; the farther the waves travel, the more energy they accumulate (Bromirski et al., 2002).

The shape of the coastline influences how waves interact with the shore. For instance, headlands are generally more resistant to erosion compared to bays (Limber et al., 2014). Waves can erode the coast in various ways, such as undercutting cliffs, which may lead to their collapse. They also transport sediment along the coast, contributing to the development of beaches and dunes (Ramalho et al., 2013). Additionally, waves can deposit sediment, resulting in the formation of various coastal landforms, including spits, bars, and tombolos (Balasubramanian, 2011).

Sea level rise refers to the long-term increase in the average level of the oceans, caused by factors such as the melting of glaciers and ice sheets, along with the thermal expansion of seawater (Cazenave & Cozannet, 2014). This phenomenon poses a significant threat to coastal communities around the world, leading to issues such as erosion, flooding, and the loss of vital habitats (Nichols, Zinnert & Young, 2019). The impacts of sea level rise vary by geographic location, with low-lying coastal areas being especially susceptible to intense waves and currents (Frihy & El-Sayed, 2013).

Comprehending the causes and effects of sea level rise is essential for implementing strategies to safeguard coastal communities from its impacts. Approaches to mitigate sea level rise include decreasing greenhouse gas emissions, adapting to increasing sea levels, and conserving coastal ecosystems (Roberts et al., 2017).

Currents refer to the movement of water within the ocean. They play a role in the erosion of coastlines, sediment deposition, and the formation of coastal landforms (Kaliraj et al., 2014). The formation of currents is influenced by factors such as wind, the Earth's rotation, and variations in temperature and salinity within the water (Klemas, 2012). The most prevalent type of current is wind-driven currents, which occur when wind blows across the ocean's surface. This wind creates friction that causes the water to move, with the current's direction determined by the wind's direction (Wu et al., 2018).

Geostrophic currents are generated by the Earth's rotation, which deflects wind-driven currents, causing them to flow parallel to the coastline (Balasubramanian, 2011). Density currents are generated by differences in temperature and salinity in the water; warmer water is less dense than colder water, and saltier water is denser than fresher water. These density variations lead to water moving from areas of higher density to areas of lower density (Talley, 2002). The effects of currents on shoreline changes can be substantial, as they can erode coastlines, deposit silt, and form various coastal landforms.

For instance, longshore currents can transport sediment along the coastline, leading to the formation of beaches and dunes (Da Silva et al., 2012) The rate of change caused by currents varies substantially depending on the strength of the current, the form of the coastline, and the type of sediment present. Shorelines exposed to strong currents, for example, are more likely to erode than shorelines protected from these forces (Da Silva et al., 2012)

Tides are the periodic rise and fall of sea levels, driven by the gravitational forces exerted by the moon and the sun. The moon's gravitational pull is strongest on the side of the Earth that faces it and weakest on the opposite side (Garrett &

Maas, 1993). This difference in gravitational attraction causes a bulge of water on the side facing the moon, leading to a high tide. Conversely, the water on the side away from the moon also bulges, though to a lesser extent, creating a low tide (Masselink et al., 2014).

Tides have a large influence on coastline change. They have the ability to erode the coast, deposit silt, and produce coastal landforms. Tidal forces, for example, can erode cliffs and beaches and deposit silt in estuaries (Dean & Dalrymple, 2004). The rate of shoreline change caused by tides is affected by the intensity of the tides, the configuration of the coastline, and the type of sediment present.

Shorelines subjected to strong tides are more vulnerable to erosion compared to those shielded from such forces. Spring tides, which are the highest tides, happen when the sun and moon align, enhancing their gravitational effects (Wang et al., 2018). Conversely, when the sun and moon are at right angles to one another, their gravitational forces counterbalance, resulting in the lowest tides, known as neap tides. Additionally, the strength of tides is influenced by the morphology of the coastline; tides tend to be stronger along indented shorelines, such as those with bays and estuaries, than along straight shorelines (Bird, 2008). These natural processes can interact to produce intricate patterns of shoreline change. For example, waves may erode the coastline and deposit sediment in a bay. This sediment can subsequently be transported by currents to another part of the coast, where it may either contribute to shoreline erosion or lead to further sediment deposition.

The pace with which the shoreline changes can differ significantly depend on the location and the natural processes involved. For example, shorelines that are exposed to strong waves and currents are more likely to experience erosion than shorelines that are protected from these forces (Labuz, 2015). Shoreline change is a natural process that has been occurring for millions of years. However, human activity is also accelerating shoreline change in some areas. For example, coastal development, dredging, and pollution can increase erosion and disrupt natural processes that help to protect the coast.

Shoreline change can be significantly influenced by coastal development. Building constructions along the coast, such as seawalls or breakwaters, can interrupt natural processes that help protect the coast from erosion and flooding (Rangel-Buitrago et al., 2018). Seawalls, for example, are built to keep waves from reaching the coast. This can help to keep the property safe from flooding, but it can also cause erosion (Alves et al., 2020). Waves that would typically impact the shore are forced to reroute their energy, which can cause erosion of the beach.

Breakwaters are constructed to safeguard property from flooding; however, they can also adversely affect shoreline change. Breakwaters are built offshore to deflect waves, which can help to protect beaches from erosion (Schoonees et al., 2019). However, breakwaters can also trap sediment, which can prevent beaches from naturally replenishing themselves. In addition to seawalls and breakwaters, other forms of coastal development can also contribute to erosion. For example, constructing roads and parking lots can remove vegetation that is vital for stabilizing the coastline. The removal of this vegetation can heighten the coast's susceptibility to erosion (Jackson et al., 2011). Recognizing the potential impacts of coastal development on shoreline change is crucial for implementing strategies to mitigate these effects. Methods such as safeguarding natural features, planning developments carefully, and using alternative materials have been adopted to address the consequences of coastal development on shoreline change (Alves et al., 2020; Spalding, 2014).

Dredging involves the removal of sediment from the seabed or the bottom of a river (Manap & Sandirasegaran, 2016). This sediment is often used to create land or to deepen channels. However, dredging can also have a negative impact on shoreline change. When sediment is stripped from the coast, it can make the shoreline more susceptible to erosion (Hakkou et al., 2018). This is because the sediment helps to protect the coast from the force of the waves. In addition, dredging can also disrupt the natural processes that help to replenish beaches. For example, dredging can remove sediment that would normally be deposited on beaches by waves. This can lead to beaches becoming narrower and less stable (Hanley et al., 2014). Understanding the potential effects of dredging on shoreline change is crucial for implementing measures to mitigate these impacts. Some strategies to reduce the effects of dredging on shoreline change include:

- Reducing the amount of sediment that is removed: The amount of sediment that is removed during dredging can be reduced by using more efficient dredging techniques.

- Re-depositing the sediment: The sediment that is removed during dredging can be re-deposited on the coast to help protect it from erosion.
- Planning for dredging: Dredging should be planned carefully to minimize the impacts on shoreline change. For example, dredging should only be done in areas where it is necessary to protect property from flooding.

Pollution has the potential to have a large impact on shoreline change. Pollutants dumped into the water can harm coastal ecosystems and make them more prone to erosion (Zhou et al., 2022). Oil spills, for example, can destroy marine life and ruin beaches. Sewage can contain harmful bacteria and viruses that can pollute the water and make it unsafe for swimming and recreation (Shuval, 2003). It can also contain nutrients that can promote the growth of algae, which can smother vegetation and make the coast more vulnerable to erosion.

Pollution can also interfere with natural mechanisms that protect the coast from erosion (Wallentnus et al., 2007). Pollution, for example, might suffocate flora that helps to support the coast. The elimination of vegetation may increase the coast's vulnerability to erosion. Recognizing the potential effects of pollution on shoreline change is essential for taking measures to mitigate these impacts. Some approaches to reduce the effects of pollution on shoreline change include:

- Reducing pollution: Pollution can be reduced by reducing the amount of pollutants that are released into the environment. This can be done by using cleaner fuels, recycling, and reducing waste.

- Cleaning up pollution: Pollution that has already been released into the environment can be cleaned up. This can be done by using methods such as oil spill cleanups and sewage treatment.
- Protecting coastal ecosystems: Coastal ecosystems can be protected by creating marine protected areas and by reducing the amount of development in coastal areas.

Chapter Summary

This section reviews the literature on coastal zone studies, defining them as dynamic environments influenced by natural and human factors. It highlights their importance to societal needs and vulnerability to population growth and development pressures. The chapter presents theoretical frameworks such as Catastrophe Theory and the Driver-Pressure-State-Impact-Response Framework. It examines coastal processes, including erosion, sediment transport, and deposition, highlighting the importance of remote sensing and GIS technologies in monitoring and analyzing these processes.

CHAPTER THREE

EMPIRICAL REVIEW

Introduction

This chapter reviews previous studies on beach dynamics and its effects on socio-economic activities. This review is structured around themes developed in alignment with the research questions that guide this study. These themes are spatio-temporal analysis of shoreline changes, the relation between Land cover changes and changes in beaches, granulometric characteristics of beaches, anthropogenic driving forces influencing changes in beaches, Linkages between changes in beaches and human activities and national policies on coastal management in Ghana.

Spatio-Temporal Analysis of Shoreline Changes

Changes in shorelines over time are a major concern for coastal stakeholders, especially since a significant portion of the global population lives and works in coastal regions (Boye et al., 2018). These changes bring about consequences that affect the lives of people in these regions. Consequently, many researchers have committed to analyzing the spatiotemporal changes in shorelines using various methodologies.

Eludoyin, Oduore, and Obafemi (2012) conducted a study on Bonny Island in Rivers State, Nigeria, to investigate shoreline changes over time. They utilized Landsat Thematic Mapper (TM) imagery with a spatial resolution of 30m by 30m for the years 1986, 2001, 2003, and 2006, along with Niger sat imagery of the same resolution for 2004. Their findings indicated both short-term and long-term changes in the shoreline, highlighting a sustained and largely irreversible recession, with little accretion noted in most areas of the study site (Eludoyin, Oduore, & Obafemi, 2012).

Additionally, Emran et al. (2016) analyzed shoreline and land area changes on Sandwip Island in Bangladesh using multi-temporal satellite imagery. Their study found that roughly 64 km^2 of the island's original land area was lost from 1980 to 2014, primarily in the western, southwestern, and southern regions. These areas showed more significant landward movement and higher rates of shoreline change, with maximum net shoreline movement reaching about 3.8 km and endpoint rates exceeding 100 m per year in certain locations. In contrast, accretion occurred along the northern and northeastern shores of the island at comparatively slower rates, with net shoreline movement of approximately 2.8 km and endpoint rates of around 100 m per year.

Over the past 20 years, the Kuwaru coastal area has been subjected to continuous threats from both physical and non-physical processes. Research by Mutaqin (2017) highlighted that this coastal region predominantly comprises loose sediment materials that are easily eroded and redeposited in response to disturbances, with shoreline change being a significant threat. The analysis of shoreline change utilized the End Point Rate (EPR) technique, revealing that the Kuwaru coastal area has experienced considerable changes since 1995. Specifically, from 1995 to 2015, the shoreline shifted landward by more than 50 meters. Extreme weather conditions during the East Monsoon contribute to destructive waves, with sea waves reaching heights of up to 5 meters affecting the southern part of the region from the southeast.

Sui et al. (2020) aimed to examine the spatiotemporal characteristics of coastline changes in Indonesia from 1990 to 2018, highlighting that coastlines are affected not only by natural processes such as erosion, siltation, and disasters but also by significant pressures from human activities, including urban expansion, resource development, and pollution. The researchers utilized Landsat images from 1990 to 2018 and employed the Index of Coastline Utilization Degree (ICUD) along with various methods to evaluate changes in land and sea patterns across different scales. Their findings revealed that Indonesia's total coastline length increased by 777.40 km over the past 28 years, with a reduction of 5995.52 km in natural coastlines and an increase of 6771.92 km in artificial coastlines. Furthermore, the study observed that the trend for the Indonesian coastline primarily involved expansion into the sea.

Alemayehu et al. (2014) conducted a study on the Watamu coastline, highlighting that the shoreline has been undergoing changes in recent years due to erosion and other natural factors. The research aimed to identify trends in shoreline changes and their contributing factors. To perform the analysis, the researchers utilized aerial photographs from 1969 and 1989, along with a recent satellite image from 2010, to digitize the shoreline. The 9.8 km segment of the Watamu shoreline was divided into 245 transects spaced 40 meters apart to calculate change rates. The rates of shoreline change were assessed using the End Point Rate (EPR), Net Shoreline Movement (NSM), and Weighted Linear

Regression (WLR) methods within the Digital Shoreline Analysis System (DSAS). The results from these three analyses indicated that the Watamu beach shoreline has retreated over the past 41 years. While the findings aligned with the EPR shoreline change analysis, some areas identified by EPR exhibited signs of accretion.

Additionally, research by Appeaning Addo (2015) focused on the trends in shoreline evolution of the Volta Delta in Ghana. The study divided the shoreline into four sections based on orientation and human interventions. Data for the analysis included satellite imagery from the years 1986, 1991, 2001, 2004, and 2013. The trends were statistically analyzed using AMBUR software. The findings revealed that over the 27-year period studied, the shoreline is accreting at an average rate of approximately 0.53 m per year. This result is noteworthy, as previous studies had reported erosion rates of about 8 m per year in the area.

The city of Lagos, Nigeria, has experienced a rapid population increase driven by economic and commercial activities, leading to ongoing changes in land use and land cover (LULC) over the years (Akinluyi et al., 2018). Akinluyi et al. (2018) employed the Digital Shoreline Analysis System (DSAS) within the ArcGIS environment to establish transects and calculate statistical parameters for the shoreline. They utilized Landsat TM, ETM, and OLI imagery from the years 1984, 1990, 2000, 2004, and 2016. Their findings indicated a mean shoreline decrease of -0.59 m per year, with 73.1% of transects experiencing erosion and 61.8% showing accretion. Furthermore, the endpoint rate (EPR) and net shoreline movement (NSM) analyses revealed an average shoreline change of -0.57 m per year and -18.1 m over the period from 1984 to 2016, respectively. The study also noted that the significant accretion rates observed along most sections of the shoreline can be attributed to beach nourishment activities.

Ekong (2017) aimed to detect shoreline and land-use changes to assess the trends and nature of changes in Ibeno, Akwa Ibom State, Nigeria. Using Landsat and Ikonos imagery along with GIS techniques, the study analyzed changes over a span of 22 years (1986 to 2008) across three time periods. The results revealed that the total length of the extracted shoreline from the 1986 Landsat image was 46.162 km, while the lengths for 2006 and 2008 were 45.811 km and 45.942 km, respectively. These varying lengths indicate that shoreline changes have occurred. Overall, using the endpoint rate, Ekong (2017) found that from 1986 to 2006, the net erosion change of the shoreline was -31,432.78 m, whereas from 2006 to 2008, there was a net accretion change of 360.18 m. The rate of shoreline change was evaluated using 449 transects spaced 100 meters apart across the entire study area. The average erosion rate for the study period was -3.9 m per year, while the average accretion rate was 2 m per year.

Research by Jonah et al. (2016) examined the changes in the Elmina, Cape Coast, and Moree coastlines in Ghana over a period of 38 years. The study utilized available datasets to analyze developments from 1974 to 2005, as well as from 2005 to 2012. By integrating shoreline data from 1974, 2005, and 2012 into a Geographic Information System (GIS) using ArcGIS software, the researchers generated statistics for net shoreline movement and endpoint rates with the Digital Shoreline Analysis System extension. The findings indicated a consistent trend of erosion across all three time periods. This research provides significant foundational data on the conditions of the Elmina, Cape Coast, and Moree coastlines, making it a valuable resource for coastal engineers, managers, and policymakers in Ghana who aim to mitigate risks and manage the coastline effectively. Coastal erosion is a major threat to coastlines worldwide. Many developed nations have implemented long-term strategies to manage and reduce the speed of this phenomenon. However, in most developing countries, including Ghana, coastal erosion management receives inadequate attention. Consequently, there is limited commitment to effectively monitor and address this issue, leaving many coastal communities and important historical sites in Ghana at significant risk from the destructive forces of sea erosion.

The transformation of shorelines and the occurrence of coastal erosion, driven by natural processes such as rising sea levels and harmful human activities, continue to pose significant challenges in coastal regions worldwide. This issue is particularly pressing in developing countries with limited adaptive capabilities, leading to increased vulnerability of many coastal socio-ecological systems, as noted by Ankrah, Monteiro, and Madureira (2023). To explore advancements in research and policy recommendations regarding shoreline change and coastal erosion in West Africa, the study employed a systematic approach. A total of 113 documents were collected from the Scopus and Web of Science databases, and after applying specific criteria, 43 documents were selected for analysis. The findings indicated substantial progress in research on shoreline change and coastal erosion since 1998, with most studies originating from Ghana. Natural factors such as rising sea levels were identified as the main causes of shoreline change and erosion in West Africa. However, human activities, including sand mining, dam construction, and land encroachment, were also found to contribute to these problems in the region. Since 2004, there has been an increasing reliance on remote sensing and Geographic Information System (GIS) techniques for data collection and analysis related to shoreline change and erosion. Nevertheless, combining remote sensing with field observations is essential for accurately assessing the extent of erosion issues and informing policymaking.

Relation Between Land Cover Changes and Changes in Beaches

Kaliraj, Chandrasekar, Ramachandran, Srinivas, and Saravanan (2017) conducted a study to assess changes in land use and land cover (LULC) over a decade, utilizing Landsat ETM+ and TM images along with the Maximum Likelihood Classifier (MLC) algorithm. The research focused on the Level II category of the USGS-LULC Classification System, aiming to analyze transformations in various LULC categories between 2000 and 2011. The classified land use and land cover (LULC) features included beach face land cover, cultivable lands, plantation and shrub vegetation, fallow land, barren land, settlements and built-up areas, water bodies, and mining zones. A geodatabase was established for each LULC feature, encompassing attributes such as name, location, area, and spatial distribution. The analysis revealed that a significant portion of sandy beaches, foredunes, uplands, Teri dunes, and other nearby landforms, along with plantations, cultivable lands, fallows, and barren areas, had been converted into built-up regions, showing an increase of more than twofold over the 10-year period.

Using GIS techniques, the change detection matrix indicated that a total area of 45.90 km^2 across various land use and land cover (LULC) features underwent periodic shifts or transformations. This included an encroachment of 1.24 km^2 of beach face land cover for built-up areas and 0.63 km^2 for placer mining. Additionally, 0.21 km^2 of this land cover was converted into wetlands and saltwater bodies. The expansion of built-up areas and settlements over the past decade was directly linked to population growth, which poses a considerable threat to coastal resources. The accuracy assessment of the classified images revealed an overall accuracy of 81.16% for 2000 and 77.52% for 2011, with Kappa coefficient values of 0.83 and 0.76, respectively. Ground truth verification using 120 samples (10 samples per class) showed an accuracy of 89% for the classified features, confirming the reliability of the LULC classification for studies on land use and land cover change. The geodatabase of LULC features serves as a valuable resource for sustainable land management in the coastal region.

Boampong (2020) conducted a study in Greater Accra, Ghana, focusing on changes in land use, land cover, and shorelines using basic GIS techniques. The research identified that erosion rates were significantly higher in the eastern part of the region, particularly around the Volta estuary, compared to the western side in Accra. Analysis of land cover changes showed a marked decline in vegetation in Greater Accra, especially near the coast, between 1996 and 2017. However, there was a notable increase in mangrove areas within the Densu Delta and Ada in the Volta River estuary. Urbanization and land use changes were primarily concentrated along the coast from 1996 to 2002 but gradually extended into the peri-urban areas of Greater Accra from 2002 to 2017. The study employed Google Earth and Landsat satellite images, which were effective in assessing shoreline and land use changes in the region. This availability of satellite imagery can help overcome data limitations in areas like Greater Accra that lack comprehensive information. The findings of this study provide valuable insights for decision-making related to Integrated Coastal Zone Management (ICZM) in the region.

Nath et al. (2023) conducted a study to identify and analyze periodic changes in land use and land cover (LULC) using the USGS LULC classification method and satellite images from 1975 to 2018. The research area was divided into three littoral zones (LZs) to examine LULC transformations over time and evaluate the impact of human activities on coastal environments. The focus was on five specific LULC features: built-up areas, vegetation, soil, sand, and shallow-water regions. The main goal was to investigate human encroachment in near-shore areas and the conversion of soil and sand into built-up regions over the 43-year period using geospatial techniques. Geodatabases were developed for each LULC feature to assess changes in their respective areas. Statistical analyses of the datasets were performed to identify trends in land cover changes within each category, highlighting increasing rates of deforestation and urbanization driven by population growth (Nath et al., 2023).

The results indicated an increase in shallow-water areas, which significantly contributed to coastal erosion. In LZ I, the shallow-water area grew from 1 km^2 to 4.55 km^2, while in LZ II, it expanded from 1.7 km^2 to 13.56 km^2, leading to a total increase of 11.86 km^2 in shallow-water zones. The study also noted a positive change in vegetation, which rose from 2.82% (4.13 km^2) to 15.46% (22.07 km^2). An accuracy assessment of all classified images showed an overall accuracy rate exceeding 85%. Additional accuracy analysis using Kappa coefficient statistics revealed that all classified images attained an accuracy of 80% or higher. This information can help policymakers understand the potential environmental impacts linked to activities such as coastal development and agricultural expansion. By implementing suitable measures, these impacts can be addressed before they escalate.

Granulometric Characteristics of Beaches

Research conducted by Akpofure, Edirin, Akana, and Tombra (2019) on grain size analysis and sedimentology of beach sediments in Lagos, southwestern Nigeria, identified a predominance of medium-grained sediments and a scarcity of coarse sands, indicating conditions of moderate to high energy deposition. The graphic standard deviation in their analysis ranged from 0.01φ to 0.81φ, demonstrating a sorting range from very well sorted to moderately well sorted, with an average of 0.52φ, which is considered moderately well sorted. This variation indicates that some sediments were sorted in a high-energy environment. Linear discriminant functions analysis highlighted a shallow marine beach environment characterized by turbulent waters, with contributions from aeolian sources.

Research by Abdulkarim et al. (2014) analyzed beach sediments from four selected locations—Badagry, Takwa, Alpha, and Eleko beaches in Lagos, Nigeria—to determine the statistical parameters of their grain size distribution. The findings revealed that Badagry and Alpha beaches had medium-grained sands, with average mean values of 1.10 φ and 1.14 φ, respectively. In contrast, Eleko beach sediments were coarsely grained, with an average mean value of 0.56 φ, while Takwa Bay beach sediments were fine-grained and very well sorted, averaging 2.25 φ. This suggests that the coarse-grained sediments at Eleko beach are deposited under high-energy conditions, making them less vulnerable to erosion compared to the fine-grained sediments at Takwa Bay, which are deposited in low-energy conditions and are therefore more susceptible to erosion. The grain size and quantity of sand on a beach are influenced by wave energy and the geological sensitivity of the sediments to erosive forces (Abdulkarim et al., 2014).

Further research by Ayodele and Madukwe (2019) conducted a grain size analysis on sixty-four samples of surficial sediments collected from the dunes, backshore, and beach face of Bonny beach to assess grain size distribution and statistical parameters. Their analysis revealed that 72.7% of the beach face samples were unimodal, 18.2% were bimodal, and 9.1% were trimodal; in contrast, the dunes and backshore samples showed 54.5% unimodal, 36.4% bimodal, and 9.1% trimodal distributions. The mean grain sizes for the dunes, backshore, and beach face were 2.0 φ (fine sand), 1.92 φ (medium sand), and 1.82 φ (medium sand), respectively, indicating that grains were slightly coarser at the beach face and finer towards the dunes. Notably, the beach face in their study area experienced slightly more erosion. The study also emphasized a dominance of medium sand, with subordinate coarse and fine sands at Bonny beach. The sedimentary structures observed suggested conditions ranging from low to high-energy environments.

Abuodha (2003) investigated the grain size distribution and heavy mineral content of beach and dune sediments along the Malindi Bay coast in Kenya using dry sieving techniques. The study found a significant correlation between heavy mineral concentrations and the geomorphological features present. Variations were observed among different geomorphological units, showing a gradual trend from the beach to the dunes. Additionally, Abuodha (2003) noted a slight decrease in grain size from the beach to the foredune. The sediment size fraction of 0.625 mm was found on the beach but was absent in the adjacent aeolian environments, except along the steep slopes of sand sheets and in interdune valleys. The berm zone seldom contained sediments larger than 1.125 mm. Furthermore, the grain size parameters at various beach locations did not display a consistent longshore variation, except near the river mouth. During the northeast monsoon, the mean grain size was coarser, sorting was less effective, and the distribution exhibited a more positive skew.

Research by Mohanty et al., (2012), on beach morphology and sedimentological characteristics at three different physical settings; Gopalpur tourist beach, Gopalpur Port, and Rushikulya olive ridley turtle nesting beach, of south Orissa coast, indicated that the environment is depositional (erosional) to the south (north) of the port round the year. The deposition was marked by a decrease in grain size while erosion was also marked by an increase in grain size in their study. Mohanty et al., (2012), further indicated that the Gopalpur tourist beach has a medium grain size and experiences severe erosion during monsoon (JJAS) and recovers during winter (DJF) and pre-monsoon (MAM). The mean grain size is mostly medium to coarse in the backshore while medium to fine in the mid-shore and foreshore. During the mass nesting period (January to March), the mean grain size of the beach is predominantly fine to medium (Mohanty et al., 2012).

Yang and Shi (2019) emphasized that understanding the composition and sources of deposited sediments in watersheds is essential for investigating sediment erosion and deposition processes, as well as for managing soil loss in rivers. Their study examined the grain-size composition parameters in the Ten Kongduis, which are large arroyos transporting significant amounts of coarse sediment into the upper Yellow River. They identified two types of deposits in the drilling cores from alluvial fans and sediment profiles: those formed by hyper-concentrated flows and those resulting from non-hyper-concentrated or ordinary sediment-laden flows. Hyper-concentrated flow deposits were observed only in specific natural sediment profiles exposed on riverbank slopes. The study found that 69% or more of the sediment carried by hyper-concentrated flows primarily originates from the clasolite and loess strata in the upper reaches, with 8%–31%

sourced from desert areas in the middle reaches (Yang & Shi, 2019). In contrast, sediments transported by non-hyper-concentrated flows to the alluvial fans consist of different proportions of clasolite, loess, and dune sand, with the contributions of clasolite and dune sand roughly corresponding to the ratio of the upper drainage area to the width of the desert in the middle reaches of the kongduis.

According to Ojha et al. (2020), the volume of water flow in the Kulfo River and rainfall are key factors influencing sediment transportation in the study area. Various fluvial processes, including meandering, braided, and straight channels, along with sedimentary structures such as mud cracks, ripple marks, point bars, and bar deposits, were observed. The study indicated a general trend of decreasing energy conditions from upstream to downstream, as reflected in the grain size distribution patterns. Textural analyses showed that the sediments upstream were unimodal and moderately well sorted fine sands, indicating a single source of sediment supply in the Kulfo River. However, as one moves downstream, the textural properties of the sediments transition to bimodal to polymodal and poorly to moderately sorted medium to fine sands, suggesting multiple sources of sediment supply.

Anthropogenic Driving Forces Influencing Changes in Beaches

The consistent changes in the coastline have been attributed not only to natural factors but to human activities or anthropogenic factors as well. These anthropogenic forces influencing changes in the beaches have been extensively discussed in the literature the world over and specifically in Ghana. There are some common anthropogenic factors that have been identified, by scholars, as key driving forces in causing changes in the beaches. According to Appeaning Addo (2011), human activities, including dam construction along the Densu River, engineering efforts to control erosion, and sand mining, have led to sediment deficits that worsen coastal erosion in Accra. It is estimated that anthropogenic factors contribute to 70-90% of the coastal erosion issues in the area. The following review focuses on these key factors, with particular emphasis on the literature related to Ghana.

Foti, Barbaro, Barillà, Mancuso, and Puntorieri (2022) conducted a study to investigate the connection between shoreline erosion and human activities in Calabria. The researchers utilized historical and current cartographic Open Data, including shapefiles, maps, and satellite imagery, which were analyzed using QGIS software. Their analysis indicated a significant correlation between anthropogenic pressures, particularly the expansion of developed areas and human-made structures near the shoreline—and the incidence of shoreline erosion. This study is crucial for coastal planning and management, offering valuable insights. Moreover, the methodology employed is easily applicable and replicable, as it relies on readily accessible Open Data and free software.

Urbanization

Coastal areas are undergoing rapid urban and industrial expansion, alongside developments in oil and gas, large-scale fisheries, and tourism. A significant trend of population growth is evident in these regions, with coastal cities serving as key hubs for this growth (Olympio & Amos-Abanyie, 2013). Creel (2003) noted that urbanization significantly impacts coastal ecosystems. In

Ghana, urban areas have expanded due to improvements in infrastructure and social amenities, with many of these developments occurring along the coast. Notable facilities constructed in these coastal regions include ports, recreational areas, and tourism-related infrastructure.

Recreational and tourism activities along the coast are essential due to their socioeconomic importance. However, Boampong (2020) notes that these activities can lead to changes along the coastline. Such changes may either degrade coastal ecosystems or result in the development of more resilient systems. Boampong (2020) emphasizes that the economic benefits derived from coastal areas, such as industrialization and urban settlements, are often prioritized over their ecological value. This emphasis results in the transformation of natural landscapes and vegetation, which help protect the coastline, into developed areas.

A prevalent example of built structures in many coastal areas is the construction of ports. The establishment and expansion of ports are economically significant for coastal nations, as increased ship traffic and industrial growth in these areas enhance access to raw materials and create job opportunities. However, researchers have identified several challenges associated with port construction. Kudale (2010) and Boampong (2020) pointed out that the vertical and perpendicular expansion of coastal structures can have serious repercussions. They argued that port development disrupts natural littoral drift processes, resulting in undesirable erosion and accretion along the coastline.

In the study area, Dei (1972) identified urbanization as a contributing factor to beach erosion. According to Dei (as cited in Jonah et al., 2016), his research concluded that the coastlines of Elmina, Cape Coast, and Moree have been experiencing erosion since the early 1970s, coinciding with the onset of rapid urbanization along the coast.

Hard engineering and its effect on the beach

Humans have attempted to adopt measures to combat coastal erosion which includes hard engineering. Gracia, Rangel-Buitrago, Oakley, & Williams (2018) refers to these engineering structures as hard stabilization structures. The literature indicates that such measure despite its positives is also a contributing factor to the changes along the beaches (Addo, 2018; Appeaning-Addo, 2013; Gracia et al., 2018). According to Appeaning-Addo (2011), the construction of jetties and groynes has resulted in coastal erosion on adjacent shores by disrupting sediment transport in the littoral zone. In a prior study, Dickson (1965) (cited in Addo, 2009) found that jetties built in 1906 to protect and stabilize navigation channels at the old Accra harbor trap sediment on the up-drift side, while the down-drift side is deprived of sediment. This has led to alterations in the shoreline, with the up-drift side developing a sandy beach and the down-drift side experiencing significant erosion. The accumulation of sand on the up-drift side of the jetties has attracted sand mining activities, further exacerbating the erosion caused by waves and currents, thereby degrading the coastal environment and damaging coastal infrastructure.

Similarly, Appeaning-Addo (2009) found that engineering interventions, such as the construction of groynes in Keta, can worsen coastal erosion by shifting the problem to adjacent coastlines. In the case of the Keta Sea defense project, erosion issues have resurfaced between Horvi and Brekusu (NADMO, 2007; Oteng-Ababio, 2010).

Coastal engineering structures built in the Accra coastal zone are designed as management strategies to stabilize or reclaim eroded beaches, protect navigation channels, and shield coastal properties from wave damage and flooding. These structures interact with active waves and currents, influencing sediment transport processes in their surrounding areas (Addo, 2009). Mitigation measures, such as revetment, can result in negative environmental impacts that undermine the natural character of coastal areas. While these "hard" engineering solutions may effectively manage shoreline retreat and protect beachfronts, they also induce changes in the geomorphic features of adjacent shorelines. Such interventions can create new challenges for neighboring regions and, in some instances, may exacerbate existing problems (Wellens-Mensah et al., 2002).

Sand mining

Sand mining is widely acknowledged in the literature as a significant anthropogenic factor affecting beaches. Jonah, Adjei-Boateng, Agbo, Mensah, and Edziyie (2015) conducted an observational study to assess the impacts of sand mining on coastal erosion along the Cape Coast coastline. They discovered that sand mining activities were taking place on nearly all sandy beaches in the region. Through a detailed analysis of the volume of sand extracted from six major mining sites and an evaluation of shoreline changes, they established a link between sand mining activities and the rate of local coastal erosion. They cautioned that if sand mining continues at its current pace, the Cape Coast area may ultimately lose most of its recreational beaches, jeopardizing the beach tourism industry and increasing the vulnerability of coastal communities to flooding.

Similarly, Armah and Amlalo (1998) observed that, despite a ban on sand mining along Ghana’s beaches, the activity continues as a source of sand for construction. Mensah (1997) noted that its contribution to the construction industry's output increased from 17% in 1986 to 21% in 1993. Ibe and Quelennac (1989) attributed the prevalence of sand mining to the abundant resources, low extraction costs, and high demand for sand in the construction sector (Osterkamp & Morton, 2005).

Addo (2011) contended that unchecked sand mining activities along the Accra coast have resulted in significant shoreline erosion. He pointed out that beach sand from the eastern and central parts of Accra has been used for constructing Tema Township since the 1950s, as well as for other important structures like the State House. This sand extraction has decreased the sediment budget available for littoral transport and reduced the beach volume, allowing waves to directly impact the cliff face. Addo concluded that this may be a key factor behind the severe erosion observed in these coastal areas.

A study by Anim, Nkrumah, and David (2013) emphasized the significant impact of sand mining on beach erosion. They argued that sand serves as a protective barrier between the sea and the land, and uncontrolled sand mining results in various coastal environmental issues. Specifically, they highlighted that sand mining is highly detrimental to beach fauna and flora, negatively impacts beach aesthetics, and often harms other coastal ecosystems, such as wetlands. The sand mining process has accelerated coastal environmental degradation at an alarming rate, with the extent of this damage evident in many locations.

In an earlier study, Mensah (1997) conducted a thorough investigation into the causes and effects of sand mining in Ghana. Using participant observation, interviews, and focus group discussions in three coastal communities, Mensah identified the destruction of beaches as one of the most significant impacts of sand mining. He observed that beaches that were once "sandy with occasional rocks" have been transformed into degraded areas, now located about 2.5 meters below an "artificial" cliff (Mensah, 1997, p. 12).

Jonah and Adu-Boahen (2014) also observed that beach sand mining is common along the Elmina-Cape Coast-Moree coastline, taking various forms. The volume of sand extracted from the beach varies based on the mode of transportation and the intended use of the sand. Jonah, Adams, Aheto, Jonah, and Mensah (2017) noted that despite the illegality of sand mining (Ministry of Environment Science and Technology, 2014), the widespread nature of the activity and the lack of effective environmental regulations enforced by relevant authorities have created a perception among coastal communities that such practices are acceptable. This has led to a belief that the coast has an unlimited supply of natural resources, including sand and stone.

According to Appeaning Addo et al. (2008), coastal erosion in Faana is primarily caused by the dam constructed over the Densu River and the Kokrobite irrigation scheme. Additionally, the shoreline's unique orientation (approximately east-west) causes incident waves to break at an angle, generating longshore currents that facilitate littoral drift, while rising sea levels impact the effectiveness of tidal currents. Moreover, human activities such as sand mining have reduced sediment supply to the littoral zone, resulting in an imbalance in the sediment budget. Similarly, Sanjaume and Pardo-Pascual (2005) pointed out that the littoral dune system is essential for maintaining the sedimentary equilibrium of beaches; the removal of dunes can disrupt this balance and lead to increased beach erosion.

Effect of Changes in Beaches on Human Activities

The coastal area is vital for residents, recreation, tourism, fisheries, and agriculture, serving as a key source of socioeconomic development for local communities. Changes to the beaches have significant implications for the socioeconomic conditions of those living in coastal regions (MOSTI, 2000). While these communities traditionally relied on natural sources of income such as marine productivity and agriculture, they may now need to seek alternative income sources. Boateng (2012) contended that coastal erosion represents a significant threat to both human life and economic development in the country. He emphasized that "over 60% of major industries, urban settlements, tourism, heritage, and conservation sites are located in the coastal zone" (Boateng, 2012, p. 384).

Coastal erosion affects the social and economic well-being of local communities, threatens cultural heritage, and hinders the development of coastal tourism. In the western part of the Accra coast, 17 coastal residents have lost their homes to erosion over the past 26 years (Campbell, 2006). Additionally, coastal retreat has reduced natural fish landing sites and degraded the coastal environment (Oteng-Ababio, Owusu & Addo, 2011).

In their study on the effects of shoreline changes on the Nkontompo community, Olympio and Amos-Abanyie (2013) found that there have been instances of displacement within the community, with residents moving to other parts rather than leaving the area entirely. In one incident, around 368 people were left homeless due to tidal waves that swept away their houses, shops, and other social infrastructure (Ghanaian Times, 2003). The authors estimated that around 1,168 individuals have been displaced over the past 26 years due to the retreating shoreline at Nkontompo, resulting in the loss of numerous buildings, roads, service facilities, and land to the sea. Other regions along Ghana's coastal belt may face similar issues in the future (Olympio & Amos-Abanyie, 2013). Their findings indicated that erosion caused the collapse of a Community Centre, the Chief's palace, and other facilities, exposing their foundations. Additionally, a major street traversing the town was washed away, along with utility lines such as electricity poles and standpipes.

Oteng-Ababio, Owusu, and Addo (2011) argued that constructing a sea defense wall to address coastal erosion conflicts with the fishing profession, potentially restricting the community's fishing activities, which are their primary source of livelihood. Moreover, since most Ghanaian fishers participate in small-scale artisanal fisheries using wooden canoes launched from the beach, the exposure of beach rocks due to sand mining directly threatens the sustainability of the local fishing industry, which is the primary livelihood for coastal residents (Kruijssen & Asare, 2013, as cited in Jonah et al., 2017).

National Policies on Coastal Zone Management in Ghana

Various scholars, including Jonah et al. (2015), have examined national policies and interventions for managing coastal erosion in Ghana. They argue that unless the underlying causes of erosion are addressed, the government's investment in expensive engineering-based sea defense projects to protect communities will be ineffective and wasteful.

Boateng (2012) found that the coastal management strategies implemented in Ghana to address coastal erosion have, in fact, become significant contributors to the problem. He argued that while focusing on hard protection measures at specific high-risk locations may stabilize the shoreline in those areas, it worsens erosion elsewhere along the coast. This view is supported by Appeaning Addo, who noted that Ghana lacks a comprehensive coastal zone policy, leading to the overexploitation of coastal resources (Aryee, 2014). Similarly, Jonah et al. (2016) concluded that Ghana still lacks a holistic policy or integrated plan for managing coastal erosion.

The persistent emphasis on ad hoc measures in coastal management has resulted in minimal commitment to integrated management strategies. Dadson, Owusu, and Adams (2016) concluded that erosion and accretion are active forces driving changes along the shoreline from Cape Coast to Sekondi. They recommended that policies and interventions at both the national and local levels to address shoreline challenges should significantly involve the communities living along the coast.

Jonah, Mensah, Edziyie, Agbo, and Adjei-Boateng (2016) found that the 2014 National Environmental Policy lacks specific action plans and only acknowledges the necessity of managing the marine and coastal zone. As a result, management practices have remained traditional, reactive, and site-specific, primarily relying on hard engineering approaches, which come with their own unique challenges for the coastal environment.

Ghana lacks a specific policy for integrated coastal zone management; however, several related policies aim to protect the coastal zone. These include the National Wetlands Policy, Tourism Development Policy, National Environment Policy, Mineral Policy, and Wildlife Conservation Policy. The issue of inadequate integrated coastal management strategies is not confined to Ghana alone. Beach erosion is also a significant concern for authorities in Seychelles and Mauritius, where there is a lack of well-documented analyses and the technical and financial resources necessary to develop effective strategies, impacting tourism operators as well. The absence of consistent policies often results in the reliance on hard engineering structures without considering coastal dynamics or socioeconomic factors (Duvat, 2009).

Jonah et al. (2017) found that although sand and gravel mining is governed by the Minerals and Mining Act 2006, Act 703, illegal beach sand and gravel mining continues to occur frequently. This ongoing activity is largely attributed to lax enforcement of regulations and a general lack of clarity in the environmental management of beaches.

While earlier studies focused on the policies and strategies enacted by government agencies to tackle coastal erosion, Jonah et al. (2017) shifted their attention to analyzing management practices aimed at combating sand mining at the district and local levels. Their research found that in Biriwa, located in the Mfantseman District, and Moree in the Abura Asebu Kwamankese District, local chiefs had imposed a ban on the commercial extraction of beach sand. Local residents reported that these decisions by traditional leaders were influenced by complaints from other coastal users, such as fishermen and tourism operators, concerning the potential impacts of sediment mining activities. Conversely, in areas like Elmina within the Komenda Edina Eguafo Abirem Municipality, local traditional leaders appeared to endorse commercial beach sand mining along the coastline.

Participants in the study indicated that state authorities have not made adequate efforts to halt sediment mining activities along the coast. Hotel operators, specifically, raised concerns regarding the limited engagement from the Ghana Police Service, Local Assembly Authorities, and the Environmental Protection Agency in tackling these issues. Although multiple police checkpoints are situated along the main roads in the region, it was implied that commercial sediment miners are able to move their products without being apprehended.

Chapter Summary

This chapter presented a thorough examination of the literature related to shoreline changes and their driving forces. It reviewed previous studies on the spatio-temporal analysis of shoreline changes, emphasizing the use of remote sensing and GIS technologies to track and understand these changes over time. The chapter also detailed the granulometric characteristics of beach sediments, which are crucial for understanding sediment transport and deposition processes. Furthermore, it explored the anthropogenic driving forces affecting coastal areas, such as urban development, tourism, port construction, and sand mining, and assessed national policies on coastal zone management. The empirical findings underscored the significant impact of human activities on coastal dynamics and highlighted the necessity for improved management strategies to mitigate these impacts and support sustainable development.

CHAPTER FOUR

RESEARCH METHODOLOGY

Introduction

This chapter describes the study's methodology and research design. The study area, research design, target population, data sources, research philosophy, and sampling techniques are all covered in detail. The chapter also goes into detail on data collection tools, data collection procedures, data analysis, and ethical issues. A synopsis of the debate on the employed techniques comes at the end. Please paraphrase this for me while keeping the in-text citations intact.

Study Area

The study area includes Cape Coast Metropolis and Komenda Edina Eguafo Abirem Municipality, two nearby districts. The study's main focus is the Cape Coast-Elmina coastline, which stretches 16 point two kilometers from Cape Coast Castle to Coconut Grove Beach Resort, via Elmina Beach Resort and Elmina Castle. The Atlantic Ocean (also known as the Gulf of Guinea) borders Cape Coast Metropolis and Komenda Edina Eguafo Abirem Municipality on the south. The Twifo-Hemang-Lower Denkyira District borders the Komenda Edina Eguafo Abirem Municipality to the east, the Cape Coast Municipality to the north, and the Mpohor–Wassa East District in the Western Region to the west. The municipality has a population density of 319 per square kilometre and a total area of 452 per square kilometre (Ghana Statistical Service [GSS], 2021).

