

**MONITORING SHORELINE CHANGE USING
MEDIUM RESOLUTION MULTI-TEMPORAL
SATELLITE IMAGERY: A CASE STUDY OF
KETA, GHANA**

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DECLARATION

This is to certify that this thesis is the result of research undertaken by Philip-Neri Jayson-Quashigah under the supervision towards the Award of the M.Phil Degree in the Environmental Science Programme, University of Ghana.

 1/02/2012

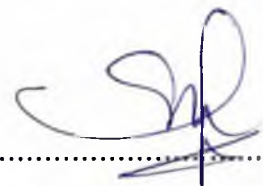
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ABSTRACT

Shoreline change analysis provides important information upon which most coastal zone management and intervention policies rely. Such information is however mostly scarce for very large and inaccessible shorelines mostly due to expensive field work. This study investigated the reliability of medium resolution satellite imagery for mapping shoreline positions and for estimating historic rate of change.

Both manual and semi-automatic shoreline extraction methods for multi-spectral satellite imageries were explored. Five shoreline positions were extracted for 1986, 1991, 2001, 2007 and 2011 covering a medium term of 25 years period. Two additional shoreline positions for 2010 and 2011 were extracted and used for accuracy assessment. Rates of change statistics were calculated using the End Point Rate and Weighted Linear Regression methods. Approximately 283 transects were cast at simple right angles along the entire coast at 200m interval.

Uncertainties were quantified for the shorelines ranging from $\pm 4.1\text{m}$ to $\pm 5.5\text{m}$ with accuracy of mapping the shoreline at 15m resolution estimated to be $\pm 1\text{m}$. The results show that the Keta shoreline is a very dynamic feature with average rate of erosion estimated to be about $-2\text{m/year} \pm 0.44\text{m}$. Individual rates along some transect reach as high as -16m/year near the estuary and on the east of the Keta Sea Defence site. The study confirms earlier rates of erosion calculated for the area and also reveals the influence of the Keta sea defence on erosion along the eastern coast of Ghana. The research shows that shoreline change can be estimated using medium resolution satellite imagery.

DEDICATION

I dedicate this work to my parents Joseph and Josephine Quashigah and to my brothers and sisters and all loved ones and friends who in diverse ways have contributed to my success. I Love you all and may God richly bless you.



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To my Lord and Saviour Jesus Christ who gave meaning to my life and has brought me this far, be all Glory, honour and adoration forever and ever, Amen. I am so grateful to the Lord for seeing me through this study for giving me strength and wisdom to complete this work successfully.

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LIST OF ABBREVIATIONS

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
DSAS	Digital Shoreline Analysis System
EPR	End Point Rate
ETM+	Enhanced Thematic Mapper Plus
GCP	Ground Control Points
GIS	Geographic Information System
GLDD	Great Lakes Dredge and Docks
GPS	Global Positioning System
HWL	High Water Line
ICZM	Integrated Coastal Zone Management
JK	Jack Knifing
KSDP	Keta Sea Defence Project
LiDAR	Light Detecting and Ranging
LR	Linear Regression
MS	Multi-Spectral
NOAA	National Oceanic and Atmospheric Administration
NSM	Net Shoreline Movement
OLS	Ordinary Least Squares
RMS	Root Mean Square
SMP	Shoreline Management Planning
SLR	Sea level rise
TM	Thematic Mapper

UTM	Universal Transverse-Mercator
VNIR	Visible Near Infrared
WGS	World Geodetic System
WLR	Weighted Linear Regression

CHAPTER ONE

INTRODUCTION

1.1 Overview

As humankind move to the twenty first century, environmental changes are predicted to accelerate, with unknown and potentially devastating consequences (Lunetta, 1999). The coastal zone is the most dynamic interface between land and sea and represents a challenging frontier between human civilization and environmental conservation. Worldwide, over 38% of human population lives in the coastal zones and this population is on the increase (Wang, 2010). Due to the wide range of natural resources available, the zone is considered suitable for residential, communication, recreational and economic development. They are highly valued and greatly attractive as sites for resorts, vacation destinations as well as for port, harbor and industrial facilities. It also provides some of the most productive and richest habitats on earth (Shan and Hussain, 2010; Korakandy, 2005; Charlier and Charlier, 1995).

Currently coastal zones are facing intensified natural and anthropogenic disturbances including sea level rise, coastal erosion, over exploitation of resources among others. Over 70% of the worlds beaches are experiencing coastal erosion and this presents a serious hazard to many coastal regions (Appeaning Addo et al., 2008). According to Zhang (2010), awareness of the quality of global coastal ecosystems being adversely impacted by multiple driving forces has accelerated efforts to assess, monitor and mitigate coastal stressors. Monitoring spatio-temporal changes of coastal environments

can help understand among others, the spatial distribution of erosion hazards, predicting their development trend and supporting the mechanism research on coastal erosion and its counter measures.

For coastal zone monitoring, shoreline extraction from remotely sensed data in various times is a fundamental work. The shoreline, which is defined as the position of the land-water interface at one instant in time (Gens, 2010) is a dynamic feature and is an indicator for coastal erosion or accretion. The processes of erosion and accretion affect human life, cultivation and natural resources along the coast. Rapid shoreline changes can create catastrophic social and economic problems along populated strands. Design of viable land-use and protection strategies to reduce potential loss is necessary and this requires comprehension of regional shoreline dynamics (Blodget et al., 1991; Chu et al., 2006).

Coastal management and engineering design require information about where the shoreline is, where it has been in the past, and where it is predicted to be in the future (Boak and Turner, 2005). According to Alves (2007), the analysis of historical shoreline data can be useful to identify the predominant coastal processes operating in specific coastal locations using lateral change rates as an indicator of shoreline dynamics. The real importance of such studies is to avoid decisions based on insufficient knowledge, wrong assessments or arbitrary decisions, leading to losses in resources and infrastructure that could have been prevented.

Shoreline changes occur over a wide range of time scales from geological to short lived extreme events (Apeaning Addo, 2009). These changes are mainly associated with waves, tides, winds, periodic storms, sea-level change, and the geomorphic processes of erosion and accretion and human activities (Van and Bihn, 2008). While there is no doubt that shorelines are changing, the nature of changes is complex and the magnitude is uneven and vary from one point to another (Camfield and Morang, 1996). The detection and measurement of shoreline changes is therefore an important task in environmental monitoring and coastal zone management (Van and Bihn, 2008). According to Apeaning Addo (2009) historic shoreline change information, which portray a cumulative outcome of the processes that altered the shoreline for the periods analysed, facilitate formulating effective coastal management strategies and planning by revealing trends.

The study of changing shorelines has become more than a topic of scientific curiosity with the increasing population in coastal areas (Moore, 2000). Data sets spanning several years are desirable as a basis for such studies. Shoreline monitoring is however a challenging task. The conventional ground surveying methods used for monitoring shorelines can achieve high accuracy of measurement, but is labour intensive, costly and time consuming (Van and Bihn, 2008; Kuleli, 2010; Apeaning Addo, 2009). This limits the generation of consistent data and monitoring large and inaccessible areas especially in developing countries.

Satellite remote sensing techniques provide a synoptic vision of the Earth that is not possible to obtain other than by exhaustive and expensive field evaluations. Data from remote sensors allow analysis of a region with sufficient accuracy in an efficient, rapid and low-cost way (Berlanga-Robles and Ruiz-Luna, 2002). It also helps in analysing areas that are poorly accessible or rapidly changing (Chu et al., 2006). The use of remote sensing data is therefore increasingly becoming a more effective option for monitoring shoreline change. Over the years, geomorphologists, oceanographers and geologists have developed interpretation keys for mapping coastline geomorphic features using aerial photographs; however, few studies of this type have used images generated by remote sensing orbital instruments (Kawakubo, 2011). Though the use of aerial photographs tends to be effective in this case, the frequency of acquisition, cost and coverage presents a challenge. Furthermore, the spectral range of these sources is minimal and may introduce errors in shoreline interpretation (Alesheikh et al., 2007).

Multi-spectral remote sensing satellites provide digital imagery in various spectral bands, including the near infrared where the land-water interface is well defined. Furthermore this approach has advantages: not time consuming, inexpensive to implement, large ground coverage, and the capability for repeat data acquisition and monitoring (Van and Bihn, 2008). The principal limitation of satellite images is arguably their low spatial resolution when compared to photographs taken from aircraft (Kawakubo, 2011).

According to White and El-Asmar (1999), the synoptic capability of Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) imagery enables monitoring

of large sections of coastlines at relatively coarse (30 m) spatial resolution. Areas of rapid change can be identified and targeted for more detailed monitoring in the field, or using higher resolution images. Rates of erosion and deposition can be estimated crudely, and areas where change appears to be accelerating can also be identified. Other sensors including SPOT (Le Systeme Pour d' Observation de la Terre), RADAR (Radio Detecting and Ranging), ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), provide similar capabilities. Though high resolution orbital data have become available only recently, it is difficult to perform multi-temporal studies for periods longer than 10years (Kawakubo, 2011).

In developing countries like Ghana with a total shoreline of about 540km and mostly inaccessible, it is expensive to monitor using aerial photographs and high resolution imagery. There is the need to assess the effectiveness of medium resolution satellite derived data for monitoring shoreline temporal differences especially where there is lack of such data. With Landsat now freely available, there is the need for more research to explore its capability.

1.2 Significance of Study

Ghana's coastal zone represents about 6.5% of the land area of the country, yet houses 25% of the nation's population. This small strip of land now hosts 80% of the industrial establishments in Ghana. Environmental degradation of coastal areas has been identified

as key issues in Ghana's Environmental Action Plan. Poverty, ailing human health and rapid urbanisation are very much evident (Armah and Amlalo 1998).

Over 70% of the 550km coastline is sandy (Armah and Amlalo, 1998). Coastal erosion, flooding and shoreline retreat are serious problems along the coast. According to Ly (1980) the eastern coast has been identified as the most erodible stretch with rates as high as 4m/year prior to the construction of the Akosombo Dam on the river Volta. The construction of the Dam in the early 1960's has supposedly reduced sediment supply to this coast offsetting the balance between the sediment lost to longshore drift and replenishment (Ly, 1980). Erosion rates increased reaching as high as 8m/year around 1970.