The Twifu Hemang Lower Denkyira District borders the Cape Coast Metropolis to the north and the Abura Asebu Kwamankese District to the east. Its largest point, Brabedze, is roughly 17 kilometres from Cape Coast, the Central Region's capital, and it encompasses an area of about 122 square kilometres (Ankrah et al., 2023, CCMA, 2017). The two towns come together to create a composite area that is located between 5° 02' N and 5° 15' N in latitude and between 1° 09' W and 1° 35' W in longitude. A Google Earth image of the study area is shown in Figure 2 below, along with the main road network, the boundaries of the two municipalities, and a few selected communities.

The Cape Coast-Elmina coastline was selected for this study due to its unique and dynamic coastal processes, socio-economic importance, and vulnerability to environmental changes. This stretch of Ghana’s coastline experiences highly variable shoreline dynamics, with sections undergoing severe erosion, sediment deposition, and anthropogenic modifications. Cape Coast and Elmina are among the most historically significant and economically vital coastal towns in Ghana, supporting fishing, tourism, and urban infrastructure, making them ideal locations for analyzing the interactions between natural coastal processes and human interventions. Furthermore, this coastline has been the site of various coastal management interventions, including sea defence structures, harbour developments, and sand nourishment projects, which significantly alter beach morphology. Additionally, the Cape Coast-Elmina area falls within Ghana’s high-energy littoral zone, experiencing strong wave action, tidal currents, and sediment transport, which contribute to the dynamic nature of the beaches. Given its socioeconomic significance, environmental vulnerability, and complex coastal processes, the study of changing beach dynamics in Cape Coast and

Elmina offers critical insights into shoreline evolution, providing scientific evidence for sustainable coastal management and policy formulation.

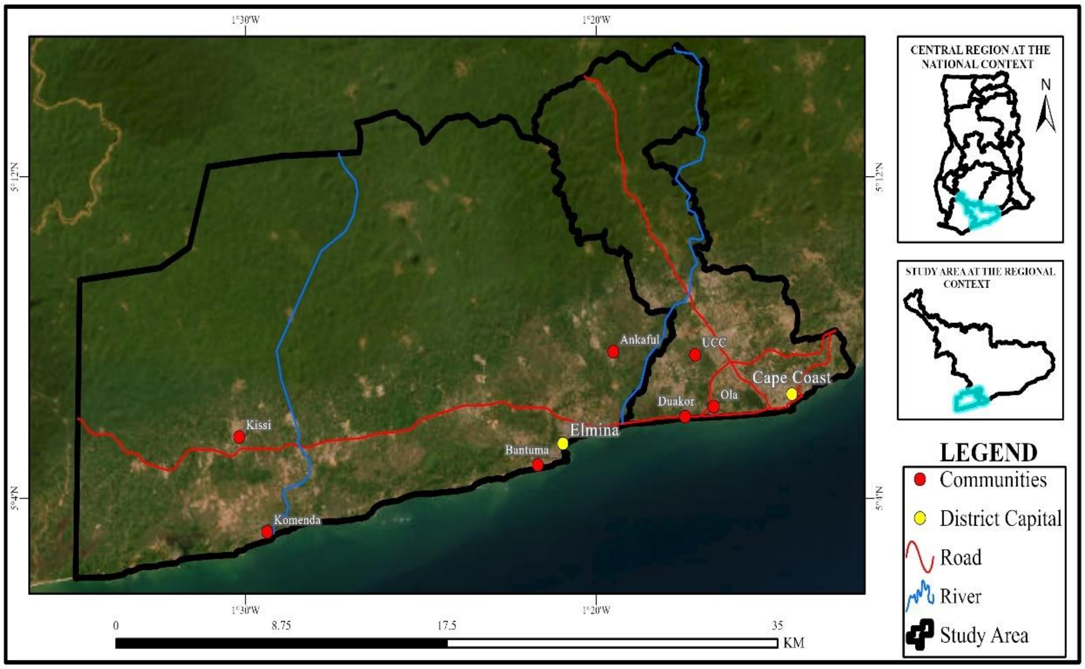

Figure 2: Map of the study area

Source: Osei, 2021.

Physical Features of Cape Coast Metropolis and Komenda Edina Eguafo Abirem Municipality.

Relief and drainage

The topography of the Komenda Edina Eguafo Abirem Municipality and the Cape Coast Metropolis is primarily undulating and features notable batholiths. Both regions are dominated by these geological formations, which are primarily made of schist with additional granite and pegmatite rocks. The relief of the area has been greatly shaped by the presence of these batholiths (CCMA, 2017).

This terrain is scattered with hills that are usually covered in deposits of sand and clay silts. Inland, the hills and slopes are relatively sharp. Conversely, valleys are the areas between hills and batholiths that are typically covered in clayey gravel and can occasionally have exposed lateritic soils (Adu-Boahen et al. 2020). These geomorphic features highlight the varied composition of surface materials and reflect changes in erosional processes and sedimentary deposition over time. There are valleys filled with different streams that flow into the Atlantic Ocean and the coastal lagoon in between the hills. There are numerous lagoons along the coastal zone, including Benya, Brenu, Susu, Abrobi, and Ankwanda. A thriving salt industry is supported by these lagoons.

The research area's relief features and drainage pattern are closely related. Several valleys facilitate the movement of rivers and streams, the main waterway in the Cape Coast Metropolis being the Kakum River. The Kakum River holds hydrological significance as it provides essential water for both household and industrial uses in the area.

Minor streams also meander around the terrain, frequently ending in wetland areas. Among these, the Fosu Lagoon in Bakaano is notable for being a major source of drainage, drawing water from several lesser streams (CCMA, 2017). This complex web of watercourses affects the distribution of habitats and ecosystems across the landscape in addition to contributing to the hydrological dynamics of the area.

Moreover, the northern parts of the Metropolis exhibit a contrasting topography, characterized by low-lying areas conducive to agricultural activities. This disparity in relief underscores the spatial heterogeneity within the study area, with distinct zones offering varying opportunities and challenges for land use and development.

Climate

Because of their tropical climate, Ghana's Cape Coast Metropolis and Komenda Edina Eguafo Abirem Municipality experience year-round high temperatures. The climate in these places is warm and muggy, with daytime highs of 21 to 35°C. Just before the main rainy season, in February and March, are the hottest months, and in June, July, and August are the coolest. Rainfall has a greater effect on climate variability in the Metropolis than temperature. While the Cape Coast Metropolis frequently records monthly rainfall totals exceeding 200 mm during heavy rain events, the Komenda Edina Eguafo Abirem Municipality experiences a double peak in rainfall, with annual totals between 750 mm and 1,000 mm (Boateng, 2022; GSS, 2010).

There are two distinct seasons in the warm and humid climate of the Cape Coast Metropolis and Komenda Edina Eguafo Abirem Municipality: the rainy season and the dry season. Although it can also pose environmental problems, the rainy season is characterized by heavy rainfall, which is essential for agriculture and other water-dependent industries. On the other hand, low rainfall and high temperatures during the dry season cause the air to become more dusty and particulate matter-filled, which can be harmful to people's health.

Vegetation

The Komenda Edina Eguafo Abirem Municipality in Ghana has primarily tropical vegetation, with a mix of agricultural land, mangrove swamps, and dense forests. In addition to providing habitats for a wide variety of wildlife, such as birds, reptiles, insects, and primates, this lush vegetation also provides essential ecosystem services like soil conservation and water management. Because they serve as a barrier against coastal erosion and essential habitat for many fish species and other aquatic organisms, the coastal mangrove swamps are especially important.

Similar to the vegetation of the Komenda Edina Eguafo Abirem municipality, the vegetation of the Cape Coast Metropolis is primarily characterized by tropical rainforest, with a mix of other vegetation types including mangrove swamps and savanna grasslands. The area is also home to a rich and diverse array of plant species. The forest is dominated by tall trees, such as mahogany and iroko, with a dense undergrowth of smaller trees, shrubs, and other vegetation. This vegetation provides important habitat for a variety of wildlife, including birds, monkeys, and other mammals.

The Cape Coast Metropolis and Komenda Edina Eguafo Abirem Municipality currently have shrubs that are approximately 1.5 meters high, grasses, and a few solitary trees as their vegetation. Due to land clearing for agriculture, the production of charcoal, bushfires, and other human activities, secondary vegetation has taken the place of the original dense scrub vegetation, which was supported by rainfall. At the moment, coastal regions have less trees per square mile than interior forest regions. On the other hand, secondary forests have survived over time in the northern regions of the two districts, mostly because of lower population densities and comparatively little ecological disturbance (CCMA, 2017; Owusu-Sekyere et al., 2011).

Geology

The Cape Coast - Elmina coastline offers a varied geological environment sculpted by complex processes extending over millions of years. The Cape Coast Metropolis, dominated by Tertiary sedimentary rocks such as sandstones, shales, and limestones, captures a wealth of geological past. These formations have been shaped over time by weathering and erosion, producing fertile soils that are suitable for farming. The city is located on a small coastal plain that is bordered by low-lying hills. Due to its low elevation and close proximity to the ocean, this plain, which is mainly composed of sandy soils, is susceptible to coastal erosion and flooding.

The presence of towering cliffs and rocky outcrops along the coastline bears testimony to dynamic geological processes. These landforms, resulting from uplift and erosion, exhibit steep and rugged features, offering vital habitats for diverse plant and wildlife species. Moreover, they serve as prominent attractions for tourists, owing to their scenic beauty and geological significance. Notably, the region boasts karst features such as sinkholes, caves, and underground streams, further enriching its geological diversity and uniqueness.

In contrast, the Komenda Edina Eguafo Abirem municipality is characterized by Precambrian basement rocks constituting the basement complex.

Comprising granites, gneisses, and migmatites, these ancient rocks represent some of the oldest formations in the area. Composed primarily of quartz, feldspar, and mica, they exhibit exceptional stability and resilience, underscoring their geological significance.

Coastline

The Cape Coast–Elmina coastline presents a varied array of coastal landforms and defenses along its stretch. The area is categorized into four zones. The categorization of the coastline into four distinct zones was scientifically justified based on well-defined geomorphological, hydrodynamic, socio-economic, and ecological criteria. Coastal environments are inherently heterogeneous, exhibiting spatial variability in factors such as erosion intensity, sediment deposition, wave energy, land use patterns, and human activities. The division into four zones allowed for a more systematic, comparative, and site-specific analysis, facilitating the identification of coastal processes, risks, and management needs.

Beginning with Zone 1, which encompasses the area from the western Elmina Castle to the Elmina Beach Resort, a juxtaposition of rocky coast and sandy beaches characterizes the landscape. Notable features include jetties and rock revetments erected to protect the fish processing plant and adjacent infrastructure, highlighting efforts to bolster coastal resilience.

Zone 2 extends from the Benya Estuary to the Kakum River Estuary, featuring predominantly rocky shores interspersed with pockets of sandy beaches.

Multiple rock revetment sea walls have been strategically deployed to combat coastal erosion, with partial shielding provided to the Elmina Beach Resort area.

Moving eastward, Zone 3 stretches from the Kakum River Estuary to the De Breeze Beach Resort, marked by a mix of rock outcrops and sandy stretches. Flood vulnerability is apparent, necessitating the establishment of rock revetments to safeguard the adjacent road and settlements. However, the straight shoreline configuration leaves this area susceptible to wave action.

Finally, Zone 4 encompasses a continuous expanse of sandy beaches, the longest in the research region, flanked by vital infrastructure such as schools, hospitals, and coastal communities.

Erosion mitigation measures include concrete seawalls and groynes, underscoring efforts to protect key facilities from wave-induced impacts.

Research Philosophy

This study was underpinned by the pragmatism philosophical paradigm. The pragmatism philosophical paradigm posits that to obtain holistic knowledge about a phenomenon under study, there is the need to use the combination of the positivist and interpretivist paradigms (Creswell & Clark, 2017). Uddin and Hamiduzzaman (2009) explain that the positivist paradigm asserts that genuine knowledge is derived from direct sensory experience and claims a monopoly over scientific knowledge, while interpretivists aim to understand phenomena by examining individual cases. Pragmatism is employed to clarify concepts and research hypotheses by evaluating their practical implications (Moon & Blackman, 2014).

Creswell and Creswell (2018) suggest that rather than concentrating on a single philosophical paradigm, researchers should utilize all available approaches to gain a comprehensive understanding of the issue at hand. Pragmatists advocate for employing diverse methods when studying a phenomenon, rather than sticking to one specific method (Creswell, 2009; Moon & Blackman, 2014). This philosophy was adopted for the study as it facilitated a deeper understanding of the research problem and objectives. By doing so, it minimized the limitations associated with both positivist and interpretivist philosophies while benefiting from the strengths of each.

Research Design

The concurrent mixed methods approach was the research design used in this study. This design allows for simultaneous use of quantitative data, such as satellite images and sampled beach sediments, and qualitative data, such as observations and interviews. The concurrent mixed methods design enables researchers to tackle a broad array of methodological challenges. Consequently, it allows for the collection of various types of data simultaneously. Additionally, this approach facilitates the integration of results from different data sources, aiding in the comparison and contrast of issues.

Data Sources

Primary and secondary data were both used in this investigation. Primary data were gathered with the aid of tools like interview guides and focus groups. These primary data, which also included samples of beach soil, were provided by participants and respondents from the study area. For the study, additional secondary data were acquired, including satellite images.

The Earth Explorer website of the United States Geological Survey (USGS) and the Copernicus Open Access Hub provided the remotely sensed data used in this study. Sentinel photos from 2015 and 2020 could be viewed via the Copernicus Open Access Hub, while Landsat images from 1991 and 2002 could be downloaded from the USGS Earth Explorer. Since 2015, the Sentinel 2A missions have been collecting images, which has resulted in an adequate amount of data for spatiotemporal analysis. Sentinel data are also publicly available due to their open-source nature. Sentinel images, specifically the optical bands with a spatial resolution of 10 m, were thought to be appropriate for this study due to their advantages. Sentinel images have spatial resolutions of 10 m, 20 m, and 30 m. The sources, dates of acquisition, and spatial resolutions of the images used in the study are listed in Table 1 below.

Table 1: Details of satellite data used for the study

Satellite	Spatial resolution (m)	Acquisition date	Source
Landsat 5 TM	30	27/01/1991	USGS Earth Explorer
Landsat 7 ETM+	30	17/02/2002	USGS Earth Explorer
Sentinel 2A	10	12/04/2015	Copernicus Hub
Sentinel 2A	10	05/02/2020	Copernicus Hub

Source: Osei, 2020.

Target Population

Stakeholders from the community and governmental organizations, as well as chosen residents of the Cape Coast and Elmina coastal areas, made up the study's target population. Community members were chosen based on the expectation that they would provide insights into their perspectives on changing beach dynamics and socio-economic activities. Additionally, the involvement of stakeholders, including government officials, chiefs, and community members, contributed to validating the study's findings.

Sampling Procedure

Two (2) sampling procedures were used for this study. One focused on the human element and involved purposive sampling while the other, which focused on the soil component, involved systematic sampling.

The purposive sampling procedure concerning the human element was used in selecting the communities and participants for this study. By using purposive sampling procedure, the researcher was able to gather data from particular groups of people because they had the right information for the phenomenon under study.

First, four (4) communities namely Ola, Duakor, Marine and Awunafomu. Ola and Duakor are coastal communities of the Cape Coast Metropolitan Area while Marine and Awunafomu are coastal communities of the Komenda Edina Eguafo Abirem Municipal Area. These communities of the study were purposively selected mainly due to their proximity to the beaches.

Second, two key informants (opinion leaders), from each of the four communities were also selected purposively. Lastly, leaders of government institutions such as the Coastal Development Authority (CODA), Environmental Protection Authority (EPA), Fisheries Commission, Cape Coast Metropolitan Assembly (CCMA) and Komenda Edina Eguafo Abirem Municipal Assembly.

Concerning the soil data sampling, a systematic approach was used. This was achieved by starting from the Kakum estuary and collecting beach sediment samples at intervals of 100 m to the east and to as far as the Cape Coast castle. A similar activity was carried out by starting from the Kakum estuary and collecting beach sediment samples at intervals of 100 m. In the circumstance however, the movement from the Kakum estuary was to the west, passing through interesting locations such as the Elmina Beach Resort, the enclave of the Benya estuary, the Elmina Castle, and to the Coconut Grove Beach Resort.

These soil samples were picked with soil core sampler to a depth of 15 cm and put into transparent polythene bags with zip seals for laboratory analysis. For each sample, the locational information (coordinates) was captured with a Garmin Etrex 20 handheld GPS. The laboratory analysis was conducted at the Department of Fisheries and Aquatic Sciences (DFAS) laboratory of the University of Cape Coast. The study, among other objectives sought to assess the seasonal variability in the particle size distribution of the beach sediment samples. As a result, the beach sediment sampling was carried out in two (2) periods - dry season and wet season. The dry season sampling of the beach sediment was done for five days

(21st February 2020 to 25th February 2020). Beach sediment sampling for the wet season was done over four days (18th July 2020 to 21st July 2020).

Data Collection Instrument

Aligned with the research objectives, conceptual framework, research philosophy, research approach, and research design, this study employed several data collection instruments to gather both primary and secondary data. This section primarily focused on the primary data collection instruments, namely the focus group discussion guide (refer to Appendices A) and interview guides (refer to Appendices B and C). These instruments were selected based on their appropriateness for measuring the phenomena under study.

The focus group guide facilitated gathering information from selected community members, while the semi-structured interview guide was utilized to gather insights from key stakeholders such as chiefs or opinion leaders and government officials.

A semi-structured interview guide was utilized to obtain information from stakeholders. This choice was made due to the flexibility it offers researchers in probing for emerging themes and ideas.

The guide comprised four modules. Module 1 investigated changes in beaches along the Cape Coast-Elmina coastline, while Module 2 examined anthropogenic drivers of these changes, and Module 3 focused on the effects of beach alterations on human activities along the Cape Coast-Elmina coastline.

Data Collection Procedure

The data collection procedure involved conducting focus group discussions with selected community members. To enhance participation and contribution, participants were divided based on gender, resulting in two focus group discussions per community. These discussions took place in community centres, facilitated by two individuals with distinct roles: one led the discussion, while the other handled recording, note-taking, and encouraging participation. Each focus group comprised eight participants.

Prior to the discussion, participants received a briefing on its purpose, provided consent for recording, and were assigned pseudonyms to safeguard their identities. Each discussion lasted for 40-60 minutes. Additionally, face-to-face interviews were conducted with stakeholders such as chiefs and government officials responsible for coastal and land use management.

Interviews were scheduled in advance, with participants briefed on the study's purpose and consent obtained for recording. Each interview also lasted between 40-60 minutes.

Pre-Test of Research Instruments

Upon an assessment of the synergy between the research objectives, conceptual framework, and data collection, a pre-test of the research instruments was conducted. Pre-testing is a vital preliminary phase in the research process that involves assessing the suitability and effectiveness of research instruments before they are used in a full-scale study. As emphasized by Dillman, Smyth, and Christian (2014), pre-testing is essential for survey instruments, as it allows researchers to identify and rectify any issues related to question wording, response options, or the overall survey structure.

This practice ensures that the survey questions are clear and comprehensible to the target population, thereby enhancing the reliability and validity of the data collected. Additionally, pre-testing enables researchers to refine data collection procedures, such as interview protocols or observational methods, as highlighted by Creswell and Creswell (2018). The use of small-scale target groups for pre-testing can help researchers identify and address potential problems and ambiguities in their instruments (Tourangeau, Rips, & Rasinski, 2000). As such, pre-testing is a crucial step in research methodology that contributes to the success and rigor of the subsequent data collection and analysis processes.

This study utilized the In-depth Interview Guide and Focus Group Discussion Guide to collect primary data for analyzing the research objectives. Pre-testing of these qualitative data collection instruments involved subjecting the In-depth interview guide and Focus Group Discussion Guide to a preliminary evaluation before the actual data collection begins. As Morse and Field (1995) suggest, such an activity allows researchers to gauge the clarity of the questions and prompts, ensuring that they are easily comprehensible to the target population.

In the view of Alasuutari (2010), pre-testing helps to uncover any cultural or contextual factors that may affect respondents' interpretation of the questions. In view of that, the Principal Researcher, together with four (4) Research

Assistants conducted a pre-testing exercise in Anomabo, a coastal community in the Abura Asebu Kwamankese District to determine participants' understanding, interpretations and responses to the questions indicated on the two data collection instruments.

Similarly, the research team also used the opportunity to familiarize themselves with the field exercise concerning the expected duration of the various interviews and the possible challenges they are likely to encounter during the actual data collection process. The Anomabo community was chosen for the pre-testing exercise given that it shared similarities with the selected study sites (Elmina-Cape Coast Coastline) in terms of physical and socio-cultural contexts. The pre-testing exercise took place between 5th May 2021 and 21st May 2021.

As indicated by Dillman, Smyth, and Christian (2014), one of the primary outcomes of pre-testing is the refinement of research instruments. The pre-testing exercise was extremely useful and through this process, the principal researcher was able to identify and rectify ambiguities, errors, or issues in the wording of some questions and response options, leading to clearer and more reliable data collection tools. The exercise also prompted the interviewers on how to manage time to have fruitful and interactive interviews with both the key informants and the selected group for the Focus Group Discussions during the actual data collection.

Data Processing and Analysis

Concurrent research design provides instructions for handling and analyzing data. According to this recommendation, data should be handled and analyzed independently for both quantitative and qualitative information. To detect convergence and divergence, they should be blended in the presentation of the findings.

Laboratory Analysis of Sampled Beach Sediments

Sampled beach sediments of the Cape Coast – Elmina coastline (study area) were captured over four zones (Zones 1, Zone 2, Zone 3, and Zone 4). Zone 1 and Zone 2 constituted the Elmina front, while Zone 3 and Zone 4 constituted the Cape Coast front.

Seventeen (17) sample points were selected from Zone 1 and Zone 2 of Elmina for the dry season, while in the wet season, fourteen (14) sample points were used. The difference in the reduced observed number of sample points was due to the inaccessibility of three sample points (stations 11,12,13) as a result of the approved construction of a facility at the site. In Cape Coast, seventy-five (75) sample points were used in the dry season and these same stations were again used during the wet season. A total of 183 sampled beach sediments were analyzed at the laboratory.

The sampled beach sediments, brought to the laboratory in sealed transparent polythene, are usually wet due to the seawater content. To remove the moisture and organic matter present, the samples are dried in a laboratory oven at a temperature of 105° C for three days. After drying, the samples were kept in air-tight containers until the day of use at the laboratory.

The Dry Sieving Method (Folk, 1980; McManus, 1988) was used for the granulometric analysis of sampled soil samples taken from the beach. With the

Dry Sieving Method, a stack of 5 sieves set, with mesh numbers 5, 10, 35, 60, and 120; by Fieldmaster was employed for the particle size analysis in the laboratory.

Plate 1: Fieldmaster's Dry Sieve set used at the laboratory for the particle size analysis.

Source: Department of Fisheries and Aquatic Science's laboratory, UCC (2021).

To carry out the dry sieving method, the content of each sampled beach sediment (dried) is poured into a container and stirred to a uniform mix. 500 g of the mix (sediment) is fetched into a pan with the aid of an electronic weighing scale. The content of the pan is then poured into the topmost sieve of the Fieldmaster's Dry Sieve set and covered with the lid. The sieve set is then shaken manually in three sessions (each session takes about 3 minutes). After the shaking of the sieve set, the proportion of particles retained (percent retained) by each sieve (representing a range of particle diameter) and for each sample was recorded.

Plate 2: Electronic weighing scale used for assessing 500 g of sampled sediment

Source: Department of Fisheries and Aquatic Science's laboratory, UCC (2021).

Plate 3: Manual shaking of sieves set by the researcher

Source: Department of Fisheries and Aquatic Science's laboratory, UCC (2021).

Table 2 below displays information on the mesh numbers (#) for the sieve and its equivalence in particle size (diameter) in micrometer (µm) and millimeter (mm) scale.

Table 2: Mesh label and particle size (diameter) for Fieldmaster sieve

Mesh No. (#)	Particle Size (µm)	Particle Size (mm)
5	4000	4.000
10	2000	2.000
35	500	0.500
60	250	0.250
120	125	0.125

Source: Osei, 2021.

The GRADISTAT program (Blott & Pye, 2001) version. 9.1 was used to process further results obtained from the laboratory to generate a frequency diagram, cumulative frequency, and specific variables of statistical significance to be determined. The frequency distribution indicates the level of modality of the distribution, while the frequency curves describe the transport medium of the sediments.

Particle Size Distribution of Sampled Beach Sediments

Frequency distribution (graphs) and frequency curves are basic ways of portraying the nature and distribution of particle size of sampled sediments of an environment. The frequency graphs depict the sediments' modal distribution, whereas the curves describe the sediments' transport medium.

Frequency Distributions

The individual and cumulative weight (retained) percentages were calculated and recorded on a form (refer to Figure 3 below).

SIEVE ANALYSIS DATA

1. DATE STARTED
2. PROJECT
3. EXCAVATION
4. DATE COMPLETED
5.
6. SAMPLE NUMBER
7. PREWASHED (x one) YES NO
8. ORIGINAL SAMPLE WEIGHT
9. + #200 SAMPLE WEIGHT
10. − #200 SAMPLE WEIGHT

11. SIEVE SIZE	12. WEIGHT OF SIEVE	13. WEIGHT OF SIEVE SAMPLE	14. WEIGHT RETAINED	15. CUMULATIVE WEIGHT RETAINED	16. PERCENT RETAINED	17. PERCENT PASSING

18. TOTAL WEIGHT RETAINED IN SIEVES (Sum Column 14)
19. ERROR (8 - 23)
20. WEIGHT SIEVED THROUGH #200 (Weight in pan)
21. WASHING LOSS (8 - (9 + 10))
22. TOTAL WEIGHT PASSING #200 (20 + 10)
23. TOTAL WEIGHT OF FRACTIONS (18 + 22)
24. REMARKS

USCS ______
PERCENT - G ______
PERCENT - S ______
PERCENT - F ______

25. ERROR (Percent)

ERROR (19) / ORIGINAL WT (8) × 100 =

26. TECHNICIAN
27. COMPUTED BY (Signature)
28. CHECKED BY (Signature)

Figure 3: Form used for calculating and recording measurements using dry sieve method

Source: Osei, 2021.

The phi (Φ) values of the sieve's mesh size are related to the particle size diameter by the expression (Folk and Ward, 1957; Folk, 1980, Remmache et al. 2020);

$\Phi = -3.32192 \log D$, where D = diameter (in mm) of the particle.

The particle size (measured in phi) was plotted along the x-axis, while the individual sample weight retained (expressed as a percentage) was plotted on the y-axis. This resulted in a visual chart that displayed the particle size distribution (histogram) and frequency curve for each sample.

A smooth line through a set of plots of per cent weight retained against the size of each sieve (particle size expressed using the phi scale) is used to assess the modality of the particle size distribution.

Table 3 shows the mesh number (#) of each sieve, its corresponding particle size in micrometer (μm) and millimeter (mm); and the transformed value on the phi scale.

Table 3: Mesh label, particle size in sub-meter units, and phi scale

Mesh No. (#)	Particle Size (μm)	Particle Size (mm)	Particle Size in phi (Φ)
5	4000	4.000	-2
10	2000	2.000	-1
35	500	0.500	1
60	250	0.250	2
120	125	0.125	3

Source: Osei, 2021.

The average particle size (Mean), denoted as Mz, the spread of particle size about the average particle size (Sorting), denoted as σ, the degree of asymmetry of the particle size distribution (Skewness), denoted as SK_1, the degree of reworking of the particle (Kurtosis), denoted as K_G are the key statistics used in describing the particle size distribution.

Folk and Ward (1957) approach to calculating these statistics has been the preferred option for many researchers, underpinning the application of Gradistat v. 9.1 (Blott and Pye, 2001). Equations 1, 2, 3, & 4 below (Folk and Ward, 1957) are used to obtain the various particle size parameters of mean, sorting, skewness, and kurtosis for each sampled beach sediment, and these are consequently used in describing the particle size distribution of the beach sediments.

$$\text{Mean (Mz)} = \frac{(\Phi16+\Phi50+\Phi84)}{3} \quad (1)$$

$$\text{Sorting } (\sigma) = \frac{(\Phi84-\Phi16)}{4} + \frac{(\Phi95-\Phi5)}{6.6} \quad (2)$$

$$\text{Skewness } (SK_1) = \frac{(\Phi84+\Phi16-2(\Phi16))}{2(\Phi84-\Phi16)} + \frac{(\Phi95+\Phi5-2(\Phi16)))}{2(\Phi95-\Phi5)} \quad (3)$$

$$\text{Kurtosis } (K_G) = \frac{(\Phi95-\Phi5)}{2.44(\Phi75-\Phi25)} \quad (4)$$

In the equations above, $\Phi5$, $\Phi16$, $\Phi25$, $\Phi50$. $\Phi75$, $\Phi84$, and $\Phi95$ are the phi values of the 5th, 16th, 25th, 50th, 75th, 84th and 95^{th} percentile of the cumulative frequency curve of the sample beach sediment.

Table 4 below contains information on derived phi (Φ) values of mean, sorting, skewness, and kurtosis and their interpretation according to Folk and Ward (1957).

Table 4: Values of statistical measure outcomes and their interpretation.

STATISTICAL MEASURE	VALUES (RANGE)	INTERPRETATION
	(-1.00) to 0.00	'Very coarse sand'
	0.00 to 1.00	'Coarse sand'
MEAN	1.00 to 2.01	'Medium sand'
	2.00 to 3.00	'Fine sand'
	3.00 to 4.00	'Very fine sand'
	Less than 0.35	'Very well sorted'
	0.35 to 0.50	'Well sorted'
	0.50 to 0.70	'Moderately well sorted'
SORTING	0.70 to 1.00	'Moderately sorted'
	1.00 to 2.00	'Poorly sorted'
	2.00 to 4.00	'Extremely poorly sorted'
	Greater than 4.00	'Very poorly sorted'
	(-1.00) to (-0.30)	'Very coarse skewed'
	(-0.30) to (-0.10)	'Coarse skewed'
SKEWNESS	(-0.1) to 0.10	'Symmetrical'
	0.10 to 0.30	'Fine skewed'
	0.30 to 1.0	'Very fine skewed'
	Less than 0.67	'Very platykurtic'
	0.67 to 0.90	'Platykurtic'
KURTOSIS	0.90 to 1.11	'Mesokurtic'
	1.11 to 1.50	'Leptokurtic'
	1.50 to 3.00	'Very leptokurtic'
	Greater than 3.00	'Extreme leptokurtic'

Source: Adopted from Folk and Ward (1957).

Processing and Analysis of Satellite Images

Landsat 5 image of 1991, Landsat 7 image of 2002, and Sentinel 2A images of 2015 and 2020 respectively, were used in the spatial and temporal analysis involving land use land cover and shorelines changes from 1991 to 2020.

Landsat 5 TM satellite data have 7 spectral bands. Six of them are of spatial resolution 30 m – B1 (0.45 - 0.52 μm), B2 (0.52 - 0.60 μm), B3 (0.63 - 0.69 μm), B4 (0.76 - 0.90 μm), B5 (1.55 - 1.75 μm), and B7 (2.08 - 2.35 μm), and a thermal band of spatial resolution 120 m [B6 (10.40 - 12.50 μm)].

Landsat 7 ETM+ satellite data have 8 spectral bands. Six of them are of 30 m spatial resolution – B1 (0.45 - 0.52 μm), B2 (0.52 - 0.60 μm), B3 (0.63 - 0.69 μm), B4 (0.76 - 0.90 μm), B5 (1.55 - 1.75 μm), and B7 (2.08 - 2.35 μm), a thermal band of 60 m spatial resolution [B6 (10.40 - 12.50 μm)] and a panchromatic band of 15 m spatial resolution B8 (0.52 - 0.90 μm).

Sentinel-2A has 13 spectral bands. Four of them are of 10 m spatial resolution – B2 (0.49 - 0.56 μm), B3 (0.56 - 0.67 μm), B4 (0.67 - 0.71 μm), B8 (0.84 - 0.87 μm), six of them are of 20 m spatial resolution – B5 (0.71 - 0.74 μm), B6 (0.74 - 0.78 μm), B7 (0.78 - 0.84 μm), B8A (0.87 - 0.95 μm), B11 (1.61 - 2.19 μm) and B12 (2.19 - 2.89 μm) and two bands at 60 m six bands at 20 m spatial resolution – B9 (0.95 - 1.38 μm) and B10 (1.38 - 1.61 μm).

The bands are defined intervals of electromagnetic energy used by sensors in remote sensing for capturing information about the surface of the Earth. For land use land cover and shoreline change studies; green, red and infra-red energy (bands) combinations. For Landsat 5 and Landsat 7, these are band 2, band 3, and band 4 while for Sentinel 2A, it is band 3, band 4 and band 8.

The four satellite images were all georeferenced using a second-order polynomial geometric model involving 50 ground control points (GCPs) in the Erdas Imagine software. Root mean square (rms) error values of 0.3, 0.2, 0.4, and 0.2 were obtained after resampling each of the images using the nearest neighbour method. Atmospheric correction model FLASSH in ENVI software was applied to all the images to improve on the visual appearance of the images to further enhance the classification process of the image to map out land use land cover classes and the extraction of the shorelines.

A high spectral resolution multispectral image and a high spatial resolution panchromatic image are integrated in the pan-sharpening image fusing technique. In real life, this method is used to produce a final result with high spectral and spatial resolution qualities appropriate for a given application. An output image with a spatial resolution of 15 m was obtained by pan-sharpening the Landsat 7 image using the multispectral bands (bands 2, 3, and 4) of 30 m spatial resolution and a panchromatic band (band 8) of 15 m spatial resolution.

Each of the four photos was duplicated. Essentially, this resulted in two sets of identical data: one set was utilized for the analysis and classification of land use and cover, and the other set was extracted and used to study shoreline change.

Using ArcGIS software, the coastlines of the Elmina and Cape coasts were extracted from two Landsat images from 2002 and 1991 as well as two Sentinel images from 2015 and 2020 that were downloaded from the USGS Earth Explorer and Copernicus websites. Using UTM projection, the analysis data were kept organized in a personal geodatabase. Creating a baseline and adding more attributes came after the shorelines were extracted from the satellite data, combined into a single file, and given attributes. To get ready for more analysis with the Digital Shoreline Analysis System (DSAS), these actions were taken in ArcGIS. Casting transects, defining shoreline calculation parameters, computing change rate statistics, joining the output to the created transect feature class, and displaying the results were the steps involved in using DSAS.

After careful analysis of each satellite image, the shorelines were digitalized with the highest level of visual accuracy as a polyline feature class. The border between land and water as seen in satellite photos was designated as the shoreline. All four of the satellite photos have undergone this digitization process. Five attribute fields were assigned to the shorelines: Shape, Shape Length, DATE_ (which indicates the original survey month, day, or year), UNCERTAINTY values, and Object ID (a unique identifier for each transect). After then, every unique shoreline feature was combined into a single feature class. One hundred meters out from the oldest shoreline, an offshore baseline was created (1991). By using the buffer method, a buffer of 100 meters was established from the original shoreline. Every other transect uses this baseline as a point of reference. The auto-generated fields for Object ID and Shape Length, ID (beginning at 0 if the baseline is divided into multiple segments), Group (1 for land, 0 for sea), whether the baseline is OFF shore (0) or ON shore (1), and Cast Direction (0 for left and 1 for right of the baseline) are among the attribute fields for the baseline. Only the ID is required out of the four user-defined fields; the other three are optional.

A qualitative changes analysis (Net Shoreline Movement) was determined using the four-shoreline data from the satellite images and visualizing the changes in shoreline for 30-year period (1991-2020). To calculate the Shoreline Movement, the subsequent steps are carried out using DSAS and the Default parameters are set in the Dialogue box, “Baseline” is selected as 'Baseline layer', “ID” is selected for 'Baseline ID Field', “Offshore” is selected for the Baseline Placement and “Shorelines” is selected as “Shoreline layer”, “DATE_” is selected Shoreline “Date Field” and a default data uncertainty of “10”.

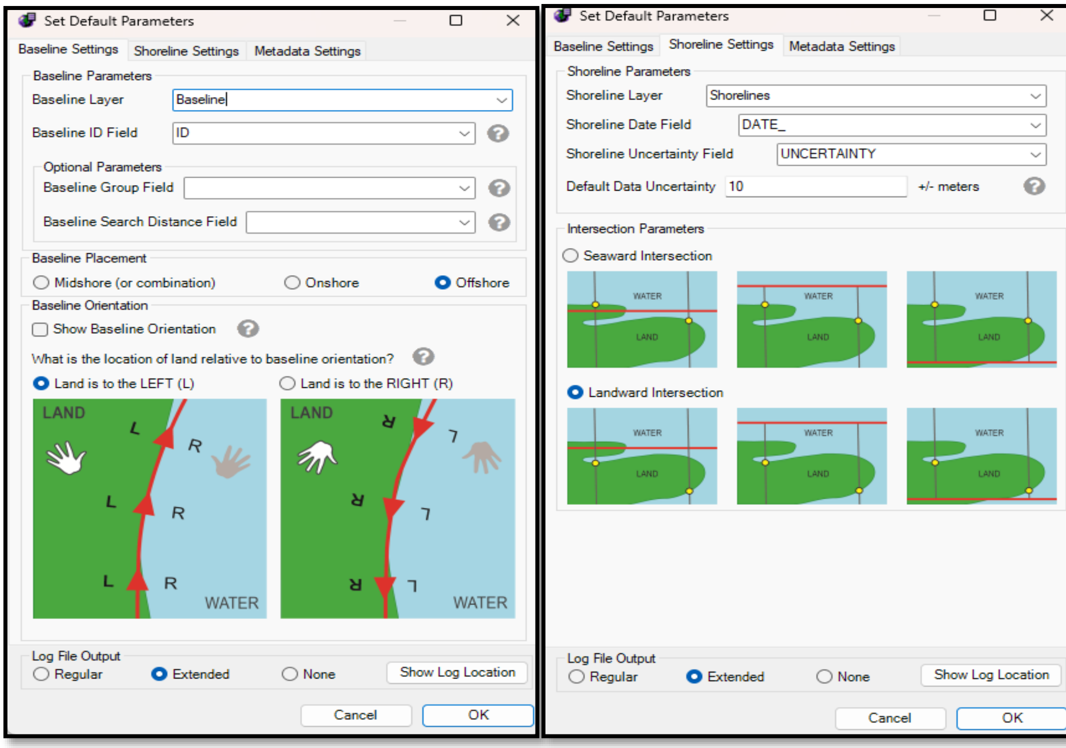

Figure 4: Settings used for casting the transects

Source: Osei, 2021.

For 'Cast Transect Setting', 'Transect Spacing' is set at 50 and for 'Transects length' is assigned 350. As the feature class is in UTM projection the DSAS takes the spacing and length in meters. The spacing was determined after observing different options of 10 m, 50 m, 100 m, and 500. The transects were cast. The 50 m spacing of transects cause intersections in some few locations and this was edited so that the transects do not cross. The 50 m spacing was therefore adopted and used in the analysis. Transects length was determined based on the maximum distance between the baseline and the beyond the farthest shoreline which for Cape Coast is 290 m. Therefore, 350 m length was selected as transect length. In Metadata setting the details of the user, organization and area for which the work is carried out are entered.

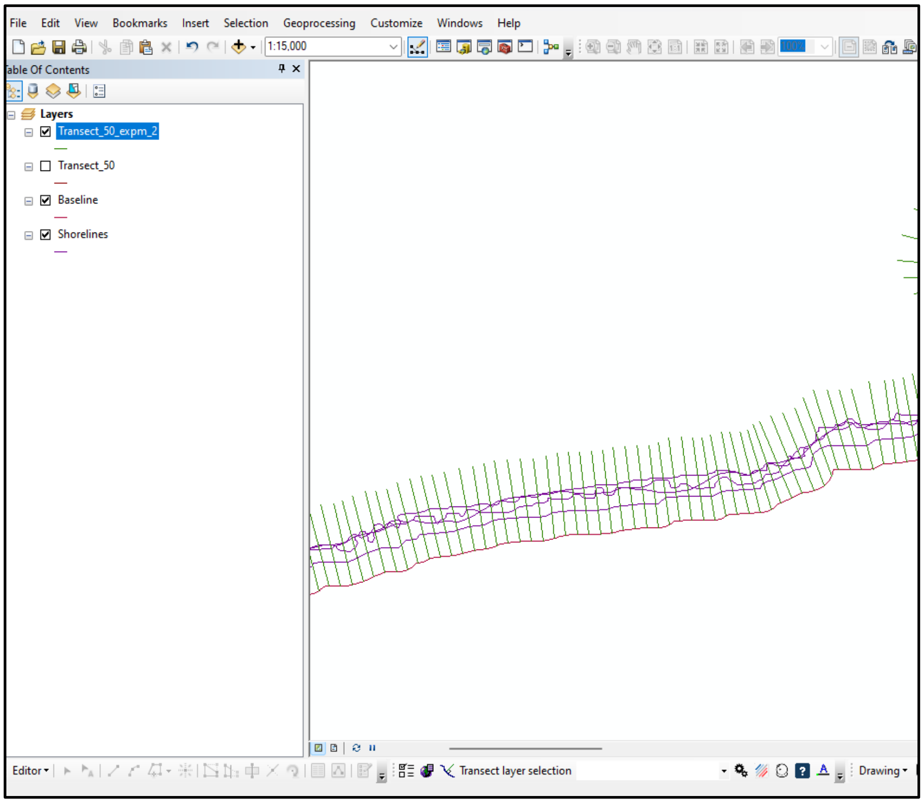

Figure 5: Portions of generated transects displayed in Arc GIS.

Source: Osei, 2021.

Zones and Transects

The study area was divided into two sections: the Cape Coast section and the Elmina section, based on the administrative boundaries of the Cape Coast Metropolitan Area and Komenda Edina Eguafo Abirem Municipality. Transects were auto-generated by DSAS, oriented perpendicular to the baseline and primarily aligned in the north-south direction. The Cape Coast section was designated as the eastern part of the study area, while the Elmina section was designated as the western part.

Elmina Section

This is the eastern part of the study area with a coast length of 7 km. The Segment contains 142 transects starting from Transect no. 1 to Transect no. 142. The section is divided into two zones: Zone 1 (Transect no. 1 to Transect no. 74) and Zone 2 (Transect no. 75 to Transect no. 142). The Elmina township, Elmina Castle and Coconut Groove Hotel are located in this section.