The high erosion rates have varied implications for this coast. According to Chen (1998), shoreline variations have direct impact on economic development and land management. There is evidence of loss of land to the sea and lagoon due to erosion and flooding, among others, which affects land availability and the way in which land is used as well as the livelihoods of the people along this coast (Fiadzigbey, 2005; Akyeampong, 2001). The stretch which also serves as a nursing ground for a number of endangered species is also being lost (Kofigah, 2005). There have been interventions such as the Keta Sea Defence Project (KSDP) which involved stabilization of the shoreline with break water and groynes, construction of a flood control structure and land reclamation from the lagoon (GLDD, 2001). These among others have influenced the accretion and erosion patterns along this coast (Appeaning Addo, 2009; Boateng, 2009).

Due to the economic and ecological importance of this zone, there is the need for understanding these changes and the driving forces which will help in developing effective Integrated Coastal Zone Management strategies for the Zone. However, there is little data for example on shoreline change available on these processes. This has been attributed to the expensive and labour intensive nature of field work, inadequate skilled personnel, among others (Armah and Amlalo, 1998; Appeaning Addo, 2009; Boateng, 2009). Also the vast and inaccessible nature of parts of the coastline makes it difficult to study.

Furthermore, Boateng (2009) proposed the need for a holistic management of Ghana's shorelines and this requires a general assessment of the changing nature of the shoreline over long time periods and for larger areas. It has also been recognized that there is the need to assess geomorphic processes at large scales for example, tens of kilometres and over years to centuries in order to plan sustainable and spatial integrated measures (Appeaning Addo, 2009). The need for the current study therefore arose from the prevailing situations along this coast and the need to assess the influence of the KSDP on shoreline change.

Overall, this study was to investigate the capability of using Landsat TM, ETM+ data and ASTER imagery for monitoring the dynamic shoreline of Keta and for estimating change rates for the area which will provide relevant information for planning and intervention.

1.3 General Objective

The main objective of this study was to use medium resolution multi-temporal and multi-spectral remote sensing data to extract and detect shoreline changes from 1986 to 2011 and discuss the possible underlying factors and the implications of such changes for the management of the zone.

1.3.1 Specific objectives were:

1. Identifying change in shoreline positions from 1986 to 2011
2. Statistically estimating historic shoreline rate of change
3. Assessing the influence of the KSDP on erosion

1.4 Justification of Objectives

Effective management strategies are required to deal with the risks arising from coastal erosion. These strategies rely on observations of historic coastline locations and movement through time (Dar and Dar, 2009 and Appeaning Addo, 2009). Identifying the position of the shoreline at any point in time is therefore important for change detection. The first objective will provide such information based on the imagery dates which span from 1986 to 2011. This would provide shoreline information that is particularly lacking for shoreline change analysis in the area.

Based on the extracted shoreline positions, change detection was carried out and shoreline change rates calculated. This provided information on the nature of shoreline change (erosion and accretion patterns). Hotspots could also be identified and targeted for planning and interventions as well as predicting future changes. According to Maiti and Bhattacharya (2009), the study of the rate of change in shoreline position is important for a wide range of coastal studies, such as development of setback planning, hazard zoning, erosion-accretion studies, regional sediment budgets and conceptual or predictive modelling of coastal morphodynamics. The third objective sought to discuss shoreline change looking at the underlying factors (natural and anthropogenic) based on both literature and field work, focusing on the influence of the KSDP (Figure 1.1).

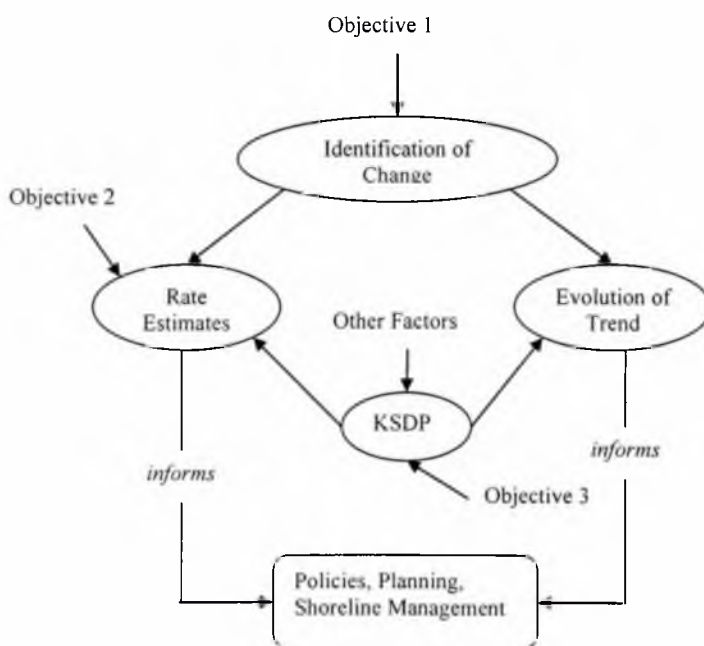


Figure 1. 1 Flow Chart for Objectives

Overall information about shoreline changes would provide basis for the implementation of sound coastal zone management strategies, coastal environmental protection policies and sustainable coastal development and planning schemes (Apeaning Addo, 2009). Detecting shoreline changes over the 25 years period will therefore help analyse the changes that have occurred both before and after the completion of the KSDP and also help in identifying the driving forces in order to enhance management practices in the area.

1.6 Thesis Organization

This thesis is organized into 7 chapters with a list of references and appendices. Chapter 2 discusses the concepts behind the study including the coastal zone and shoreline change detection and analysis based on satellite imagery. Chapter 3 discusses the study area in terms of location geology and hydrology. The problem of erosion along this coast is discussed as well as major interventions such as the KSDP. Chapter 4 looks at the materials and methodology used in this study to achieve the set objectives. Chapter 5 presents the results for shoreline extraction and change detection and discuss the patterns of change with attention to the period before and after the KSDP. Chapter 6 discusses the possible factors affecting shoreline change in the study area based on previous works and current results. Chapter 7 concludes the research with summaries and recommendations for policy formulation as well as further research.

CHAPTER TWO

DEFINITIONS AND CONCEPTS

2.1 Introduction

Various works have been done on coastal and shoreline monitoring. This chapter defines and discusses the various concepts related to the study based on literature review. It focuses on the shoreline, its definition and changing nature (erosion and accretion) as well as factors affecting change. It also discusses shoreline change detection and monitoring based on the application of remote sensing and Geographic Information System (GIS) tools.

2.2 Defining Coastal Zones

The boundary between the land and ocean is generally not a clearly defined line, but occurs through a gradual transitional region. The name given to this transitional region is usually 'coastal zone' or 'coastal area' (Kay and Alder, 2005). The concept of coastal zone is not defined with geographical precision. It encompasses generally the expanses on both sides of the "land-sea boundary"; the inner part of the coastal shell and its hinterland (Charlier and Charlier, 1995). There is therefore interaction between the two parts, the terrestrial and marine environments. It is also defined to include areas of continental shelves, islands, or partially enclosed seas, estuaries, bays, lagoons, beaches,

and terrestrial and aquatic ecosystems within watersheds that drain into coastal waters (Wang, 2010).

Defining the limits of a coastal zone is limited by various factors. According to Kay and Alder (2005), at policy level four possible criteria can be used; fixed distance definitions, variable distance definitions, definition according to use or hybrid definitions. The Coastal Zone Indicative Management Plan (CZIMP) by the Environmental Protection Agency (EPA) Ghana in 1990 defined the coastal zone in Ghana as the line joining the landward limits of the lagoons, lagoonal depressions, marshes and estuarine swamps together with the intervening interfluvial areas (Armah and Amlalo, 1998). On the average, this line approximates 10km extension from the coastline (except at river estuaries and some lagoons) and is enclosed by the 30m contour. The rationale behind the extended landward limits is to ensure the inclusion of the catchment areas of the coastal streams or parts thereof for the purposes of effective land use, environmental planning and monitoring (Armah and Amlalo, 1998).

2.3 Challenges of Coastal Zones

Coastal zones have been degraded by exploitative activities such as removal of mangroves, sand mining, erosion from coastal development, poor land management, industrial pollution (Wong, 2010). Currently the zone is facing intensified natural and anthropogenic disturbances including sea erosion, sand mining, forest/mangrove destruction and urbanization.

Over 70% of the world's beaches are experiencing coastal erosion (Bird 1996; cited in Appeaning Addo, et al., 2008) and this presents a serious hazard to many coastal regions. Sea level rise (SLR), change of storm climate and human interference has been identified as causes of coastal erosion (Zhang et al., 2004). Coastal erosion threatens installations and industries; contaminate water aquifers, sand bars and arable land.

According to Karl et al. (2009) global climate change imposes additional stress on coastal environments through sea level rise. Rising sea levels is associated with elevated tidal inundation, increased flood frequency, accelerated erosion, rising water tables, increased saltwater intrusion, and a suite of ecological changes. These biophysical changes are expected to cause various socio-economic impacts including loss of land infrastructure and coastal resources as well as decline in associated economic, ecological, cultural and subsistence values (Dolan and Walker, 2004).

2.4 Defining Shoreline

According to Bird (1985), the term shoreline denotes the water's edge; it is usually equivalent to the high spring tide shoreline. The National Oceanic and Atmospheric Administration (NOAA) (n.d.), states the shoreline shown on nautical charts represents the line of contact between the land and water at a selected vertical datum. In areas affected by tidal fluctuations, this is usually the mean high-water line. In confined coastal waters of diminished tidal influence, a mean water level line may be used. It is also defined as the high waterline or wet dry boundary (Oertel, 2005). Simply put the position

of the land–water interface at one instant in time defines the instantaneous shoreline (Gens, 2010).

Due to the dynamic nature of the idealized shoreline boundary, investigators have typically adopted the use of shoreline indicators to define the shoreline for practical purposes. A shoreline indicator is a feature that is used as a proxy to represent the “true” shoreline position (Boak and Turner, 2005). These indicators are classified into two groups. The first group is made up of visually discernable coastal features such as previous high tide line, the wet/dry boundary and the vegetation line. The second group is based on specific tidal datum for example mean high water or mean sea level (Boak and Turner, 2005; Alves, 2007). In this way, shoreline definition and delineation depends on the selected shoreline indicator and are subjective (Alves, 2007).

According to Moore (2000), the line between wet and dry sand, which can usually be clearly seen on aerial photographs and images, is the most commonly used proxy for shoreline position. The wet/dry line closely approximates the high water line (HWL) which in turn approximates the mean HWL.