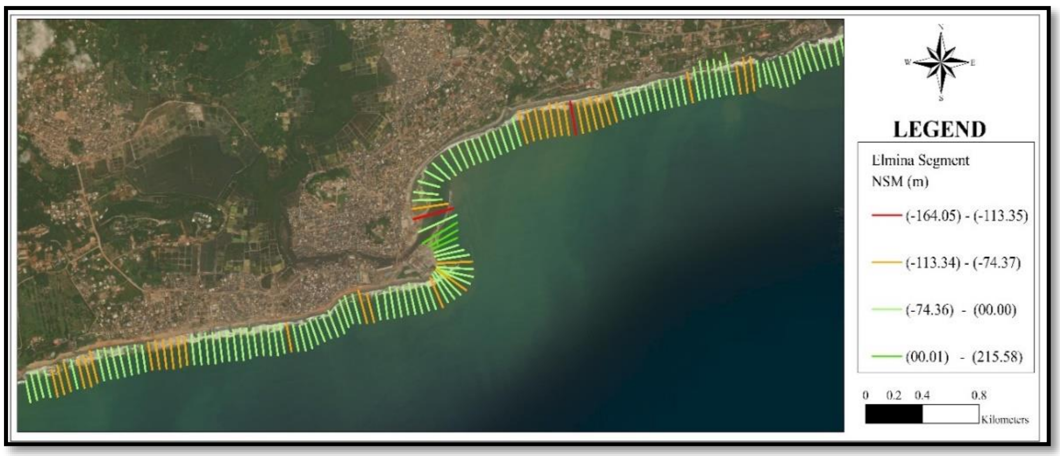

Figure 6: Display of transects in Elmina section (Zone 1 and Zone 2)

Source: Osei, 2021.

Cape Coast Section

This describes the western part of the study area which has a coast length of 9 km. The section contains 181 transects starting from transect no. 143 to Transect no. 323. This section is divided into two zones – Zone 3 (Transect no. 143 to Transect no. 228) and Zone 4 (Transect no. 229 to Transect no. 323) and the details of transects are shown in Figure 6. The coastal front of Duakor University of Cape Coast, Ola, and the Cape Coast Castle are in the section.

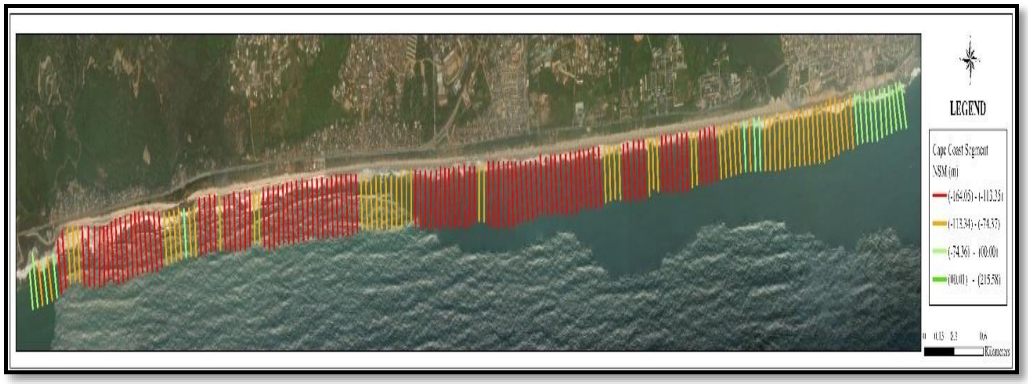

Figure 7: Display of transects in Cape Coast section (Zone 3 and Zone 4)

Source: Osei, 2021.

Statistical Methods Used

Linear Regression Rates

To evaluate the rate of change, statisticians employ the Linear Regression Rate (LRR). It builds a model that shows the relationship between shoreline points along a transect using the least squares regression line (Himmelstoss et al. 2021). This approach takes into account all the data, irrespective of fluctuations in accuracy or trends. As stated by Crowell et al. (1997) as well as Dolan et al. (1991), established and proven statistical principles serve as the foundation for the LRR computation. At each DSAS transect, shoreline data spanning at least four years is needed to accurately calculate long-term change rates (Natarajan et al. 2021). This method can be applied effectively because there are four coastlines. When estimating shoreline change rates, the linear regression approach assumes that changes will occur steadily over time, especially between the earliest and most recent shoreline dates. However, some areas do not follow a linear pattern, suggesting that the rates of shoreline change have not been consistent over time.

In such cases, the linear regression model applied to the data is expected to demonstrate lower quality, as indicated by a significantly low R value (Natarajan et al., 2021).

End Point Rate

According to the 2021 DSAS 5.1 user guide, the end point rate (EPR) was determined by dividing the net shoreline movement (NSM) by the time interval between the oldest and most recent shoreline measurements. In addition to any known information, such as erosion and accretion rates, magnitude, or cyclical trends, it requires the minimum values of two shoreline dates (Crowell et al. 1997; Dolan et al., 1991). The shoreline positions used in the End Point Rate method covered the period from 1991 to 2020. The rate of change in meters was calculated using the Universal Traverse Mercator projection. The entire shoreline is considered when calculating the EPR (Erosion Potential Rate) over 30 years. By comparing the oldest shoreline from 1991 to the most recent shoreline from 2020 and considering all intermediate shorelines in between, this method makes it possible to calculate the rate of change. This makes it easier to determine the regions and times during which recovery occurs, as well as the division and period in which erosion is most rapid. This formula is used to calculate it:

$$\text{EPR} = \left\{ \frac{d_{2020} - d_{1991}}{t_{2020} - t_{1991}} \right\} \text{ m per year}$$

The results are categorized according to direction and speed of movement. If the movement of the shoreline exhibits a landward trend at a velocity of less than -2.9 m per year, it is deemed to possess a high erosion rate. Conversely, if the rate of landward movement falls within the range of -2.89 to -0.5 m per year, the erosion rate is classified as low. If the rate of landward movement or seaward progression falls within the range of -0.49 m per year to +0.5 m per year, the coastal area is classified as stable. On the other hand, if the shoreline shifts seaward at a rate of +0.51 to +5.7 m per year, it is considered an accreting or prograding coast. Furthermore, if the rate exceeds +5.71 m per year, the coast is characterized as having high accretion.

Table 5: Shoreline analysis details on rate, classification and symbol

Rates (m / yr)	Classification	Symbols
< -2.0	'High Erosion'	
-2.0 to -0.5	'Moderate Erosion'	
-0.49 to 0.5	'Stable Coast'	
0.51 to 2.0	'Moderate Accretion'	
> 2.0	'High Accretion'	

Source: Osei, 2021.

Net Shoreline Movement

A statistical measure known as net shoreline movement (NSM) is used to measure the actual physical displacement between the oldest and most recent shoreline along each transect that is oriented perpendicular to the shorelines (Himmelstoss et al., 2021). Rather than providing data on rates, the NSM gives distance information. It is determined as NSM = $\{d_{2020} - d_{1991}\}$ m

Qualitative Data Analysis

Qualitative data analysis can be time-consuming and complex, but it can also provide rich insights into people's attitudes, behaviours, and experiences. Several software tools are available to help with qualitative data analysis, including QDA Miner, NVivo, and Atlas ti. The qualitative data was analyzed using the QDA Miner software. It was chosen since the QDA Miner is easy to use when retrieving, coding, annotating and analyzing documents.

The interview conducted was received and transcribed fully without leaving out a statement because every little detailed information was useful to the study. The analysis was done under various themes according to the objectives of the study. Each of the objectives was analyzed in detail based on the responses from the respondents and the observations made on the field. The study converted audio into text format, organized them in a spreadsheet or database, read and re-read the data, and took notes on key emerging themes and patterns. Identify and label segments of the data that relate to specific themes or categories and use codes to tag sections of the data that have similar meanings. The data was analyzed by comparing and contrasting codes, looking for relationships between themes and patterns, and identifying any outliers or anomalies

Ethical Consideration

Throughout the study process, ethical considerations were given top priority and closely followed. First, the University of Cape Coast's Institutional Review Board provided ethical approval. By submitting a proposal on the study and the different data-gathering tools, clearance was acquired. To help with the data collection, the head of the Department of Geography and Regional Planning provided letters before the data collection. These letters served as documentation of the authorization and eligibility for the data collection. A community entry was made before the data collection to let the leaders know what the purpose of the study was and how important it was that they participate. This was backed by the letter received from the Head of Department. Respondents and participants were guaranteed anonymity, confidentiality, informed permission, and privacy before to the initiation of each data collection. They were also told of the goal of the study and that their participation was optional. This guaranteed the safety of the field assistants, researchers, study participants, and research responders.

Limitations of the Study

Despite the study's comprehensive approach, certain limitations were encountered. Firstly, limited Availability of High-Resolution Historical Data. Some older satellite imagery had lower spatial resolution, which could impact shoreline change detection accuracy. To remedy the limitation, the researcher used a combination of multiple datasets (Landsat, Sentinel-2, drone surveys) and ground-truthing to improve data reliability. Again, Temporal Variations in Tidal Influences: Tidal fluctuations may affect shoreline position measurements. To avoid this, standardized shoreline delineation using mean high-water line (MHWL) approaches and cross-referenced data with tidal records. Anthropogenic Modifications Affecting Natural Trends: Coastal defences and urbanization may have altered natural beach dynamics, potentially skewing results. Here the researcher differentiated between natural and human-induced shoreline changes, incorporating historical records, policy documents, and local knowledge.

Finally, Weather and Accessibility Challenges: Field surveys were sometimes constrained by adverse weather conditions and limited access to some coastal locations. To remedy the situation, the researcher conducted multiple field visits during different tidal and seasonal conditions to ensure comprehensive data collection. By implementing these mitigation strategies, the study maintained high scientific rigor, ensuring that findings accurately reflect the changing beach dynamics of the Cape Coast-Elmina coastline without compromising data integrity.

Chapter Summary

This chapter described the study's methodology and research design, with an emphasis on Ghana's Cape Coast-Elmina coastline. It included a description of the target population, sampling techniques, data sources, data collection tools, and research philosophy. The study area included Komenda Edina Eguafo Abirem Municipality and Cape Coast Metropolis, with detailed descriptions of their geographic and demographic characteristics. Quantitative data collection involved systematic sampling of beach sediments, using GPS for location tracking, and laboratory analysis of samples taken from the beaches; and the use of satellite images of various years covering the period 1991-2020 for the extraction of shoreline positions for shoreline change analysis and land use land cover change analysis using the categorization of satellite photos into classes based on land use and cover. Focus groups and semi-structured interviews with stakeholders and members of the community provided the qualitative data. In addition, the chapter also addressed ethical considerations, ensuring adherence to ethical standards and respect for participants' rights and privacy.

CHAPTER FIVE

SPATIAL AND TEMPORAL CHANGES ALONG BEACHES OF CAPE COAST - ELMINA COASTLINE

Introduction

This chapter details the outcomes of modifications made to two key dynamics: shoreline movement along the Cape Coast and Elmina coastal fronts, and land use and land cover in the Cape Coast Metropolitan Area and Komenda Edina Eguafo Abirem Districts. Beginning with the changes that have taken place over a 30-year period, under four time series - 1991 to 2020, 1991 to 2002, 2002 to 2015, and 2015 to 2020 - the chapter delves into each of these periods. It also illustrates the gains or losses for each land cover class for the study period and provides changes for each land cover class over the course of the 30 years (1991–2020) through change detection. Additionally, an analysis is done on changes related to the movement of the shoreline between 1991 and 2020. At the end of the chapter, the effects of changes in shoreline positioning, land cover, and land use on human activities within the study area are determined.

Land Use Land Cover Classification 1991 – 2020

Using the Support Vector Machine algorithm, the section examined classified satellite images from 1991, 2002, 2015, and 2020. It also examined changes in land cover and land use for the Cape Coast Metropolitan Area (CCMA) and Komenda Edina Eguafo Abirem (KEEA) from 1991 to 2020, 1991 to 2002, 2002 to 2015, and 2015 to 2020. Based on the classification scheme of

Anderson et al. (1976), the images were divided into six (6) land cover classes: built-up, dense vegetation, sparse vegetation, water, wetland, and barren land.

Land use land cover classification of 1991

The classified satellite images for the year 1991 as shown in Figure 7 and Table 6 revealed that a high proportion of the land area was largely covered by sparse vegetation – 97.33 sq. km (80.74%) in CCMA and 346.96 sq. km (77.03%) in KEEA. Dense vegetation is the second dominant land cover class across the both districts – 10.59 sq. km (8.79%) in CCMA and 54.72 sq. km (12.15%) in KEEA. In CCMA, the sparse vegetation is found in the central to the northern portion, while in KEEA, sparse vegetation is found at the central to north-east area of the district. Dense Vegetation in CCMA, is found more concentrated at northern fringes of the district boundary and the south western corridors of the coastal belt.

Built-up covers 6.51 sq. km (5.4%) of the Cape Coast Metropolitan Area and are found dominantly in the southern portion of the district, while in Komenda Edina Eguafo Abirem district, it covers 7.62 sq. km (1.69%) and are found generally scattered across the middle and southern portion of the municipality. The wetlands class for the two districts are found spatially in pattern in the south and close to the coast. The extent of the wetland cover in Cape Coast Metropolitan Area is 5.31 sq. km (4.40%), which is less compared to that of Komenda Edina Eguafo Abirem district 39.36 sq. km (8.74%).

Water and barren land classes collectively represented a minimal proportion of the landscape. In Cape Coast Metropolitan Area, their representations are 0.67 sq. km (0.56%) and 0.13 sq. km (0.11%) respectively while in Komenda Edina Eguafo Abirem district, it is 1.76 sq. km (0.39%) and 0.03 sq. km (0.00%). The water class, mainly lagoons and rivers were found in the south in both districts. They all interestingly empty themselves into the sea.

Table 6: Statistics on land use land cover classification from 1991 to 2020

	1991				2002			
	CCMA		KEEA		CCMA		KEEA	
Class	Area (sq. km)	Percent (%)	Area (sq. km)	Percent (%)	Area (sq. km)	Percent (%)	Area (sq. km)	Percent (%)
Built-up	6.51	5.40	7.62	1.69	23.01	19.09	16.31	3.62
Dense Vegetation	10.59	8.79	54.72	12.15	6.15	5.10	43.27	9.61
Sparse vegetation	97.33	80.74	346.96	77.03	86.59	71.84	353.74	78.53
Water	0.67	0.56	1.76	0.39	0.82	0.68	3.61	0.80
Wetland	5.31	4.40	39.36	8.74	3.88	3.22	33.49	7.43
Barren Land	0.13	0.11	0.03	0.00	0.09	0.07	0.03	0.01
Total	120.54	100.00	450.45	100.00	120.54	100.00	450.45	100.00

	2015				2020			
	CCMA		KEEA		CCMA		KEEA	
Class	Area (sq. km)	Percent (%)	Area (sq. km)	Percent (%)	Area (sq. km)	Percent (%)	Area (sq. km)	Percent (%)
Built-up	27.63	22.92	23.26	5.16	31.35	26.01	40.98	9.10
Dense Vegetation	0.05	0.04	2.04	0.45	8.91	7.39	7.67	1.70
Sparse vegetation	90.30	74.91	388.23	86.19	78.32	64.97	396.62	88.05
Water	0.62	0.51	1.79	0.40	0.64	0.53	1.35	0.30
Wetland	1.90	1.58	35.13	7.80	1.15	0.95	3.75	0.83
Barren Land	0.04	0.04	0.00	0.00	0.17	0.15	0.08	0.02
Total	120.54	100.00	450.45	100.00	120.54	100.00	450.45	100.00

Source: Osei, 2022

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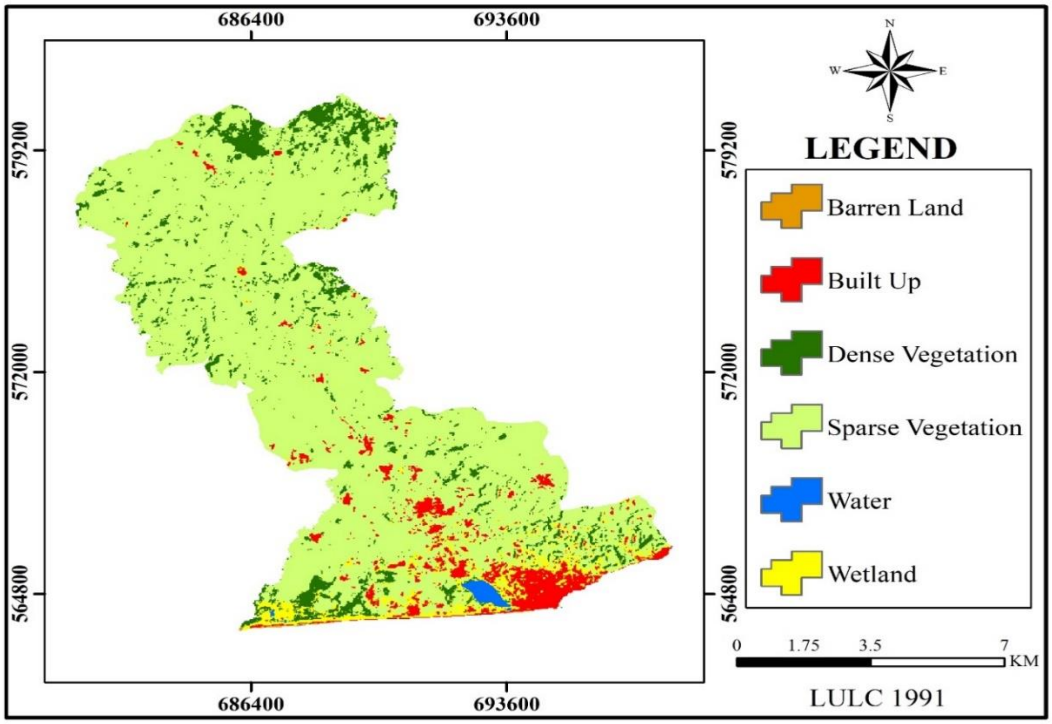

Figure 8: LULC Map of Cape Coast Metropolitan Area for 1991

Source: Osei, 2021.

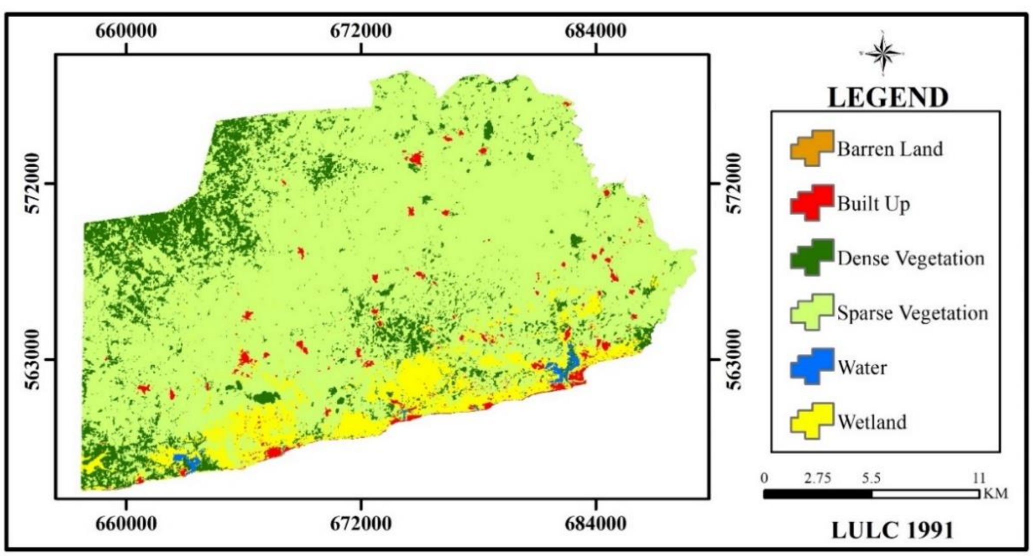

Figure 9: LULC Map of KEEA Municipality Area for 1991

Source: Osei, 2021.

Changes in Land use land cover 1991-2002

Comparing the 1991 land use land cover classification to that of 2002 (Figures 7 & 9 for CCMA; Figures 8 & 10 for KEEA) across the 12 years indicates that the land use land cover of the two municipalities has undergone some changes. The visual presentation of the image as seen between Figure 7 and Figure 9 shows a significant change, as the coverage of built-up has increased from 6.51 sq. km (5.4%) to 23.01 sq. km (19.09%) in the Cape Coast Metropolitan Area. Similarly, built-up in KEEA also depicts an increase from 1.69 sq. km (1.69%) to 16.31 sq. km (3.62%). The built-up expansion in Cape Coast Metropolitan Area is seen to be moving along the coastal area at the Southern western portion (particularly by settlements such as Duakor, Apewosika, Amamoma that are close to the University of Cape Coast) and through the central corridor of the municipality defined by the main road from Cape Coast (Pedu junction) to Abura to Jukwa and eventually Twifo Praso in the northern part of the municipality; where land as a resource for infrastructure development was available. This change is similar to that found in Komenda Edina Eguafo Abirem district, where the expansion of built-up areas is towards the northern portion.

On the numerical figures presented in Table 6, the 1991 to 2002 analysis showed that the land area occupied by dense vegetation in the two municipalities had decreased. In CCMA, dense vegetation cover decreased from 10.59 sq. km (8.79%) in 1991 to 6.15 sq. km (5.1%) in 2002 while in KEEA experienced a decrease from 54.72 sq. km (12.15%) to 43.27 sq. km (9.61%). Regarding Sparse Vegetation, CCMA had a decrease in the area of coverage from 97.33 sq. km

(80.74%) in 1991 to 86.59 sq. km (71.84%) in 2002 but KEEA rather experienced an increase in sparse vegetation from 346.33 sq. km (77.03%) in 1991 to 353.74 sq. km (78.53%) in 2002. This can be explained by the fact that most of the green spaces of sparse and dense vegetation are converted to build-up areas through urbanization.

Wetland coverage recorded for the year 2002 in Cape Coast Metropolitan Area was 3.88 sq. km (3.22%), a decrease from 5.31 sq. km (4.40%) in 1991. In Komenda Edina Eguafo Abirem district, the coverage was 33.49 sq. km (7.43%) in 2002, down from a previous value of 39.36 sq. km (8.47%) in 1991. From Table 6, it can be observed that the landcover, and water, experience an increase from 0.67 sq. km (0.56%) in 1991 to 0.82 sq. km (0.68%) in 2002 for CCMA, while in KEEA the coverage did increase from 1.76 sq. km (0.39%) in 1991 to 3.61 sq. km (0.80%) in 2002. Lastly, barren land, with the least coverage among the six classes in the base year 1991, had a decrease in CCMA from 0.13 sq. km (0.11%) in 1991 to 0.09 sq. km (0.07%) in 2002. In the case of KEEA, only traces of the class are found throughout the 12-year period.

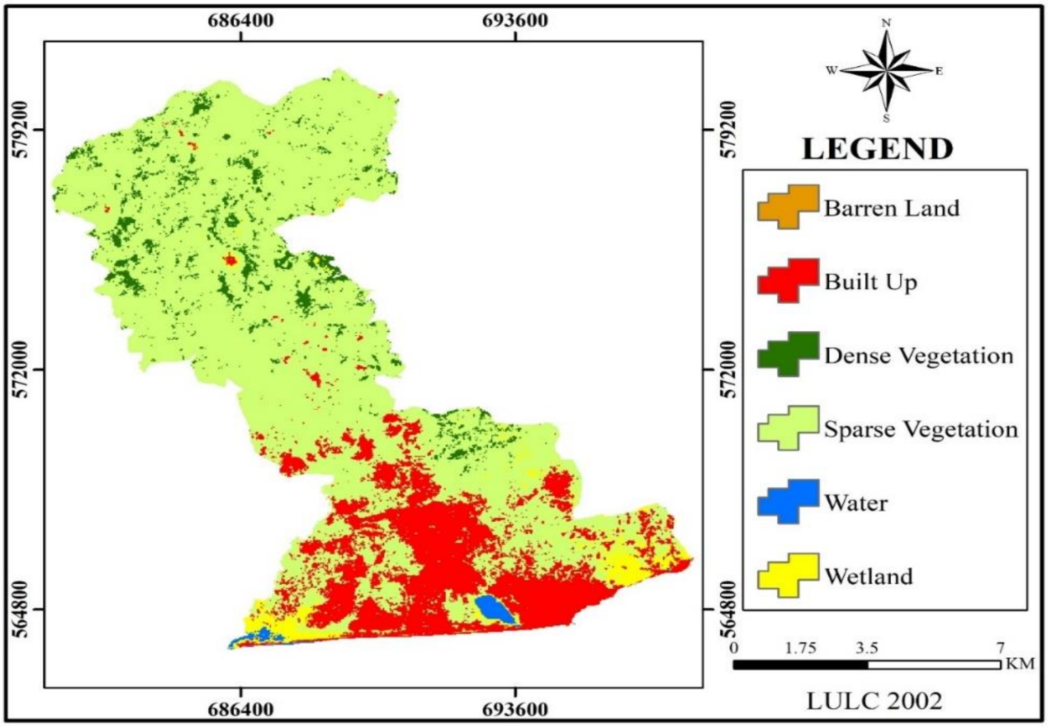

Figure 10: LULC Map of Cape Coast Metropolitan Area for 2002

Source: Osei, 2021.

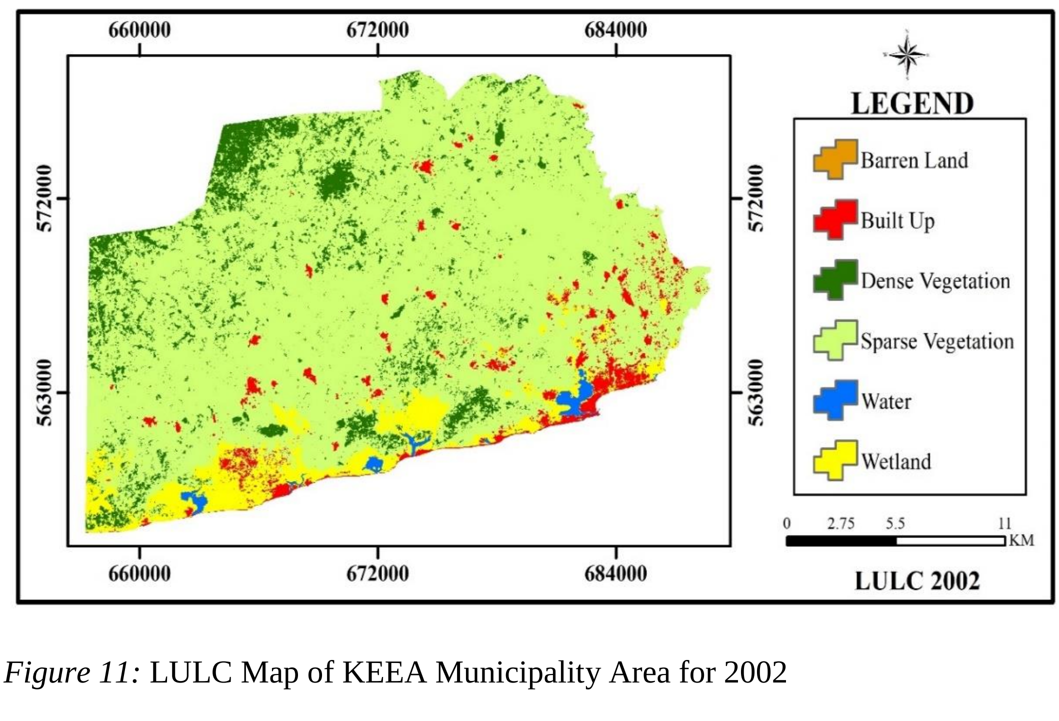

Figure 11: LULC Map of KEEA Municipality Area for 2002

Source: Osei, 2021.

Changes in Land use land cover 2002-2015

The examination of land use and land cover dynamics spanning from 2002 to 2015 in the Cape Coast Metropolitan Area (CCMA) and the Komenda Edina Eguafo Abirem (KEEA) district, as depicted in Figures 9, 10, 11, and 12, echoes trends observed in the preceding period from 1991 to 2002 (Figure 8).

Notably, there is a discernible trend of change within specific land cover categories. The built-up area notably expanded, with Cape Coast Metropolitan Area witnessing an increase from 23.01 sq. km (19.09%) in 2002 to 27.63 sq. km (22.92%) in 2015, and the Komenda Edina Eguafo Abirem district experiencing a rise from 16.31 sq. km (3.62%) to 23.26 sq. km (5.16%) during the same period. This trend underscores the process of urbanization and concomitant population growth within these coastal regions, indicative of escalating demands for infrastructure and housing (Figure 9). Duku et al. (2023) corroborates this observation, affirming the expansion of built-up areas at the expense of agricultural land and vegetative cover. Similarly, Forkuo et al. (2020), in their study published in "Land," investigating land-use changes in KEEA from 1986 to 2018, present findings aligning with the aforementioned trend, demonstrating an increase in urban sprawl at the cost of agricultural land.

The most conspicuous change observed during the specified period (2002-2015) was the decline in dense vegetation. In KEEA, dense vegetation decreased from 43.27 sq. km (9.61%) in 2002 to 2.04 sq. km (0.45%) in 2015. Similarly, in CCMA, dense vegetation cover reduced from 6.15 sq. km (5.10%) in 2002 to 0.05 sq. km (0.04%) in 2015. These changes were primarily attributed to the encroachment of urbanization on green spaces, predominantly concentrated in the northern sectors of both districts. Adjei Mensah, Kweku Eshun, Asamoah, & Ofori (2019) provide insightful commentary on the overarching trends of urban sprawl leading to the diminution of vegetation and green areas.

Conversely, sparse vegetation experienced an increase in both KEEA and CCMA. In KEEA, sparse vegetation expanded from 353.69 sq. km in 2002 to 388.23 sq. km in 2015, constituting a 9.77% increase. In CCMA, sparse vegetation emerged as the predominant land cover category, signaling a shift towards a more open landscape.

Wetlands, vital for biodiversity and environmental equilibrium, underwent notable alterations. Wetlands in KEEA expanded from 33.43 sq. km in 2002 to 35.13 sq. km in 2015, reflecting a 5.11% increase in land cover. Conversely, in CCMA, wetlands decreased from 3.32% to 1.58%. Particularly in the case of CCMA, the reduction in wetlands suggests the likely conversion of significant areas of wetlands to other land uses, including built-up areas. These transformations underscore the significance of monitoring and conserving wetland ecosystems in coastal regions. Namara et al. (2016) emphasized on the complex relationship of natural processes, human activities, and climate change impacting wetlands.

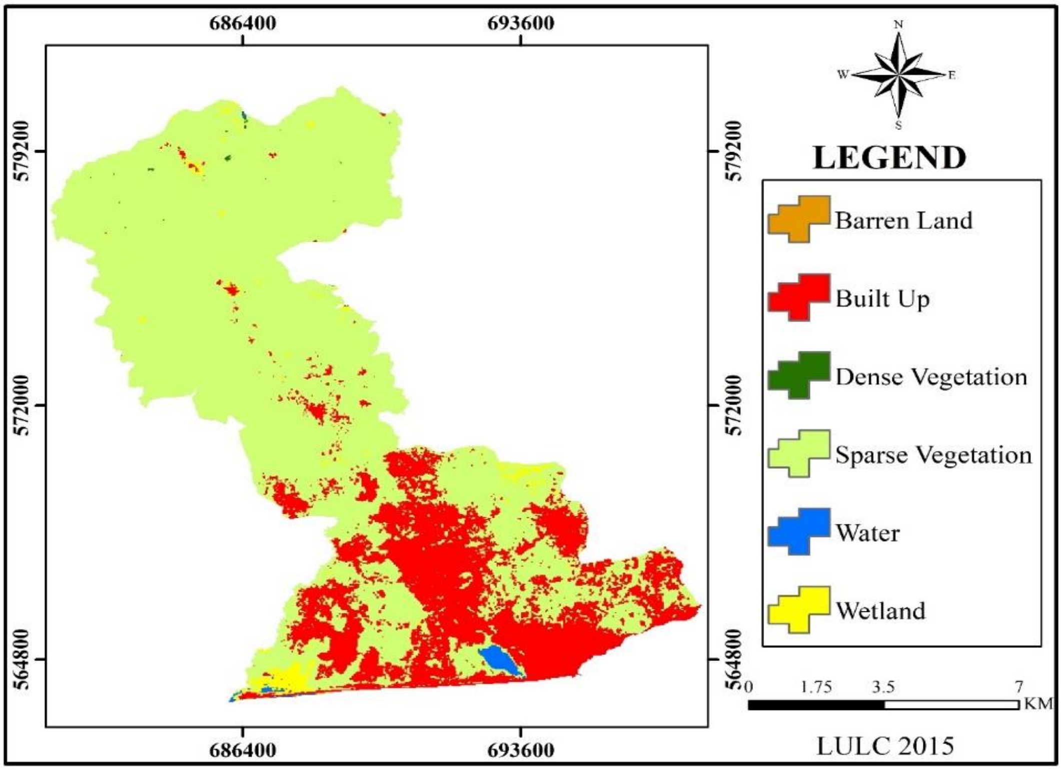

Figure 12: LULC Map of Cape Coast Metropolitan Area for 2015

Source: Osei, 2021.

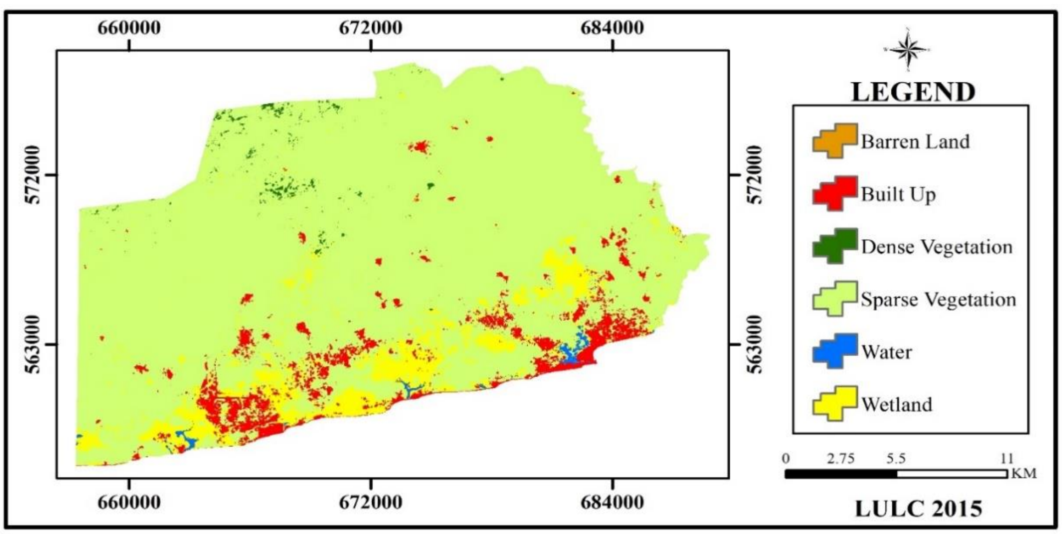

Figure 13: LULC Map of KEEA Municipality Area for 2015

Source: Osei, 2021.

Changes in Land use land cover 2015-2020

Results of the 2020 land use land cover classification, compared to that of the year 2015 revealed that the landscape is still evolving with built-up area, dense vegetation, and barren land, all experiencing an increase in their coverage (Figures 11 & 13 for CCMA; Figures 12 & 14 for KEEA). Sparse vegetation in each district continues to have the greater share of the coverage whilst barren land had the least coverage in both districts.

In the Cape Coast Metropolitan Area, the built-up area expanded from 27.63 sq. km (22.92%) in 2015 to 31.35 sq. km (26.01%) in 2020. This expansion of built-up was mainly spread out from the southern part of the metropolis to all directions – west, east, and north. The expansion results from the conversion of sparse vegetation, and wetland area to built-up (urbanization and infrastructure development). Concurrently, dense vegetation witnessed a remarkable surge, escalating from a mere 0.05 sq. km (0.04%) to 8.91 sq. km (7.39%). This surge in vegetation cover is more of a natural regeneration process facilitated by conservation efforts and climate-related factors.

Similarly, in the KEEA municipality, substantial changes in land use were observed during the study period. The built-up area exhibited a significant expansion, escalating from 23.26 sq. km (5.16%) in 2015 to 40.98 sq. km (9.10%) in 2020. This increase reflects the rapid urbanization and infrastructural development within the municipality, which is likely driven by population growth and economic activities (GSS, 2014). Moreover, dense vegetation witnessed a notable increase, rising from 2.04 sq. km (0.45%) to 7.67 sq. km (1.70%), as a result of natural vegetation regeneration within the area. Conversely, there was a decline in wetland coverage, which decreased from 35.13 sq. km (7.80%) to 3.75 sq. km (0.83%) over the five years.

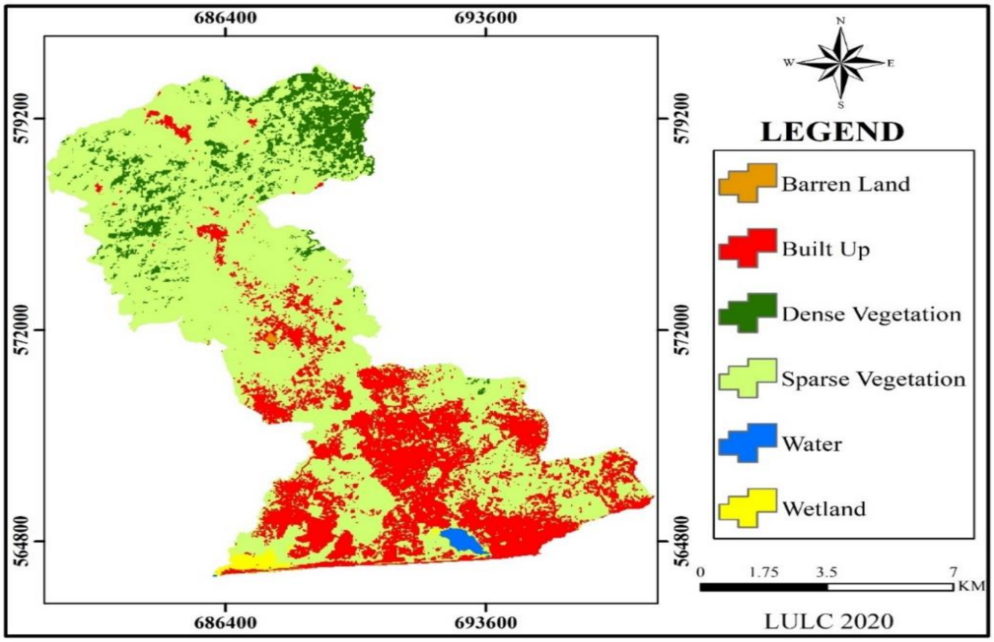

Figure 14: LULC Map of Cape Coast Metropolitan Area for 2020

Source: Osei, 2021.

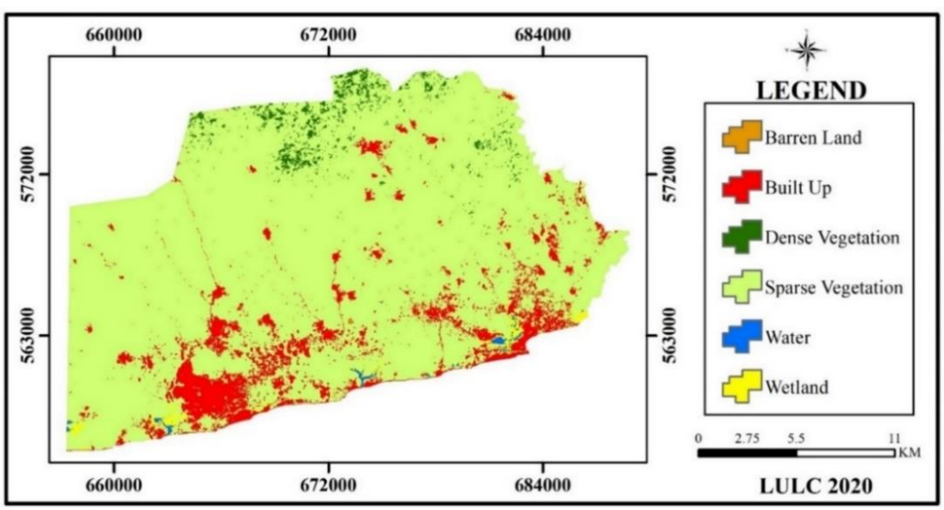

Figure 15: LULC Map of KEEA Municipality Area for 2020

Source: Osei, 2021.

The results of the land use land cover classification, shown in (Figures 7, 9, 11 & 13 for CCMA; Figures 8, 10, 12 & 14 for KEEA) and the statistics from Table 6 give a general impression of the land cover trends from 1991 to 2020.

Figure 15 below is a composite map generated by merging the two districts (CCMA and KEEA) as one unit for the years 1991 and 2020 and overlaid with the mapped shoreline (in black) of the year 2020. It provides visual evidence and support for the expansion of built-up, particularly, along the coast of the study area.

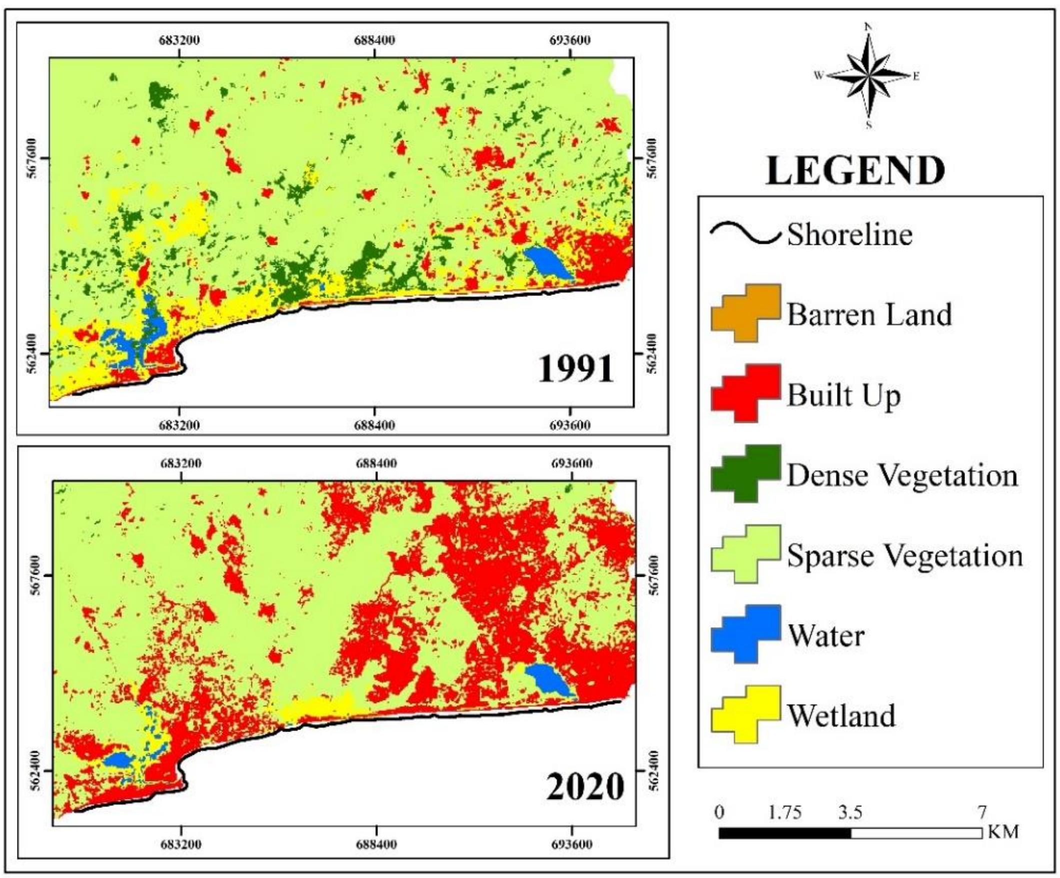

Figure 16: Composite LULC Map of CCMA and KEEA for 1991 and 2020

Source: Osei, 2021.