2.5 Factors affecting Shoreline Change

Historically, coastlines are in a continual state of change; present shore locations are the result of erosional and depositional forces. Shorelines are influenced by numerous factors including changes in sea level, tidal regime, sediment supply, periodic storms, action of

waves and winds as well as human modification. Recent studies in various geographic regions indicate that shoreline erosion has become a major problem (Selvavinayagam, 2009; Hall et al., 1986).

The transport of material along the coast is linked to natural forces such as waves, tidal movements, long- and cross-shore currents, and wind. Anders and Byrnes (1991) discussed five of the primary factors that may change shoreline position: 1) wave and current processes, 2) sea level change, 3) sediment supply, 4) coastal geology and morphology, and 5) human intervention.

2.5.1 Wave and Current action

The driving force behind almost every coastal process is wave action (Pethick, 1984). Ocean waves are energy travelling along the interface between ocean and atmosphere, often transferring energy from a storm far out at sea over distances several thousand kilometers (Tarbuck and Lutgens, 2010). The breaking waves in the near-shore zone and the near-shore currents are responsible for the transportation of beach sediments that results in shoreline change. The larger the waves, the more sediment will be moved (Davis and Fitzgerald, 2004).

Waves approach the shoreline at an angle depending on the shoreline orientation and produce longshore currents. The larger the waves, the faster the longshore currents. Such highly energetic conditions will cause significant removal of sediment or rock depending

on the nature of the coastal material (Davis and Fitzgerald, 2004; Tarbuck and Lutgens, 2010).

As wave action causes sediments to become temporarily suspended currents serve as agents for moving them (Davis and Fitzgerald, 2004). An ocean current is a continuous, directed horizontal movement of ocean water generated by the forces acting upon this mean flow, such as breaking waves, wind, coriolis force, temperature and salinity differences and tides (Davis and Fitzgerald, 2004). Strong longshore currents may move at a meter per second, a velocity that is capable of transporting large volumes of sand (Davis and Fitzgerald, 2004).

Tides are the periodic (occurring at regular intervals) variations in the surface water level of the oceans, bays, gulfs, and inlets. They are the result of the gravitational attraction of the sun and the moon on the earth. Tides originate from the oceans and progress towards the coastline (NOAA, 2011). The tidal current significantly affects the size, sorting and distribution of sediment over most of the sea floor (“Go Metal Detecting”, 2008).

2.5.2 Sea Level Rise

Sea level rise has been identified as the principal forcing function in shoreline retreat along sandy coasts worldwide (Bird, 1996). It controls the type and magnitude of all coastal processes: tidal range, breaker type, longshore current velocities, sedimentation rates, etc (Pethick, 1984). The Bruun (1962) rule concept suggests that the entire beach

profile will shift landward and upward in response to SLR (Figure 2.1). On an equilibrium coast a sea level rise would result in a landward migration of the transverse shore profile, with coastline retreat, and the transference of sand from the beach to the nearshore zone. As the shoreline is displaced landward, there is increased opportunity for erosion by waves and currents since the waves break more inland. This condition is the single most important factor in the wide spread erosion of present shorelines (Davis and Fitzgerald, 2004; Allersma and Tilsman, 1993).

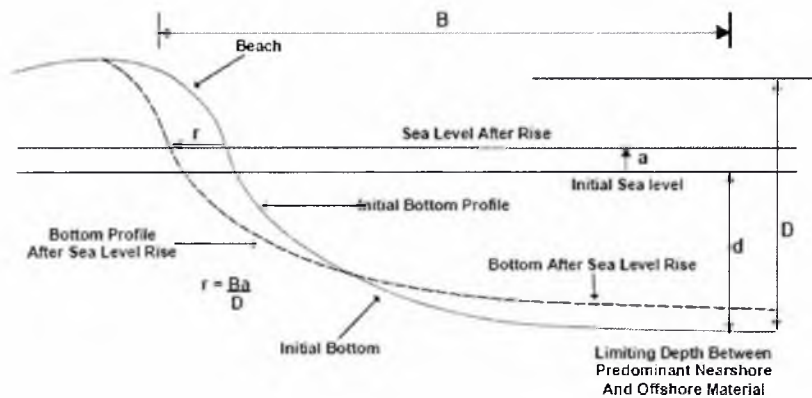


Figure 2. 1 The Bruun Rule for Shoreline Response to Sea Level Rise (Bruun, 1962)

The net change of sea level during the 5000 years of Holocene is relatively small, but the present rate of rise (over the last 100 years) is much greater than the average (Allersman and Tilsman, 1993). According to Davis and Fitzgerald (2004), annual rate of global sea level rise is about 2.5mm and there are indications that this will increase over the next century. However, there are some locations where sea level rise is much higher up to about 10mm yr⁻¹. Considering a common coast with a 1m vertical change over a

horizontal distance of 50m, the 10mm yr^{-1} SLR (1m per century) would lead to a displacement of the shoreline of 50m landward.

2.5.3 Sediment Supply

The main supply of sediments comes from rivers and coastal erosion (Allersma and Tilsman, 1993). Rivers supply over 90% of the total marine sediment (Pethick, 1984). Deltas and estuaries are found where rivers contribute sediment to the coast. This positive sediment budget either infills the existing embayment or augments adjacent coastal sediment compartment (Woodroffe and Leon, 2010).

According to Bird (1985), apart from sectors where the coast has advanced because of land reclamation or sediment accumulation alongside artificial structures, the main sectors of propagation have been on beaches supplied with sediment from river mouths. Elsewhere, rates of progradation of deltas and coastal plains have accelerated when fluvial sediment yields have increased as the result of soil erosion due to deforestation, overgrazing, or cultivation of steep hinterlands. There have also been examples of the onset of erosion on deltaic coastlines following dam construction on rivers and consequent reductions in water flow and sediment yield to river mouths. Examples include the Nile delta after the construction of the Aswan High Dam in 1964, the Volga and the Zambezi (Bird, 1985).

The constant shifting of sediment along shorelines presents a fundamental challenge to the prediction of beach behaviour (Barnhardt, 2009). Sediment budget is therefore very important in understanding shoreline changes. The premise behind coastal sediment budget is that, if more sediment is transported into an area than transported out of an area, shoreline accretion results. Conversely, if more sediment is transported out of an area than is transported in, shoreline erosion results (NOAA, n.d.).

2.5.4 Types of Coast

Coasts are generally categorized as rocky, sandy, muddy coasts, coral reefs or estuaries and deltas and these are affected differently by the action of waves and currents (Woodroffe and Leon, 2010). Whereas cliffs are generally resistant and change only over long time scales, with evidence of substantial changes over geological time scale in response to adjustments of sea level, sandy shorelines are much more responsive at instantaneous and event time scales, influenced by wave energy and antecedent conditions (Woodroffe and Leon, 2010). Sandy coasts due to their soft geology are vulnerable to erosion. Erosion along one stretch of sandy beach may be responsible for accretion or reduced erosion of a nearby beach downdrift (Morton, 2004).

Estuaries and deltas are predominantly depositional environments with sediments being supplied from upstream. This supply leads to deposition and hence accretion in and around the river mouth. Sediments are also redistributed through longshore drifts

supplying sediments to adjacent shores. If the waves and currents remove more sediment than is being delivered to the shore, then retreat occurs (Morton, 2004).

Muddy coasts are commonly found along low-energy shorelines which either receives annual supply of muddy sediments, or where unconsolidated muddy deposits are eroded by wave action (Flemming et al., 2000). Coral reefs on the other hand supply sand to adjacent beaches and control the rates of beach erosion by reducing the energy of incoming waves (Wielgus et al., 2010).

2.5.5 Anthropogenic Factors

The pressures of increasing population, industrialization, land reclamation, sea defence projects, construction of harbors and dams modify coastal processes. According to Bird (1985), sea walls and other structures have been built to stop erosion on cliffs, beaches and delta coastlines. Many times, these lead to increased erosion along most shores (Davis and Fitzgerald, 2004). Furthermore, human activities such as sand mining, harvesting of mangrove and other vegetations as well as coral reefs that help stabilize shorelines have rendered most shoreline more vulnerable to erosion.

Each of the elements that contribute to shoreline change does not operate regularly, at constant rates. Its strength changes through time, sometimes in combination with other elements, or in ways that are contrary to the action of other elements. Over time, the combined effect of several factors of variable strength may result in more complex

patterns in the rates of change, and sometimes it may even lead to abrupt shifts in drift direction or the reversal in the sediment movement process from deposition to erosion, or vice-versa (Moran, 2003).

2.6 Shoreline Management

The impact of coastal erosion is a significant problem for coastal managers especially in the face of increasing population along coastal zones. Coastal management programs must minimize loss of life and property caused by erosion and sea level rise, while continuing to protect natural coastal resources. Therefore, the solution to shoreline erosion is not as simple as hardening shorelines with bulkheads, riprap, or groins to wall off the sea (Castellan, 2007).

According to Boateng (2006), management strategies in Ghana, both past and existing, have largely focussed on the provision of hard protection at specific locations where risk levels to life and economic assets are high. In most cases, such ‘ad hoc’ management interventions classically tend to stabilise the shoreline at the protected section and aggravate the situation elsewhere along the shoreline (“knock-on effects”).

Due to the cumulative impacts and unsustainable nature of such protection works, others have developed more holistic and sustainable approaches (Boateng, 2009). In the United Kingdom (UK), for example, shoreline management planning (SMP) have been developed and extensively used (Pontee and Townend, 1999). The principal aim of SMP

is to provide the basis for sustainable strategic coastal defence policies and to set objectives for the future management of the shoreline that take full account of the interrelationships between the coastal dynamics and other environmental and planning policies of co-operating authorities (Boateng, 2006).

According to Boateng (2006), Ghana has the capability for implementing SMP based on similarities in physical, legislative and coastal management responsibilities. However, there are gaps in data on a number of coastal variables that serve as bases for implementing such management approaches. This includes current rates of erosion and accretion, hydrodynamic processes and sea level rise (Boateng, 2009; Armah and Amlalo, 1998).