The variations seen between 1991 and 2020 can be explained by the catastrophe theory and the DPSIR framework. The theory of catastrophe, first put forth by Thom in the 1970s and made popular by Zeeman in 1976, describes how changes in land cover and use happen gradually over time (Stewart, 1983). According to this theory, slow changes in land use and land cover may be the cause of quick changes in coastal environments and human activity on beaches. Examples of small changes in input variables that can have a major and sudden effect on the coastal ecosystem are urbanization and the disappearance of wetlands.

In contrast, the DPSIR framework was first presented in 1993 by the Organization for Economic Cooperation and Development (OECD). This framework offers a methodical approach to comprehending the intricate relationships between states, pressures, driving forces, impacts, and responses pertaining to changes in land use and land cover, as well as their effects on human activities in coastal environments and beaches. The cause-and-effect relationships between human actions and environmental changes are modeled using this technique.

Additional analysis, including change detection, was done with reference to the conceptual underpinnings of the catastrophe theory, which quantifies the changes that take place through mathematical methods. Furthermore, an assessment of the factors that cause landscape modifications was carried out, followed by a study of their outcomes.

Change Detection

Both municipalities' land use land cover classifications reflect changes over the past 30 years. Rate of change and 'Combinatorial And' analysis were used to understand the changes. The rate of change analysis was the percentage difference between 1991 and 2020 for each land cover class. Table 7 shows land cover class change rates for both municipalities.

Table 7: Land use land cover changes 1991-2020

Class	Change in area (sq. km)		Percentage change in area (%)		Rate of change (sq. km p.a.)	
	CCMA	KEEA	CCMA	KEEA	CCMA	KEEA
Built-up	24.84	33.36	381.57	437.80	0.83	1.11
Dense vegetation	-1.68	-47.05	-15.86	-85.98	-0.06	-1.57
Sparse vegetation	-19.01	49.66	-19.53	14.31	-0.63	1.66
Water	-0.03	-0.41	-4.48	-23.30	0.00	-0.01
Wetland	-4.16	-35.61	-78.34	-90.47	-0.14	-1.19
Barren land	0.04	0.05	30.77	166.67	0.00	0.00

Source: Osei, 2022.

The findings of the rate of change analysis, which are outlined in Table 7, demonstrated that between the years 1991 and 2020, both municipalities had an increase in the prevalence of two of the land cover classes – Built-up and Barren Land. However, the change in the case of built-up was extensive. On the other hand, dense vegetation and wetlands experienced a reduction over the same period with wetlands suffering the more.

The built-up category within the municipalities of CCMA and KEEA. CCMA has experienced a substantial increase of 24.84 sq. km, signifying a

381.56% expansion in built-up areas. Meanwhile, KEEA has seen an even more remarkable rise of 33.36 sq. km, equating to a staggering 437.87% surge in built-up spaces. This rapid urbanization, averaging 0.83 sq. km per year for CCMA and 1.11 sq. km per year for KEEA, is of paramount importance in monitoring urban expansion. Such changes have significant implications for coastal geomorphology, including potential shifts in shoreline dynamics and heightened pressure on coastal ecosystems (Figure 15)

The Barren Land class has exhibited minimal alterations in both municipalities. CCMA experienced a slight increase of 0.04 sq. km, reflecting a 30.77% change, while KEEA saw a slightly higher rise of 0.05 sq. km, representing a notable 166.67% alteration. The negligible rate of change in barren land areas for both regions indicates that transformations in this category have had a limited impact on coastal geomorphology.

Both CCMA and KEEA experienced declines in the dense vegetation class. CCMA saw a reduction of 1.68 sq. km (15.86%), while KEEA experienced a more dramatic decrease of 85.98 sq. km (47.05%). Also, wetlands in CCMA experienced a reduction of 4.16 sq. km (78.34%), and KEEA saw a more significant decline of 35.61 sq. km (90.47%). The loss of wetlands is of concern, as they play a vital role in flood regulation, water purification, and wildlife habitat. Anthropogenic activities, such as drainage and land reclamation, are likely responsible for the substantial decreases in wetland areas.

Sparse vegetation experienced a mixed effect. In CCMA, it decreased by 19.01 sq. km (19.53%), while in KEEA, it increased by 14.31 sq. km (49.66%).

These changes may be related to land management practices, such as afforestation and reforestation efforts in KEEA, aimed at restoring degraded areas. In CCMA, the decline in Sparse Vegetation could be attributed to conversion for urban and agricultural purposes, influencing sediment transport and coastal dynamics.

The water class remained relatively stable in both regions, with minimal changes of -0.03 sq. km (-4.48%) in CCMA and -0.41 sq. km (-23.30%) in KEEA.

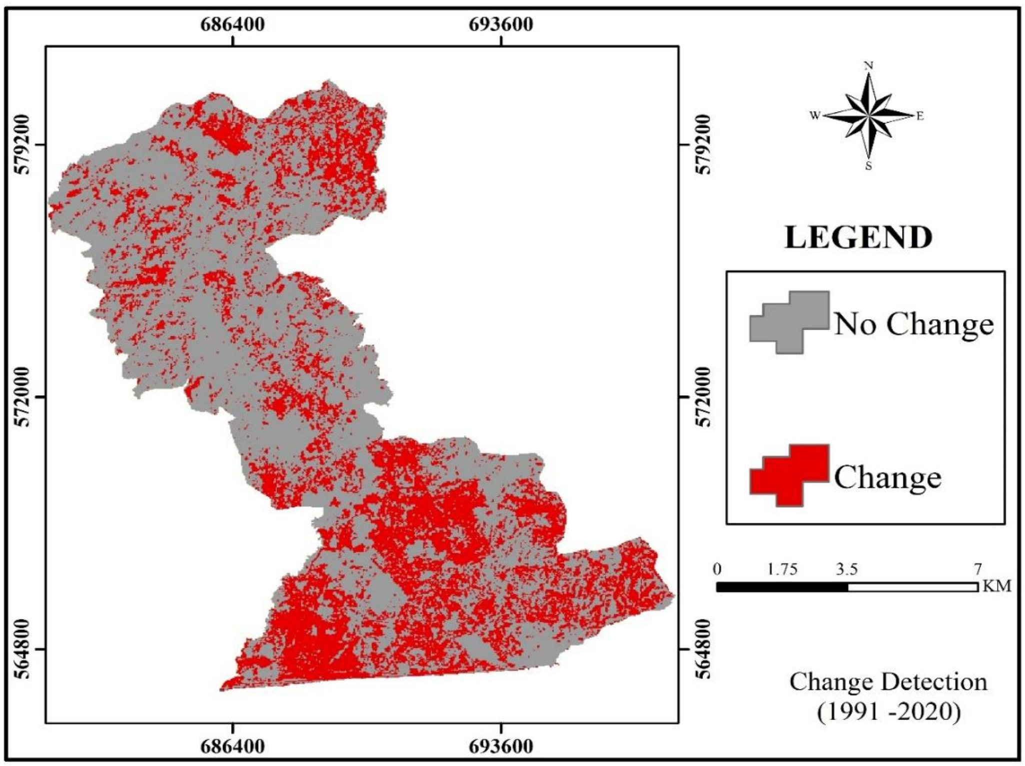

Figure 17: Change detection analysis for CCMA, 1991 – 2020.

Source: Osei, 2021.

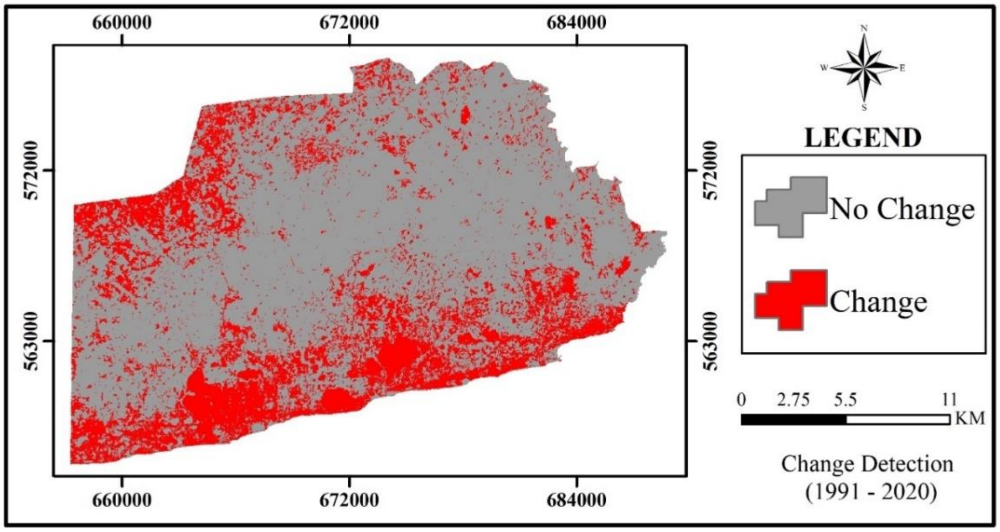

Figure 18: Change detection analysis for KEEA, 1991 – 2020.

Source: Osei, 2021.

Consequently, a further examination was undertaken utilizing the "Combinatorial And" tool within ArcMap version 10.5 to ascertain the specific categories that had undergone a transition from one state to another. The analytical tool produces two outputs: maps (Figure 16 and Figure 17) and basic statistics that illustrate the proportions of landscape types that have undergone changes estimated using the statistics provided in Table 8.

Figure 16 and Figure 17 show that the two municipalities' land cover has changed almost completely from one class to the other. This observation suggests that the landscape of both areas is subject to constant change. A notable percentage of the transformation took place in the southern part of the Cape Coast Metropolitan Area, whereas in KEEA Municipality, the experienced changes were primarily in the southern and northern regions. The changes that have emerged within the diverse categories of landcover classes are outlined in Table 8.

Table 8: Change Detection Statistics from 1991 to 2020

	1991 -2020 (Cape Coast Metropolitan Area)						
Class	Built-up	Dense Vegetation	Sparse vegetation	Water	Wetland	Barren Land	Total
Built-up	**6.13**	0.00	0.35	0.00	0.01	0.02	6.51
Dense Vegetation	0.86	**2.16**	7.25	0.01	0.32	0.00	10.60
Sparse vegetation	20.55	6.75	**69.99**	0.00	0.03	0.11	97.43
Water	0.00	0.00	0.00	**0.58**	0.07	0.00	0.66
Wetland	2.74	0.00	1.82	0.03	**0.71**	0.00	5.31
Barren Land	0.07	0.00	0.00	0.00	0.01	**0.03**	0.13
Total	30.35	8.91	79.41	0.64	1.16	0.17	120.64
	1991 -2020 (KEEA Municipal)						
Class	Built-up	Dense Vegetation	Sparse vegetation	Water	Wetland	Barren Land	Total
Built-up	**7.01**	0.00	0.65	0.00	0.10	0.01	7.77
Dense Vegetation	1.33	**1.87**	50.83	0.03	0.61	0.02	54.68
Sparse vegetation	19.99	5.81	**320.64**	0.00	0.06	0.03	346.53
Water	0.10	0.00	0.03	**0.83**	0.80	0.00	1.77
Wetland	12.76	0.00	23.90	0.37	**2.16**	0.01	39.20
Barren Land	0.03	0.00	0.00	0.00	0.01	**0.00**	0.05
Total	41.23	7.68	396.05	1.23	3.72	0.08	450.00

Source: Osei, 2022.

Table 8 illustrates that, in neither municipality, between 1991 and 2020, bare land did not transform into other landscape classifications or vice versa. Variations in the amount of barren land can be the cause of changes in covered area. Furthermore, Table 8's data shows that the Cape Coast Metropolitan Area's Built-Up area has seen a rise in the types of land cover, including wetlands, barren land, sparse vegetation, and dense vegetation.

The category of land cover that significantly contributed to the built-up area consisted of approximately 20.55 square kilometers of sporadically vegetated land. At 0.077 square kilometers, barren land was the land cover class with the least amount of conversion to built-up area. The Cape Coast Metropolitan Area covered a land area of 6.13 square kilometers when it was fully developed. Therefore, over the past thirty years, there has been a significant increase in built-up areas. However, many built-up areas changed into LULC categories (land use/cover) that are different from conventional land use, such as bare land, wetlands, and sparse vegetation. It is noteworthy to emphasize that the conversion rate seen in built-up regions is rather modest, with the largest converted area of 0.35 sq. km, predominantly characterized by sparse vegetation.

Similarly, Table 8 demonstrates that built-up areas in KEEA Municipality benefited greatly from sparse vegetation encompassing an area of 19.9 sq. km. The KEEA Municipality had the least amount of conversion from barren land to built-up areas, which was approximately 0.03 sq. km of barren land. In terms of built-up areas converting to other classes, it was discovered that sparse vegetation recorded the greatest value of 0.65 sq. km while barren land recorded the least value of 0.01 sq. km. This difference in values is because sparse vegetation is more difficult to classify than barren land. It is interesting to note that both municipalities had sparse vegetation significantly being converted to built-up areas.

Implications of Land Use Land Cover Changes for Human Activities on Beaches.

The most striking revelation from the study is the substantial increase in built-up areas in both municipalities. CCMA witnessed a growth of 24.84 sq. km (381.56%), while KEEA experienced an even more remarkable surge of 33.36 sq. km (437.87%). This rapid urbanization, averaging 0.83 sq. km per year for CCMA and 1.11 sq. km per year for KEEA, highlights the burgeoning trend of urban development particularly along the coast. The implications of this expansion are far-reaching, influencing not only the physical landscape but also impacting human activities reliant on coastal resources.

Conversely, wetlands, crucial ecosystems for biodiversity and coastal resilience, suffered significant declines. CCMA saw a reduction of 4.16 sq. km (78.34%), and KEEA experienced an even more substantial decline of 35.61 sq. km (90.47%). This reduction poses challenges for various human activities, particularly those dependent on wetland ecosystems. Loss of wetlands may adversely affect landing sites for canoes used in fishing, impacting the livelihoods of coastal communities.

Once more, the fishing industry faces challenges as a result of both the expansion of built-up areas and the reduction of wetlands. Fishermen may compete more fiercely for available spots if there are fewer canoe landing sites. Furthermore, traditional fishing grounds may disappear as a result of developed areas replacing alternative land use and land cover categories like wetlands and sparse vegetation. This change may hinder the fishing industry's future growth and the socioeconomic advancement of coastal communities.

Coastal regions often serve as recreational hubs, attracting tourists and locals alike. The increase in built-up areas may encroach upon recreational spaces, limiting opportunities for leisure activities. Additionally, the reduction in wetlands, which act as natural buffers, may expose sandy beaches to increased erosion risks. This puts the stability of the coastline in jeopardy, which affects not just recreational areas but also the long-term sustainability of coastal ecosystems.

Changes in Shorelines along the Beaches

The study area was split into four distinct zones, numbered Zone 1, Zone 2, Zone 3, and Zone 4, that ran from west to east. Zones 3 and 4 make up the Cape Coast section, while Zones 1 and 2 represent the Elmina section. The Erosion Progress Rate (EPR) and Linear Regression Rate (LRR) techniques were used to estimate the rates of erosion and accretion from 1991 to 2020. The maximum accretion rate in the Cape Coast section was 8 point42 m per year, while the maximum erosion rate in the Elmina section was −4.12 m per year, based on the LRR values. With the highest accretion rate of 7.47 m per year and the highest erosion rate of -4.67 m per year in the same areas, the EPR estimates were almost identical. In Elmina, the shoreline has moved forward by 133.44 m and backward by 213.58 m over the previous three decades, according to the Net Shoreline Movement (NSM) values.

Elmina Section

The region under consideration in this study is the eastern portion, which encompasses a coastline measuring 3.6 kilometres in length. The zone has a total of 74 transects, numbered consecutively from 1 to 74. The Coconut Grove Beach Resort, Awunafomu Community, and the Elmina Castle are situated within the defined region.

The Coconut Grove Beach Resort, which has a shoreline spanning 0.6 kilometres, has been divided into transects consisted of 1 through 12. A sea defence wall can be observed extending from transect 9 to 20 and from transect 36 and 69. Additionally, groynes are present between transect 25 and 34. Transects 13 to 51 encompass the Awunafomu community, which is characterized by a coastline measuring 2.2 kilometres in length. A 2.3-kilometre-long sea defence wall has been put to safeguard the Awunafomu. The Elmina Castle is situated within the geographical region delineated by transects 69 to 74.

Net Shoreline Movement (NSM) values for Zone 1 range from -13.11 to -103.97 meters, indicating a predominant erosional trend along the Elmina shoreline. The interpretation of NSM reveals High Erosion for all transects within Zone 1. The End Point Rate (EPR) values in Zone 1 vary between -0.46 and -3.84 meters per year. These values correspond to Moderate Erosion to High Erosion, with the majority (138 of 142 transects) falling under the category of High Erosion. Linear Regression Rate (LRR) values in Zone 1 range from 0.21 to -3.79 meters per year. Similar to NSM and EPR, the LRR analysis indicates High Erosion along the coastline of Zone 1.

In contrast, Zone 2 displays a different pattern. NSM values range from -133.44 to 213.58 meters, suggesting a mix of erosional and accretional processes. Transects 74 to 76 demonstrate High Accretion, with positive NSM values indicating a gain in shoreline position. EPR values for Zone 2 vary between -4.67 and 7.47 meters per year. While High Erosion is observed in transects 77 to 79, High Accretion is evident in transects 74 to 76, showcasing the dynamic nature of Zone 2. LRR values for Zone 2 range from -4.12 to 8.42 meters per year. The analysis reveals High Erosion in transects 77 to 79 and High Accretion in transects 74 to 76, further supporting the diverse shoreline changes observed in Zone 2.

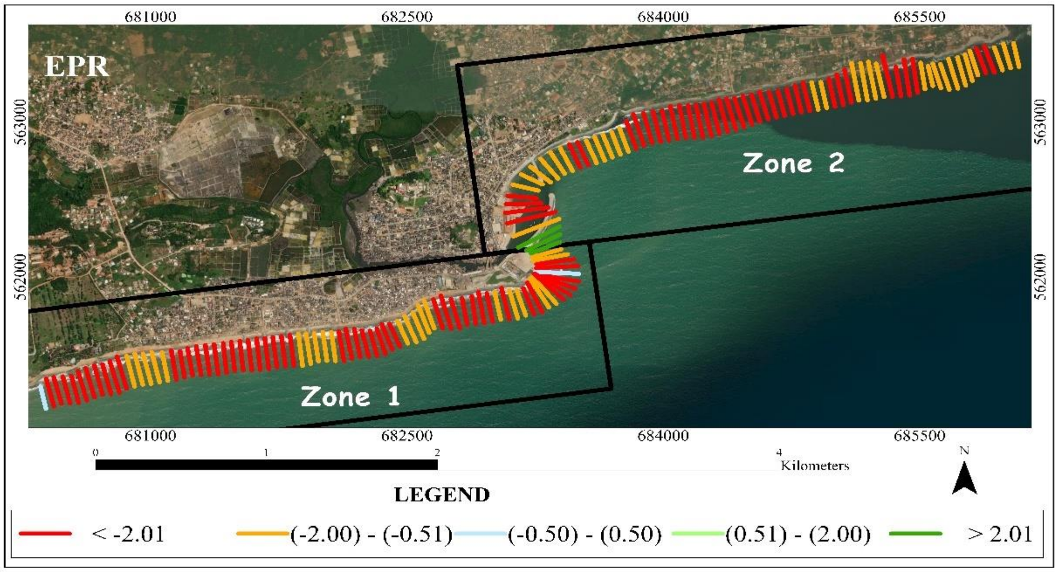

Figure 19: End Point Rate for Elmina Section

Source: Osei, 2021.

The comparison of extracted shorelines from various years reveals significant fluctuations within this area. The analysis conducted using DSAS v. X reveals that there has been substantial erosion along the coast of Zone 1 during the period spanning from 1991 to 2020. The Zone 1 shoreline undergoes varying shifts, ranging from -3.64 m to 7.47 m per year, as determined by the EPR method. On average, the shoreline migrates at a rate of -2.04 m per year. The LRR method was utilized to determine the annual shoreline movement for the Zone. The results from Figure 18 indicate the movement ranges from -3.22 to 8.42 m per year, with a mean of -2.00 m per year. The value obtained through the LRR method is comparatively lower than that of the EPR method. Within the

Zone 1 region, a significant proportion of the coastal area, specifically 97.3%, is subject to erosion. Conversely, a minor fraction, amounting to 1.3%, exhibits accretion, primarily concentrated at Transect 74. A mere 1.3% of the coastal area in zone 1 exhibits stability, characterized by the absence of erosion or accretion processes. Negative values are found along 70 of the 74 transects in Zone 1. Transects along which accretion is noticed are located in the Estuary near Elmina Castle and are due to the accretion of sediments on the Western side of the Castle for protection of the structure.

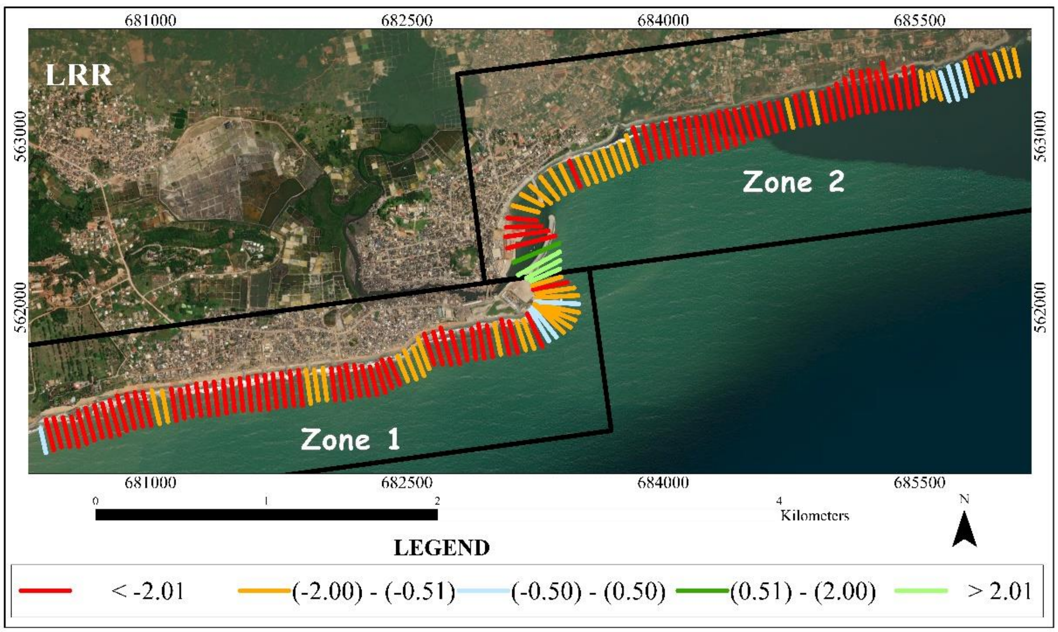

Figure 20: Linear Regression Rate for Elmina Segment

Source: Osei, 2021.

Zone 2

This study encompasses the Zone 2, spanning a length of approximately 4.22 kilometres. Within this zone, there are a total of 67 transects, numbered from 75 to 142. The geographical area under consideration encompasses Elmina Town, spanning from transect 74 to 92, Elmina Beach Resort, spanning from transect 100 to 108, and the Iture Community, spanning from transect 129 to 142. Elmina Township has a coastal length of approximately 1.2 kilometres, Elmina Beach Resort has a coastal length of 345 meters, and Iture Community has a coastal length of 560 meters.

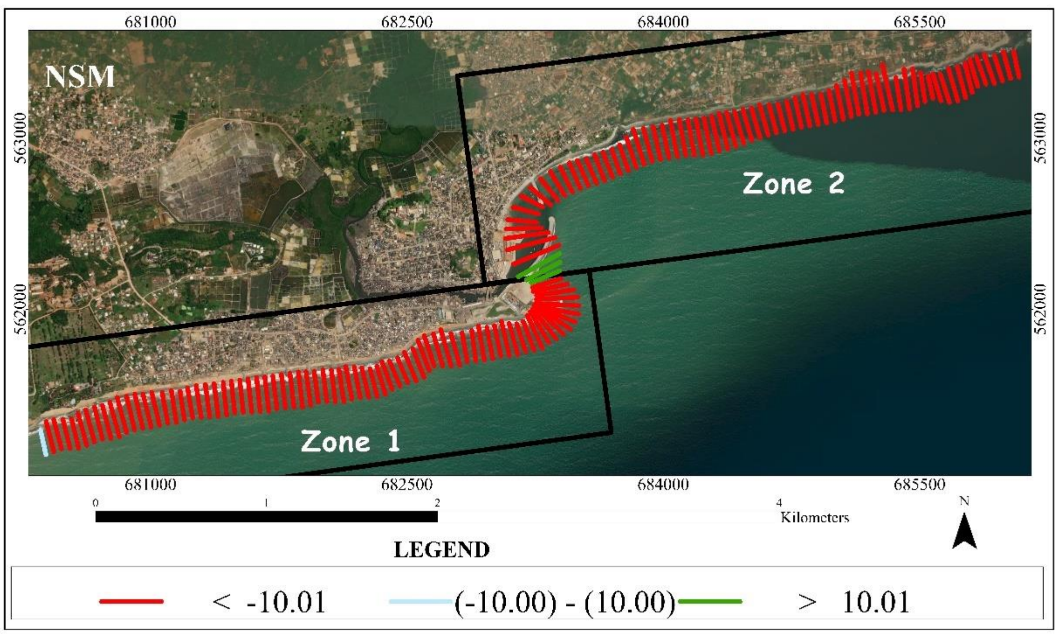

Figure 21: Net Shoreline Movement for Elmina Section

Source: Osei, 2021.

The analysis conducted using DSAS (as depicted in Figure 20) reveals that Zone 2 experienced substantial erosion during the period spanning from 1991 to 2020. The dominant category of coastal areas is characterized by high erosion, followed by low accretion.

The average annual movement is determined to be -2.01 m, indicating that erosion is the predominant process in Zone 2. The shoreline displacement, as determined by the NSM method, varies between -4.67 m and -0.63 mdot. The LRR method is used to calculate the shoreline movement, which results in an average of -1 point97 meters per year and a range of 0 point96 meters to -4 point12 meters per year. There is accretion at the Benya Estuary in the coastal region between transects 75 and 77. The rates produced by the LRR method range from 0.96 to 7.98 m per year, while the rates produced by the EPR method range from -0.63 to 7.4 m per year. A continuously stable coastal region with change rates ranging from -1.09 m to -1.81 m per year (determined by the EPR method) and from -0.11 m to -0.44 m per year (determined by the LRR method) is present within the Iture communities. There is a considerable amount of erosion on Traverse 78, which is located in the Kakum Estuary.

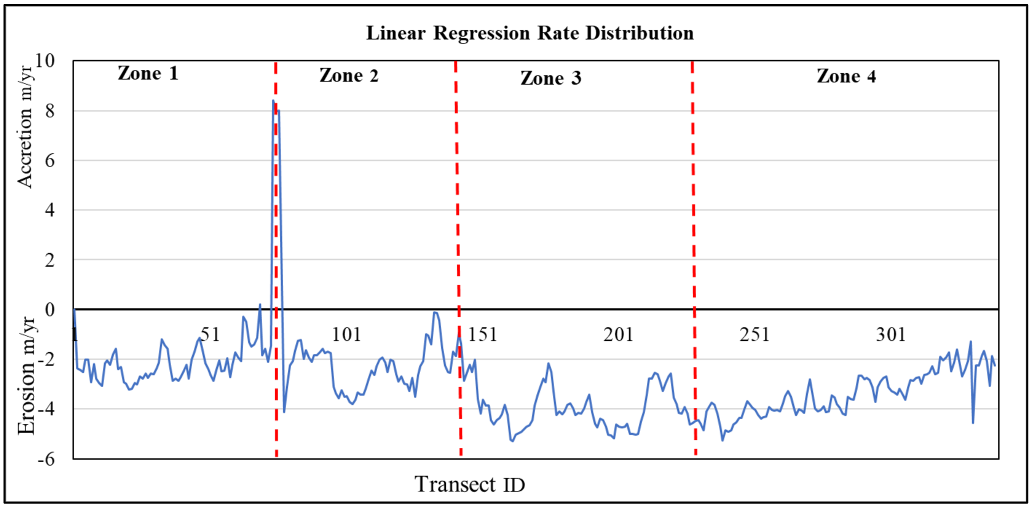

Figure 22: Profiles of erosion and accretion in the four different zones of Elmina-Cape Coast shoreline using LRR estimated between 1991 and 2020.

Source: Osei, 2021.

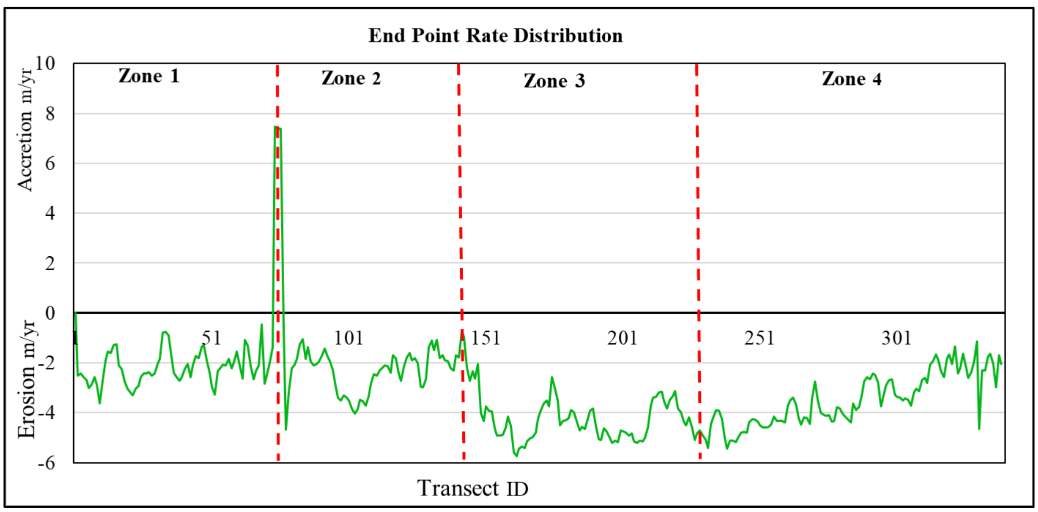

Figure 23: Profiles of erosion and accretion in the four different zones of Elmina-Cape Coast shoreline using EPR estimated between 1991 and 2020.

Source: Osei, 2021.

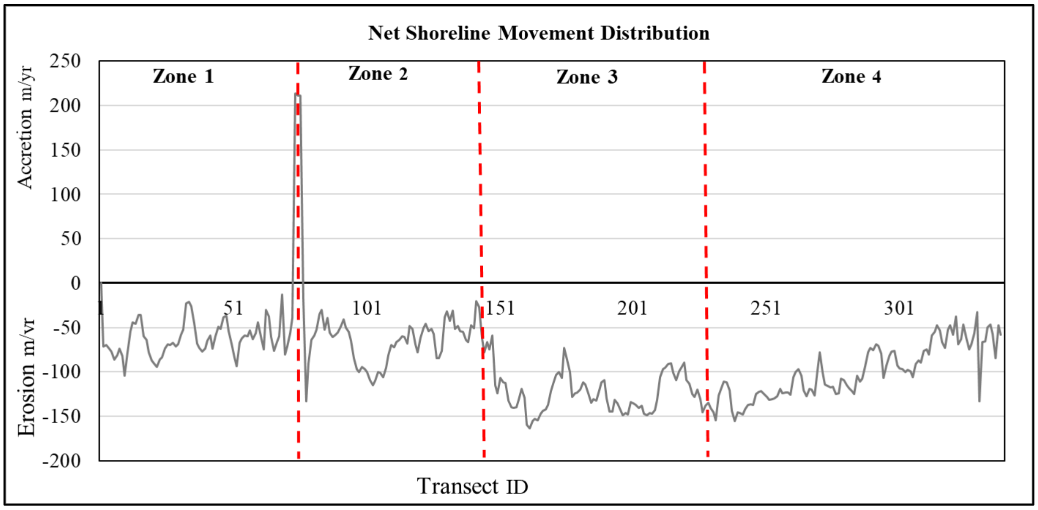

Figure 24: Profiles of erosion and accretion in the four different zones of Elmina-Cape Coast shoreline using NSM estimated between 1991 and 2020

Source: Osei, 2021.

Table 9: Summary of shoreline changes between 1991 and 2020 using LRR, EPR and NSM

Shoreline Segment	Linear Regression Rate		End Point Rate		Net Shoreline Movement	
	High	Low	High	Low	High	Low
Elmina	8.42	-4.12	7.47	-4.67	213.58	-133.44
Cape Coast	-1.36	-5.3	-0.95	-5.74	-27.05	-164.05

Source: Osei, 2021.

Zone 3

This stretch is about 4.3 km coastal length with sandy beach. This Zone contains 86 transects starting from 143 to 228. Beach resort like Shipyard Beach Resort, Heritage Beach Resort and Hutchland Beach Resort (constructed after the year 2020) under temporary license approval by CCMA, are situated along this coastal zone. These beach resorts are covered by transect 190 to 204 and transect 226 to 228. The results of analysis using DSAS (Table 9) for Zone-3 show that the shoreline shift ranges from -0.95 m to -5.74 m per year by EPR method and the average migration is -4.24 m per year. By LRR method the shoreline migration is calculated to vary between -1.71 m per year and -5.26 m per year with a mean of -3.94 m per year.

The location of the beach resorts along this stretch are affected by the extension erosion (Fig 24) due to the massive anthropogenic activities. The change rate shows high erosion consisting of 98 percent of the transect along Zone 3 while only 2 percent of the transects are characterized as moderate erosion as show in Figure 24. The LRR analysis shows the massive erosion activities occurring along the coast as 26 percent of the transect indicate moderate erosion while 74 percent shows high erosion as depicted in Figure 25. The result of NSM shows that the varying levels of erosion from 1991-2020 (Zone 3) as between -27.05 m and −138.09 m, with an average distance of shoreline change as −121.20 m.

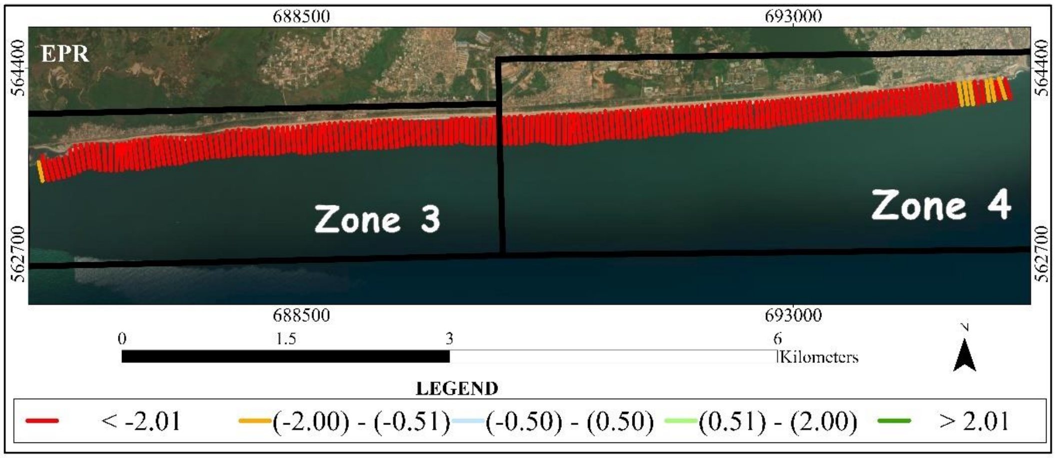

Figure 25: End Point Rate for Cape Coast Section

Source: Osei, 2021.

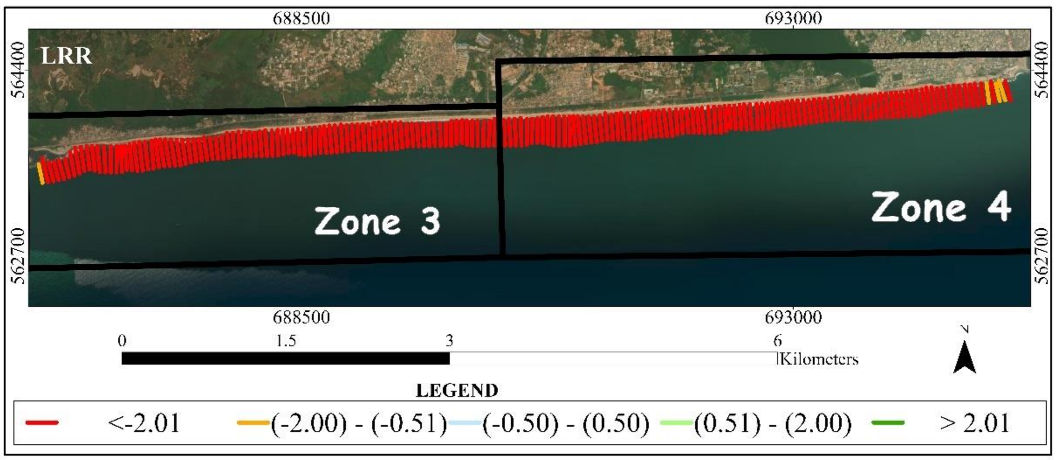

Figure 26: Linear Regression Rate for Cape Coast Segment

Source: Osei, 2021.

Zone 4

This stretch is about 4.7 km in coastal length and extends from transect 229 to 323. The stretch covers the De Breeze Beach Resort, the Ola Community to Cape Coast Castle. A sea defence line is located along transect 298 to 323. The zone contains 95 transects and the details of transects are shown in Figure 26. The results of analysis using DSAS (Figure 26) show that between 1991 to 2020, the coast along Zone 4 underwent significant erosion. The shoreline shift ranges from -1.33 m to -5.43 m by EPR method and the average migration is -3.70 m per year indicating that high erosion is dominant in Zone 4. By LRR method the shoreline migration is calculated to vary between -1.71 m per year and -5.26 m per year with a mean of -3.59 m per year

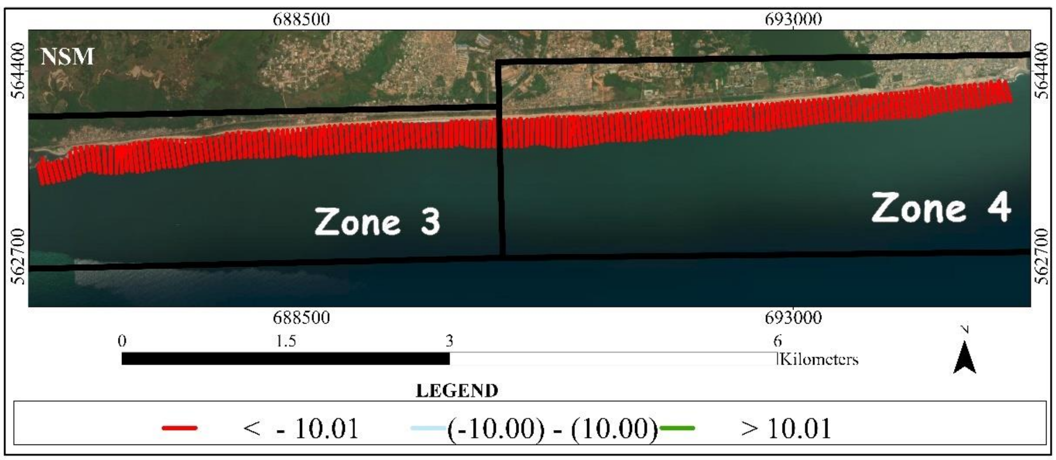

Figure 27: Net Shoreline Movement for Cape Coast Segment

Source: Osei, 2021.

Implications of Shoreline Changes for Human Activities on Beaches.

In Zone 1 of Elmina, the shoreline displays an average migration of -2.04 m per year according to the EPR method, with 97.3% of the coastal area undergoing erosion. Limited areas, like Transect 74, experience accretion due to sediment buildup from structural protection.

Conversely, Zone 2 witnesses' substantial erosion with an average annual movement of -2.01 m. Accretion, is however, observed at the Kakum Estuary region, highlighting localized stability. The implications for human activities, such as fishing and recreational ventures, are evident as erosion restricts landing sites for canoes and limits expansion in the fishing industry.

Zone 3, spanning 4.3 km with sandy beaches, is home to beach resorts and experiences high erosion rates averaging -4.24 m per year (EPR). The presence of beach resorts is affected by anthropogenic activities, leading to massive erosion.

In contrast, Zone 4, covering 4.7 km, exhibits significant erosion dominance with an average migration of -3.70 m per year (EPR). The Ola Community to Cape Coast Castle faces high erosion, impacting coastal activities. Both zones underscore the vulnerability of sandy beaches and the challenges faced by human settlements.

Sandy beaches in both zones experience severe erosion, as indicated by the LRR method, raising concerns about beach stability and health. The analysis reveals a substantial reduction in shoreline distances, signifying potential threats to beach ecosystems and recreational activities. Beach resorts in Zone 3 and Zone 4 face challenges from erosion, affecting the stability of the coastline and the overall health of the sandy beaches.

Chapter Summary

In this chapter, remote sensing data covering three decades was used to study the morphological changes along the Cape Coast-Elmina coastline. According to the analysis, both natural and human-caused changes have significantly altered the morphology of beaches. Identifying important drivers like wave action, sediment supply, and anthropogenic factors like urban development and sand mining, the chapter described the patterns of erosion and accretion observed along various beach segments. The results emphasized the constant difficulties in properly managing these coastal environments as well as their dynamic character. In order to mitigate the negative effects of beach erosion and promote sustainable coastal development, integrated strategies are essential, as the chapter's conclusions for coastal management made clear.

CHAPTER SIX

ASSESSING CHANGES IN GRANULOMETRIC CHARACTERISTICS OF BEACHES ALONG THE CAPE COAST - ELMINA COASTLINE

Introduction

The coastal dynamics of Ghana's Cape Coast – Elmina coastline have been subject to increasing scrutiny due to their vulnerability to various environmental factors. Understanding the dynamics of coastal beaches is crucial for various reasons including coastal management, habitat conservation, and hazard mitigation. Research on the size of the particles in beach sediments provides vital evidence about the properties of the sediments themselves and the environments in which they are deposited. (Rajaganapathi et al., 2013; Rashedi and Siad, 2016) Through meticulous laboratory analysis and advanced statistical techniques, this study investigates the sedimentary compositions and their seasonal variations along this coastline.

Frequency distribution of beach sediments

The laboratory analysis results were further processed using Gradistat v.9.1 software. All of the sampled sediments from the beaches along the study area's coastline have a unimodal distribution. This represents the dominance of one sedimentary stock. The frequency distributions and representative frequency curves for Zones 1, 2, 3, and 4 of the sampled sediment during the dry season are shown in Figures 28, 29, 30, and 31.

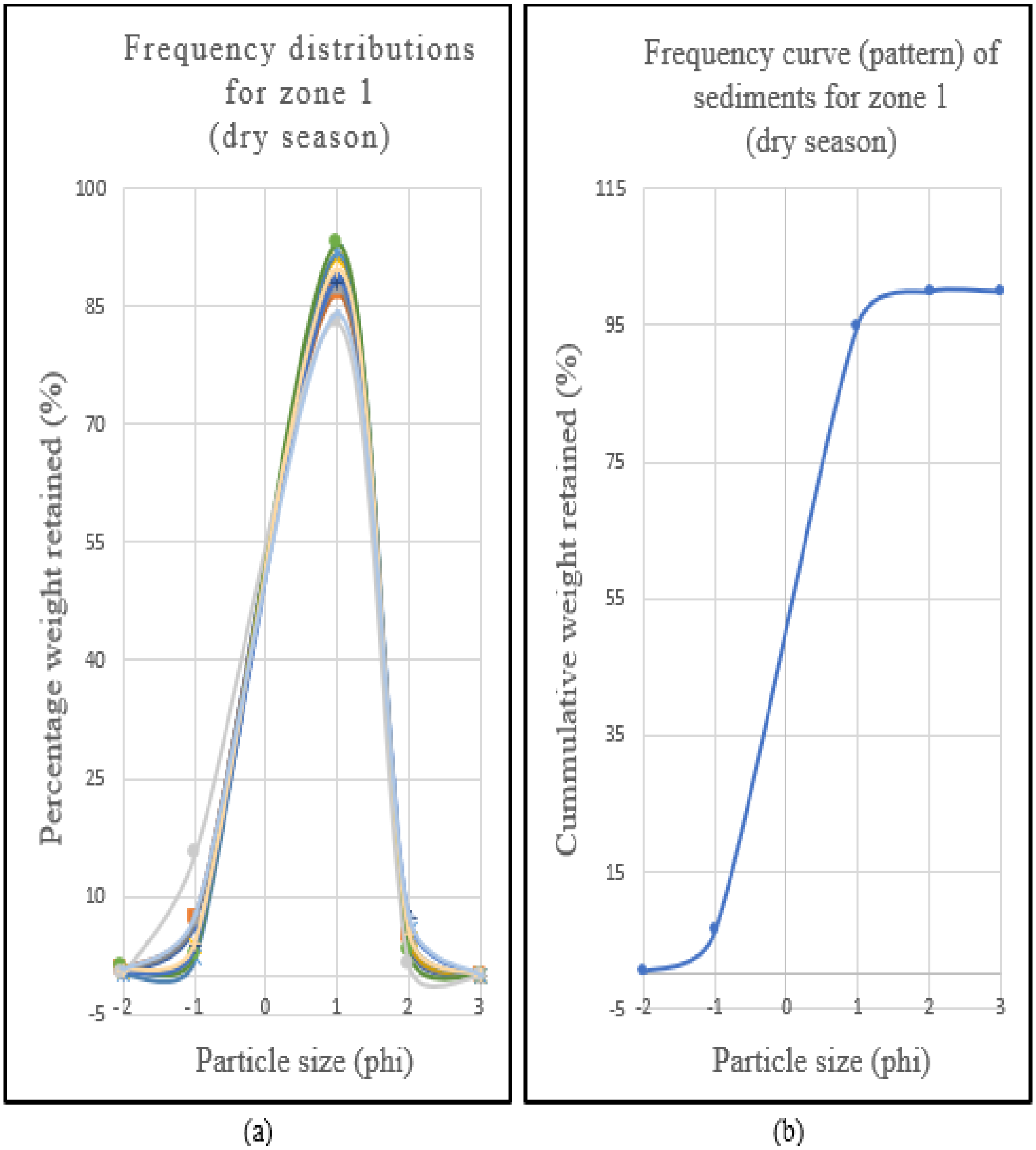

Figure 28: Frequency distribution and curve for zone 1 (dry season), (a) Frequency distribution of zone 1 sediments; (b) Frequency curve of zone 1 sediments.

Source: Osei, 2021.

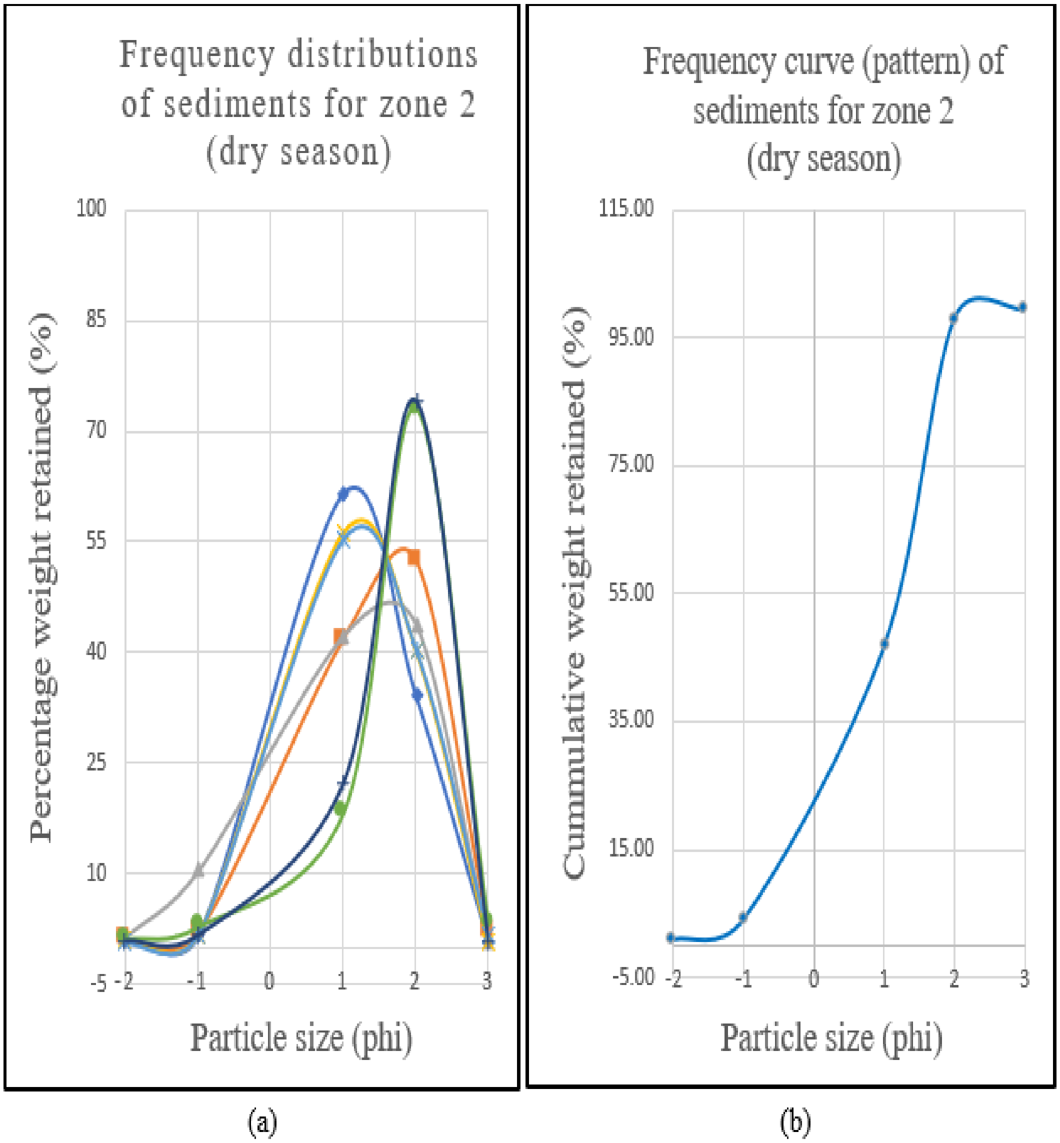

Figure 29: Frequency distribution and curve for zone 2 (dry season), (a) Frequency distribution of zone 2 sediments; (b) Frequency curve of zone 2 sediments.

Source: Osei, 2021.

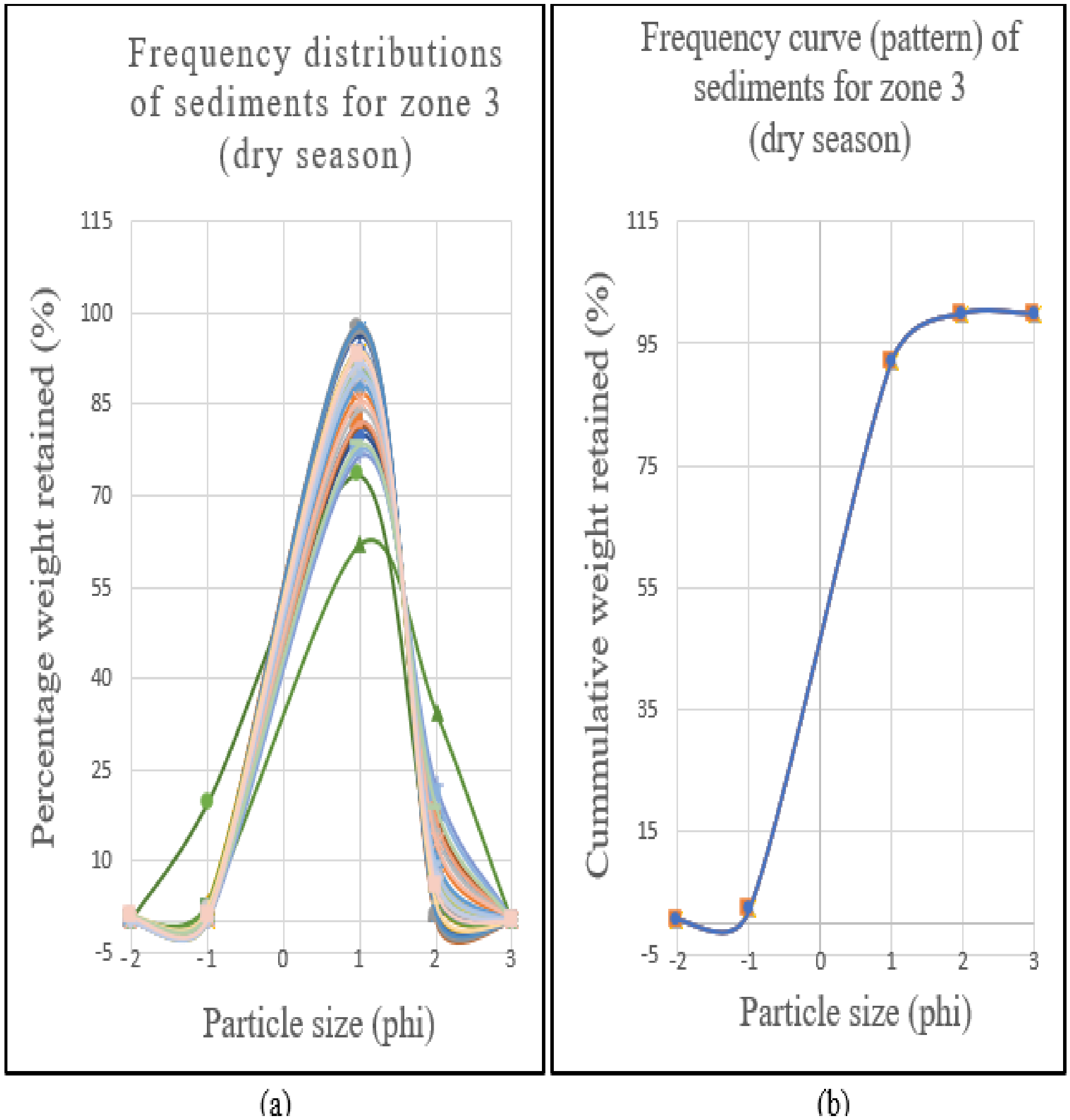

Figure 30: Frequency distribution and curve for zone 3 (dry season), (a) Frequency distribution of zone 3 sediments; (b) Frequency curve of zone 3 sediments.

Source: Osei, 2021.

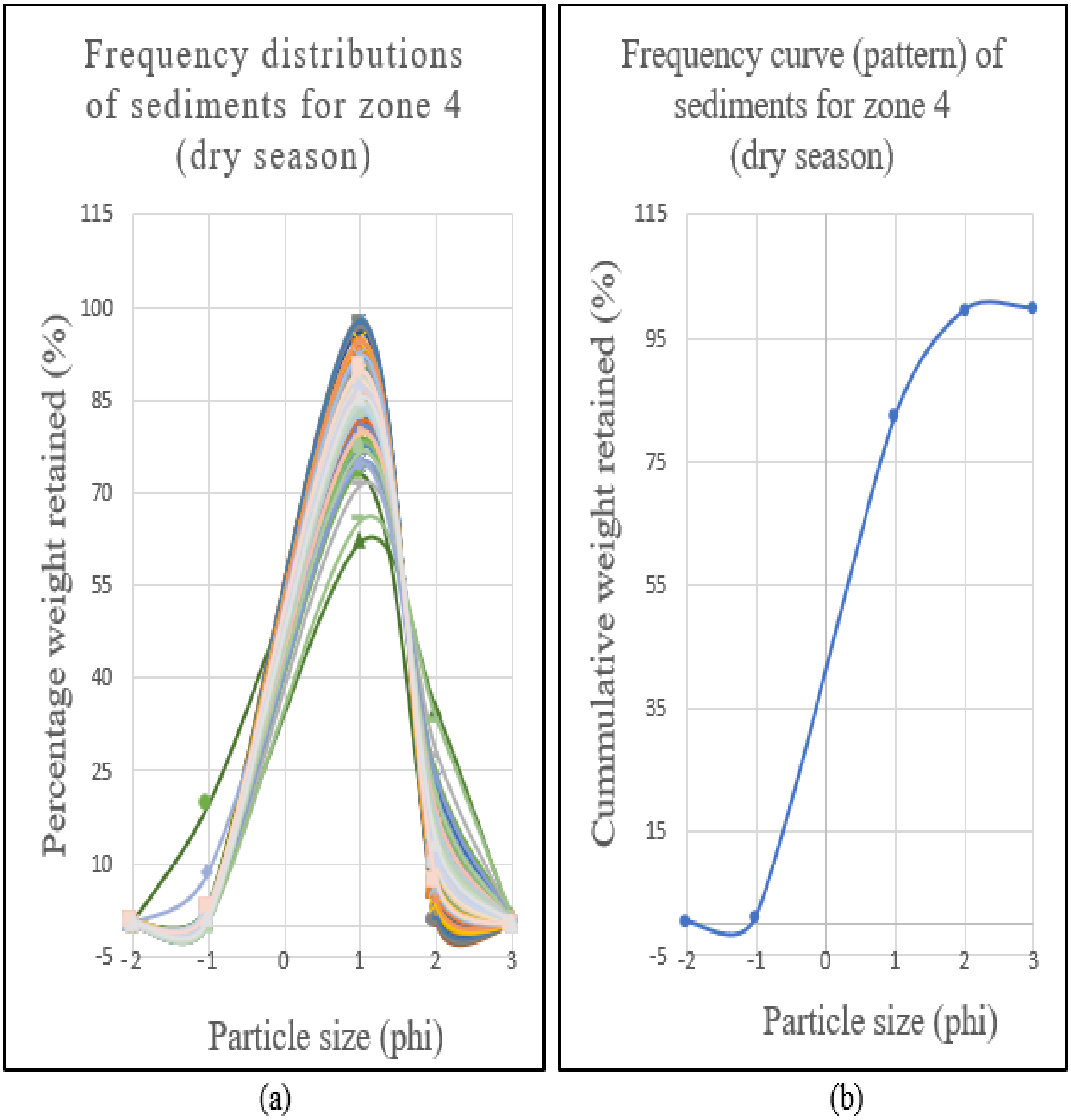

Figure 31: Frequency distribution and curve for zone 4 (dry season), (a) Frequency distribution of zone 4 sediments; (b) Frequency curve of zone 4 sediments.

Source: Osei, 2021.

Figures 32, 33, 34, and 35 are frequency distributions and representative frequency curves for Zone 1, Zone 2, Zone 3 and Zone 4 respectively, of sampled sediment in the wet season.

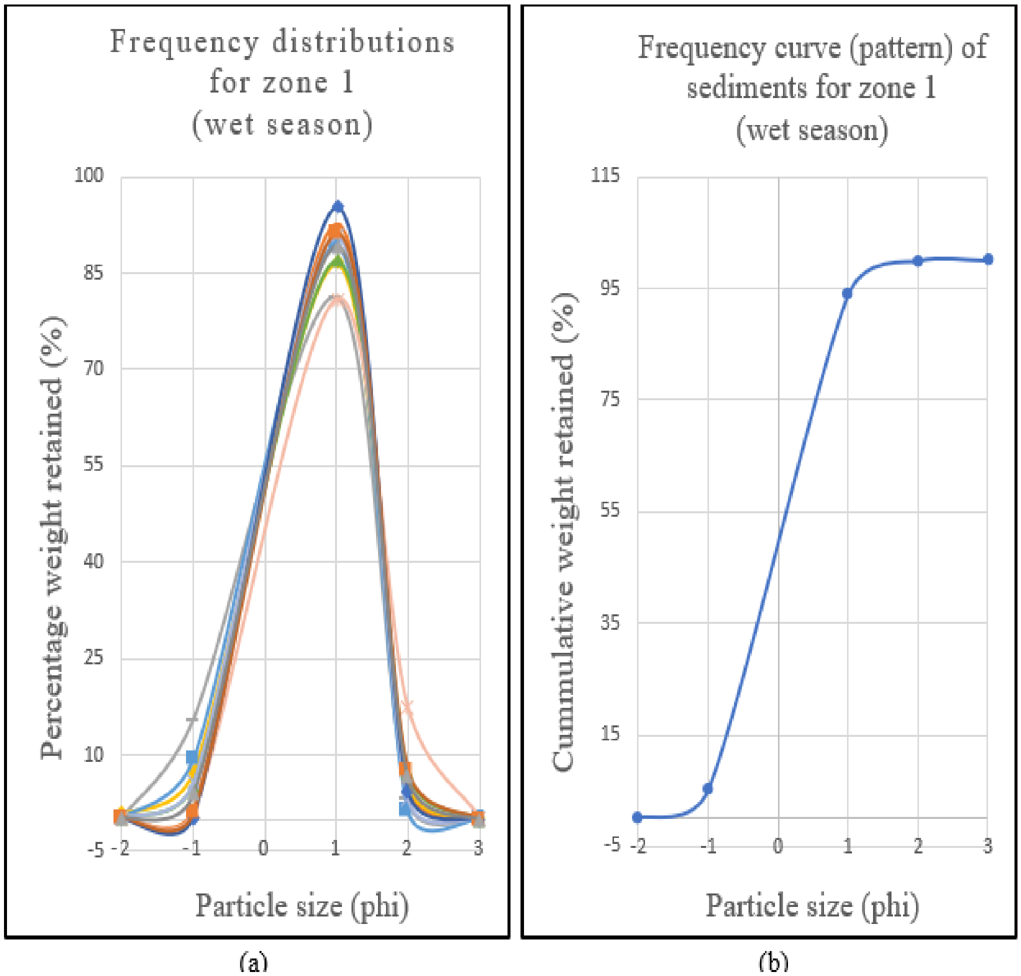

Figure 32: Frequency distribution and curve for zone 1 (wet season), (a) Frequency distribution of zone 1 sediments; (b) Frequency curve of zone 1 sediments.

Source: Osei, 2021.

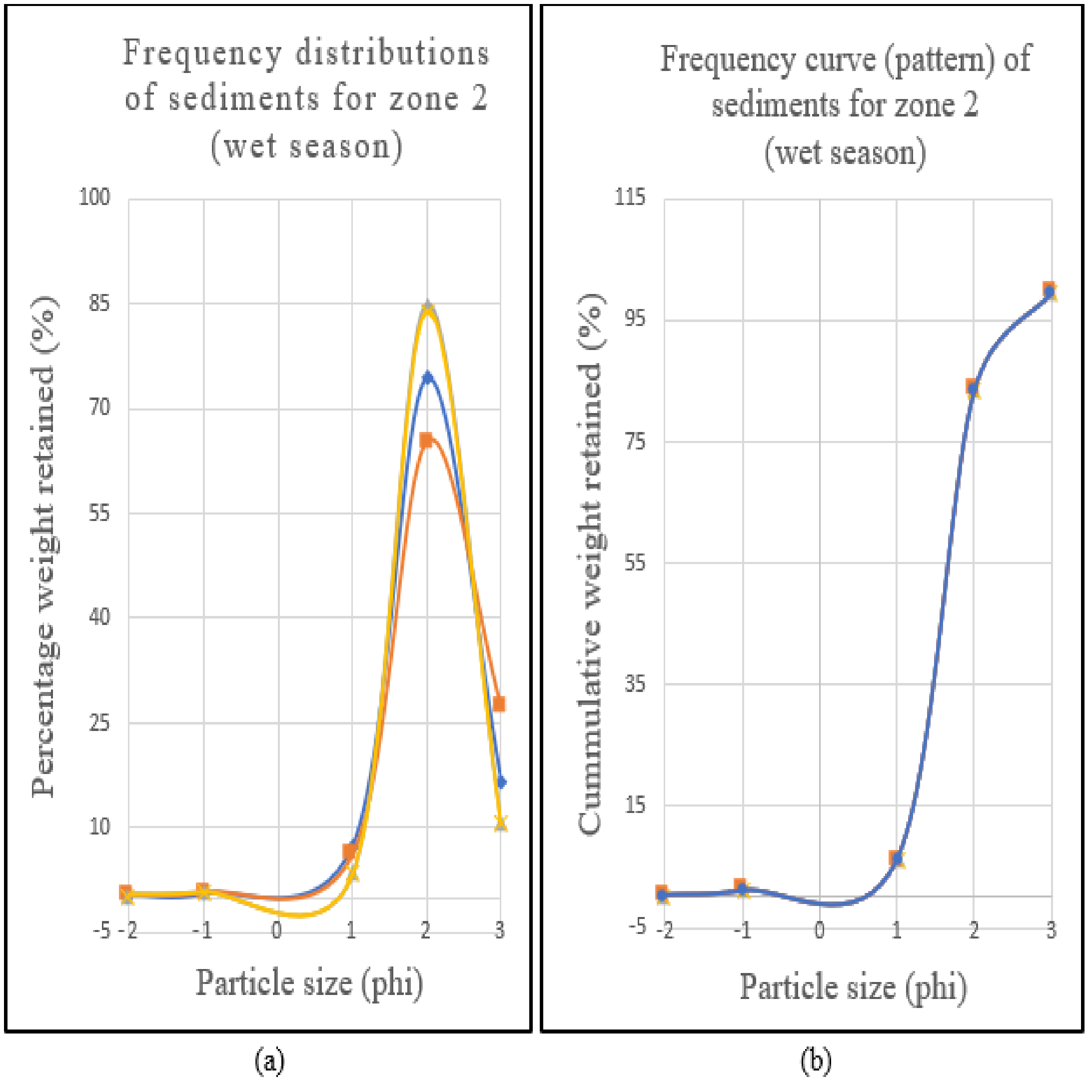

Figure 33: Frequency distribution and curve for zone 2 (wet season), (a) Frequency distribution of zone 2 sediments; (b) Frequency curve of zone 2 sediments.

Source: Osei, 2021.

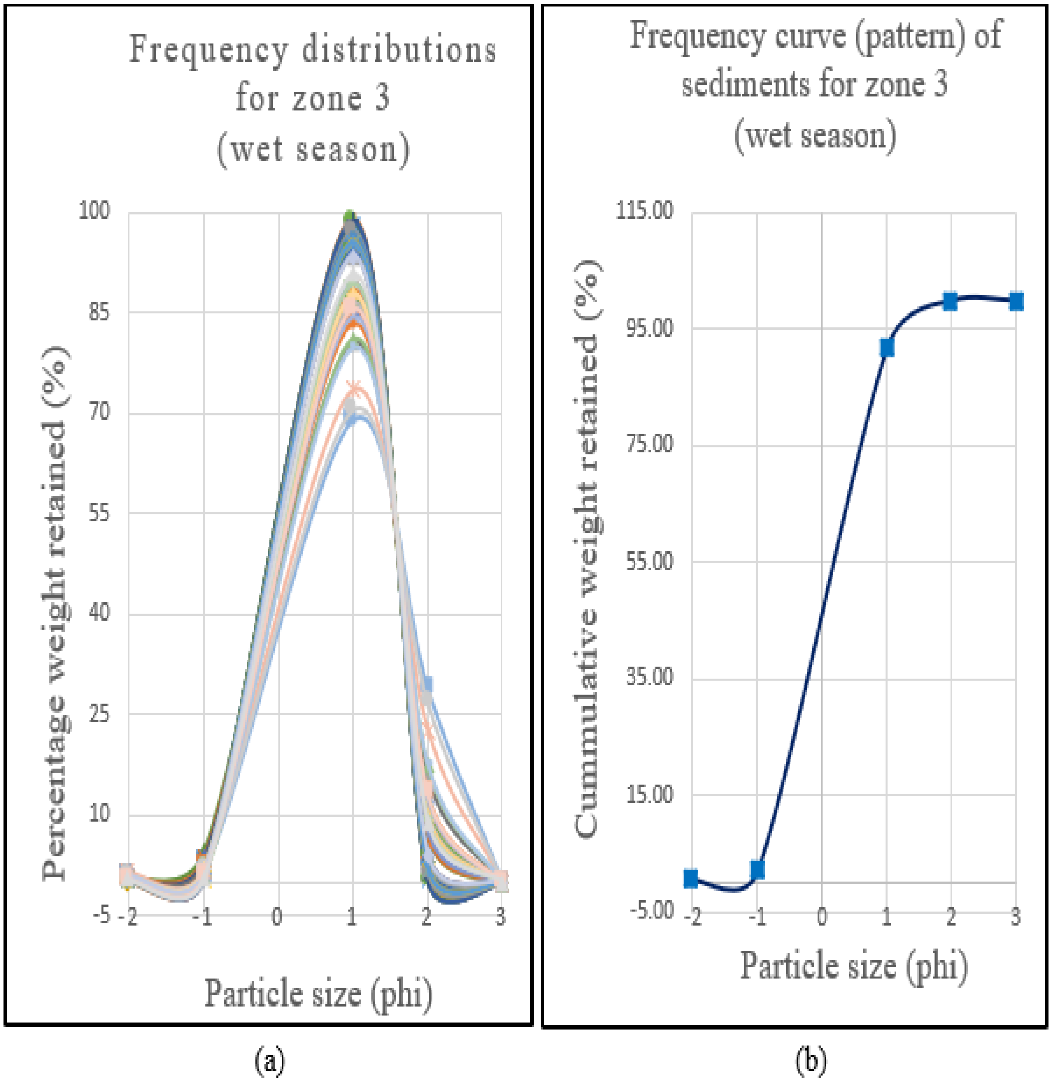

Figure 34: Frequency distribution and curve for zone 3 (wet season), (a) Frequency distribution of zone 3 sediments; (b) Frequency curve of zone 3 sediments.

Source: Osei, 2021.

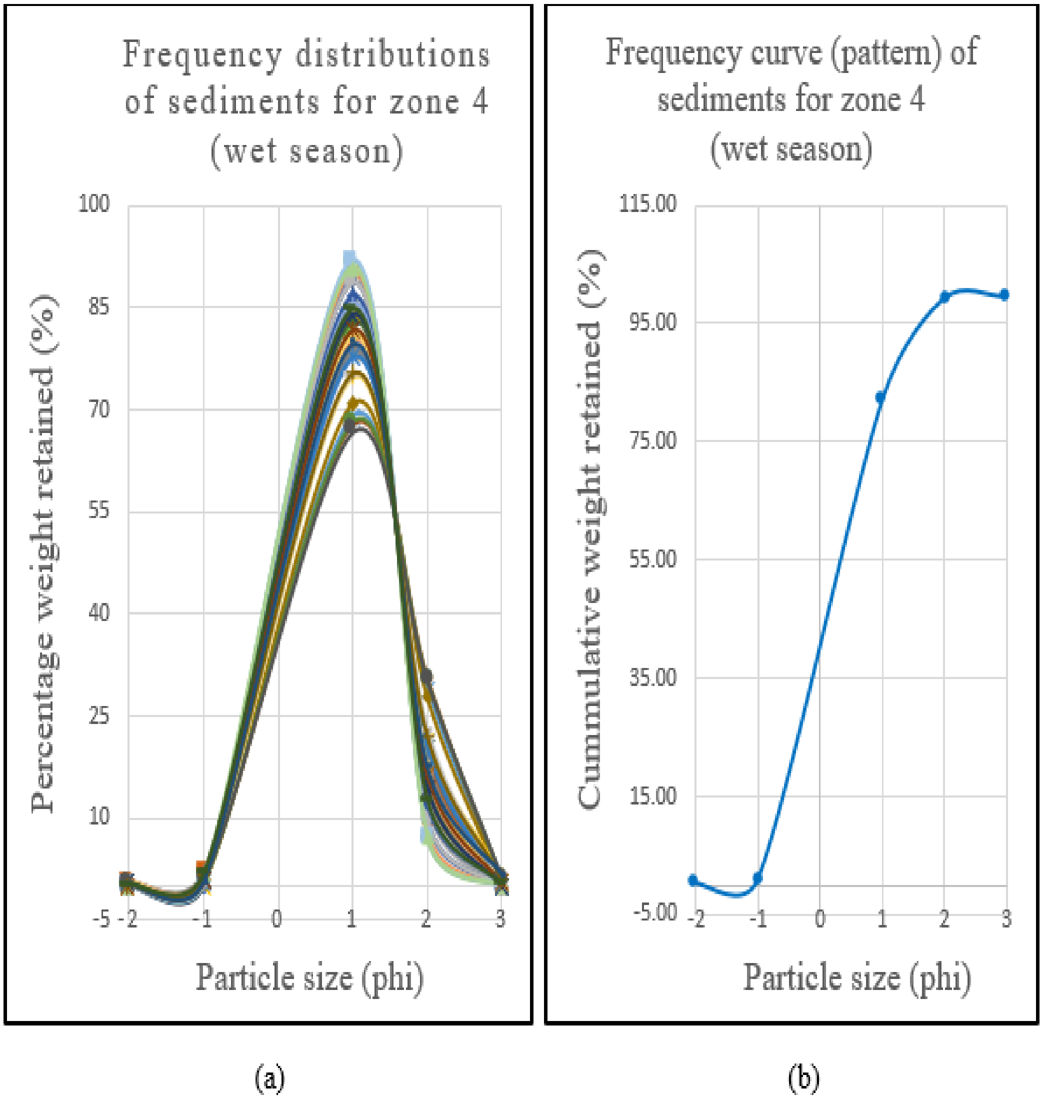

Figure 35: Frequency distribution and curve for zone 4 (wet season), (a) Frequency distribution of zone 4 sediments; (b) Frequency curve of zone 4 sediments.

Source: Osei, 2021.

Particle-Size Analysis of Beach Sediments

Zone 1 and Zone 2 together represent the Elmina beach and were considered the western and eastern part of Elmina in the study. Zone 3 and Zone 4 made up the Cape Coast beach, with Zone 3 representing the western and Zone 4 representing the eastern part of Cape Coast in this study.

Elmina Beach in the dry season

Table 10 displays a summary of the results for Zone 1 and Zone 2 on the mean, sorting, skewness, and kurtosis of sediments sampled in the dry season from Elmina. Appendix D provides information on the statistical analysis of all sampled beach sediments of Zone 1, while Appendix E provides the interpretation of the statistics so determined. Similarly, Appendix F provides information on the statistical analysis of all sampled beach sediments of Zone 2, while Appendix G provides the interpretation of the statistics determined.

Zone 1 exhibits a mean (Mz) of -0.022Φ, with an average of -0.173Φ to 0.035Φ among the sediments sampled (see Table 10 below). This suggests that there is a shift in the sediment's particle sizes from very coarse to coarse sand. The sediments that were sampled showed a sorting (σ) index that varied from 0.656 Φ to 0.825 Φ, indicating that the distribution of particle sizes around the mean particle size was moderately well-sorted to partially sorted. All sampled zone sediments were symmetrical, as indicated by the skewness (SK1) values, which ranged from -0.083 to 0.059, a measure of the degree of asymmetry in the particle size distribution of sediments. Sands had kurtosis (KG) values ranging from 0.738 to 0.957. A shift from platykurtic to mesokurtic in the distribution peak is indicated by this. An orthophoto map of Zone 1 is presented in Figure 36 below, along with the results of the sorting analysis and the locations of the sediments studied.

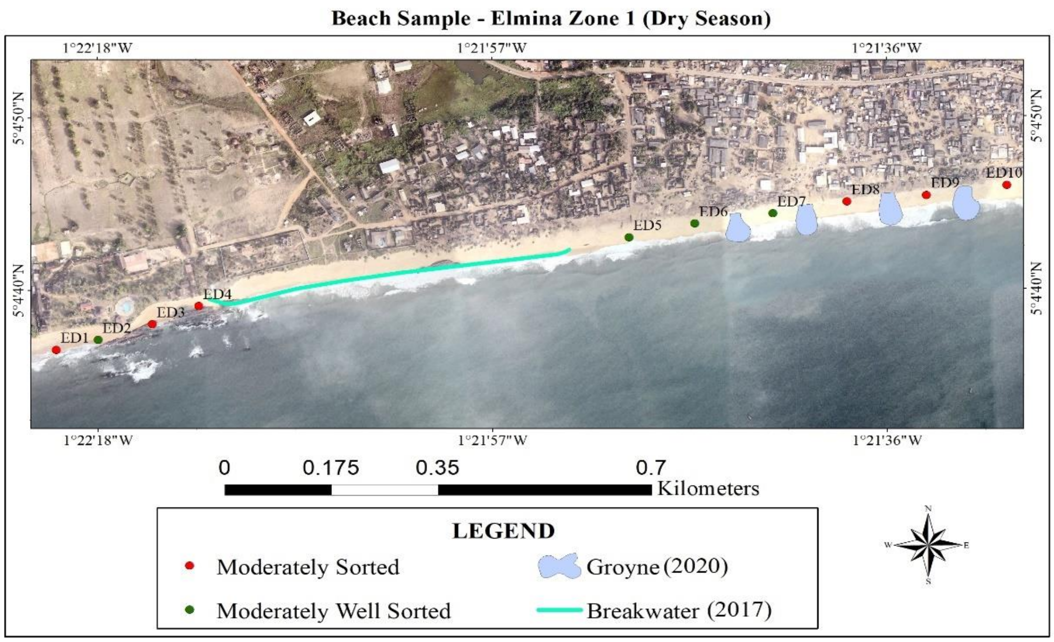

Figure 36: An orthophoto map of Zone 1, showing locations of sampled beach sediments in the dry season and outcome of laboratory analysis.

Source: Osei, 2022.

With an average of 0.760Φ, the mean (Mz) values of the sampled sediments in Zone 2 and during the dry season ranged from -0.501Φ to 1.160Φ (Table 10). This indicates a change in sediment particle sizes from medium to coarse sand. With a range of 0.813Φ to 1.164Φ, the sorting (σ) index of the sediments under study showed that the distribution of particle sizes around the mean particle size varied from moderately sorted to poorly sorted. Asymmetry levels in the sediment particle size distribution ranged from extremely coarse skewed to symmetrical, according to the skewness (SK1) values, which varied from -0.492 to -0.032. The range of values for sediment kurtosis (KG) was 0.718 to 1.749. The peak of the distribution shows platykurtic to very leptokurtic fluctuation. The geolocation of the sediment samples and the outcomes of the sorting analysis are displayed on the orthophoto map of Zone 2 in Figure 37 below.

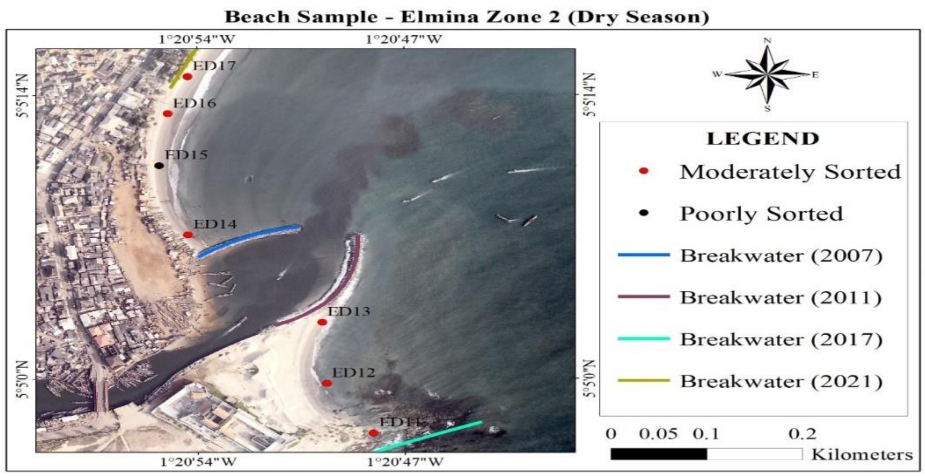

Figure 37: An orthophoto map of Zone 2 showing locations of sampled beach sediment in the dry season and the outcome of laboratory analysis.

Source: Osei, 2022.

Cape Coast Beach in the Dry Season

Table 11 summarizes the results for Zones 3 and 4 about the mean, sorting, skewness, and kurtosis of the sediments collected from Cape Coast during the dry season. Appendix H contains the statistical analysis of all the Zone 3 beach sediment samples, and Appendix I provides an explanation of the findings. Once more, Appendix J offers details on the statistical examination of every beach sediment sampled in Zone 4, and Appendix K offers an interpretation of the results.

In Zone 3, the mean (Mz) values of the sediments sampled range from -0.214Φ to 0.485Φ with an average of 0.093Φ (Table 11). This suggests that there is a shift in the sediments' particle sizes from very coarse to coarse sand. The type of distribution of particle sizes around the mean particle size varied from moderately well sorted to moderately sorted, according to the sorting (σ) index of the sediments sampled, which ranged from 0.623Φ to 0.955Φ. All of the zone's sampled sediments were symmetrical, as indicated by the skewness (SK1) values, which indicate the degree of asymmetry in the particle size distribution of the sediments. These values ranged from -0.050 to 0.097. The kurtosis (KG) values of the sediments varied from 0.727 to 0.906, and the distributions of all the sample peaks were platykurtic (Appendix I). The figure below, Figure 38, shows the location of the sediments that were sampled as well as the sorting analysis results.

Beach Sample - Cape Coast Zone 3 (Dry Season)

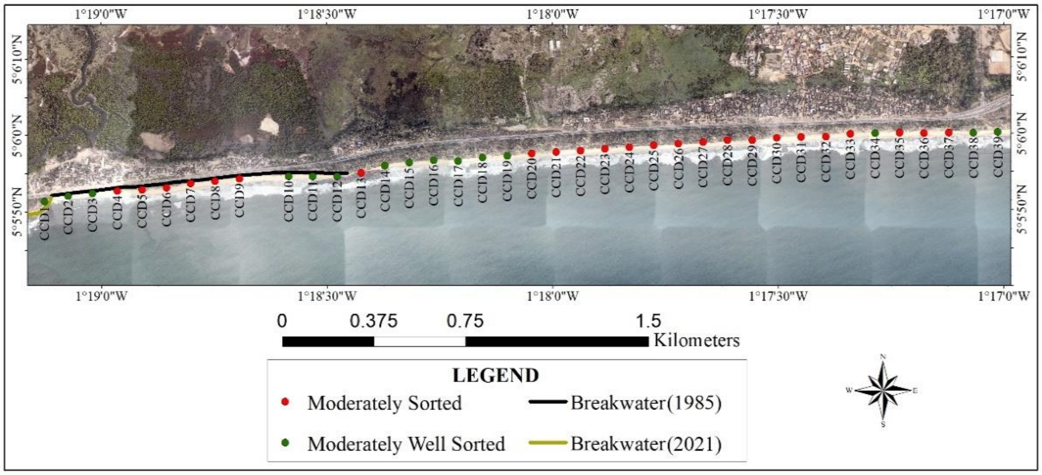

Figure 38: An orthophoto map of Zone 3 showing locations of sampled beach sediments in the dry season and outcome of laboratory analysis.

Source: Osei, 2022.

The mean (Mz) values of the sampled sediments for Zone 4, during the dry season, ranged from -0.019Φ to 0.500Φ (Table 11), with an average of 0.157Φ. Every sediment sampled contained coarse sand (Appendix K). The sediments that were analyzed showed a sorting (σ) index that varied from 0.646Φ to 0.933Φ, suggesting that the distribution of particle sizes around the mean particle size was partially sorted to somewhat sorted. The values of the skewness (SK1) varied from -0.003 to -0.097. Appendix K shows that every sediment sampled was symmetrical. The values of sediment kurtosis (KG) varied from 0.971 to 0.737. This suggests that peak 2 of the distribution fluctuates from platykurtic to very leptokurtic. The locations of the sediment sample locations during the dry season and the results of the sorting analysis are shown in the orthophoto map of Zone 4 in Figure 39 below.

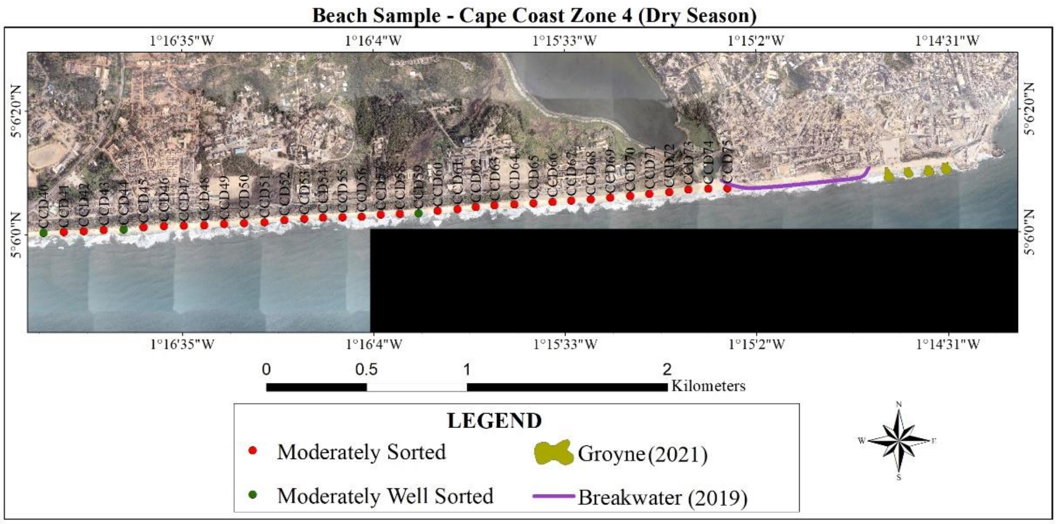

Figure 39: An orthophoto map of Zone 4 showing locations of sampled beach sediment in the dry season and outcome of laboratory analysis.