2.7 Remote Sensing of Coastal Environments

Coastal zones consist of highly productive and sensitive ecosystems, such as estuaries and lagoons. Due to the dynamic nature of these systems, monitoring conditions by means of remote sensing is essential for sustainability (Berlanga-Robles and Ruiz-Luna, 2002). It is difficult to implement conventional field survey, requiring huge workload, high costs and long periods. Meanwhile, remote sensing techniques have been applied in coastal monitoring and environmental management for several years, with the characteristics of large acquisition area, huge amount of information, short period of operation and the suitability for comparative analysis (Cracknell, 1999). Moreover,

integrated use of remotely sensed data and GIS techniques provides powerful tools for monitoring and analyzing coastal temporal–spatial changes (Zhang, 2010).

According to Alesheikh et al. (2007), from 1807 to 1927, all coastline maps have been generated through ground surveying using the plane table and rod. From the 1920s, the aerial photogrammetric survey method became the primary shoreline mapping technique. Until the 1980s, aerial photographs were known as the sole source for coastal mapping and remain the most common data source for determining past shoreline positions (Liu, 2009; Alesheikh et al., 2007; Boak and Turner, 2005). Several studies still rely on aerial photographs for shoreline analysis due to the availability of archived photographs which is favourable for long term change detection. However, the number of aerial photographs required for coastline mapping, even at a regional scale, is enormous. This is also challenged by difficulties in determining the shoreline and various forms of distortion such as tilt and scale differences between photos (Boak and Turner, 2005; Dellepiane et al., 2004; Crowell et al., 1991).

The launch of the first Earth Resources Technology Satellite (ERTS-1) in 1972 (later renamed Landsat 1), enabled the United States to initiate its technological capability for the monitoring of environmental resources and the study of ecosystems processes from space (Lunetta, 1999). Since that time, the utility of space-based remote sensing has been demonstrated and their potential applications for long term monitoring recognized (Lunetta, 1999). Currently there are a wide range of sensors in space capturing data of the surface of the earth. These include the Landsat TM and ETM+, SPOT, RADAR, SAR

(Synthetic Aperture Radar), ASTER, QuickBird, WorldView 1 and 2, among others (Wang, 2010; Lunetta, 1999). These have varied capabilities for shoreline mapping.

There are various sources of data for shoreline mapping; however, the choice of data or sensor is influenced by factors such as availability of data, coverage, cost of acquisition, and resolution. In principle, the accuracy of shoreline detection depends on the spatial resolution of the data source. The higher the spatial resolution of the imagery, the higher the accuracy of the detected shoreline. Furthermore, active sensors such as SAR and airborne LIDAR allow acquisition independent of day light conditions and are increasingly becoming products of choice (Gens, 2010; Liu, 2009; Dellepiane et al., 2004). For example, the advent of the airborne LIDAR technology has led to a more cost effective and better accuracy for shoreline mapping (Liu, 2009). It must be noted that, high resolution satellite imagery was developed more recently and hence long term analysis cannot be carried solely based on such imagery.

2.7.1 Shoreline Extraction from Remote Sensing Imagery

Various studies have been carried out using satellite imagery for shoreline extraction and change detection. Manual delineation has been the common approach. Chu et al. (2006) and Cui and Li (2010) used Landsat TM and Multi-Spectral Scanner (MSS) to study the pattern of erosion and accretion at the Yellow River delta. The mean high tide line as the shoreline proxy was delineated manually by the same person at the same scale to ensure

high accuracy. This approach is definition subjective and relies on individual skills (Boak and Turner, 2005).

Marfai et al. (2008) used data from topographic maps, Landsat and IKONOS to monitor shoreline dynamics in Semarang, Indonesia. Visual interpretation and band analysis was used for extracting the shoreline. Bo et al. (2000) employed fuzzy connectivity analysis for the semi-automatic extraction of the shoreline using Landsat, SAR and aerial photographs. Ghanavati et al. (2008) used Landsat TM and ETM+ to monitor geomorphological changes at Hendijan River Delta in south-western Iran using both band analysis and manual digitization. Maiti and Bhattacharya (2009), applied thresholding, edge detection and manual digitizing to extract shoreline from Landsat MSS, TM, ETM+ and ASTER imagery to monitor shoreline change and prediction on the East coast of India.

Other studies have employed automatic methods for extracting and analysing shorelines. These include, Van and Binh, 2008; Chand and Acharya, 2010 and Kuleli, 2010; Dewidar and Frihy, 2007; El-Asmar and White, 2002; Frihy et al., 1994; Li and Damen, 2010; Liu and Jezek, 2004. Methods used include, band ratio, thresholding and edge detection, classification, among others. It is evident that there is no single acceptable method for extracting shoreline from imagery.

The most common method used is the visual interpretation even though it's mostly subjective (Gens, 2010). However, researchers are focusing on developing automatic

methods for shoreline extraction to overcome the problems associated with this method. For example, specialized tools like the BeachTools, an extension of ArcViewTM and algorithms implemented using ArcGISTM are being explored for automatic extraction of shorelines (Gens, 2010; Liu, 2009).

2.7.2 Sources of Error in Shoreline Mapping

Erosion rates can only be as accurate as the data from which they are derived and the methods by which they are calculated. Potential sources of error are those introduced by data sources and measurement methods (Moore, 2000). Determining and digitizing the high water line introduces errors as well as registering maps in different coordinate systems to the same coordinate system and projection.

According to Camfield and Morang (1996), environmental variables such as sun angle and haze add complexity and ambiguity to identification of the true shoreline. Some mapped shoreline changes are therefore just artifacts of differences in water levels rather than actual change. Though less literature is available on accounting for errors in mapping shoreline from low to medium resolution imagery, it is obvious that the resolution of such data introduces major errors in mapping shorelines. Furthermore, atmospheric conditions and type of sensor also affects the imagery quality and hence the information derived from it. Such images according to Gens (2010) are however less affected by tidal ranges.

According to Crowell et al. (1991), regardless of how thoroughly the data have been scrutinized and corrected, some degree of error will remain. Therefore these must be accounted for when analysing shoreline change.

2.8 Shoreline Change Analysis

Change detection is a process used to identify differences of the state of an object or phenomenon on successive images observed at different times (Singh 1989). Shoreline change analysis is either a linear measure of the horizontal shift in shoreline position landward or seaward or as the quantity of material added to, or lost from, the coast (Bird, 1985). The analysis of shoreline variability, erosion and accretion trends is fundamental to a broad range of investigations undertaken by coastal scientists, coastal engineers, and coastal managers. Shoreline change can be calculated through various methods, including net shoreline movement (NSM), end point rate (EPR), average of rates, linear regression, weighted linear regression and Jack-knifing among others (Coward et al., 2010; Genz et al., 2007 Himmelstoss, 2009).

2.8.1 Net Shoreline Movement (NSM)

The NSM reports a distance, not a rate. The NSM is associated with the dates of only two shorelines. It reports the distance between the oldest and the youngest shorelines for each transect. This represents the total distance between the oldest and youngest shorelines. If

this distance is divided by the number of years elapsed between the two shoreline positions, the result is the end point rate (Himmelstoss, 2009).

2.8.2 End Point Rate (EPR)

This method calculates rate of change by using the earliest and most recent shoreline positions (Figure 2.2). The distance between the two shorelines (mostly the oldest and most recent) is measured and divided by the number of years that have elapsed. This can be mathematically represented as:

$$R_1 = \frac{Dm}{T}$$

Where R_1 is the rate, Dm is the distance in meters between the two dates and T is the time between the two shoreline positions.

The EPR is the most commonly used due to the computational ease and because only two shorelines are required (Dolan et al., 1991).

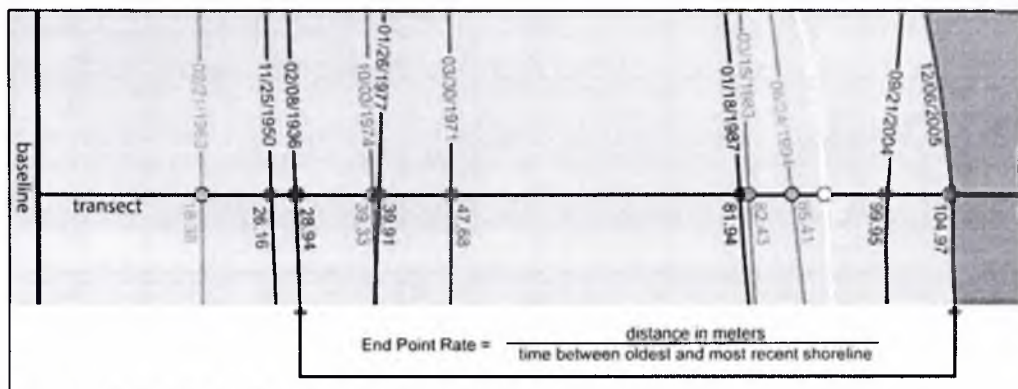


Figure 2. 2 End Point Rate (Himmelstoss, 2009)

Given that only the end points are used, the information contained in the other data points is entirely omitted. A major drawback is if one or both end points are erroneous, the calculated erosion rate will be inaccurate (Cowart et al., 2010; Genz et al., 2007; Crowell et al., 1993).

2.8.3 Average of Rates

With this method individual EPRs are calculated from the shoreline positions where more than two are available. Foster and Savage (1989) developed an equation that incorporates the accuracy of the shoreline position data and magnitude of rate-of-change to determine if any given EPR meets a minimum time criterion (T_{min}).

$$T_{min} = \frac{\sqrt{(E_1)^2 + (E_2)^2}}{R_1}$$

Where E_1 and E_2 are measurement errors in the first point and second point, respectively and R_1 is the EPR of the longest time span for a particular transect. EPRs are determined between all data point pairs and are removed if the time interval is less than the specified minimum. All EPRs that pass the criterion are averaged to determine the shoreline change rate (Genz et al., 2007; Dolan et al., 1991).

An advantage of this method is all 'good' data, that is the all EPRs that survive the minimum time span are utilized and short term variability are also filtered. A drawback however is that the minimum time criterion can be affected by large errors or small EPRs. The method is also biased, giving more influence to EPRs of short time span (Genz et al., 2007; Dolan et al., 1991).

2.8.4 Linear Regression Rate (LRR)

The linear regression approach also referred to as the ordinary least squares (OLS) statistic is determined by fitting least-squares regression lines to all shoreline points for a particular transect. The least squares regression assumes independent Gaussian errors and estimates the trend of shoreline data by minimizing the sum of the squared residuals between the data and line. The slope of the line is an estimate of the shoreline rate-of-change (Figure 2.3). The assumption of Gaussian errors is usually valid, since the sum of many sources of error tends towards Gaussian distribution (Genz et al., 2007; Dolan et al., 1991).

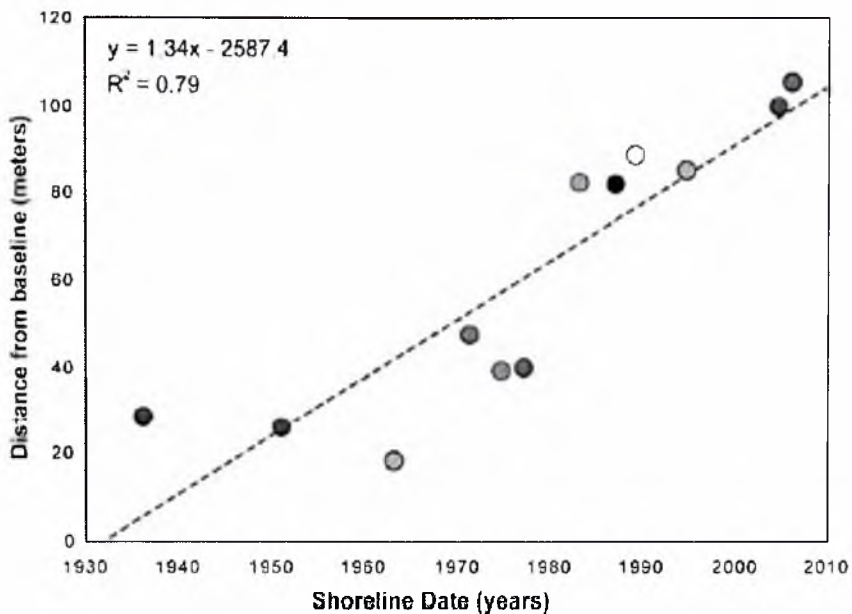


Figure 2. 3 Linear Regression Rate (Himmelstoss, 2009)

A major advantage of LR is that all data available is used and the method is purely computational. The calculation is also based on accepted statistical concepts and it is easy to employ (Genz et al., 2007; Dolan et al., 1991).

2.8.5 Jackknifing Method

The jackknifing method (JK) uses multiple OLS fits to determine the shoreline change rate (Figure 2.4). The method uses all possible combinations of LRs given by omitting one point for each iteration. A different point for each line is omitted, resulting in a different slope for each line. The slopes are averaged to provide a shoreline change rate (Genz et al., 2007, Dolan et al., 1991).

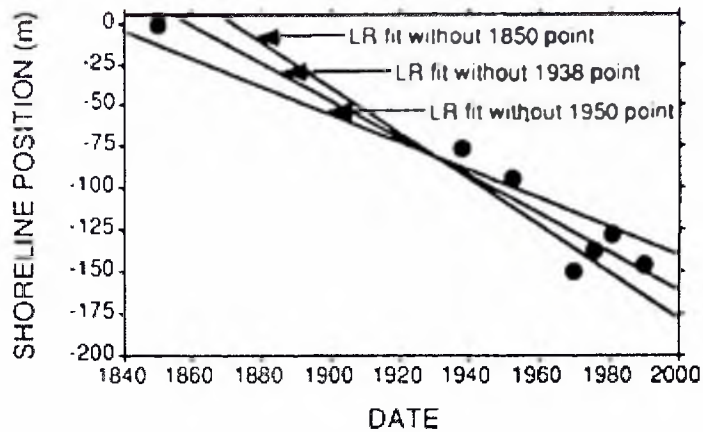


Figure 2. 4 Jackknifing Method (Dolan et al., 1991)

The JK method as the LR is purely computational. It has the advantage of decreasing the influence of clustering data and extreme data points. However, computing all possible linear trends is not efficient (Genz et al., 2007, Dolan et al., 1991).

2.8.6 Weighted Linear Regression (WLR)

In computing weighted linear regression, more reliable data (i.e. shoreline positions with smaller uncertainty) are given greater emphasis or weight towards determining a best-fit line (Figure 2.5). The weight (w) is defined as a function of the variance in the measurement (e).

$$w = 1/(e^2)$$

Where e is the shoreline uncertainty value

Since uncertainty of the shoreline feature is used to calculate a weight, this approach requires that uncertainties in shoreline positions be identified; however this is difficult in most cases.

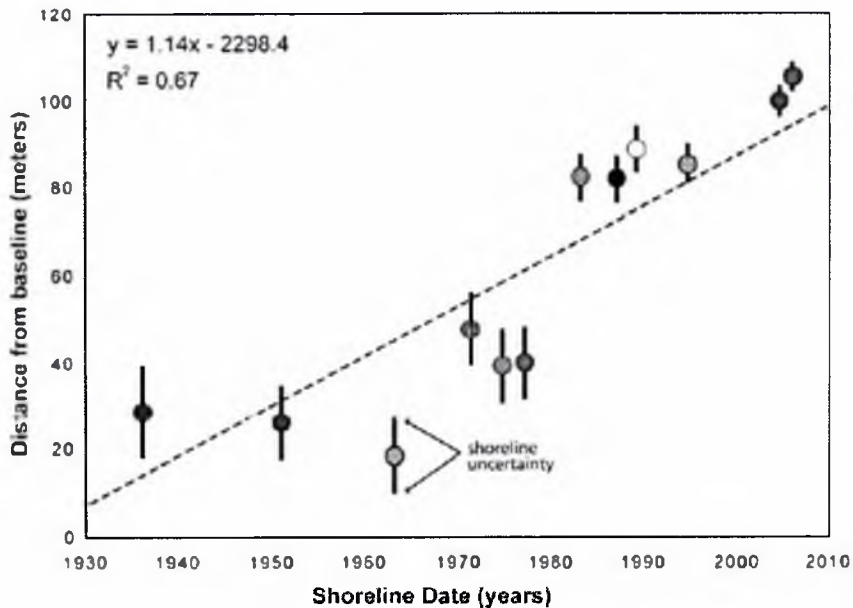


Figure 2. 5 Weighted Linear Regression Rate (Himmelstoss, 2009)

This method is also sensitive to outliers even if their weights are small. Furthermore if the calculated uncertainties do not accurately express the real deviations, then the resulting rate may under estimate or overestimate the true rate (Genz et al, 2007).

2.8.7 Comparison of Methods

Aside the methods discussed in the previous subsections, other statistical methods are available and new ones being developed. Selecting the method to use is influenced by

factors such as availability of data and uncertainties involved in mapping shoreline positions. If only two shoreline positions are available the obvious option is to use the EPR. Where more than two shoreline positions are available, which is mostly the case, the linear regression methods are employed. According to Genz et al. (2007), when uncertainties are mostly understood, weighted methods are recommended; conversely, if uncertainties are poorly understood, LRR and the JK and their related methods are recommended.

2.9 Long Term and Short Term Rates of Change

Shoreline change rates can be based on long term data or short term. Boateng (2009), defined the period up to 20 years as short term, 20 to 50 years as medium term and anything above that as long term. According to Crowell et al. (1993), data sets for obtaining consistent long term rates of change should cover at least 60–80 years in order to span short term storm events and natural decadal scale variability. Studies such as Hapke et al. (2010) used data spanning decades (200years) for calculating long term rates of change. Also studies by Appeaning Addo et al. (2008) used 98 years span of data to detect and estimate shoreline rate of change at the regional scale. Such data also provide more reliable input for future projections.

However access to such long term data is lacking especially in developing countries and for inaccessible shorelines. In such cases rates are calculated for shorter terms. Periods varying from a few years to about 50years may be considered a short term. Hapke et al.

(2010) considered the period up to 30 years as short term in analysing shoreline change rates along the New England and Mid Atlantic Coast.

CHAPTER THREE

PROFILE OF STUDY AREA

3.1 Introduction

This chapter discusses the profile of study area in terms of location, geology, hydrology and economic activities. It also looks at the problem of sea erosion along the eastern coast with emphasis on Keta and some of the interventions adopted to mitigate the situation with focus on the KSDP.

3.2 Location and Characteristics

The coastal zone of Ghana is generally divided into three sections, the western, central and eastern (Ly, 1980) (Figure 3.1). The Eastern coast, which is about 149km, stretches from Aflao (Togo Border) in the East to the Laloi Lagoon west of Prampram. The shoreline studied covers about 52 km of this stretch, from the eastern side of the Volta estuary to Blekusu on the east of Keta. This shoreline generally falls within the Keta Municipality. The area falls roughly between latitudes 5° 25' and 6° 20' North and between longitude 0° 40' and 1° 10' East.

The landscape consists of a large shallow lagoon, named the Keta Lagoon, surrounded by marshy areas with a sandbar (sand spit) separating the lagoon from the Gulf of Guinea and a number of creeks along the coast.