Source: Osei, 2022.

Table 10: Summary results of statistical analysis for samples taken from Elmina in the dry season.

			Mean	Sorting	Skewness
ELMINA	Zone 1	Min	-0.173	0.656	-0.083
		Average	-0.022		
		Max	0.035	0.825	0.059
	Zone 2	Min	0.501	0.813	-0.492
		Average	0.760		
		Max	1.160	1.164	-0.032

Source: Osei, 2022.

Table 11: Summary results of statistical analysis for samples taken from Cape Coast in the dry season.

			Mean	Sorting	Ske
CAPE COAST	Zone 3	Min	-0.214	0.623	-0
		Average	0.093		
		Max	0.485	0.955	0
	Zone 4	Min	0.019	0.646	-0
		Average	0.516		
		Max	0.005	0.933	-0

Source: Osei, 2022.

Elmina Beach in the Wet Season

Table 12 summarizes the findings for Zones 1 and 2 with regard to the mean, sorting, skewness, and kurtosis of the sediments collected from Elmina during the wet season. Appendix M explains the statistics that were determined, while Appendix L offers details on the statistical analysis of all the beach sands examined in Zone 1. Similar to this, Appendix N offers details on the statistical analysis of all Zone 2 beach sediment samples that were sampled, and Appendix O offers an interpretation of the results.

The mean (Mz) of the sediments sampled in Zone 1 (Appendix L) during the rainy season ranged from -0.160Φ to 0.217Φ, with an average of 0.010Φ (Table 12). This suggests that the sediments' particle sizes ranged from extremely coarse sand to coarse sand (Appendix M). The sediments analyzed had sorting (σ) indices ranging from 0.643Φ to 0.830Φ (Table 12), a sign that the level of sorting ranged from moderately sorted to fairly well sorted (Appendix M). Appendix L shows values ranging from -0.081 to 0.093 for skewness, while Appendix M shows that all sediments examined were symmetrical. Appendix L shows that the values of sediment kurtosis (K_G) ranged from 0.738 to 0.890. This suggests that the peaks of the distributions were platykurtic (Appendix M) for all the samples. Figure 40 below is a map of the zone showing samples taken during the wet season and the outcome of laboratory analysis on sorting.

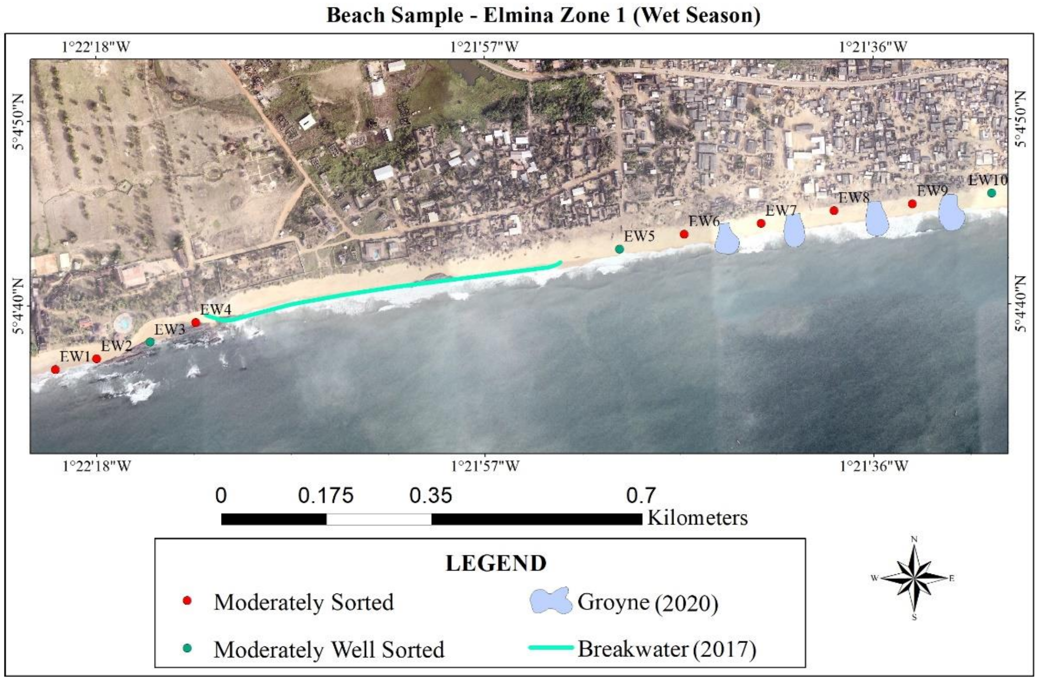

Figure 40: An orthophoto map of Zone 1, showing locations of sampled beach sediment in the wet season and outcome of laboratory analysis.

Source: Osei, 2022.

The sediments sampled during the wet season in Zone 2 had mean (Mz) values ranging from 1.534Φ to 1.733Φ, with an average of 1.593Φ (Appendix N). The sediments' particle sizes were all medium sand (Appendix O). The sediments analyzed had sorting (σ) indices ranging from 0.428Φ to 0.710Φ in Appendix N, which indicated that the degree of categorization changed from well-sorted to moderately sorted (Appendix O). Samples' particle size distribution skewness values varied from -0.042 to 0.151 (Appendix N), suggesting that the samples were symmetrical to finely skewed (Appendix O). Appendix N shows that the values of sediment kurtosis (K_G) ranged from 1.054 to 1.609. This suggests that the samples' distribution peaks ranged from platykurtic to extremely leptokurtic

(Appendix O). Figure 41 below is a map of zone 2 showing locations of samples taken in the wet season and the outcome of laboratory analysis on sorting.

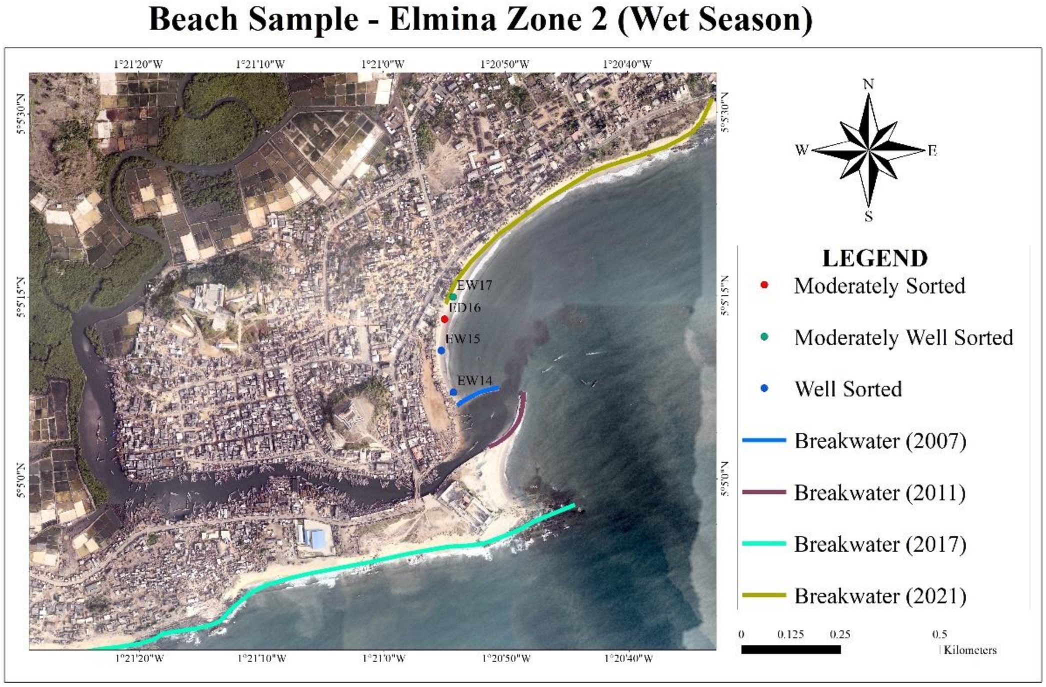

Figure 41: An orthophoto map of Zone 2, showing locations of sampled beach sediments in the wet season and outcome of laboratory analysis.

Source: Osei, 2022.

Cape Coast Beach in the Wet Season

The findings for Zone 3 and Zone 4 regarding the mean, sorting, skewness, and kurtosis of the sediments obtained from Cape Coast during the dry season are summarized in Table 13. The statistical analysis of all the Zone 3 beach sediment samples is presented in Appendix P, and the interpretation of the resulting statistics is given in Appendix Q. Again, Appendix R provides information on the statistical analysis of all sampled beach sediments of Zone 4, while Appendix S provides the interpretation of the statistics determined.

-0.015Φ to 0.409Φ were the range of values obtained for the mean (Mz) of sediments sampled in the wet season in zone 3 (Table 13) with an average of -0.079Φ. This indicates that the particle sizes of sediments varied from very coarse sand to coarse sand (Appendix P). The sorting (σ) index of the sediments examined ranged from 0.618Φ to 0.929Φ (Appendix P), indicating that the degree of sorting varied from moderately well sorted to moderately sorted (Appendix Q). With regards to skewness, values ranged from 0.000 to 0.091 (Appendix P), but all sediments sampled were symmetrical (Appendix Q). Sediment kurtosis (K_G) values varied from 0.738 to 0.888 (Appendix P). This indicates that the distribution's peak for all samples were platykurtic (Appendix Q). Figure 42 below is a map of zone 3 showing locations of samples taken in the wet season and the outcome of laboratory analysis on sorting.

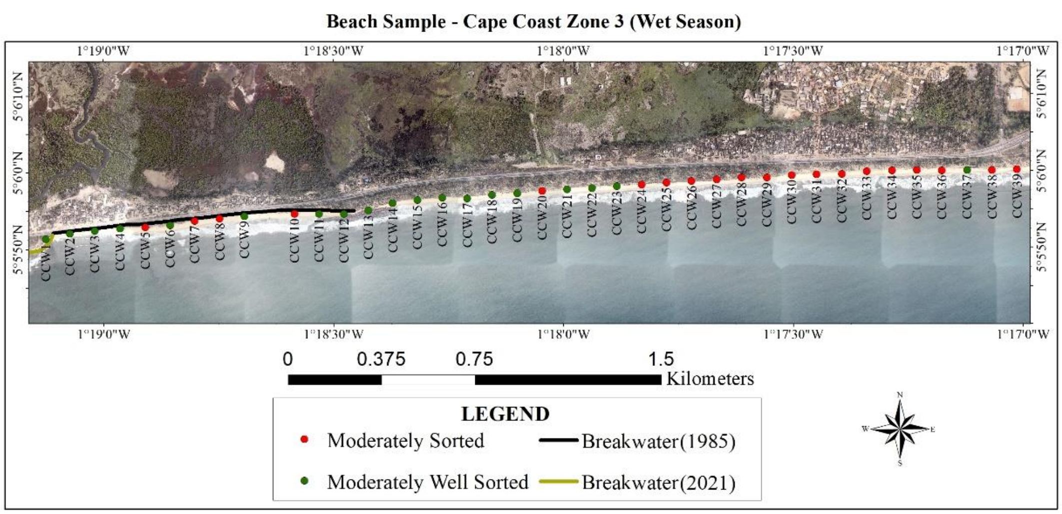

Figure 42: An orthophoto map of Zone 3, showing locations of sampled beach sediment in the wet season and outcome of laboratory analysis.

Source: Osei, 2022.

In zone 4, mean (Mz) values of sediments sampled in the wet season ranged from 0.060Φ to 0.466Φ with an average of 0.226Φ (Table 13) and particle sizes of sampled sediments were all coarse sand (Appendix R). The sorting (σ) index of the sediments examined ranged from 0.703Φ to 0.939Φ (Appendix R) with all sampled sediments being moderately sorted (Appendix R). The skewness values in the particle size distribution of samples ranged from 0.027 to 0.112 (Appendix R), indicating a variation from symmetrical to fine-skewed samples (Appendix S). The values of sediment kurtosis (K_G) ranged from 0.750 to 0.897. (Appendix R). This means that all of the samples' distribution peaks were platykurtic (Appendix S). Figure 43 below is a map of zone 4 showing locations of samples taken in the wet season and the outcome of laboratory analysis on sorting.

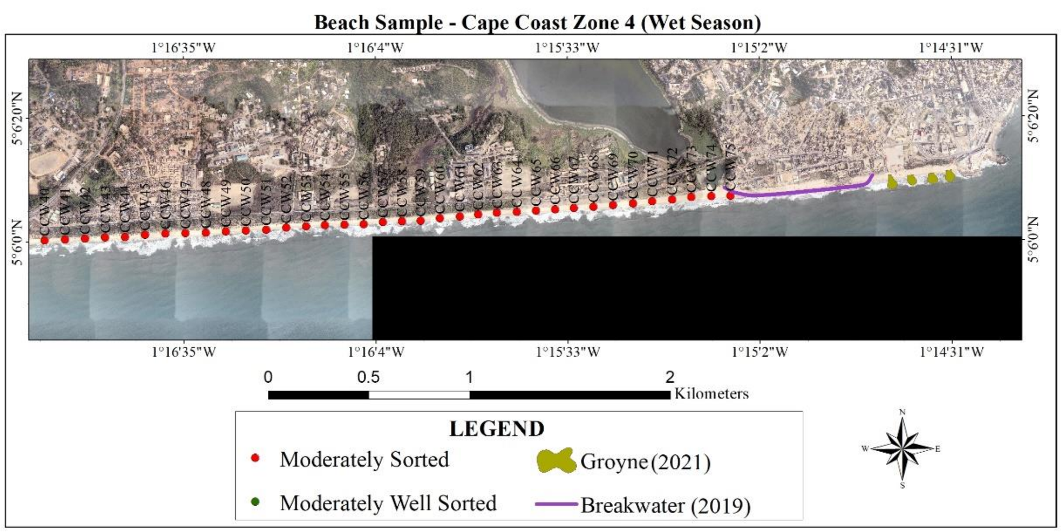

Figure 43: An orthophoto map of Zone 4, showing locations of sampled beach sediment in the wet season and outcome of laboratory analysis.

Source: Osei, 2022.

Table 12: Summary results of statistical analysis for samples taken from Elmina in the wet season.

			Mean	Sorting	Skewness	Kurtosis
ELMINA	Zone 1	Min	-0.160	0.643	-0.081	0.738
		Average	0.010			
		Max	0.217	0.830	0.093	0.890
	Zone 2	Min	0.534	0.428	-0.042	1.054
		Average	1.593			
		Max	1. 733	1.710	0.151	1.609

Source: Osei, 2022.

Table 13: Summary results of statistical analysis for samples taken from Cape Coast in the wet season.

			Mean	Sorting	Skewness	Kurtosis
CAPE COAST	Zone 3	Min	-0.015	0.618	0.000	0.738
		Average	0.077			
		Max	0.409	0.929	0.091	0.888
	Zone 4	Min	0.060	0.703	0.027	0.750
		Average	0.226			
		Max	0.466	0.939	0.112	0.897

Source: Osei, 2022.

Depositional Environment of Sediments

A mathematical equation known as the "linear discriminant function" (after Sahu, 1964) was used to categorize the various environmental processes or circumstances based on the mean, sorting, skewness, and kurtosis of particle size data.

Sahu's (1964) linear discriminate functions of Y1 (Aeolian, beach), Y2 (Beach, shallow agitated water), Y3 (Shallow marine, fluvial), and Y4 (Fluvial, Marine turbidity) interpreted the deposition process and environment. In the dry season, Appendix T displays the values of Y1, Y2, and Y3. In the wet season, Appendix U displays the values of Y1, Y2, and Y3, which were utilised to analyse the environment of deposition of all samples in the research region.

Seasonal Variability at Elmina Beaches

In the dry season at Elmina Beach, Zones 1 and 2 displayed variations in sediment characteristics. Zone 1 showed a range of particle sizes from very coarse sand to coarse sand, while Zone 2 exhibited variations from coarse sand to medium sand. This means that, in general, particle sizes in Elmina ranges from very coarse sand in the west to medium sand in the east. The sorting indices ranged from moderately well sorted to poorly sorted, indicating a diverse spread of particle sizes in both zones. Symmetrical skewness values suggested a relatively balanced distribution of sediments in both zones, while kurtosis values ranged from platykurtic to very leptokurtic, indicating fluctuations in the peak distribution.

However, during the wet season, both zones exhibited a shift towards finer sediments, with Zone 1 ranging from very coarse sand to coarse sand and Zone 2 comprising medium sand. Sorting indices indicated well to moderately sorted sediments, and skewness values showed variations from symmetrical to fine-skewed distributions. These changes in sediment characteristics between seasons could be attributed to wave energy, sediment transport, and weathering processes (Agbetossou et al., 2023; Pradhan et al., 2020; Tulashie et al., 2022).

Seasonal Variability at Cape Coast Beaches

Similar to Elmina, Cape Coast Beaches in the dry season (Zones 3 and 4), display variations in sediment characteristics. Both zones consisted of very coarse sand to coarse sand, with sorting indices ranging from moderately well sorted to moderately sorted. Symmetrical skewness values and platykurtic kurtosis values indicated a relatively balanced and stable sediment distribution.

In the wet season, Zones 3 and 4 exhibited a shift towards finer sediments, with sorting indices indicating moderately well-sorted sediments. Skewness values showed symmetrical distributions, and kurtosis values remained platykurtic. The observed changes in sediment characteristics may be linked to seasonal wave patterns, sediment transport, and weathering processes (Agbetossou et al., 2023; Bramha et al., 2017; Tulashie et al., 2022).

Comparison between Elmina and Cape Coast Beaches

Comparing Elmina and Cape Coast beaches, both displayed similar trends in sediment characteristics during the dry and wet seasons. In both regions, there was a shift towards finer sediments in the wet season, with moderately well-sorted distributions. The symmetrical skewness and platykurtic kurtosis values suggested stable sediment conditions.

This finding is corroborated by Pradhan et al., 2020. The similarities between the two locations could be attributed to wave conditions, longshore drift currents, and sediments from probable lagoons such as Brenu, Susu, and Ankwanda, located on the western side of Elmina. (Addo, 2018; Agbetossou et al., 2023; Tulashie et al., 2022)

Stability of Beaches at Elmina to Erosion and Human Activities

The stability of Elmina Beaches against erosion appears to vary between zones and seasons. In the dry season, Zone 1 exhibited moderately well-sorted sediments, suggesting a relatively stable beach condition. However, Zone 2 displayed poorly sorted sediments, indicating potential vulnerability to erosion. In contrast, however, the zone has experienced accretion due to the Benya estuary, a bay and a constructed breakwater (Figure 41).

In the wet season, both zones showed finer sediments, with well sorted to moderately sorted distributions, suggesting increased stability against erosion. The seasonal variability in beach stability at Elmina may be influenced by factors such as wave energy, sediment transport, and weathering processes especially physical weathering at Zone 2 (Addo, 2018; Agbetossou et al., 2023; Ayodele & Madukwe; 2019; Tulashie et al., 2022).

Additionally, the coarse nature of sediments at zone 1 is likely to support recreational activities as coarser sediments are generally more comfortable to walk and lounge on. Finally, coarser beach sediments are preferred for the construction of coastal structures, making them vulnerable to activities such as sand mining or mining.

Stability of Beaches at Cape Coast to Erosion and Human Activities

Cape Coast Beaches demonstrated stability against erosion, with both zones displaying moderately well-sorted sediments in both dry and wet seasons. The symmetrical skewness and platykurtic kurtosis values indicated balanced sediment distributions. This stability could be attributed to factors such as coastal morphology, sediment sources, and regional hydrodynamics (Addo, 2018, Agbetossou et al., 2023, Ayodele & Madukwe, 2019, Tulashie et al., 2022). Consequently, the coarse nature of sediments at Zone 3 & Zone 4 may probably support recreational activities as coarser sediments are generally more comfortable to walk and lounge on. Again, the preference of coarse beach sediments for building houses and other facilities along the coast exposes such resources to exploitation through activities like sand mining.

Interrelationship of Textural Parameters

To differentiate between depositional environments, various textural parameters have been represented as bivariate plots (Friedman, 1979). These plots are founded on the premise that statistical parameters effectively reflect changes in the fluid flow mechanisms involved in sediment transport and deposition (Sutherland & Lee, 1994). Several researchers have suggested that these plots can be used to identify sedimentation processes across different environments (Martins, 2003; Srivastava & Mankar, 2009; Sutherland & Lee, 1994). The bivariate plot comparing mean size and sorting reveals that the samples are primarily situated in the middle tile, indicating that they are predominantly coarse-grained and moderately sorted (Figure 44).

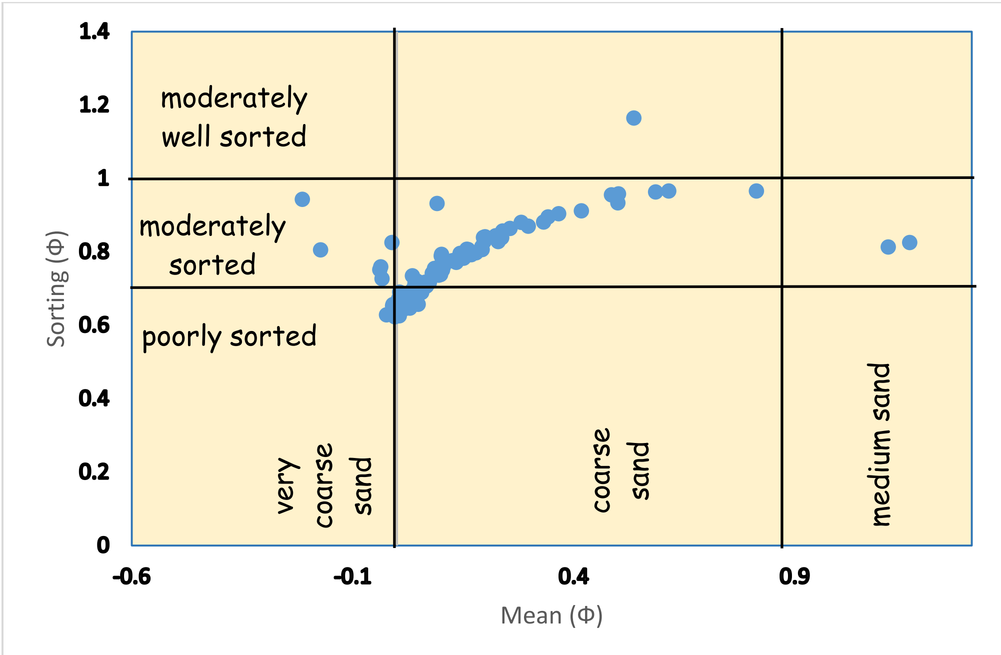

Figure 44: Plot showing the bivariant relationship between Mean and Sorting. Source: Osei, 2022.

Typically, mean particle size and sorting are hydraulically controlled, such that moderately sorted sediments tend to have a mean size within the coarse fraction. This trend was observed in the beach sediment samples from Cape Coast and Elmina. The plot of sorting against skewness helps differentiate between river and beach sediments (Flemming, 2007; Friedman, 1967; Friedman, 1961). In this study, the sorting versus skewness plot indicates that the samples are largely symmetrical and moderately sorted (Figure 45), confirming their classification as beach sediments.

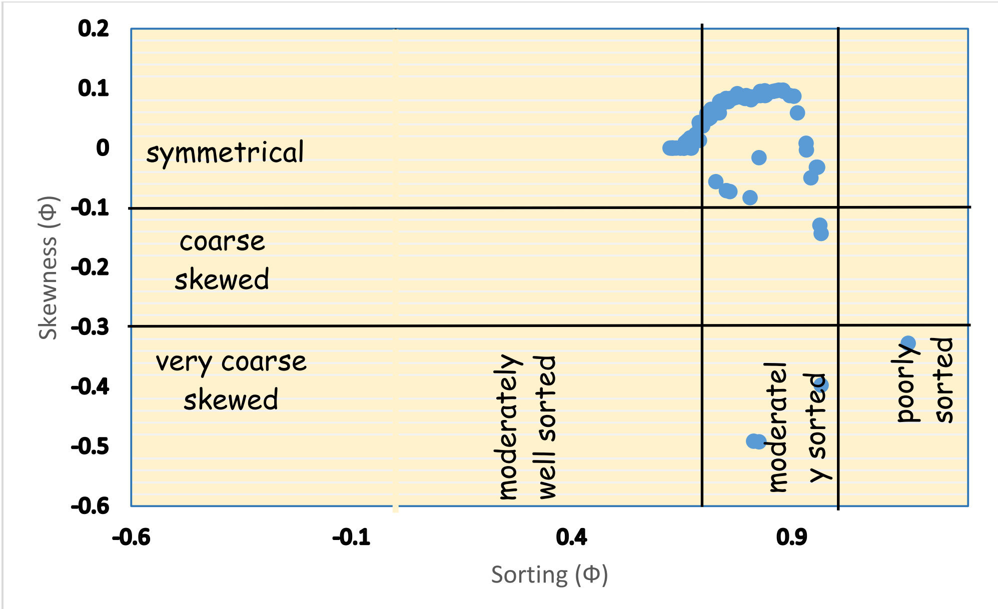

Figure 45: Plot showing the bivariant relationship between Sorting and Skewness

Source: Osei, 2022.

The plot of skewness against kurtosis (after Friedman, 1961 and Figure 46) reveals that the sediments are dominantly pure sand. The sediments were largely symmetrical and mesokurtic.

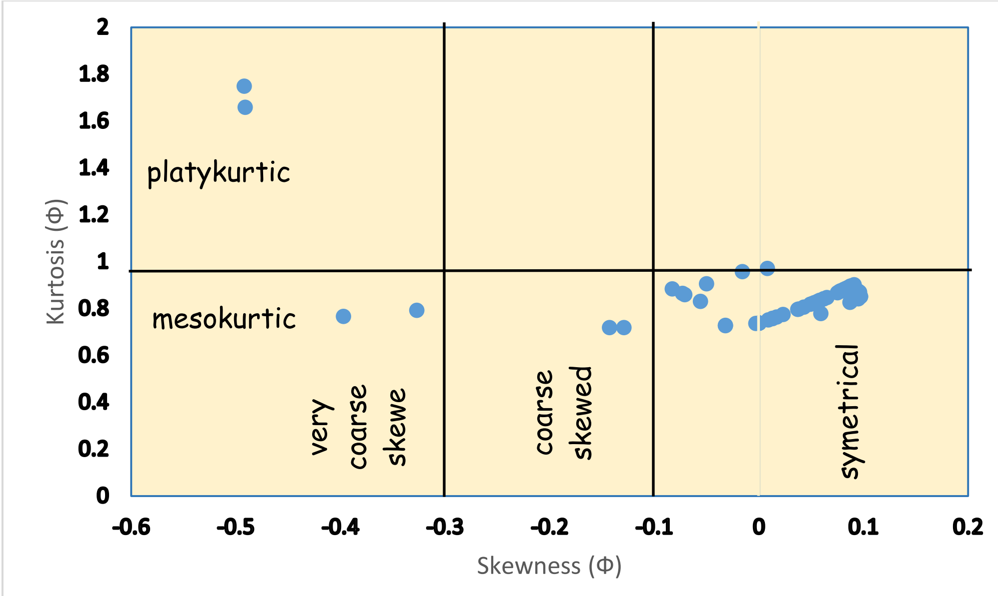

Figure 46: Plot showing the bivariant relationship between Skewness and Kurtosis

Source: Osei, 2022.

Linear Discriminant Function Analysis

Linear discriminant function analysis is an effective technique for identifying the environment during sedimentation. Sahu (1964) noted a distinct relationship between variations in energy and fluid dynamics, along with the different processes and settings where sediments accumulate. To better determine depositional environments, this study employed linear discriminant function analysis (Sahu, 1964).

A plot of Y1 versus Y2 for the samples shows that most of the samples analyzed (73% in the dry season and 69% in the wet season) were classified within the beach littoral sub-environment, while the remaining samples (27% in the dry season and 31% in the wet season) were categorized in the beach shallow sub-environment (Figure 47 and Figure 48). The data indicates that the samples were primarily deposited through beach and shallow marine processes.

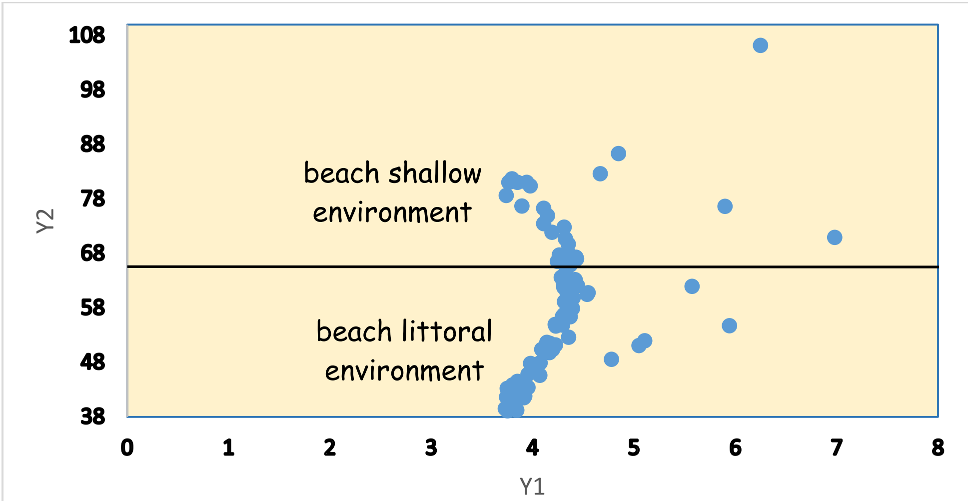

Figure 47: Linear discriminate function plots of Y1 versus Y2 indicating depositional environments in the dry season.

Source: Osei, 2022.

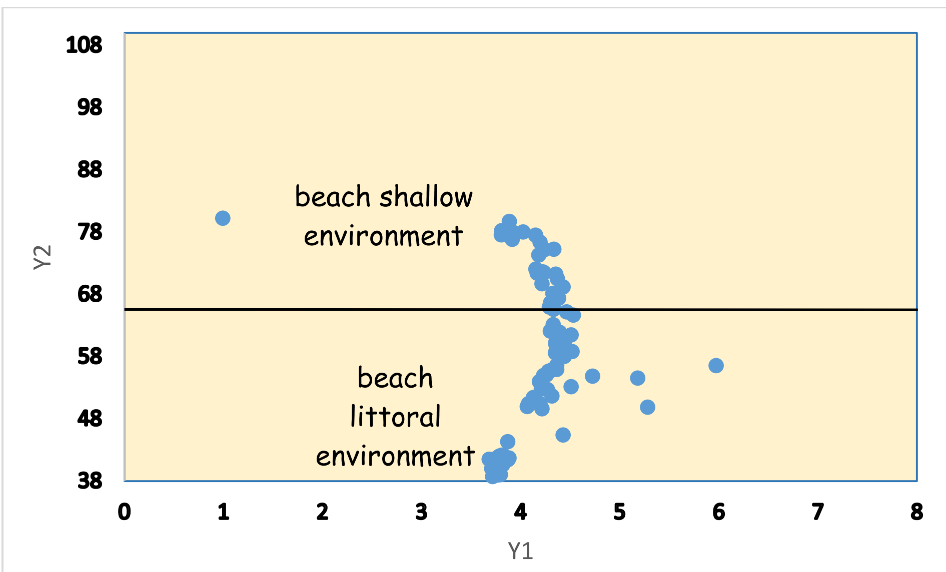

Figure 48: Linear discriminate function plots of Y1 versus Y2 indicating depositional environments in the wet season.

Source: Osei, 2022.

The plot of Y2 versus Y3 distinguishes between fluvial and shallow marine sub-environments. The results show that most of the samples analyzed (91% in the dry season and 90% in the wet season) were classified within the shallow beach sub-environment, while the remaining samples (9% in the dry season and 10% in the wet season) were identified as belonging to the shallow fluvial sub-environment (Figure 49 and Figure 50). The data indicate that the samples were primarily deposited through beach and shallow marine processes, with some evidence of fluvial deposits. Field observations at locations exhibiting fluvial deposit characteristics indicated that these areas are associated with runoff and drain discharge from nearby communities and cliffs.

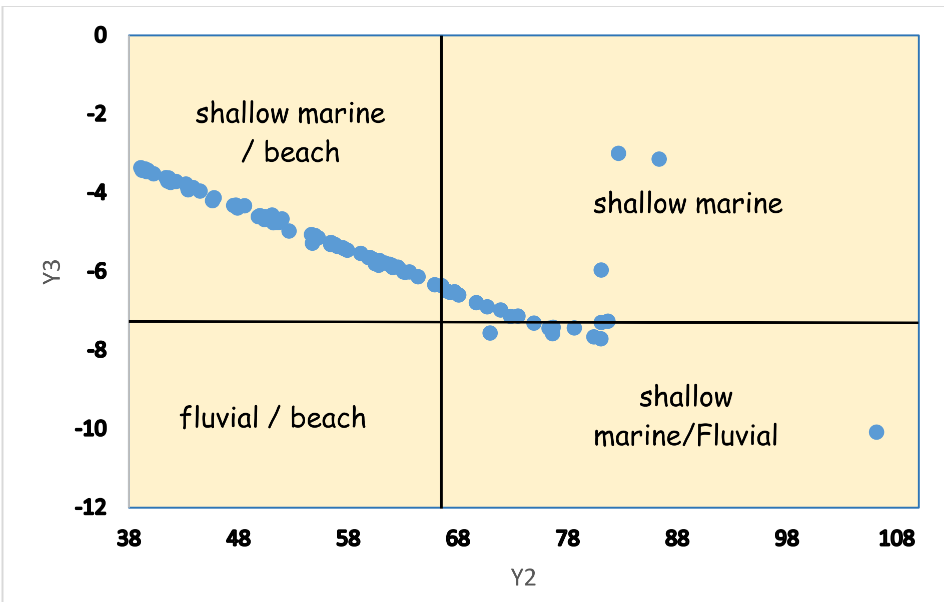

Figure 49: Linear discriminate function plots of Y2 versus Y3 indicating depositional environments in the dry season.

Source: Osei, 2022.

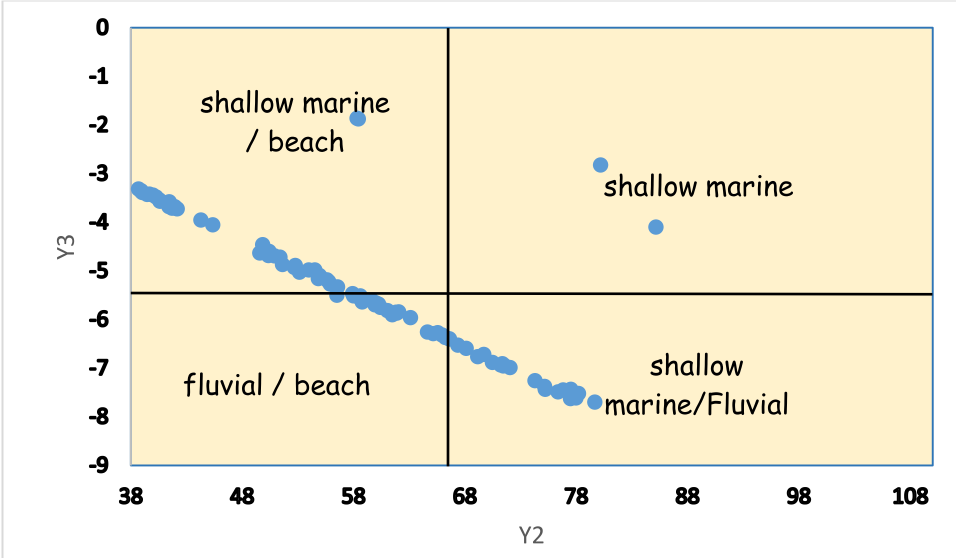

Figure 50: Linear discriminate function plots of Y2 versus Y3 indicating depositional environments in the wet season.

Source: Osei, 2022.

Comparison with Previous Studies

Dei (1972) conducted a morphological and sedimentologically study of the Central Plains of Ghana. The study revealed that climatic oscillations have influenced the evolution central coast of Ghana. The study further revealed that beach sediments of the coast of Elmina and Cape Coast (Beach 11) were dominantly fine particles, well-sorted marine and aeolian deposits.

A study by Anim (2019) on beach erosion analyse seasonal variability in beach morphology of five beaches (Abakam [along the Cape Coast Coastline], Ada, Atokor, Kedzi and Keta) along the Ghanaian coastline. The results of the study showed that for the Abakam beach in both dry and wet season, particle size of beach sediments ranged from fine to medium and were moderately sorted.

In this study, results of seasonal variability in Cape Coast beach showed in both dry and wet seasons that, particle size of beach sediments ranged from coarse to very coarse and the sorting index dominantly being moderately sorted.

Analysis of the results of the studies revealed a pattern of increasing mean particle size of beach sediments over the years from fine to very coarse. The change and associated direction of shift may probably be due to an increase in wave energy as indicated by Tulashie et al., 2022.

Chapter Summary

This chapter focused on analyzing the granulometric properties of beach sediments along the Cape Coast-Elmina coastline. The results revealed significant variations in sediment characteristics of beaches in the various zones of the study area across seasons, influenced by factors such as wave energy, sediment supply, and human activities. The chapter discussed how these granulometric properties points to the nature of sediment transport and depositional agent, beach morphology, and beach stability. Understanding these characteristics was emphasized as crucial for predicting sediment behaviour and informing effective beach management strategies.

CHAPTER SEVEN

LINKAGES BETWEEN CHANGES IN BEACHES AND HUMAN ACTIVITIES

Introduction

The relationship between changes in beaches and human activities is complex and multifaceted. Anthropogenic interventions along coastlines, such as urban development, tourism, port construction, and sand mining, significantly impact on beach morphology and sediment dynamics (Ghaffari et al., 2019). These activities disrupt natural sediment transport processes, altering the stability and shape of coastlines (Angnuureng, 2023; Ankrah, 2023). Beach erosion, a result of human interference with coastal environments, increases vulnerability to hazards and impacts ecosystems. Understanding this relationship is crucial for effective coastal management strategies that balance human needs with ecosystem preservation and resilience (Ekow, 2015). Thus, the results of the data collection and analysis regarding the connections between alterations to beaches and human activity were the main focus of this chapter. The main topics covered in this chapter were the effects of human activity on beaches, and changes to the beach that have been observed because of it. The findings are then examined and contrasted with the body of empirical research on shoreline analysis and coastal erosion that has already been published.

Demographic Characteristics of Participants

The sociodemographic details of the respondents are presented in this section. The sociodemographic data collected for this study comprised age, sex, education level, marital status, length of time in the community, and occupation.

The study conducted included a total of 69 participants who participated in 4 Focus Group Discussions (FGDs) and 8 scheduled interviews. For the FGDs, two were held at Marine and Awunafomu communities of Elmina and the other two were held at Duakor and Ola communities of Cape Coast. For the scheduled interviews, two individuals each, from Marine, Awunafomu, Duakor, and Ola were involved. The distribution of participants consisted of 35 individuals from Cape Coast and 34 from Elmina. The choice of these locations likely aimed to capture perspectives from diverse geographical settings, considering Elmina and Cape Coast are historic coastal towns in Ghana. The participants' demographic details provided insight into the makeup of the study population. The participants' average age ranged from 45 to 54 years, suggesting that they were a relatively young to middle-aged group. This demographic profile suggests a wealth of life experiences and perspectives within the study group, which can be valuable for obtaining a nuanced understanding of the research topic. Education is a crucial factor influencing perspectives and responses in any study. In this case, most participants had attained at least a Junior High School education, suggesting a baseline level of formal education within the group. This educational background may influence the participants' ability to comprehend and engage in discussions on the research topic, contributing to the overall richness of the data. The reported average duration of residence among participants in the community was noted to be over 31 years. This information is significant as it indicates a long-term residency within the community.

The participants with extended community tenure are likely to possess in-depth knowledge of local dynamics, cultural nuances, and community history, providing valuable context to the study. Occupational background is another important demographic variable. The majority of the participants were engaged in fishing activities. This occupational commonality suggests a shared experience among participants, potentially influencing their perspectives on the research topic. Understanding the participants' occupations is crucial, especially if the study focuses on a subject related to their daily lives or work. The gender distribution among participants was noted as imbalanced, with 44 men and 27 women included in the study. Gender balance is a consideration in research design to ensure that diverse perspectives are represented. The imbalance in this study might be intentional, reflecting the occupational composition of the community, where fishing is traditionally associated with male participation.

Additionally, the study involved seven participants from four different key institutions. Two participants were from the Cape Coast Metropolitan Assembly (CCMA), which is responsible for developing and implementing plans, programs, and strategies for effective resource mobilization aimed at the district's overall development. Two participants were from the Komenda-Edina-Eguafo-Abrem (KEEA) Municipality, which focuses on utilizing available resources efficiently to promote sustainable development through strong leadership, fiscal responsibility, quality services, transparency, and active grassroots participation to ensure equitable growth across all sectors within the framework of good governance and security. Furthermore, one participant was from the Fisheries Commission, one from the Regional Administrator of the Coastal Development Authority (CODA), and one from the Environmental Protection Authority (EPA).

The participants' average age ranged from 45 to 54 years, indicating a relatively young to middle-aged group. This demographic diversity suggests a blend of experience and contemporary perspectives among the participants. Most participants had attained at least a tertiary education, suggesting a baseline level of formal education among the group. This educational background suggests a high level of expertise and knowledge in their respective fields. The average length of stay of participants in the community was 11-20 years. In terms of work experience, the participants were employed in their respective fields for 5 to 10 years, indicating a moderate level of professional experience. Gender distribution among the participants was imbalanced, with seven men and zero women included in the study. Overall, the study comprised professionals from the four institutions. The age range, educational attainment, work experience, length of stay in the community, and gender distribution provide a good basis for involving the participants in a study of this nature.