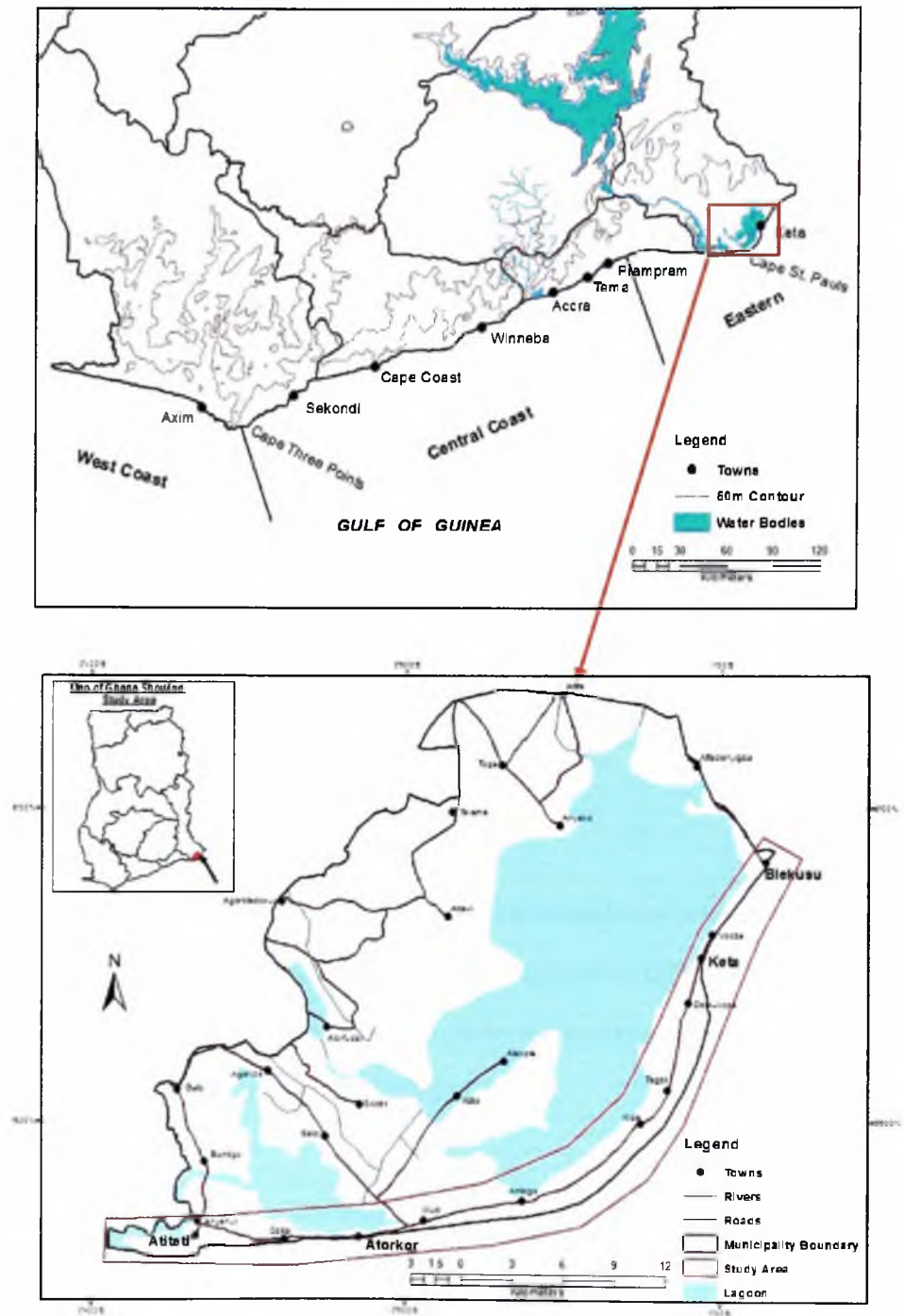


Figure 3. 1 Location of the Study Area (after Ly, 1980; Ghana Survey Department)



Figure 3. 2 One of the largest Creeks at Atiteti (Author, June, 2011)

The sand spit is narrow; barely more than 2.5km at its widest point with a general elevation up to 2m above mean sea level (Awadzi et al., 2008; Boateng 2009).

3.3 Geology

The study area basically falls within the geological setting referred to as the Keta basin. The basin is filled with 870m of Paleozoic marine and non-marine sediment deposits. This soft geology generally comprises quaternary rocks and unconsolidated sediments made up of clay, loose sand and gravel deposits (Akpati, 1978).

Recent deposits rest on a series of continental beds of Middle tertiary age. The rocks are unconsolidated limonitic argillaceous sands and gritty sands with persistent gravelly beds at their base. The tertiary sands rest on Cretaceous and Eocene age marine shale, glauconitic sandstone and limestone (Boateng, 2009; UNEP, 2004).



Figure 3. 3 Sandy Coast, Atiteti (Author, June, 2011)

The Volta River System, the main source of sediment supply to this basin, consists of a larger drainage basin, broad delta plain, narrow shelf, steep upper slope, and a large basin floor. Recent mapping of the sea bed topography reveals the presence of numerous canyons (valleys) from the shelf all the way to the deepwater. This shows that active erosion is taking place at the sea floor (Manu et al., 2005).

3.4 Climate

The climate is dry equatorial with an average annual rainfall below 1000mm and unevenly distributed over the year. There are two maxima. The main season occurs between May and July when the south westerly monsoon winds dominate with a minor occurring between late August and early October. From November to February the north

eastern harmattan winds dominate giving rise to a long dry season (Awadzi et al., 2008; Allersma and Tilsman, 1993).

The winds are generally weak. The monthly average wind speed in Ada ranges between 1.7 m/s and 2.6 m/s (Sorensen, 2003). Temperatures are quite high with mean monthly temperature of about 30°C in the warmest month, March and about 26°C in the coldest month, August. The average minimum diurnal temperature is about 25°C and average maximum is about 33°C (Dickson and Benneh, 1995).

3.5 Waves, Tides and Current

Two types of wave approach this coast, the seas generated by the weak, local monsoon and the swell generated by storms in the southern part of the Atlantic Ocean. The global wave model data from NOAA (Table 3.1) shows that average wave height for the area between 1997 and 2006 is 1.39m but may reach a height of about 3m. They normally arrive from the direction between south and south west with an average period of 10.91s but may reach a maximum of 19.68s.

Table 3. 1 Wave and Wind Data

	Hs (m)	Tp (s)	Wave Direction (° from)	Wind Speed (m/s)	Wind Direction (from)
Average	1.39	10.91	194.21	4.65	213.04
Max	2.82	19.68	330.64	11	358.94
Min	0.43	3.11	46.37	0.03	1.1

Source: Svasek Hydraulics, (2006)

This coast is influenced by a semi-diurnal tide with an average range of about 1m. The tidal currents caused by this tides are weak. Stronger currents occur in inlets and estuaries. The Guinea current flows offshore from west to east with velocity between 1 m/s (max 1.5 m/s) in summer and 0.5 m/s (max 0.7 m/s) in winter (Allersma and Tilsman, 1993; Sorenson et al., 2003).

3.6 Vegetation

The zone falls within the coastal savanna zone of Ghana and is relatively dry. Vegetation normally comprises of coastal strands and mangrove. At the fringes of the Lagoon, the vegetation consists of small and scattered clumps of short trees and mangrove. Both red (*Rhizophora sp.*) and white (*Aveicennia sp.*) mangroves are found especially near the estuary (Figure 3.4a). Patches of the grass *Paspalum sp.* and the herb *Sesuvium portulacastrum* as well as the sedge *Cyperus articulates* and the cat-tail *Typha domingensis* are common (Sorensen et al., 2003; Kufogbe, 1997). Coconut plantations (Figure 3.4 b) are also found along the entire coast especially around the Cape St. Paul

and the estuary. Some of this coconut vegetation is being destroyed by the erosion around Atorkor. Vegetation along the coast helps keep sediments in place.

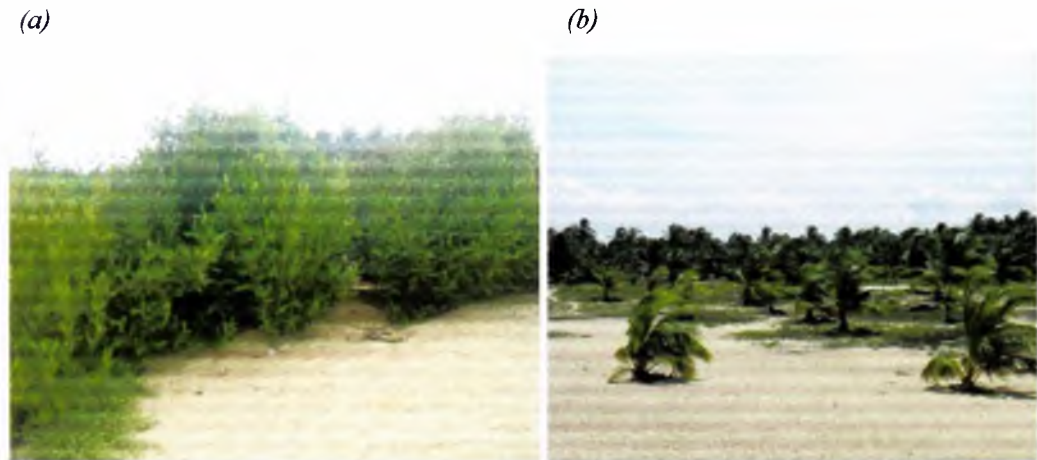


Figure 3. 4 Vegetation: (a) Mangrove, (b) Coconut (Author, June, 2011)

3.7 Settlement and Economic Activities

Generally, the population of Keta has been growing at a relatively low rate of 0.5% since 1970 and 1.3 between 1984 and 2000 (Ghana Statistical Service, 2005). The average population density for the area is 164 persons/km² with figures reaching 500 persons/km² for areas between Keta and Anloga which compares favourably to densities in Greater Accra (609.7 persons/km²) (Ghana Statistical Service, 2005). Population of the area shows an increasing trend until the onset of the recent sea erosion when people began to migrate to other towns (Keta Municipal Assembly, 2011).

The main economic activity of the people living in the area is fishing, both from the sea and the lagoon. Marine fishing is carried out along the 75km stretch of coastline from Aflao in the east to the Volta River at Atiteti/Anyanui (Kufogbe, 1997). Communities around the Keta lagoon are also involved in fishing from the lagoon. Shallot and other vegetable farming occur extensively on the sand spit throughout the year. The zone is also noted for coconut and mango plantation farming. Poultry farming is also an important contributor to the local economy (Nukunya, 1997).

Wood cutting (Mangrove harvesting) is an important economic activity. This is intensive around Anyanui, Atorkor and Salo for domestic and commercial use. Both the red and the white mangrove are harvested (Keta Municipal Assembly, n.d). The mining of sand within the Keta Municipality until recently was an established economic activity. Places like Dzita, Atorkor, Dzelukope, Tegbi and Woe are extensively mined. Salt is also mined along the banks of the lagoon though this is restricted to the dry season (Keta Municipal Assmbly, n.d, Ahiawodzi, 1997).

3.8 Land Use

Keta inherits a system of land ownership that is common to the people of the sandbar. The allodial title to land is vested in the clan heads but often a piece of land is associated with an individual rather than a whole clan, lineage or family. Such a land is usually one of the numerous patches, which were not claimed by any of the clans during the time of their early settlement in the area because the sites were considered unproductive or

useless at the time. They therefore remained no man's land until much later when they were claimed by the said individuals (Fiadzigbey, 2005).