Changes in Beaches along Cape Coast-Elmina Coastline

Beaches are dynamic ecosystems constantly shaped by natural forces and human activities. Over time, these stunning coastal landscapes undergo various changes influenced by factors like erosion, sediment movement, and sea level rise. Perceived changes in beaches often reflect a blend of personal experiences, environmental alterations, and evolving perspectives. Individuals might notice shifts in the appearance, size, or cleanliness of beaches due to natural processes like erosion, sediment deposition, or human-related factors such as development and tourism. Climate change-induced impacts like sea level rise or intensified storms can significantly alter the perceived state of beaches, leading to concerns about disappearing coastlines or changing recreational opportunities. People's perceptions of beach changes can vary widely based on their familiarity with the area, past experiences, and awareness of environmental issues, highlighting the complex interplay between subjective observation and actual transformations occurring along these dynamic coastal environments. As such, the perceptions of the participants were explored regarding the changes in beaches along Cape Coast-Elmina coastline since their stay in their respective communities. It was revealed that some participants have observed gradual changes while others have observed drastic changes in the beaches while others do not see any significant changes in the beaches. For instance, a 76-year-old male participant in Duakor had this to say:

> *I have lived here for the past 47 years, some of the changes I have observed are that, I know there are seasons where we cut the coconut, there used to be lots of coconut trees around, I remember when I was little, we used to play football all the way to the beach area. I recall, around 1979, 1980 thereabout, when they constructed the first sea defence, the*

> *volume of the water went up, and it continued to go up till now, we used to catch lots of fishes as well. Our forefathers could catch fish just at the nearshore without going deep into the deep sea, because there were no gravels in the sea then, but now, we have discovered that, there are some gravels in the sea, which has destroyed our business. Now, when we go fishing, it is difficult to drag our nets, so we have to organize people who are good in diving to help drag the net ashore, we sometimes lose them to the action of the waves and some challenges faced under the water, we always lose the materials used in fishing. Frankly, the changes I have seen with regards to the sea is that, the destruction of the coconut trees, there used to be buildings along the beach through to the beach at OLA, but the action of the waves has destroyed all those houses and coconuts because the sea (FGD, 2022).*

Another 54-year-old female participant in Duakor added:

> *I can also say that, some of the changes I have observed is that, our forefathers initially had the buildings along the present-day beach area, the sea was really far from us, before one could see the sea or get closer, you needed to really walk for long. Our forefathers built along the beach, they actually smoked fishes around the beach area, but now*

what we have noticed is that the sea is much closer to us now (FGD, 2022)

An official from the CCMA also had this to say:

I realized that it is a gradual change that has been happening, because sometimes, if you go there, you will realize that the sea has retreated and at other times too, it advances inland, so I think is something gradual. I did indicate that we used to go to the sea site to relax and where we used to relax is far gone, is lost to the sea. When you look at the stretch from the Lagoon to Abakam to Duakor, up to Da Breeze area and then towards the Bakaano to Philip Quaicoe Boys". [IDI, 2022].

Again, an officer from the EPA also indicated that:

Yes, changes in terms of the coastline, yes there have been changes, in some areas, there has been erosion towards the coast, so the sand is being taken into the sea, so the sea is advancing more towards the land. There are cliffs that are developed in some areas as a result of the washing of the sand, also there has been some coconut trees that are being washed away, and this is as a result of the sand being taken out of their roots, so there have been changes along the coast, pointing to sand being lost as a result of sea erosion [IDI, 2022].

Finally, an official from the planning officer of the CCMA indicated that:

> *I have spent close to 10 years in Cape Coast, so let's say about 9 years and more and I live in Ekon which is also very close to the sea, so from my house to the beach front is just a walking distance, and I have observed a lot of changes, as far as the shoreline of that area is concern, because I quiet remember there is this hotel close to the beach front, and sometimes after close of work on Fridays to Saturdays, we use to take our mattresses and place it there and lie for some time then when it is midnight we wake up and come home, but as a speak now, that portion of the beach front where we used to lie is about 200m to the sea now, so what it means is that the sea keeps advancing towards the community. Again, there was something like a gym, an improvised gym, where we used to go and exercise, it was about 300m away from the sea, and as I speak now, part of the house, the building, in fact where we used to gym is off, it is just left with part of the building which is there, so I know for sure that we are losing a lot of land to the sea in terms of destruction of the coastline [IDI, 2022].*

When residents observe changes in beaches, it carries significant implications for both the local environment and the well-being of the communities close to the beach. Beaches are integral components of coastal ecosystems, and alterations in their features, such as erosion, accretion, or changes in sediment composition, can signal broader environmental shifts. Residents often interpret these changes through the lens of their lived experiences, impacting on their perceptions of environmental health and safety. Additionally, alterations in beach morphology can have practical consequences, affecting recreational activities, tourism, and property values. Residents may develop greater awareness of the potential consequences of sea-level rise or human activities on their coastal area. As a result, these insights may inspire community involvement in environmental conservation, promote advocacy for sustainable coastal management, and foster cooperation with authorities to address the changing dynamics of their coastal surroundings.

Duration of Changes

The duration of perceived changes in beaches varies widely based on the nature and extent of the alterations. Some beach transformations, like seasonal shifts in sand distribution or temporary changes due to storms, might be relatively short-lived, lasting weeks or months. However, longer-term alterations caused by factors such as coastal erosion, sea level rise, or human developments can persist for years, decades, or even longer, significantly impacting the beach landscape. The perception of these changes often depends on the frequency of visits and individual observation, as well as the rate at which natural processes or human activities continue to influence the beach environment. Understanding both the temporary and enduring changes is crucial for managing and conserving these dynamic coastal ecosystems. As a result, data was gathered from the participants on how long they have observed these changes. The analysis showed that changes in the beach width had been occurring for the past 5 to 10 years now. Residents and institutional officers had some observations to share. For instance, a 68-year-old male participant at Elmina (Marine) indicated that:

> *It was around 1987 to 1988, the Axim people were not getting fish so they came here to work. 1997, 1988, 1989 to 1992 that this change came. When we don't go anywhere, we relaxed as gentlemen and ladies but we can see that with time there was moving forward and moving backwards in that sequence. So around 1992 to 1993 then the changes occurred (FGD, 2022).*

Another 72-year-old participant in Duakor added that:

> *Okay from the 60s to 66, that was when it started gradually, also during this period, there was less enlightenment, so people didn't really pay much attention to these changes, additionally, there was no harbors, like the Tema harbor. I can say that, the construction of Tema harbor destroyed a lot of things in the Volta Region. The construction of the harbors is affecting us here in this community (IDI, 2022).*

An officer from the planning department of the KEEA also noticed these changes:

I will say for the past five years I use to see waves; you see waves drops on the road, the Takoradi road, sometimes but not very often. Sometimes you see that. That is why I have said that I have experience with this for the past 6 years [IDI, 2022].

Another officer from the EPA office added that:

It has been going on for a long time, less say about 10 years [IDI, 2022].

Observing the duration of changes in beaches holds significant implications for residents and institutions, influencing both community resilience and coastal management strategies. Research by Gravois et al. (2017) highlights the importance of real-time monitoring in coastal areas, enabling residents to make informed decisions about property investments and facilitating adaptive strategies in response to changing beach conditions. Additionally, studies such as that by Zhang et al. (2019) emphasize the role of timely observations in predicting and mitigating the impacts of climate-induced beach changes. This awareness enhances the ability of local institutions to implement effective policies and strategies for sustainable coastal development (Doria et al., 2019). By understanding the duration of beach changes, residents and institutions can proactively engage in conservation efforts, community education, and collaborative decision-making, fostering a more resilient and adaptive approach to coastal management (Bosman et al., 2020; Thomalla et al., 2021).

Natural Factors for Change

Despite the anthropogenic factors that influence changes in beaches, there are some natural factors such as sea level rise and wave actions that are responsible for these changes. Natural factors contribute significantly to changes in beaches, continually shaping their form and character. Erosion, driven by waves, currents, and storms, is a primary force altering coastlines, gradually wearing away sand and sediment. Sediment movement, influenced by tides, winds, and coastal currents, redistributes sand along shores, affecting beach profiles and sizes. Additionally, sea level rise, a consequence of climate change, poses a long-term threat by eroding beaches, submerging coastlines, and impacting their overall stability. These natural processes, while integral to the dynamic nature of beaches, can also lead to changes in beach morphology and the surrounding coastal environment over varying timescales. Hence, data were gathered from the participants on these natural factors and the analysis indicated that natural factors such as climate change or extensive sea wave action were responsible for the changes in the beaches. The analysis revealed that Act of God, Climate Change and Sea level rise were the natural causes of the beach changes. For instance, a 57-year-old male participant in Ola had this to say about beach changes as part of God’s plan:

> *As you can see, everything God creates grow just like I and you are growing, that is the same way the sea is expanding. That is the reason why it has come forward by itself. According to one or two researchers I have heard from, there are ice in the sea, so as the sun scorches it melts the ice, making it to expand. The sea can move back naturally and can also move forward, so it is expanding by itself (FGD, 2022).*

Another participant revealed a similar response by saying that:

The sea that has moved forward, it is what is supposed to happen. Looking at my age and experience, it has been raining very well and as it rains, it makes the sea large and more and more. As it expands it will definitely come inland. It is not the doing of mankind. It is God's plan. This coastal area needs something like sea defense stones to prevent the water from coming in land. sometimes the sea defense will affect our work that is why we keep saying that they should do something that will help we the fishermen as well, like doing something that we can store our fishing boats and other stuff like a Harbor. That is all [FGD, 2022).

An official from the Fisheries Commission in the CCMA also had this to say about how climate changes are responsible for the changes:

I also realized that it might be climate change, and that is the sea level is rising and I realized that even the glaciers at the Greenland are melting at a faster rate and the sun too, we have been experiencing extreme sunshine nowadays so it boils down to my believes that sea level might be rising, and as it rises, it come more inland (IDI, 2022).

Similarly, an official from the Development Planning office of the CCMA also shared his view on the contribution of climate change to the changes in beaches:

Oh yes, I would say largely, we can associate it to the issue ofclimate change where we have the sea being heated up, and as a *result may cause some of these changes to the coastline, then I would also say, lately, we have been experiencing heavy rains and you know heavy rains when it happens, the rivers and the Lagoons get full and mostly into the sea, so that sort of expansion would also come to play, and would also cause destruction to the coastline, I think largely, these are the natural causes I can speak about (IDI, 2022)*

An officer from the EPA office of the CCMA were of the view that changes in beaches were as a result of extensive tidal or sea wave action:

Some are natural, we have a situation where the sand actually is moved by wave action, so the sea actually moves the sand, so it moves from one place and deposited at another place along the shore, so in some areas, you will see more of the erosion, at the same time, some other parts, you will see more deposition so, the sea itself moves the sand, then we have the sea-level rise as we have heard due to climate change, and that is also pushing the sea towards the land and increases the action of the erosion. We also have areas where people are developing into the sea, so they are actually reclaiming the sea and developing structures and that is also pushing the sea towards the land, and that is not really under our control, and this pushes the volume of water towards the land (IDI, 2022).

Width Changes of Beach Size

The width of the beach is the distance between the dune crest and shoreline position at high tide. The width changes of a beach, often referred to as beach size, fluctuate because of a combination of natural and human-induced factors. Natural forces such as tides, waves, and seasonal variations influence the width of a beach, causing it to widen or narrow over time. Storms, erosion, and sediment movements also play pivotal roles in altering beach width. Human activities, including coastal development, engineering structures, and sand extraction, can disrupt natural sediment flow, leading to changes in beach width. These fluctuations in beach size are dynamic and can occur gradually or rapidly, impacting the overall shape and functionality of coastal areas. Examining the changes in the width of beaches is crucial for future shoreline management planning. It is also a benchmark for determining the rate of beach erosion. Hence, changes in the width of the beach were also explored. Evidently, data gathered revealed that participants had noticed that the width of the beaches have been highly reduced. They believed that the former width of the beach has been reduced to about half of its width though they were not certain about the exact rate of reduction. Officials from the institutions selected for the study had similar responses. For instance, an official from the Fisheries Commission of the CCMA had this to say:

In actual fact, formerly, it was wider than now, so if I may estimate, let's say formerly if was 30m, now is about half of that size which is 15m now (IDI, 2022).

Another officer from the EPA of the CCMA added that:

> *I know it has moved, but as to which extent, it's a bit difficult to say. It will be difficult, but I can say 20m towards the land, not the stretch, but say 20m towards the land [IDI, 2022].*

Also, a Development Planning Officer at CCMA indicated that:

> *I can actually give an estimation, more of an accurate estimation, but that if the Philip Quaicoe Boys School to the Lagoon that stretch, I cannot really give any better estimation, but I know we have lost a significant portion of the land to the sea (IDI, 2022).*

Finally, a Development Planning Officer at KEEA also confirmed that:

> *So, the width of the beach, basically is been reduced, as in where tourism activities normally happen is being eroded and advancing towards the roads, and recreational activities are therefore limited and I am sure the sustainability of the lives of the flora and fauna at the beaches and the ecosystems and dynamics that happens at the shorelines of the sea is being affected. So basically, by observation, but not scientific measurement, I can say, it has reduced (IDI, 2022).*

When residents and institutions can observe a reduction in beach width, it carries significant implications for coastal communities and management strategies. The reduction in beach width is often associated with processes like erosion, storm surges, or sea-level rise, impacting the resilience of coastal areas. Research by Vitousek et al. (2017) underscores the critical role of beach width in buffering the impacts of coastal hazards, emphasizing the importance of monitoring and managing width reduction to enhance community resilience. Moreover, studies such as that by Ranasinghe et al. (2020) highlight the socio-economic implications of reduced beach width, including increased vulnerability to property damage and heightened risks during extreme weather events. This awareness enables local institutions to implement proactive measures, including beach nourishment or the development of sustainable coastal infrastructure, as highlighted by the findings of Sénéchal et al. (2015). Timely observations of beach width reduction empower residents and institutions to engage in adaptive planning, ensuring the long-term sustainability of coastal communities.

Anthropogenic Drivers of the Changes in Beaches Along the Cape Coast - Elmina Coastline

Anthropogenic factors are human activities that can significantly impact beaches and contribute to changes in their characteristics. These activities significantly impact beach size and width through various actions that alter natural coastal dynamics. Coastal development and infrastructure, such as buildings and seawalls, disrupt the natural flow of sediment along coastlines, often leading to narrower beaches. Sand mining for construction purposes reduces available sediment, contributing to beach erosion and diminished width. Furthermore, activities like dredging, which extract sand from coastal areas for navigation or construction projects, directly reduce the volume of sediment available to replenish beaches, causing them to shrink. Human-induced climate change, marked by rising sea levels and increased storm intensity, accelerates erosion and further reduces beach size and width. Therefore, obtaining data on these anthropogenic activities is crucial in managing and mitigating these anthropogenic impacts to preserving the health and resilience of beaches as critical coastal ecosystems. The results from the field data showed that there were four main anthropogenic drivers of the changes in beaches along Cape Coast-Elmina Coastline which include; sands winning, development of recreational sites, urbanization, and sea defense.

Sand mining

Field evidence indicates that sand mining is a significant factor influencing changes along the Cape Coast-Elmina coastline. In Ghana, sand mining refers to the collection and transportation of beach sand and gravel fragments, which are used as raw materials for constructing houses and other built facilities for accommodation. In this regard, sand mining occurs at the various beaches of Cape Coast and Elmina Coastline. Participants revealed that excessive sand mining along the Cape Coast and Elmina Coastline caused the changes in beaches. Most of the people, especially in coastal communities, engaged in individual and commercial sand mining due to easy access and closeness to the beaches. Also, some participants voiced that beach sand is richer than inland sand for construction purposes. Moreover, beach sand is cheaper as compared to inland sand, therefore, some sneak themselves at odd hours or night to win beach sand. A 48-year-old male participant in Duakor indicated that:

> *Well, constant sand mining will draw the sea closer to us, so I believe if we were not doing any sand mining, the sea wouldn't have*

advanced towards us, because when the waves hit the coast, the coastline is high, it will block the water from flooding the community, but because of sand mining, the coastline is lower and this has aided the advancement of the sea (IDI, 2022).

An official from the Development Planning Office of the CCMA also had this to say:

I will say both because of the sand mining that has caused this sea erosion, had it not been that sand mining, this thing wouldn't have occurred. The sand mining has caused the behavior of the sea (IDI, 2022).

Another official from the Fisheries Commission of the CCMA added that:

Yes, let me start from Elmina, around the area where the Anlo people are staying now, actually, I realize people have been winning sand there so the sea is advancing inland, and also coming down to Bantuma area too the same thing is happening, before the commencement of the sea defense in the area. There is winning of sand, molding of blocks by some of the community members along the beach, they take the sand and use them or sell them to make blocks or items out of cement, so definitely, they are scooping the sand and when the take, the sand comes back (IDI, 2022).

Finally, an official from the EPA office of the CCMA indicated that:

For me the first human activity I would say has to do with sand mining, on daily bases, the amount of sand that is lifted from the coastline is unquantifiable. Right from at least I can say that of Ekon, from morning till evening they mine the sand, because that is the main source of sand for molding blocks for the people of Cape Coast, especially those communities along the coast, so on daily bases, right from morning, afternoon, and evening, they go to draw sand from there (IDI, 2022).

When residents and institutions can identify sand mining as a cause of beach changes, it holds profound implications for coastal management and community well-being. Sand mining, often associated with the extraction of sand from beaches for construction purposes, can lead to erosion, reduced beach width, and increased vulnerability to coastal hazards. Research by Kalligeris et al. (2019) emphasizes the adverse impacts of excessive sand mining on coastal ecosystems, including habitat loss and increased erosion risks. By recognizing sand mining as a contributing factor to beach changes, local institutions are better equipped to regulate and monitor extraction activities, as highlighted by the findings of Young and Griffiths (2020). The awareness of the environmental consequences allows for the implementation of sustainable sand mining practices and policies to protect coastal resilience. Community engagement and education, as discussed by Micallef et al. (2012), become essential tools for fostering responsible resource management and minimizing the socio-economic impacts on coastal communities.

Development of Recreational Sites

Creation of recreational facilities also accounted for the changes in changes in beaches along Cape Coast - Elmina Coastline. Cape Coast and Elmina is known for a lot of tourist activities. Therefore, many people have developed recreational sites along the Cape Coast –Elmina Coastline for recreational and entertainment purposes. Beaches have long been acknowledged as primary areas for leisure and recreation for both residents and tourists. In the quest to develop these entertainment sites, facilities are put up along the coast that cause changes in the beaches. Some officials of the selected institutions indicated responses regarding how the setting up of recreational centres have contributed to changes in the beach. An official from the Fisheries Commission of the CCMA revealed that:

> *Yes, for now let me say for the past 5 years now when these recreational facilities were built along the beach, it might also be a factor, because they were not there formerly, but now a lot are on the beach (IDI, 2022).*

Another official from the EPA office of the CCMA added that:

> *As for activities along the coast like resorts and others, I have my doubt, and I say so because, the areas where resources were developing or developed and people are patronizing, because of their presence, the sand winners are not able to go and win sand in those areas, you will rather realize that the deposited sand remain along the coast closer to the resort,*

that's if the area is prone to deposition and it builds up, so as to whether their actions are enhancing erosion, I actually doubt that except of course they may also take some of the sand to construct their facilities (IDI, 2022).

An official from the Development Office of the KEEA added that:

The breeze and this new one too that is coming up heritage, Hutchland and you go along Komenda around this coastal shoreline. Some of these activities and expanding their residential facilities are eroding the place. I think this are some typical examples of social activities that is affecting the beach ecosystem (IDI, 2022).

A similar observation was made by an officer from the Development Planning Office:

You know, if you have used that stretch lately, you will observe that a lot of developers have erected temporary structures there, just to attract visitors. We, if I say we, I am referring to us as an Assembly, we went in to control such development, long the beach because we were not really in support of those development, and then the Physical Planning Department, that is Spatial Planning and Land use, the Regional Director, he gave an estimation and then said, the original Takoradi-Cape Coast road, that stretch, he said it was more than 500m into the sea, that is the old Takoradi-Cape Coast road (IDI, 2022).

This confirms findings from previous studies that recreational centres, such as resorts and tourist facilities, often contribute to alterations in beach morphology through activities like shoreline modification, dredging, and infrastructure development. Research by Wang et al. (2018) emphasizes the need for careful planning and management of recreational developments to mitigate adverse impacts on coastal ecosystems. Identifying such developments as contributors to beach changes enables local institutions to implement zoning regulations and environmental impact assessments, as highlighted by the findings of Williams and Araújo (2016). Additionally, community awareness, engagement, and participatory approaches, as discussed by Gössling et al. (2017), become crucial for fostering responsible tourism practices and minimizing the ecological footprint of recreational centers.

Urbanization

Urbanization is another factor that affects changes along the Cape Coast-Elmina coastline. It denotes a process of population growth and the increasing proportion of people residing in urban areas, resulting in the expansion and development of cities and towns. This phenomenon involves the migration of individuals from rural or less-developed regions to urban centers in pursuit of better economic opportunities, enhanced living conditions, and access to essential services. Therefore, participants believed that beaches have change due to the changes in the demography as a result of migration. An officer from the Fisheries Commission of the CCMA indicated that:

The changes in the beaches are all due to urbanization. Everywhere in Ghana is developing, and normally for a city to develop, the city that normally develops faster is always bordered to the sea, so, it may also be a factor [IDI, 2022).

Another official from the Development Planning Office at KEEA added that:

Basically, people are also building very close to the sea, when you go to Elmina for instance, people are building very close to the sea (IDI, 2022).

A similar response was indicated by another Development Planning Officer from the CCMA:

Yes, I actually was about to mention them, urbanization, yes, population growth, yes, because the more the population the more the demand for proper or adequate housing, and where do we get sand to put up these houses, is definitely from the sea coastline. So, the more the city become urbanized, what it means is that more people are drifting into the city and it would call for demand for housing and other social amenities and largely we depend on the coastline for our sand to make the block (IDI, 2022).

Urbanization, characterized by increased infrastructure development, population density, and altered land use, often contributes to beach erosion, sedimentation, and changes in coastal dynamics. Research by Thomalla et al. (2005) underscores the importance of understanding the impacts of urbanization on coastal environments, highlighting the need for integrated land-use planning and coastal zone management. Identifying urbanization as a driver of beach changes allows local institutions to implement measures such as setback regulations, green infrastructure planning, and sustainable urban development practices, as emphasized by McFadden et al. (2019). Community involvement and awareness, as discussed by Wong and Cheong (2013), become crucial for advocating responsible urban development and minimizing adverse impacts on coastal ecosystems (IDI, 2022).

Sea Defense

Another anthropogenic factor that accounts for the changes in beaches is the construction of sea defense. Sea defense refers to the measures and structures implemented to protect coastal areas from the erosive forces of the sea. These defenses are designed to minimize the impacts of coastal erosion, flooding, and storm surges, thereby safeguarding human settlements, infrastructure, and ecosystems along the coastline. Data gathered from the participants revealed that sea defense have some effect on the changes of beaches, however, the participants were not sure since no scientific evidence or research was backing it. This is what an officer from the Development Planning Office of the CCMA had to say about whether sea defense contributes to the changes in beaches or not due to lack of empirical evidence:

> *With the issue of the construction of a sea defence, actually, I have heard people say that the construction of the sea defence is causing a lot of destruction now to the seashore and others, but I*

don't have any scientific data to that effect, because quite recently when the construction commenced, you know they started from the castle area, people from Ekon, because I quite remember in one of our meetings, the Assembly Member for Ekon, raised that issue that we should consult the appropriate authorities to expedite actions on the development of the sea defence because they had started from that angle, so the pressure of the sea is now towards their site and is causing a lot of destructions, but I don't have any scientific data to that effect and is not something I have really observed with, so I cannot really talk about it that much (IDI, 2022).

Effects of the Changes in Beaches on Human Activities Along the Cape Coast - Elmina Coastline

Changes in beaches significantly influence human activities, impacting various aspects of recreation, economy, and infrastructure. Erosion and narrowing beaches can limit recreational space for sunbathing, sports, and tourism, affecting local economies reliant on beach-related industries. Coastal erosion also poses threats to infrastructure, risking damage to buildings, roads, and utilities located near the shore. Furthermore, alterations in beach size and width may impact biodiversity and ecosystems, influencing fishing, wildlife observation, and conservation efforts. Adapting to these changes often involves implementing coastal management strategies, such as beach nourishment or building protective structures, to sustainably accommodate human activities while safeguarding these dynamic coastal environments.

How Does the Changes Threaten the Benefits Derived from the Beach?

Beach changes pose multifaceted threats to the myriad benefits derived from these coastal environments. Erosion, a significant change, can diminish the recreational and economic value of beaches. As coastlines retreat due to erosion, the available space for sunbathing, sports, and leisure activities shrinks, impacting tourism revenues and local economies reliant on beach-related industries. Additionally, narrowing beaches can reduce biodiversity and wildlife habitats, affecting the appeal of these areas for nature enthusiasts and conservation efforts. Moreover, alterations in beach size and width can escalate coastal hazards, jeopardizing infrastructure like hotels, businesses, and residential properties located near the shore. The loss of natural protective barriers due to beach changes increases vulnerability to storm surges, flooding, and property damage. Furthermore, changes in beach ecosystems can disrupt fisheries, impacting livelihoods dependent on coastal resources. Preserving the benefits derived from beaches necessitates proactive measures, including sustainable coastal management, restoration initiatives, and adaptive strategies to mitigate erosion and safeguard these invaluable coastal environments.

Challenges Posed by the Beach to the Communities Along the Cape Coast-Elmina Coastline

Communities along coastlines face a myriad of challenges posed by beaches, particularly concerning their dynamic and constantly changing nature. Coastal erosion stands out as a significant issue, threatening infrastructure, properties, and livelihoods. As beaches recede due to erosion, homes, businesses, and critical infrastructure like roads and utilities face increased risk, leading to potential economic losses and displacement of residents. Rising sea levels intensify this challenge, exacerbating erosion and encroaching upon coastal areas, further endangering communities. Additionally, changes in beaches impact tourism and recreational activities, affecting local economies reliant on beach-related industries. Furthermore, the loss of natural protective barriers due to changes in beach size and width heightens vulnerability to coastal hazards like storm surges and flooding, posing significant risks to community safety. Balancing development with conservation efforts becomes crucial, requiring careful urban planning, sustainable coastal management, and investment in resilient infrastructure to address these challenges and ensure the long-term well-being of coastal communities.

Benefits Coastal Communities Derive from The Beach

Coastal communities derive a wealth of benefits from their proximity to beaches, fostering cultural, economic, and environmental advantages. Economically, beaches are vital hubs for tourism, attracting visitors seeking recreational activities, water sports, and leisure, thereby stimulating local economies through job creation and business opportunities in hospitality, entertainment, and retail sectors. The natural beauty of beaches also serves as a draw for real estate and property value appreciation, benefiting coastal communities. Moreover, beaches support diverse ecosystems, providing habitats for marine life, which sustain local fisheries, supporting livelihoods and food security. Beyond economic advantages, beaches serve as cultural and social hubs, offering spaces for community gatherings, cultural events, and fostering a sense of identity and pride among residents. Additionally, they provide opportunities for education, research, and environmental conservation efforts, raising awareness about coastal ecosystems and their significance. Overall, beaches play a pivotal role in enhancing the quality of life and well-being of coastal communities, offering a multitude of social, economic, and environmental benefits.

Chapter Summary

The chapter investigated the intricate relationships between beach changes and human activities along the Cape Coast-Elmina coastline. It analyzed the significant impacts of urban development, tourism, port construction, and sand mining on coastal environments, which have led to increased erosion of beach sediments. Additionally, the chapter evaluated how these environmental changes have affected human activities, heightening the vulnerability of coastal communities to hazards and influencing local livelihoods. Furthermore, it underscored the necessity for integrated coastal management strategies that reconcile human development with the conservation of coastal ecosystems, emphasizing the importance of sustainable practices to mitigate negative effects and strengthen coastal resilience.

CHAPTER EIGHT

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Introduction

This chapter offers an in-depth synthesis of the thesis examining beach changes along the Cape Coast - Elmina coastline and their impact on human activities. It summarizes the key findings, presents conclusions based on these insights, and provides actionable recommendations for policymakers, local authorities, and stakeholders to reduce negative impacts while encouraging sustainable coastal management. The chapter concludes by highlighting the study's conceptual, theoretical, and methodological contributions to knowledge, alongside suggestions for future research.

General Summary

This study sought to assess the changes in beaches between the Cape Coast and Elmina coastal zone of Ghana.

Research Objectives

Main Objective

The main objective for this study was to assess the changes in beaches and its effect on human activities along the Cape Coast - Elmina coastline.

Specifically, the study sought to:

1. Assess the spatio-temporal changes (1991-2020) along the beaches of Cape Coast - Elmina coastline.
2. Assess the changes in granulometric characteristics of beaches along the Cape Coast - Elmina coastline

3. Explore the anthropogenic drivers of the changes in beaches along the Cape Coast - Elmina coastline
4. Assess the effects of the changes in beaches on human activities along the Cape Coast - Elmina coastline; and

Research Questions

1. What spatio-temporal changes (1991-2020) have occurred along the beaches of Cape Coast - Elmina coastline?
2. What are the changes in granulometric characteristics of beaches along the Cape Coast - Elmina coastline?
3. What anthropogenic drivers have contributed to the changes in beaches along the Cape Coast - Elmina coastline; and
4. What are the effects of the changes in beaches on human activities along the Cape Coast - Elmina coastline?

Summary of Key Findings

Firstly, the analysis of land use and land cover changes from 1991 to 2020 in the Cape Coast Metropolitan Area (CCMA) and Komenda Edina Eguafo Abirem (KEEA) district reveals significant transformations driven primarily by urbanization. Sparse vegetation was initially dominant but saw mixed changes, decreasing in CCMA by 19.01 sq. km (19.53%) and increasing in KEEA by 14.31 sq. km (49.66%). Dense vegetation markedly declined in both areas, with CCMA losing 1.68 sq. km (15.86%) and KEEA 85.98 sq. km (47.05%). Built-up areas expanded substantially, increasing by 24.84 sq. km (381.56%) in CCMA and 33.36 sq. km (437.87%) in KEEA, reflecting rapid urbanization and infrastructure development. Wetlands also saw significant reductions, with CCMA and KEEA experiencing declines of 4.16 sq. km (78.34%) and 35.61 sq. km (90.47%) respectively, primarily due to anthropogenic activities. Water and barren land classes remained relatively stable with minimal changes. These shifts underscore the impact of human activities on the landscape, particularly the extensive urban expansion and its implications for coastal geomorphology and ecosystem services.

Secondly, the laboratory analysis of beach sediments from Elmina and Cape Coast beaches reveals that sediments predominantly exhibit unimodal distribution, indicating a single dominant sedimentary source. Seasonal variations show that sediments become finer during the wet season, influenced by wave energy, sediment transport, and weathering processes. Despite these variations, similar trends in sediment dynamics are observed at both beaches, driven by common underlying processes. Beach stability against erosion varies, with some zones being more vulnerable, especially during the dry season, due to factors such as coastal morphology and regional hydrodynamics. Coarse sediments in certain zones support recreational activities but are also susceptible to exploitation, like sand mining. Bivariate plots and linear discriminant function analysis further highlight the role of beach and shallow marine processes in shaping the depositional environments along this coastline.

Thirdly, the exploration of anthropogenic drivers influencing changes in the beaches along the Cape Coast - Elmina coastline revealed significant human impacts on coastal dynamics. Urbanization and infrastructure development have led to extensive land reclamation and alterations in natural landscapes, contributing to beach erosion and habitat loss. Activities such as sand mining and construction have intensified sediment depletion; disrupting sediment balance and accelerating coastal erosion. Tourism development has increased foot traffic and physical alterations to beaches, exacerbating the erosion process. These anthropogenic activities, compounded by inadequate coastal management practices, have collectively intensified the vulnerability of the coastline, underscoring the urgent need for sustainable intervention strategies to mitigate their adverse effects.

Moreover, by examining the effects of beach changes on human activities along the Cape Coast - Elmina coastline, the study revealed significant impacts on the local communities and their livelihoods. Erosion and sediment depletion have resulted in the reduction of valuable beachfront land, affecting properties, infrastructure, and tourism facilities. This has resulted in economic setbacks for businesses reliant on beach tourism, as well as reduced recreational spaces for residents and visitors. Fishing communities have faced challenges due to altered beach landscapes and degraded marine habitats, impacting fish stocks and their traditional fishing practices. Additionally, increased flooding and coastal vulnerability have threatened residential areas, leading to displacement and heightened risk during extreme weather events. These changes have also strained local resources, necessitating costly mitigation and adaptation measures.

Conclusions

Firstly, the significant reduction in dense vegetation and wetlands highlights the extensive encroachment and transformation driven by rapid urban expansion and infrastructure development. While sparse vegetation exhibited mixed changes, the substantial increase in built-up areas in CCMA and in KEEA reflects the escalating demand for residential, commercial, and industrial spaces. These changes not only alter the physical landscape but also pose serious implications for coastal geomorphology, ecosystem services, and the environmental sustainability of the study areas.

Again, the comprehensive laboratory analysis of beach sediments from Elmina and Cape Coast beaches provides critical insights into the sedimentary dynamics and their implications for coastal management. The predominance of a unimodal sediment distribution indicates a singular, dominant sedimentary source, while seasonal variations characterized by finer sediments during the wet season highlight the influence of wave energy, sediment transport, and weathering processes. The consistent trends in sediment dynamics across both beaches underscore the presence of common underlying geological and hydrodynamic processes shaping the coastline. Notably, the varying stability of beaches against erosion, particularly during the dry season, points to the need for targeted management strategies that account for coastal morphology and regional hydrodynamics. Furthermore, the presence of coarse sediments in specific zones, while beneficial for recreational activities, raises concerns about their vulnerability to exploitation, such as sand mining. Advanced analytical techniques, like bivariate plots and linear discriminant function analysis, emphasize the significant role of beach and shallow marine processes in defining the depositional environments. These findings necessitate a balanced approach to coastal zone management, prioritizing both the preservation of natural sediment dynamics and the sustainable use of beach resources to mitigate erosion risks and enhance the resilience of the Cape Coast - Elmina coastline.

Moreso, the rampant urbanization and infrastructure development have significantly altered natural landscapes through extensive land reclamation, contributing to beach erosion and habitat destruction. The exacerbation of sediment depletion from sand mining and construction activities has disrupted the natural sediment balance, further accelerating coastal erosion. Additionally, the surge in tourism development has not only increased foot traffic but also led to physical modifications of the beaches, intensifying erosion.

In addition, the findings of this study have highlighted the profound and multifaceted impacts that changes in the coastal environment can have on the local communities and their livelihoods along the Cape Coast - Elmina region. The erosion and sediment depletion affecting the beaches have led to the loss of valuable beachfront land, negatively impacting properties, infrastructure, and tourism facilities. This has resulted in significant economic setbacks for businesses reliant on beach-based activities, as well as reduced recreational spaces for residents and visitors. Fishing communities have faced challenges due to the altered beach landscapes and degraded marine habitats, disrupting their traditional fishing practices and reducing fish stocks.

Finally, while some policies have yielded positive outcomes, such as the establishment of protected areas and the implementation of erosion control measures, their overall effectiveness has been hampered by inconsistent enforcement and inadequate integration of local community needs. The study highlights the critical need for more robust, well-coordinated policy frameworks that incorporate stakeholder participation, rigorous enforcement, and continuous monitoring. This would enable the development of comprehensive solutions that enhance the resilience of the coastline and support sustainable human activities in the face of the significant environmental changes and socioeconomic impacts observed in the region.

Recommendations

Based on the findings, the following recommendations were proposed:

- Firstly, there should be stakeholder engagement and collaborations between the EPA, CODA, District Assemblies, and community members in the study areas to strengthen the systematic monitoring and evaluation of land use/land cover changes and their impacts on the coastal environment. This should include the development of comprehensive data collection and analysis systems, as well as the use of advanced geospatial technologies to track the trajectories of coastal transformation over time. The implementation of these recommendation would contribute to the development of a more sustainable and resilient coastal system, where the competing demands for economic development and environmental protection are carefully balanced, and the long-term well-being of the local communities is safeguarded.
- Secondly, the EPA in collaboration with the CODA should implement a zoning strategy for coastal management that balances conservation and

development needs. The zoning could involve dividing the coastal area into different zones based on the findings of the sediment analysis and other relevant factors such as erosion vulnerability, recreational value, and economic activities. This would allow for targeted management strategies tailored to the specific characteristics and needs of each zone. By implementing a zoning strategy, coastal managers can effectively balance the preservation of natural sediment dynamics with sustainable resource use, thereby mitigating erosion risks and enhancing the overall resilience of the Cape Coast - Elmina coastline.

- Again, it is also recommended that the CODA, EPA and community leaders should collaborate and implement strict regulations and enforcement mechanisms for coastal development activities, coupled with community engagement and education initiatives. Strict regulations could aim to control and mitigate the adverse impacts of anthropogenic activities such as land reclamation, sand mining, and tourism development on the Cape Coast - Elmina coastline. These regulations should be enforced rigorously to ensure compliance and prevent further degradation of coastal ecosystems. These actions could preserve the ecological integrity and resilience of the Cape Coast - Elmina coastline while also promoting sustainable development that benefits both people and the environment.
- Moreover, the CODA, EPA, District Assemblies and local communities within the study areas should collaborate and implement a holistic approach to coastal management that integrates community-based

adaptation strategies, sustainable livelihood initiatives, and infrastructure resilience measures. By fostering collaboration among stakeholders, including government agencies, local communities, and possibly NGOs, it becomes possible to pool resources and expertise to tackle the complex challenges posed by coastal environmental changes effectively. This collaborative effort would ensure that interventions are contextually appropriate, socially inclusive, and environmentally sustainable, ultimately enhancing the resilience of the Cape Coast - Elmina region to future environmental threats.

- Finally, it is recommended that the CODA in collaboration with the EPA prioritize the formulation and implementation of integrated coastal management plans that foster stakeholder collaboration, enforceable regulations, and adaptive management practices. Integrated coastal management plans should be developed through a participatory process that engages all relevant stakeholders, including local communities, government agencies, NGOs, and private sector actors. These plans should prioritize the preservation of natural resources, support sustainable livelihoods, and enhance the resilience of coastal communities to environmental changes. By prioritizing integrated coastal management and addressing the gaps in existing policies, coastal authorities can better safeguard the livelihoods, natural resources, and long-term resilience of communities along the Cape Coast - Elmina coastline.

Contributions to Knowledge

To begin with, this study has made some conceptual contributions to knowledge. Firstly, by investigating the dynamic interactions between the physical environment (beaches) and the human activities along the coastline, the study has contributed to a more integrated understanding of the complex coastal socio-ecological system.

Secondly, the longitudinal analysis of spatio-temporal changes in the beach characteristics could help enhance the conceptual understanding of the non-linear and often unpredictable nature of coastal geomorphological processes. The identification of the drivers and patterns of change over time could inform the development of more sophisticated conceptual models that account for the inherent complexity and uncertainty inherent in coastal environments.

Thirdly, the exploration of the anthropogenic influences on beach dynamics could contribute to the conceptual advancement of the human-environment interactions within the coastal context. By explaining the mechanisms through which human activities can modify the physical characteristics of beaches and the subsequent impacts on livelihoods and well-being, the study provides a deeper understanding of the coupled human-natural systems in coastal regions. Finally, the assessment of the effectiveness of national coastal zone management policies would offer valuable conceptual insights into the governance and institutional dimensions of coastal resource management. The identification of policy gaps and the development of more inclusive and adaptive frameworks could contribute to the evolving conceptual paradigms in the field of coastal governance and decision-making.

In addition, the study, utilizing both the Catastrophe Theory and the Driver-Pressure-State-Impact-Response (DPSIR) framework, has the potential to make significant theoretical contributions to the field of coastal systems and environmental management.

Firstly, the application of the Catastrophe Theory provided a novel theoretical lens to conceptualize the dynamic and often unpredictable nature of coastal geomorphological processes. By analyzing the beach changes through the Catastrophe Theory's mathematical models and topological structures, the study could contribute to the refinement and expansion of this theoretical framework within the coastal context, enhancing the understanding of thresholds, bifurcations, and regime shifts in beach systems.

Secondly, the use of the DPSIR framework would offer a robust theoretical foundation to unpack the complex interactions between the physical, ecological, and social dimensions of the coastal system. The application of this framework could enable the study to systematically analyze the mechanisms through which anthropogenic activities influence the beach characteristics and, in turn, impact human well-being and livelihoods, ultimately informing more effective coastal management strategies.

Furthermore, the interplay between the Catastrophe Theory and the DPSIR framework would generate novel theoretical insights by bridging the conceptual gaps between the biophysical and socio-economic components of coastal systems.

This interdisciplinary approach could contribute to the development of integrated theoretical models that can better capture the dynamic and multifaceted nature of coastal socio-ecological systems.

Methodologically, the study has made significant contributions to the field of coastal and environmental research. Firstly, the integration of both quantitative and qualitative data collection and analysis techniques provided a comprehensive, multifaceted understanding of the complex phenomena under investigation.

The combination of remote sensing data analysis, field-based measurements, and in-depth interviews with stakeholders enabled the study to capture the nuanced and context-specific dimensions of the beach changes and their impacts on human activities. This mixed methods approach could contribute to the advancement of methodological frameworks that can effectively bridge the gap between the physical and social aspects of coastal systems.

Again, the study's longitudinal design, analyzing beach changes from 1991 to 2021, would offer a robust methodological approach to investigating the spatio-temporal dynamics of the coastal environment. The diachronic analysis of satellite imagery, coupled with ground-truthing and historical data, would yield valuable insights into the trajectories of beach evolution, enhancing the methodological rigour in coastal change detection and monitoring.

Finally, the study's multidisciplinary nature, integrating concepts and methods from fields such as geography, geology, environmental science, and social sciences, could contribute to the development of innovative, cross-disciplinary methodological frameworks. This holistic approach enabled the study to capture the complex interactions between the physical, ecological, and socioeconomic components of the coastal system, ultimately strengthening the methodological foundations for integrated coastal zone management.

Areas for Further Studies

- Integrating Indigenous and Local Knowledge in Coastal Management enhances the resilience of the Cape Coast - Elmina coastline
- Beach Vulnerability Assessment and Targeted Erosion Management: A Case Study of the Cape Coast – Elmina coastline
- Explore effective mechanisms for stakeholder engagement, policy coordination, and adaptive governance in the coastal zones of Central Region
- Coastal Sediment Dynamics and Sediment Budget Analysis in Central Region: Role of seasonal variations, wave energy, and anthropogenic activities
- Modeling the impacts of Urbanization and infrastructure development on Coastal Geomorphology and Ecosystem Services in Central Region

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APPENDIX A

FOCUS GROUP DISCUSSION GUIDE FOR COMMUNITY MEMBERS

Demographics

1. Sex
2. Age
3. Marital status
4. Household size
5. Level of Education
6. Number of years stayed in the community
7. Primary Occupation
8. Other source(s) of income

Module 1- Changes in beaches along Cape Coast-Elmina coastline

9. What changes have you observed along the beach since you settled in this area?
10. How long have you known these changes?
11. What natural factors may be responsible for the changes?

Module 2- Anthropogenic drivers of the changes in beaches along the Cape Coast - Elmina Coastline

12. What are some of the human-related factors influencing changes in the beach along the Cape Coast - Elmina coastline?

Module 3- Effects of the changes in beaches on human activities along the Cape Coast - Elmina coastline

13. What are some of the benefits coastal communities derive from the beach?
14. What are some of the challenges posed by the beach to the communities along the Cape Coast-Elmina coastline?
15. From your point of view, how does the changes threaten the benefits derived from the beach?
16. From your perspective, how does the changes affect the benefits derived from the beach?
17. In your opinion, how does the changes reduce the threats of the challenges posed by the beach?
18. In your own view, how does the changes affect the challenges posed by the beach?
19. How have human activities (i.e., Fishing, Recreation & Sea Defense) being impacted positively by the changes on the beach along the Cape Coast-Elmina coastline?
20. How have human activities (i.e., Fishing, Recreation & Sea Defense) being impacted negatively by the changes on the beach along the Cape Coast-Elmina coastline?