In terms of land use, Keta is noted for its commercial and residential land uses with minimal agricultural use due to scarcity of land and poor soils and climate (Akyeampong, 2001; Nukunya, 1997). Land was also lost to the lagoon through flooding as well as to intensive sea erosion putting great pressure on existing land. Reclaiming of land from the shores of the lagoon was an important solution causing the Town to expand towards the lagoon. Residents also began to relocate to Dzelukope on the west of Keta initiating a linear growth. Government buildings were also rebuilt at Dzelukope (Akyeampong, 2001).

3.9 Erosion along the Eastern Coast

The entire coast of Ghana is influenced by longshore transport of sediment from west to east (Figure 3.5). According to Ly (1980), shoreline retreats along the eastern coast is due to the removal of sand from the unconsolidated Quaternary sediments exposed at the shoreline to the littoral zone to compensate the sand loss caused by longshore transport. Moderate erosion has been experienced at the frontage of Keta due to the loss of littoral sediment into lagoon inlet (Boateng, 2009).

Sediment supply from the Volta River is an important balance for this removal. However, shortage of littoral sediment was created (i.e. from about 71 million m³/annum to about 7

million m^3 / annum since the construction of the Akosombo Dam on River Volta beginning 1961 (Boateng, 2009; Ly, 1980). In effect there is a sediment deficit contributing to increased sea erosion along this coast. The rates reached as high as 8m/year between 1965 and 1980 (Ly, 1980).

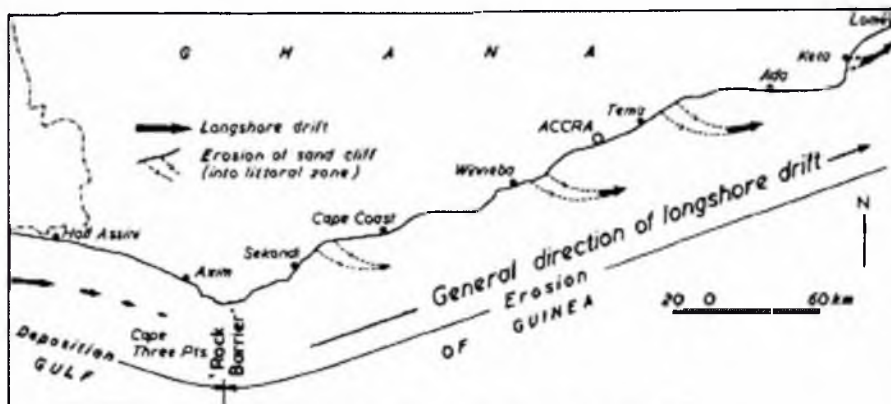


Figure 3. 5 Longshore drift along the Coast of Ghana (Ly, 1980)

3.10 Keta Sea Erosion: Mitigation and Challenges

Between 1784 and 1907 there is evidence of accretion of at least 600 feet at the Keta shore. Between 1907 and 1932, coastal erosion reversed the coastline at Keta to its 1784 position and coastal erosion had assumed alarming proportions. Thus the onset of sustained erosion at the Keta coast started around 1907 (Akyeampong, 2001).

Infrastructures such as the Evangelical Presbyterian Church and the AME Zion Church as well as government buildings have been eroded (Akyeampong, 2001). The Danish built

Fort Prinzenstein has also suffered from the sea erosion. It is estimated that 70% of the Keta Town now lies under the sea (Fiadzibey, 2005).



Figure 3. 6 Destruction of buildings at Keta (GLDD, 2000)

As a result of erosion, the sand spit became narrower especially between Keta and Havedzi cutting off the road linking these communities. The Keta market was badly affected since traders from the eastern towns could not have access to the market. The Keta St. Michael's Catholic Church was also affected.

3.4.1 Early Mitigation Measures

From 1907 the colonial government began to measure and record high water marks at Keta in order to assess the progress of sea erosion. By 1923 the destructive nature of the sea forced the government into action and plans were made to erect groynes along part of

the seashore. Timber groynes were sunk from 9th October 1923, with the aim of breaking the force of the sea waves and facilitating the deposition of sand carried by the sea in its longshore movements. This worked for some time with accretion of up to about 2 feet but by August 1926 the groynes had collapsed and erosion worsened (Akyeampong, 2001).

The Anlo State Council in 1938 built a retaining wall along the shore at Keta using iron rails and coconut trees. A wall of railway lines and palm trees was built near the Presbyterian Mission but this was washed away. However considerable accretion took place near the Roman Catholic Church (Akyeampong, 2001).

In 1951 the new African government took a major initiative to check sea erosion. The actual work started in January 1952 with a number of pile-driven groynes established. By May 1952, one of the groynes was washed away and erosion resumed especially near the Roman Catholic Church (Akyeampong, 2001). Later, in the 1960's metals were used as sea Defence structures to curb the situation. This failed because the metals quickly eroded and the sea continued to advance. Between 1972 and 1978, there were further attempts to intervene and boulders were placed at vantage points some of which remained till recently (H. James-Ocloo, Personal Communication, 8th June, 2011).

There had also been other attempts from individuals and groups using coconut stems, timber, sand bags and steel-sheet piles and concrete walls. However, none of these attempts were able to solve the problem (Dordor, 2005). As part of efforts to protect the Roman Catholic Church for example, there was the use of sand and silt from the lagoon

which was used to fill sacks to protect the shoreline. Old tyres were also woven together and used to fill the depression around the church to reduce the impact waves (J. Quashigah, personal communication, June 2, 2011).

3.4.2 Challenges

Generally, the sandy nature of the Keta beach accelerated coastal erosion since mobile sand presents no resistance to the sea. The area is also subject to land subsidence which makes it vulnerable to transgression by the sea (Akyeampong, 2001). The heavily populated shoreline also makes the impacts of sea erosion very devastating.

Attempts to curb the problem were also less effective because, the erosion points were highly unpredictable; they shifted constantly and were not confined to any definite area. Furthermore the cost of undertaking Defence works was high and government was reluctant in investing in such a project and there was less support from external sources (Akyeampong, 2001).

3.4.3 The Keta Sea Defence Project (KSDP)

As a major attempt to address the sea erosion problem at Keta, the Keta Sea Defence Project (KSDP) initiated in the early 1990's. The project commenced on December 14, 1999 and was to last a period of 50 months. The project was executed by the Great Lakes

Dredge and Docks Company (GLDD), USA in association with W.F. Baird and Associates (Conterra Limited, 2005).

The project had four major components which included (a) sea Defence works to limit further erosion (groynes, revetments, beach nourishment); (b) land reclamation from the lagoon adjacent to the town of Keta, providing an area for local inhabitants to rebuild homes that were lost to erosion; (c) construction of a road between Keta and Havedzi, re-establishing a road link between these townships lost to erosion; and (d) flood control for Keta Lagoon, providing relief from extreme flooding conditions for the inhabitants around the lagoon (GLDD, 2001). Figure 3.7 shows a section of the plan for the KSDP and Figure 3.8 is an aerial view of a section of the completed project.



Figure 3. 7 Plan of the Keta Sea Defence Project (GLDD, 2001)



Figure 3. 8 Aerial View of the Keta Sea Defence (GLDD, 2001)



Figure 3. 9 One of the Groynes at Kedzi (Author, June, 2011)

A total of 11 million cubic meters of sand were dredged from the channel for lagoon reclamation and beach fill and a total of one million tonnes of rock were produced in a quarry at Metrikasa 40km away for building roads and groynes and revetments. The project was completed on schedule in February, 2004.

A flood control structure comprising of 20 gates, 80.5m long is in place to regulate lagoon levels. An 8.5km bituminous surfaced road between Keta and Havedzi was also completed and 240 hectares of land had been reclaimed (Conterra Limited, 2005). Additional benefits from the Project include the creation of an 8km long dredged channel (11m deep) from Kedzi to Havedzi to be used for fishing, water sports and other tourism activities.

CHAPTER FOUR

METHODOLOGY

4.1 Introduction

Various approaches to shoreline mapping and change detection have been discussed in Chapter 2. The current chapter discusses the specific approach used in this study. It looks at the materials used and their sources and discusses the data processing as well as their use for change detection. Uncertainties involved mapping the shorelines and the level of accuracy was also discussed.

4.2 Materials

Materials used in this study range from medium resolution (15m-30m) to high resolution (2m) satellite imagery and GPS data. The images were collected from different sensors with varied levels of processing and quality. Other data also include wave data, photographs and literature. This section discusses the materials used, their sources and characteristics.

4.2.1 Satellite Imagery

The data used for this project included Landsat TM, ETM+ and ASTER images spanning a period of 25 years (from 1986 to 2011). Six dates of images (1986, 1991, 2001, 2007,

2010 and 2011) were acquired from the United States Geological Survey, Earth Resources Observation and Science Centre and Digital Globe. In addition, shoreline was estimated from GPS coordinates taken in 2011. The study area fell within one scene therefore only one scene was acquired for each year for the Landsat and ASTER imagery and a tiled WorldView-2 image covering a portion of the study area (Table 4.1.). The Landsat images were processed to level L1T which implies radiometric, geometric and precision corrected using the same ground control points and projected to UTM Zone 31N (USGS, 2009; Image Metadata File). The six visible and Near Infrared (NIR) bands at 30m were used in addition to the panchromatic band at 15m of the Landsat 7 ETM+ data.

The ASTER imagery was however acquired at level L1A which implies reconstructed, unprocessed instrument data at full resolution. The Visible Near Infrared (VNIR) consisting of 3 bands at 15m spatial resolution were processed for the analysis. The images were acquired between November and January which coincides with the dry season of the area. Though there were some clouds present, the region of interest (shoreline) was relatively cloud free. Furthermore due to the failure of the Scan Line Corrector (SLC) of the ETM+ in 2003 there were gaps in the 2011 data (Figure 4.1e).

The WorldView-2 image covered only a portion of the entire coast under study. The 8 multi-spectral bands at 2m spatial resolution were used in this study. The image was already tiled and projected to the UTM Zone 31N using the WGS 84 datum. It was relatively cloud free and of good quality (Figure 4.1f).