APPENDIX B

INTERVIEW GUIDE FOR KEY INFORMANTS

Demographics

1. Sex
2. Age
3. Level of Education
4. Number of years stayed in the community
5. Occupation

Module 1- Changes in beaches along Cape Coast-Elmina coastline

6. What changes have you observed along the beach since you settled in this area?
7. How long have you known these changes?
8. What natural factors may be responsible for the changes?

Module 2- Anthropogenic drivers of the changes in beaches along the Cape Coast - Elmina Coastline

9. What are some of the human-related factors influencing changes in the beach along the Cape Coast - Elmina coastline?

Module 3- Effects of the changes in beaches on human activities along the Cape Coast - Elmina coastline

10. What are some of the benefits coastal communities derive from the beach?
11. What are some of the challenges posed by the beach to the communities along the Cape Coast-Elmina coastline?

12. From your point of view, how does the changes threaten the benefits derived from the beach?
13. In your opinion, how does the changes reduce the threats of the challenges posed by the beach?
14. In your own view, how does the changes affect the challenges posed by the beach?
15. How have human activities (i.e., Fishing, Recreation & Sea Defense) being impacted positively by the changes on the beach along the Cape Coast-Elmina coastline?

16. How have human activities (i.e., Fishing, Recreation & Sea Defense) being impacted negatively by the changes on the beach along the Cape Coast-Elmina coastline?

APPENDIX C

INTERVIEW GUIDE FOR INSTITUTIONS

Demographics

1. Sex
2. Age
3. Level of Education
4. Number of years stayed in the community
5. Occupation
6. Position in Institution

Module 1: Changes in beaches along Cape Coast-Elmina coastline

7. Have you observed any changes along the Cape Cost-Elmina beach?
8. How long have you known these changes?
9. What geomorphic factors cause these changes?

Module 2: Anthropogenic drivers of the changes in beaches along the Cape Coast - Elmina Coastline

10. What are some of the human-related factors influencing changes in the beach along the Cape Coast - Elmina coastline?

Module 3: Effects of the changes in beaches on human activities along the Cape Coast - Elmina coastline

11. What are some of the benefits the communities along the Cape Coast-Elmina coastline derive from the beach?

12. What are some of the challenges posed by the beach to the communities along the Cape Coast-Elmina coastline?

13. From your point of view, how does the changes threaten the benefits derived from the beach?

14. From your perspective, how does the changes affect the benefits derived from the beach?

15. In your opinion, how does the changes reduce the threats of the challenges posed by the beach?

16. In your own view, how does the changes affect the challenges posed by the beach?

17. How have human activities (i.e., Fishing, Recreation & Sea Defense) being impacted positively by the changes on the beach along the Cape Coast-Elmina coastline?

18. How have human activities (i.e., Fishing, Recreation & Sea Defense) being impacted negatively by the changes on the beach along the Cape Coast-Elmina coastline?

APPENDIX D

SIEVE ANALYSIS DATA

1. DATE STARTED

2. PROJECT
CAPE COAST - ELMINA COASTLINE

3. SAMPLE CODE E

4. DATE COMPLETED

5. SAMPLE DESCRIPTION
LIGHT BROWN SANDY SOIL

6. SAMPLE NUMBER DS 7

7. PRE-WASHED YES NO

8. ORIGINAL SAMPLE WEIGHT 500

9. + # 200 SAMPLE WEIGHT

10. - # 200 SAMPLE WEIGHT

11. SIEVE SIZE	12. WEIGHT OF SIEVE	13. WEIGHT OF SIEVE+ SAMPLE	14. WEIGHT RETAINED	15. CUMMULATIVE WEIGHT RETAINED	16. PERCENT RETAINED	17. PERCENT PASSING
5	333.86	338.48	4.6	4.6	0.9	99.1
10	316.47	325.04	8.6	13.2	1.7	97.4
35	257.19	368.84	111.6	124.8	22.3	75.1
60	261.95	631.76	369.8	494.7	74.0	1.1
120	249.50	253.81	4.3	499.0	0.9	0.2

18. TOTAL WEIGHT RETAINED IN SIEVES (Sum column 14)

19. ERROR (8-23)

20. WEIGHT SIEVES THROUGH # 200 (Weight in pan) 207.67

21. WASHING LOSS (8-(9+10))

22. TOTAL WEIGHT PASSING #200 (20+10)

23. TOTAL WEIGHT OF FRACTION (18+22)

24. REMARKS

25. ERROR (Percent)

$\frac{\text{ERROR (19)}}{\text{ORIGINAL WT (8)}} \times 100$

26. TECHNICIAN

27. COMPUTED BY (Signature)

28. CHECKED BY (Signature)

SIEVE ANALYSIS DATA

1. DATE STARTED		
2. PROJECT CAPE COAST - ELMINA COASTLINE	3. SAMPLE CODE E	4. DATE COMPLETED
5. SAMPLE DESCRIPTION LIGHT BROWN SANDY SOIL		6. SAMPLE NUMBER DS 15 7. PRE-WASHED YES / NO
8. ORIGINAL SAMPLE WEIGHT 500	9. + # 200 SAMPLE WEIGHT	10. - # 200 SAMPLE WEIGHT

11. SIEVE SIZE	12. WEIGHT OF SIEVE	13. WEIGHT OF SIEVE+ SAMPLE	14. WEIGHT RETAINED	15. CUMMULATIVE WEIGHT RETAINED	16. PERCENT RETAINED	17. PERCENT PASSING
5	333.50	334.38	0.88	0.88	0.2	99.8
10	316.64	394.21	77.57	78.45	15.5	84.3
35	257.25	671.26	414.01	492.46	82.8	1.5
60	261.97	269.10	7.13	499.59	1.4	0.1
120	247.09	247.10	0.01	499.60	0.0	0.1

18. TOTAL WEIGHT RETAINED IN SIEVES (Sum column 14)		19. ERROR (8-23)
20. WEIGHT SIEVES THROUGH # 200 (Weight in pan) 207.67		
21. WASHING LOSS (8-(9+10))		
22. TOTAL WEIGHT PASSING #200 (20+10)		
23. TOTAL WEIGHT OF FRACTION (18+22)		
24. REMARKS		25. ERROR (Percent) ERROR (19) X 100 / ORIGINAL WT (8)
26. TECHNICIAN	27. COMPUTED BY (Signature)	28. CHECKED BY (Signature)

SIEVE ANALYSIS DATA

1. DATE STARTED

2. PROJECT
CAPE COAST - ELMINA COASTLINE

3. SAMPLE CODE E

4. DATE COMPLETED

5. SAMPLE DESCRIPTION
LIGHT BROWN SANDY SOIL

6. SAMPLE NUMBER WS 9

7. PRE-WASHED

YES NO

8. ORIGINAL SAMPLE WEIGHT. 500

9. + # 120 SAMPLE WEIGHT

10. - # 120 SAMPLE WEIGHT

11. SIEVE SIZE	12. WEIGHT OF SIEVE	13. WEIGHT OF SIEVE+ SAMPLE	14. WEIGHT RETAINED	15. CUMMULATIVE WEIGHT RETAINED	16. PERCENT RETAINED	17. PERCENT PASSING
5	333.75	335.11	1.4	1.4	0.3	99.7
10	315.47	393.38	77.9	79.3	15.6	84.1
35	257.08	662.62	405.5	484.8	81.1	3.0
60	262.13	276.56	14.4	499.2	2.9	0.1
120	246.83	247.00	0.2	499.4	0.0	0.1

18. TOTAL WEIGHT RETAINED IN SIEVES (Sum column 14)

19. ERROR (8-23)

20. WEIGHT SIEVES THROUGH # 120 (Weight in pan) 207.67

21. WASHING LOSS (8-(9+10))

22. TOTAL WEIGHT PASSING # 120 (20+10)

23. TOTAL WEIGHT OF FRACTION (18+22)

24. REMARKS

25. ERROR (Percent)

$\frac{\text{ERROR (19)}}{\text{ORIGINAL WT (8)}} \times 100$

26. TECHNICIAN

27. COMPUTED BY (Signature)

28. CHECKED BY (Signature)

SIEVE ANALYSIS DATA

SIEVE ANALYSIS DATA					1. DATE STARTED	
2. PROJECT CAPE COAST - ELMINA COASTLINE			3. SAMPLE CODE E		4. DATE COMPLETED	
5. SAMPLE DESCRIPTION LIGHT BROWN SANDY SOIL					6. SAMPLE NUMBER WS 16	
					7. PRE-WASHED	
					YES	NO
8. ORIGINAL SAMPLE WEIGHT. 500			9. + # 120 SAMPLE WEIGHT		10. - # 120 SAMPLE WEIGHT	
11. SIEVE SIZE	12. WEIGHT OF SIEVE	13. WEIGHT OF SIEVE+ SAMPLE	14. WEIGHT RETAINED	15. CUMMULATIVE WEIGHT RETAINED	16. PERCENT RETAINED	17. PERCENT PASSING
5	334.03	334.78	0.8	0.8	0.2	99.8
10	315.88	319.82	3.9	4.7	0.8	99.0
35	257.11	713.00	455.9	460.6	91.2	7.8
60	262.13	300.25	38.1	498.7	7.6	0.2
120	247.03	247.21	0.2	498.9	0.0	0.2
18. TOTAL WEIGHT RETAINED IN SIEVES (Sum column 14)					19. ERROR (8-23)	
20. WEIGHT SIEVES THROUGH # 120 (Weight in pan) 207.67						
21. WASHING LOSS (8-(9+10))						
22. TOTAL WEIGHT PASSING # 120 (20+10)						
23. TOTAL WEIGHT OF FRACTION (18+22)						
24. REMARKS					25. ERROR (Percent) ERROR (19) X 100 / ORIGINAL WT (8)	
26. TECHNICIAN			27. COMPUTED BY (Signature)		28. CHECKED BY (Signature)	

SIEVE ANALYSIS DATA

1. DATE STARTED

2. PROJECT: CAPE COAST - ELMINA COASTLINE

3. SAMPLE CODE: CC

4. DATE COMPLETED

5. SAMPLE DESCRIPTION: LIGHT BROWN SANDY SOIL

6. SAMPLE NUMBER: DS23

7. PRE-WASHED: YES / NO

8. ORIGINAL SAMPLE WEIGHT: 500.

9. + # 200 SAMPLE WEIGHT

10. - # 200 SAMPLE WEIGHT

11. SIEVE SIZE	12. WEIGHT OF SIEVE	13. WEIGHT OF SIEVE+ SAMPLE	14. WEIGHT RETAINED	15. CUMMULATIVE WEIGHT RETAINED	16. PERCENT RETAINED	17. PERCENT PASSING
5	334.33	335.10	0.8	0.8	0.2	99.8
10	316.19	318.42	2.2	3.0	0.4	99.4
35	257.07	705.96	448.9	451.9	89.8	9.6
60	261.89	309.16	47.3	499.2	9.5	0.1
120	247.10	247.34	0.2	499.4	0.0	0.1

18. TOTAL WEIGHT RETAINED IN SIEVES (Sum column 14)

19. ERROR (8-23)

20. WEIGHT SIEVES THROUGH # 200 (Weight in pan) 207.67

21. WASHING LOSS (8-(9+10))

22. TOTAL WEIGHT PASSING #200 (20+10)

23. TOTAL WEIGHT OF FRACTION (18+22)

24. REMARKS

25. ERROR (Percent)

$$\frac{\text{ERROR (19)} \times 100}{\text{ORIGINAL WT (8)}}$$

26. TECHNICIAN

27. COMPUTED BY (Signature)

28. CHECKED BY (Signature)

SIEVE ANALYSIS DATA

1. DATE STARTED

2. PROJECT
CAPE COAST - ELMINA COASTLINE

3. SAMPLE CODE CC

4. DATE COMPLETED

5. SAMPLE DESCRIPTION
LIGHT BROWN SANDY SOIL

6. SAMPLE NUMBER DS 53

7. PRE-WASHED
YES | NO

8. ORIGINAL SAMPLE WEIGHT 500

9. + # 200 SAMPLE WEIGHT

10. - # 200 SAMPLE WEIGHT

11. SIEVE SIZE	12. WEIGHT OF SIEVE	13. WEIGHT OF SIEVE+ SAMPLE	14. WEIGHT RETAINED	15. CUMMULATIVE WEIGHT RETAINED	16. PERCENT RETAINED	17. PERCENT PASSING
5	333.96	338.67	4.7	4.7	0.9	99.1
10	317.15	326.47	9.3	14.0	1.9	97.2
35	257.13	654.74	397.6	411.6	79.5	17.7
60	261.84	348.89	87.1	498.7	17.4	0.3
120	248.20	248.30	0.1	498.8	0.0	0.3

18. TOTAL WEIGHT RETAINED IN SIEVES (Sum column 14)

19. ERROR (8-23)

20. WEIGHT SIEVES THROUGH # 200 (Weight in pan) 201.67

21. WASHING LOSS (8-(9+10))

22. TOTAL WEIGHT PASSING #200 (20+10)

23. TOTAL WEIGHT OF FRACTION (18+22)

24. REMARKS

25. ERROR (Percent)

$$\frac{\text{ERROR (19)}}{\text{ORIGINAL WT (8)}} \times 100$$

26. TECHNICIAN

27. COMPUTED BY (Signature)

28. CHECKED BY (Signature)

SIEVE ANALYSIS DATA					1. DATE STARTED	
2. PROJECT CAPE COAST - ELMINA COASTLINE			3. SAMPLE CODE CC		4. DATE COMPLETED	
5. SAMPLE DESCRIPTION LIGHT BROWN SANDY SOIL					6. SAMPLE NUMBER ws 35	
					7. PRE-WASHED YES / NO	
8. ORIGINAL SAMPLE WEIGHT. 500			9. + # 120 SAMPLE WEIGHT		10. - # 120 SAMPLE WEIGHT	
11. SIEVE SIZE	12. WEIGHT OF SIEVE	13. WEIGHT OF SIEVE+ SAMPLE	14. WEIGHT RETAINED	15. CUMMULATIVE WEIGHT RETAINED	16. PERCENT RETAINED	17. PERCENT PASSING
5	335.33	339.53	3.9	3.9	6.8	99.2
10	317.20	325.86	8.4	12.3	1.7	97.5
35	257.33	696.24	438.9	451.2	87.8	9.7
60	262.46	309.49	47.1	498.3	9.4	0.3
120	246.94	246.96	0.1	498.3	0.0	0.3
18. TOTAL WEIGHT RETAINED IN SIEVES (Sum column 14)					19. ERROR (8-23)	
20. WEIGHT SIEVES THROUGH # 120 (Weight in pan) 207.67						
21. WASHING LOSS (8-(9+10))						
22. TOTAL WEIGHT PASSING # 120 (20+10)						
23. TOTAL WEIGHT OF FRACTION (18+22)						
24. REMARKS					25. ERROR (Percent) ERROR (19) X 100 / ORIGINAL WT (8)	
26. TECHNICIAN			27. COMPUTED BY (Signature)		28. CHECKED BY (Signature)	

SIEVE ANALYSIS DATA		1. DATE STARTED
2. PROJECT CAPE COAST - ELMINA COASTLINE	3. SAMPLE CODE CC	4. DATE COMPLETED
5. SAMPLE DESCRIPTION LIGHT BROWN SANDY SOIL		6. SAMPLE NUMBER WS 68
		7. PRE-WASHED YES NO
8. ORIGINAL SAMPLE WEIGHT. 500	9. + # 120 SAMPLE WEIGHT	10. - # 120 SAMPLE WEIGHT

11. SIEVE SIZE	12. WEIGHT OF SIEVE	13. WEIGHT OF SIEVE+ SAMPLE	14. WEIGHT RETAINED	15. CUMMULATIVE WEIGHT RETAINED	16. PERCENT RETAINED	17. PERCENT PASSING
5	334.16	337.23	3.1	3.1	0.6	99.4
10	316.84	321.84	5.0	8.1	1.0	98.4
35	257.26	661.71	404.5	412.5	80.9	17.5
60	262.29	348.44	86.1	498.7	17.2	0.3
120	247.02	247.34	0.3	499.0	0.1	0.2

18. TOTAL WEIGHT RETAINED IN SIEVES (Sum column 14)		19. ERROR (8-23)
20. WEIGHT SIEVES THROUGH # 120 (Weight in pan) 207.67		
21. WASHING LOSS (8-(9+10))		
22. TOTAL WEIGHT PASSING # 120 (20+10)		
23. TOTAL WEIGHT OF FRACTION (18+22)		
24. REMARKS		25. ERROR (Percent) ERROR (19) X 100 / ORIGINAL WT (8)
26. TECHNICIAN	27. COMPUTED BY (Signature)	28. CHECKED BY (Signature)

APPENDIX D

Statistical analysis of samples taken from Zone 1 in the dry season.

‘SAMPLE’	‘MEAN’	‘SORTING’	‘SKEWNESS’	‘KURTOSIS’
ED1	-0.011	0.825	-0.016	0.957
ED2	0.006	0.690	0.013	0.757
ED3	-0.173	0.805	-0.083	0.884
ED4	0.035	0.735	0.059	0.836
ED5	-0.009	0.656	0.000	0.738
ED6	0.035	0.681	0.023	0.774
ED7	0.004	0.672	0.000	0.738
ED8	-0.039	0.751	-0.071	0.859
ED9	-0.037	0.759	-0.073	0.864
ED10	-0.034	0.727	-0.056	0.830

Source: Osei, 2021

APPENDIX E

Interpretation of values for samples taken from Zone 1 in the dry season.

SAMPLE	MEAN DESCRIPTION	SORTING DESCRIPTION	SKEWNESS DESCRIPTION	KURTOSIS DESCRIPTION
ED1	'Very Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Mesokurtic'
ED2	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
ED3	'Very Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
ED4	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
ED5	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
ED6	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
ED7	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
ED8	'Very Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
ED9	'Very Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
ED10	'Very Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'

Source: Osei, 2021

APPENDIX F

Statistical analysis of samples taken from Zone 2 in the dry season.

SAMPLE	MEAN	SORTING	SKEWNESS	KURTOSIS
ED11	1.111	0.813	-0.491	1.659
ED12	1.160	0.825	-0.492	1.749
ED13	0.615	0.966	-0.143	0.719
ED14	0.585	0.963	-0.129	0.718
ED15	0.536	1.164	-0.327	0.792
ED16	0.813	0.966	-0.397	0.767
ED17	0.501	0.958	-0.032	0.728

Source: Osei, 2021

APPENDIX G

Interpretation of values for samples taken from Zone 2 in the dry season.

SAMPLE	'MEAN DESCRIPTION'	'SORTING DESCRIPTION'	'SKEWNESS DESCRIPTION'	'KURTOSIS DESCRIPTION'
ED11	'Medium Sand'	'Moderately Sorted'	'Very Coarse Skewed'	'Very Leptokurtic'
ED12	'Medium Sand'	'Moderately Sorted'	'Very Coarse Skewed'	'Very Leptokurtic'
ED13	'Coarse Sand'	'Moderately Sorted'	'Coarse Skewed'	'Platykurtic'
ED14	'Coarse Sand'	'Moderately Sorted'	'Coarse Skewed'	'Platykurtic'
ED15	'Coarse Sand'	'Poorly Sorted'	'Very Coarse Skewed'	'Platykurtic'
ED16	'Coarse Sand'	'Moderately Sorted'	'Very Coarse Skewed'	'Platykurtic'
ED17	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'

Source: Osei, 2021

APPENDIX H

Statistical analysis of samples taken from Zone 3 in the dry season.

SAMPLE	MEAN	SORTING	SKEWNESS	KURTOSIS
CCD1	-0.024	0.628	0.000	0.738
CCD2	-0.005	0.623	0.000	0.738
CCD3	-0.010	0.653	0.000	0.738
CCD4	0.158	0.807	0.081	0.881
CCD5	0.485	0.955	-0.032	0.727
CCD6	0.197	0.828	0.088	0.873
CCD7	0.056	0.707	0.053	0.825
CCD8	0.196	0.839	0.088	0.870
CCD9	0.229	0.828	0.095	0.874
CCD10	0.036	0.697	0.037	0.797
CCD11	0.028	0.655	0.000	0.738
CCD12	0.004	0.629	0.000	0.738
CCD13	-0.214	0.943	-0.050	0.906
CCD14	-0.004	0.637	0.000	0.738
CCD15	-0.013	0.631	0.000	0.738
CCD16	0.044	0.663	0.013	0.758
CCD17	0.005	0.626	0.000	0.738
CCD18	0.014	0.670	0.000	0.738
CCD19	0.048	0.657	0.009	0.752
CCD20	0.134	0.771	0.085	0.889
CCD21	0.103	0.754	0.082	0.881
CCD22	0.099	0.738	0.079	0.875
CCD23	0.102	0.753	0.081	0.881
CCD24	0.073	0.716	0.065	0.847
CCD25	0.332	0.881	0.095	0.841
CCD26	0.192	0.814	0.086	0.878
CCD27	0.168	0.792	0.084	0.886
CCD28	0.068	0.714	0.062	0.842
CCD29	0.297	0.870	0.097	0.851
CCD30	0.064	0.717	0.062	0.842
CCD31	0.091	0.742	0.079	0.876
CCD32	0.151	0.783	0.088	0.896
CCD33	0.041	0.710	0.049	0.818
CCD34	-0.004	0.655	0.000	0.738
CCD35	0.094	0.736	0.078	0.874
CCD36	0.239	0.857	0.095	0.862
CCD37	0.067	0.707	0.058	0.835
CCD38	0.041	0.669	0.017	0.763
CCD39	0.046	0.691	0.038	0.798

Source: Osei, 2021

APPENDIX I

Interpretation of values for samples taken from Zone 3 in the dry season.

SAMPLE	MEAN DESCRIPTION	SORTING DESCRIPTION	SKEWNESS DESCRIPTION	KURTOSIS DESCRIPTION
CCD1	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD2	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD3	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD4	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD5	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD6	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD7	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD8	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD9	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD10	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD11	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD12	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD13	'Very Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Mesokurtic'
CCD14	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD15	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD16	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD17	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD18	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD19	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD20	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'

CCD21	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD22	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD23	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD24	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD25	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD26	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD27	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD28	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD29	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD30	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD31	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD32	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD33	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD34	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD35	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD36	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD37	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD38	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD39	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'

Source: Osei, 2021

APPENDIX J

Statistical analysis of samples taken from Zone 4 in the dry season.

SAMPLE	MEAN	SORTING	SKEWNESS	KURTOSIS
CCD40	0.019	0.646	0.000	0.738
CCD41	0.094	0.753	0.080	0.878
CCD42	0.366	0.904	0.087	0.826
CCD43	0.237	0.838	0.096	0.870
CCD44	0.029	0.647	0.000	0.738
CCD45	0.417	0.912	0.059	0.779
CCD46	0.046	0.720	0.056	0.831
CCD47	0.158	0.792	0.087	0.893
CCD48	0.256	0.864	0.096	0.858
CCD49	0.342	0.895	0.088	0.830
CCD50	0.102	0.762	0.083	0.884
CCD51	0.161	0.806	0.085	0.888
CCD52	0.199	0.841	0.089	0.869
CCD53	0.080	0.742	0.075	0.867
CCD54	0.500	0.933	-0.003	0.737
CCD55	0.091	0.932	0.008	0.971
CCD56	0.100	0.789	0.085	0.889
CCD57	0.133	0.778	0.087	0.894
CCD58	0.092	0.740	0.077	0.873
CCD59	0.056	0.689	0.043	0.806
CCD60	0.281	0.880	0.097	0.851
CCD61	0.105	0.760	0.083	0.885
CCD62	0.223	0.844	0.094	0.869
CCD63	0.094	0.752	0.081	0.881
CCD64	0.085	0.755	0.078	0.875
CCD65	0.193	0.806	0.086	0.882
CCD66	0.179	0.797	0.085	0.889
CCD67	0.143	0.796	0.088	0.896
CCD68	0.125	0.776	0.091	0.901
CCD69	0.103	0.750	0.083	0.884
CCD70	0.095	0.758	0.081	0.881
CCD71	0.101	0.793	0.083	0.884
CCD72	0.156	0.789	0.085	0.889
CCD73	0.100	0.765	0.083	0.885
CCD74	0.041	0.715	0.051	0.821
CCD75	0.137	0.781	0.086	0.890

Source: Osei, 2021

APPENDIX K

Interpretation of values for samples taken from Zone 4 in the dry season.

SAMPLE	MEAN DESCRIPTION	SORTING DESCRIPTION	SKEWNESS DESCRIPTION	KURTOSIS DESCRIPTION
CCD40	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD41	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD42	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD43	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD44	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCD45	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD46	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD47	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD48	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD49	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD50	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD51	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD52	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD53	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD54	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD55	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Mesokurtic'
CCD56	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD57	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD58	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCD59	'Coarse	'Moderately Well	'Symmetrical	'Platykurtic'

	Sand’	Sorted’	’	
CCD60	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD61	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD62	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD63	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD64	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD65	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD66	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD67	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD68	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Mesokurtic’
CCD69	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD70	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD71	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD72	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD73	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD74	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCD75	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’

Source: Osei, 2021

APPENDIX L

Statistical analysis of samples taken from Zone 1 in the wet season.

‘SAMPLE’	‘MEAN’	‘SORTING’	‘SKEWNESS’	‘KURTOSIS’
EW1	0.026	0.714	0.043	0.807
EW2	0.072	0.714	0.063	0.845
EW3	0.041	0.643	0.000	0.738
EW4	0.217	0.830	0.093	0.875
EW5	-0.030	0.696	-0.033	0.790
EW6	0.017	0.760	0.029	0.870
EW7	-0.092	0.745	-0.080	0.878
EW8	-0.027	0.774	-0.048	0.890
EW9	-0.160	0.820	-0.081	0.881
EW10	0.035	0.670	0.013	0.758

APPENDIX M

Interpretation of values for samples taken from Zone 1 in the wet season.

SAMPLE	MEAN DESCRIPTION	SORTING DESCRIPTION	SKEWNESS DESCRIPTION	KURTOSIS DESCRIPTION
EW1	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
EW2	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
EW3	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
EW4	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
EW5	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
EW6	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
EW7	'Very Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
EW8	'Very Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
EW9	'Very Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
EW10	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'

Source: Osei, 2021

APPENDIX N

Statistical analysis of samples taken from Zone 2 in the wet season.

SAMPLE	MEAN	SORTING	SKEWNESS	KURTOSIS
EW14	1.535	0.430	0.151	1.056
EW15	1.534	0.428	0.150	1.054
EW16	1.733	0.710	0.046	1.298
EW17	1.570	0.636	-0.042	1.609

Source: Osei, 2021

APPENDIX O

Interpretation of values for samples taken from Zone 2 in the wet season.

SAMPLE	MEAN DESCRIPTION	SORTING DESCRIPTION	SKEWNESS DESCRIPTION	KURTOSIS DESCRIPTION
EW14	'Medium Sand'	'Well Sorted'	Fine Skewed	Mesokurtic
EW15	'Medium Sand'	'Well Sorted'	Fine Skewed	Mesokurtic
EW16	'Medium Sand'	'Moderately Sorted'	Symmetrical	Leptokurtic
EW17	'Medium Sand'	'Moderately Well Sorted'	Symmetrical	Very Leptokurtic

Source: Osei, 2021

APPENDIX P

Statistical analysis of samples taken from Zone 3 in the wet season.

SAMPLE	‘MEAN’	‘SORTING’	‘SKEWNESS’	‘KURTOSIS’
CCW1	-0.002	0.618	0.000	0.738
CCW2	-0.005	0.622	0.000	0.738
CCW3	-0.006	0.628	0.000	0.738
CCW4	-0.001	0.653	0.000	0.738
CCW5	0.022	0.744	0.044	0.844
CCW6	-0.002	0.651	0.000	0.738
CCW7	0.031	0.728	0.054	0.827
CCW8	0.082	0.778	0.080	0.878
CCW9	0.024	0.652	0.000	0.738
CCW10	0.152	0.824	0.079	0.875
CCW11	0.016	0.630	0.000	0.738
CCW12	-0.015	0.624	0.000	0.738
CCW13	-0.011	0.623	0.000	0.738
CCW14	-0.006	0.621	0.000	0.738
CCW15	0.006	0.628	0.000	0.738
CCW16	0.008	0.638	0.000	0.738
CCW17	0.015	0.634	0.000	0.738
CCW18	0.031	0.645	0.000	0.738
CCW19	0.024	0.651	0.000	0.738
CCW20	0.118	0.797	0.082	0.883
CCW21	0.016	0.655	0.000	0.738
CCW22	-0.001	0.641	0.000	0.738
CCW23	-0.001	0.641	0.000	0.738
CCW24	0.100	0.770	0.082	0.882
CCW25	0.057	0.730	0.064	0.846
CCW26	0.118	0.782	0.084	0.886
CCW27	0.089	0.769	0.080	0.879
CCW28	0.088	0.756	0.079	0.876
CCW29	0.409	0.929	0.042	0.764
CCW30	0.214	0.825	0.091	0.875
CCW31	0.121	0.786	0.083	0.885

CCW32	0.305	0.903	0.084	0.828
CCW33	0.372	0.923	0.060	0.786
CCW34	0.079	0.752	0.077	0.872
CCW35	0.209	0.840	0.091	0.869
CCW36	0.092	0.741	0.078	0.873
CCW37	0.021	0.655	0.000	0.738
CCW38	0.138	0.781	0.085	0.888
CCW39	0.094	0.730	0.076	0.870

Source: Osei, 2021

APPENDIX Q

Interpretation of values for samples taken from Zone 3 in the wet season.

SAMPLE	MEAN DESCRIPTION	SORTING DESCRIPTION	SKEWNESS DESCRIPTION	KURTOSIS DESCRIPTION
CCW1	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW2	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW3	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW4	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW5	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW6	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW7	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW8	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW9	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW10	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW11	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW12	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW13	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW14	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW15	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW16	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW17	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW18	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW19	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW20	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW21	'Coarse Sand'	'Moderately Well	'Symmetrica	'Platykurtic'

		Sorted'	l'	
CCW22	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW23	'Very Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW24	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW25	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW26	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW27	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW28	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW29	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW30	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW31	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW32	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW33	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW34	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW35	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW36	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW37	'Coarse Sand'	'Moderately Well Sorted'	'Symmetrical'	'Platykurtic'
CCW38	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW39	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'

Source: Osei, 2021

APPENDIX R

Statistical analysis of samples taken from Zone 4 in the wet season.

SAMPLE	'MEAN'	'SORTING'	'SKEWNESS'	'KURTOSIS'
CCW40	0.097	0.738	0.079	0.876
CCW41	0.269	0.849	0.105	0.874
CCW42	0.118	0.768	0.084	0.887
CCW43	0.296	0.864	0.101	0.858
CCW44	0.426	0.925	0.042	0.763
CCW45	0.218	0.831	0.092	0.872
CCW46	0.091	0.748	0.079	0.875
CCW47	0.457	0.923	0.028	0.752
CCW48	0.286	0.864	0.107	0.870
CCW49	0.414	0.914	0.058	0.778
CCW50	0.174	0.794	0.084	0.887
CCW51	0.181	0.802	0.086	0.891
CCW52	0.306	0.870	0.097	0.850
CCW53	0.073	0.726	0.068	0.854
CCW54	0.095	0.745	0.079	0.876
CCW55	0.347	0.903	0.097	0.841
CCW56	0.229	0.844	0.094	0.868
CCW57	0.066	0.703	0.056	0.831
CCW58	0.131	0.775	0.089	0.897
CCW59	0.245	0.862	0.099	0.867
CCW60	0.218	0.855	0.093	0.865
CCW61	0.151	0.794	0.086	0.891
CCW62	0.283	0.868	0.097	0.853
CCW63	0.463	0.927	0.033	0.754
CCW64	0.136	0.779	0.085	0.890
CCW65	0.172	0.825	0.083	0.876
CCW66	0.327	0.891	0.088	0.832
CCW67	0.209	0.829	0.091	0.874
CCW68	0.070	0.706	0.059	0.837
CCW69	0.060	0.713	0.059	0.836
CCW70	0.157	0.794	0.084	0.886
CCW71	0.203	0.822	0.092	0.882
CCW72	0.466	0.939	0.027	0.750
CCW73	0.324	0.896	0.097	0.844
CCW74	0.258	0.861	0.112	0.887
CCW75	0.127	0.790	0.086	0.892

Source: Osei, 2021

APPENDIX S

Interpretation of values for samples taken from Zone 4 in the wet season.

SAMPLE	MEAN DESCRIPTION	SORTING DESCRIPTION	SKEWNESS DESCRIPTION	KURTOSIS DESCRIPTION
CCW40	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CW41	'Coarse Sand'	'Moderately Sorted'	'Fine Skewed'	'Platykurtic'
CCW42	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW43	'Coarse Sand'	'Moderately Sorted'	'Fine Skewed'	'Platykurtic'
CCW44	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW45	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW46	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW47	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW48	'Coarse Sand'	'Moderately Sorted'	'Fine Skewed'	'Platykurtic'
CCW49	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW50	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW51	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW52	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW53	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW54	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW55	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW56	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW57	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW58	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW59	'Coarse Sand'	'Moderately Sorted'	'Symmetrical'	'Platykurtic'
CCW60	'Coarse Sand'	'Moderately	'Symmetrical'	'Platykurtic'

		Sorted’		
CCW61	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW62	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW63	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW64	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW65	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW66	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW67	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW68	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW69	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW70	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW71	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW72	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW73	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’
CCW74	‘Coarse Sand’	‘Moderately Sorted’	‘Fine Skewed’	‘Platykurtic’
CCW75	‘Coarse Sand’	‘Moderately Sorted’	‘Symmetrical’	‘Platykurtic’

Source: Osei, 2021

APPENDIX T

Results of Linear discriminant function application on samples taken from study area in the dry season.

Sample	Y1	Y2	Y3
ED1	5.5715	61.9700	-5.8464
ED2	4.0708	45.6212	-4.2003
ED3	5.9408	54.7280	-5.2823
ED4	4.3552	52.5835	-4.9755
ED5	3.9228	41.7923	-3.7409
ED6	3.9538	45.7600	-4.1322
ED7	3.9551	43.3920	-3.9233
ED8	5.0488	51.0591	-4.5678
ED9	5.1061	51.9405	-4.6631
ED10	4.7782	48.5415	-4.3303
ED11	4.6666	82.6307	-2.9999
ED12	4.8468	86.3365	-3.1494
ED13	3.7949	81.6590	-7.2689
ED14	3.8484	81.0441	-7.2953
ED15	6.2473	106.1536	-10.0826
ED16	3.7652	81.0473	-5.9675
ED17	3.9423	81.0395	-7.7094
CCD1	3.8433	39.1951	-3.4302
CCD2	3.7523	39.0815	-3.3700

CCD3	3.9118	41.5186	-3.7068
CCD4	4.4216	63.0352	-6.0188
CCD5	3.9750	80.3934	-7.6637
CCD6	4.3700	65.8805	-6.3430
CCD7	4.1090	49.9469	-4.5869
CCD8	4.4322	67.0142	-6.5041
CCD9	4.2444	66.5267	-6.3681
CCD10	4.0744	47.9035	-4.3926
CCD11	3.7859	42.2853	-3.7189
CCD12	3.7480	39.7160	-3.4332
CCD13	6.9800	70.9415	-7.5678
CCD14	3.8140	40.2563	-3.5243
CCD15	3.8180	39.6155	-3.4602
CCD16	3.8031	43.8341	-3.8694
CCD17	3.7305	39.4843	-3.4000
CCD18	3.9094	43.3721	-3.8970
CCD19	3.7492	43.1928	-3.7796
CCD20	4.3136	59.1472	-5.5472
CCD21	4.3095	56.7560	-5.3146
CCD22	4.2230	54.9595	-5.0922
CCD23	4.3096	56.6233	-5.2968
CCD24	4.1393	51.6790	-4.7521
CCD25	4.1094	73.4801	-7.1337

CCD26	4.3225	64.3480	-6.1331
CCD27	4.3064	61.7625	-5.8203
CCD28	4.1372	51.2659	-4.7140
CCD29	4.1900	71.8878	-6.9843
CCD30	4.1674	51.4854	-4.7527
CCD31	4.2766	55.2418	-5.1463
CCD32	4.3375	60.8225	-5.7201
CCD33	4.1647	49.7895	-4.6092
CCD34	3.9001	41.7844	-3.7280
CCD35	4.2289	54.6509	-5.0629
CCD36	4.3523	69.6720	-6.7939
CCD37	4.0905	50.3947	-4.6078
CCD38	3.8507	44.4772	-3.9596
CCD39	4.0089	47.5494	-4.3216
CCD40	3.7747	41.3750	-3.6188
CCD41	4.3309	56.4244	-5.2943
CCD42	4.1099	76.2875	-7.4451
CCD43	4.2630	67.6907	-6.5169
CCD44	3.7438	41.6165	-3.6273
CCD45	3.8935	76.6638	-7.4228
CCD46	4.2258	51.1747	-4.7667
CCD47	4.3577	61.7898	-5.8375
CCD48	4.3216	70.6738	-6.8996

CCD49	4.1460	74.9401	-7.3148
CCD50	4.3653	57.6109	-5.4259
CCD51	4.4184	63.1781	-6.0231
CCD52	4.4287	67.2816	-6.5376
CCD53	4.2961	54.8306	-5.1302
CCD54	3.7387	78.6091	-7.4370
CCD55	5.8971	76.6135	-7.5811
CCD56	4.5388	60.4601	-5.8029
CCD57	4.3687	59.9727	-5.6520
CCD58	4.2569	54.9709	-5.1104
CCD59	3.9776	47.7632	-4.3187
CCD60	4.3118	72.7873	-7.1421
CCD61	4.3464	57.4764	-5.3983
CCD62	4.3514	68.0800	-6.5995
CCD63	4.3326	56.3991	-5.2859
CCD64	4.3690	56.3900	-5.3136
CCD65	4.2834	63.5861	-6.0191
CCD66	4.3039	62.5304	-5.8915
CCD67	4.4420	62.0461	-5.9022
CCD68	4.3992	59.8452	-5.6464
CCD69	4.2945	56.4344	-5.2666
CCD70	4.3626	57.0101	-5.3650
CCD71	4.5473	60.7628	-5.8485

CCD72	4.3390	61.3367	-5.7869
CCD73	4.3925	57.8991	-5.4665
CCD74	4.1963	50.3494	-4.6813
CCD75	4.3613	60.2505	-5.6872

Source: Osei, 2021

APPENDIX U

Results of Linear discriminant function application on samples taken from study area in the wet season.

Sample	Y1	Y2	Y3
ED1	4.2163	49.5736	-4.6289
ED2	4.1269	51.4012	-4.7179
ED3	3.6810	41.4574	-3.5785
ED4	4.3102	66.5956	-6.3982
ED5	4.4277	45.3514	-4.0501
ED6	4.7253	54.8422	-5.1583
ED7	5.2821	49.8348	-4.4614
ED8	5.1823	54.5237	-4.9786
ED9	5.9717	56.4943	-5.5001
ED10	3.8693	44.2869	-3.9532
ED14	-1.8182	58.4216	-1.8718
ED15	-1.8250	58.3031	-1.8601
ED16	-0.3706	85.1455	-4.0975
ED17	0.9942	80.1882	-2.8219
CCD1	3.7187	38.6943	-3.3131
CCD2	3.7457	38.9523	-3.3542
CCD3	3.7793	39.4675	-3.4253
CCD4	3.8810	41.6884	-3.7089
CCD5	4.5085	53.1446	-5.0240
CCD6	3.8717	41.4223	-3.6765
CCD7	4.3154	51.6156	-4.8665
CCD8	4.5172	58.7758	-5.6356
CCD9	3.7850	41.9660	-3.6864
CCD10	4.5332	64.6438	-6.2550
CCD11	3.7078	39.9826	-3.4404
CCD12	3.7953	39.0289	-3.3885
CCD13	3.7703	38.9546	-3.3675
CCD14	3.7447	38.8914	-3.3474
CCD15	3.7363	39.6707	-3.4234
CCD16	3.7759	40.5647	-3.5369
CCD17	3.7297	40.2567	-3.4804
CCD18	3.7287	41.4875	-3.6070
CCD19	3.7788	41.8907	-3.6754
CCD20	4.5097	61.4701	-5.9016
CCD21	3.8265	42.0687	-3.7192
CCD22	3.8179	40.6063	-3.5636

CCD23	3.8179	40.6063	-3.5636
CCD24	4.4130	58.3172	-5.5257
CCD25	4.2701	52.6885	-4.9252
CCD26	4.4281	59.9311	-5.6951
CCD27	4.4424	57.9927	-5.5133
CCD28	4.3636	56.5507	-5.3273
CCD29	4.0243	77.9754	-7.6115
CCD30	4.2898	65.9278	-6.3135
CCD31	4.4402	60.4135	-5.7518
CCD32	4.3353	75.2148	-7.4346
CCD33	4.1513	77.4951	-7.6245
CCD34	4.3633	55.9126	-5.2687
CCD35	4.3832	67.3597	-6.5281
CCD36	4.2617	55.0505	-5.1231
CCD37	3.8113	42.1624	-3.7208
CCD38	4.3554	60.2389	-5.6839
CCD39	4.1900	53.9693	-4.9787
CCD40	4.2311	54.9305	-5.0899
CCD41	4.2147	69.6848	-6.7197
CCD42	4.3508	58.5931	-5.5135
CCD43	4.1660	71.3627	-6.9087
CCD44	3.9373	77.8142	-7.5532
CCD45	4.3022	66.6271	-6.4045
CCD46	4.3046	55.7642	-5.2161
CCD47	3.8051	77.5125	-7.4335
CCD48	4.2260	71.5470	-6.9413
CCD49	3.9158	76.8280	-7.4507
CCD50	4.2981	62.0553	-5.8428
CCD51	4.3280	63.1089	-5.9611
CCD52	4.1535	72.0407	-6.9865
CCD53	4.2073	52.7783	-4.8888
CCD54	4.2793	55.5994	-5.1839
CCD55	4.1964	76.3619	-7.4866
CCD56	4.3256	68.1198	-6.5945
CCD57	4.0654	49.9466	-4.5548
CCD58	4.3606	59.7008	-5.6166
CCD59	4.3686	70.4803	-6.8840
CCD60	4.4281	69.1501	-6.7609
CCD61	4.3932	61.8798	-5.8686
CCD62	4.2341	71.4474	-6.9532

CCD63	3.8064	78.2103	-7.5177
CCD64	4.3548	60.0133	-5.6579
CCD65	4.4633	65.1569	-6.2865
CCD66	4.1819	74.2874	-7.2591
CCD67	4.3325	66.2473	-6.3691
CCD68	4.0791	50.4126	-4.6018
CCD69	4.1514	50.9026	-4.6929
CCD70	4.3589	61.8056	-5.8506
CCD71	4.3301	65.5453	-6.2704
CCD72	3.8840	79.6693	-7.7001
CCD73	4.2393	75.1507	-7.3729
CCD74	4.3529	71.2046	-6.9315
CCD75	4.4548	61.0447	-5.8144

Source: Osei, 2021