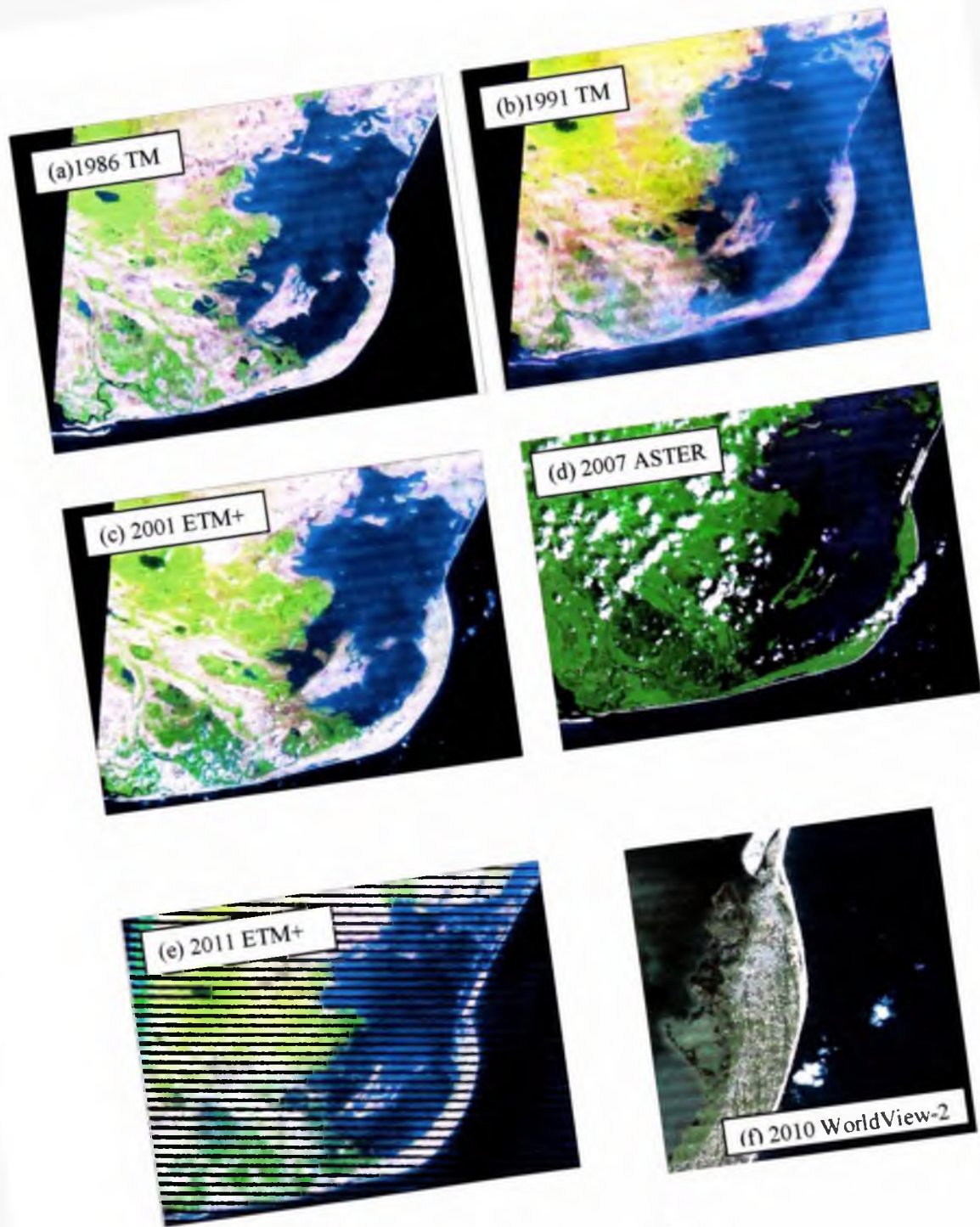


Figure 4.1 Color Composites of the Satellite Imageries

4.2.2 Other Data

Field data included ground reference points and tracking of shoreline using GPS. It also included photography, observation and interviews of some community members. Wave and wind data for the area based on the global wave model was also collected from NOAA for the period from January 1997 to January 2006. The location for the data is latitude 4°N and longitude 1°W (Svašek Hydraulics, 2006).

Table 4. 1 Imagery Data Properties

Data	Path/Row	Acquisition date	Bands	Resolution	Level of Processing
Landsat TM	192/56	1986-01-13	6MS	30m	L1T
Landsat TM	192/56	1991-01-03	6MS	30m	L1T
Landsat			6MS	30m	L1T
ETM+	192/56	2001-01-30	1 Pan	15m	
ASTER	192/56	2007-11-06	3 VNIR	15m	L1A
WorldView-2	Tiled	2010-11-10	8MS	2m	-
			1Pan	0.5m	
Landsat			6MS	30m	L1T
ETM+	192/56	2011-01-10	1 Pan	15m	

Source: Author's Construct

4.3 Image Pre-processing

Landsat images were basically ready for use in shoreline extraction. The 1986, 1991, 2001 and 2011 Landsat images were in the same projection UTM Zone 31 using the WGS 84 reference datum and GLS 2000 elevation data. However, to ensure consistency in spatial resolution, the Landsat TM data was resampled using nearest neighbour and 1st order polynomial transformation to 15m. This however does not add any spatial information to the new data and increases the uncertainty for the shoreline position.

For the Landsat ETM+ data the panchromatic band with a resolution 15m was used to sharpen the six multi-spectral bands to obtain a new image at 15m. The Gram-Schmidt pan sharpening algorithm (Laben and Brover, 1998) in ENVI which is based on principal component analysis was used. Studies by Yuhendra and Hiroaki (2011) showed this method is very good at colour recovery and sharpness. The pan-sharpening improved the spatial information of data and hence reduces the uncertainty.

The ASTER VNIR bands at 15m but were acquired at L1A. Basically at its raw stage, there was a need for geometric correction/rectification. The VNIR bands were co-registered (Image to image) to the Landsat 2001 ETM+ data using 30 visually interpreted Ground Control Points (GCP). These GCPs were used to warp and resample the ASTER using first order polynomial and nearest neighbour transformation. The total RMS error was 0.35m.

The resulting images were combined to form visible and infrared color composites using Red-Green-Blue (RGB) display (refer to Figure 4.1). For the Landsat images the bands 5, 4 and 3 were combined and bands 3, 2 and 1 for ASTER. This combination enhanced the land-water boundary and highlight subtle details not readily apparent in the visible bands alone (“Web PDX”, 2001).

4.3.2 GPS Data Collection

Three sections along the entire coastline were selected for extraction of current shoreline position. Sections around the sea defence, Cape St. Paul and Atorkor were tracked. In all, a total of about 16km of shoreline was mapped. Handheld Garmin eTrex GPS was used for tracking transects and the instrument accuracy was 3m throughout the tracking. The unit of collection was set to WGS 84 to be consistent with the other data projections. The dry/wet boundary which was also visible from the imageries was used as a reference for tracking the shoreline positions (Figure 4.2).



Figure 4. 2 Tracking the Wet/Dry Boundary

4.4 Shoreline extraction

Both manual and semiautomatic methods were explored for the extraction of the shorelines. Band ratio between the mid infrared (band 5 [b5]) and the green (band 2 [b2]) was used to identify the water-land boundary for the Landsat images except the 2011 image due to the gaps in the data. This was used to reduce the level of subjectivity in delineating the shoreline. For this study band ratio was implemented using the band ratio model in the ENVI software (i.e. $b5/b2$).

The resulting image with ratio values between 0 and 3 was sliced and segmented to form a binary image with values less than 1 being classified as water and values greater than 1 being classified as land thereby delineating the boundary between the water and the land

as the shoreline. The water class was then converted from raster to vector and exported as shapefiles for overlay in ArcMap.

In ArcMap, the extracted shorelines were overlaid on the Landsat image. The output vector however consisted of other water/land boundaries such as those of creeks and lagoons and could not be directly used for change detection. To extract the target sections, the extracted vector shoreline were overlaid on the colour composites and was used as guide to digitize the target shoreline.

Due to the differences in sensor platforms (wavelengths), the presence of clouds and cloud shadows over portions of the shoreline of the 2007 ASTER image, band analysis was considered ineffective. The 2007 shoreline was therefore manually digitized directly from the colour composite (231) of the ASTER imagery. The shoreline was digitized at the same position as for the 1986, 1991, 2001 and 2011 images and at the same scale (1:5000). For the ASTER imagery and the 2011 ETM+ data which had problems with cloud and gap, respectively, sections of the shoreline were not digitized. Shoreline data for 2007 and 2011 therefore had gaps. The 2010 high resolution imagery was also digitized.

For the tracked shoreline, the data was downloaded from the GPS using the Map source software where the tracks were extracted as line feature. The data was then saved in the '.dxf' format and opened in ArcMap and then exported as a shapefile.

4.5 Shoreline preparation and change analysis

The Digital Shoreline Analysis System (DSAS 4.2) updated by the USGS (Himmelstoss, 2009) was used for shoreline change detection. The software is an extension for ArcGIS and computes rate of change at user specified interval along the shoreline using different methods. This was chosen due to the various statistical methods available for change rate estimation. The DSAS requires that the input data be consistent and in one geodatabase for change statistic calculation.

4.5.1 Geodatabase Development

The DSAS software requires that all input data be managed within a geodatabase which also serves as the storage location for the program-generated transect feature class and related statistical output tables (Himmelstoss, 2009). A geodatabase was therefore created for the extracted shoreline positions. Each shoreline had attributes which included date, length, ID, shape and uncertainty. The date of acquisition for each image was entered for the date column while the length, ID and shape were automatically generated. Uncertainties were also quantified (refer to section 4.4.4) and entered as integers for the uncertainty column. The five shoreline positions were then appended to one shapefile and were ready for rate calculation.

4.5.1 Baseline Construction

The DSAS uses measurement baseline method to calculate rate of change statistics for a time series of shorelines. The baseline is constructed to serve as the starting point for all transects cast by the DSAS application. For this analysis the baseline was constructed by manually digitizing about 500m onshore away from the closest shoreline (Figure 4.1) taking into consideration the general orientation of the shoreline. The data was also projected to the UTM Zone 31N projection. The attributes include object_id, shape and length with an additional user generated ID column.

4.5.3 Casting Transects

Once all the inputs were ready in the database, transects were constructed. A total of 284 transects were cast along the entire stretch of coastline from east to west at a specified interval of 200m. As discussed in section 3.3, the geology for the shoreline is generally homogenous. In this case, little variation is expected for distances lesser than this. The transects were cast at simple right angles from the baseline offshore (Figure 4.3). The length of the transect was set to 900m to ensure it intercepts all the 5 shoreline positions

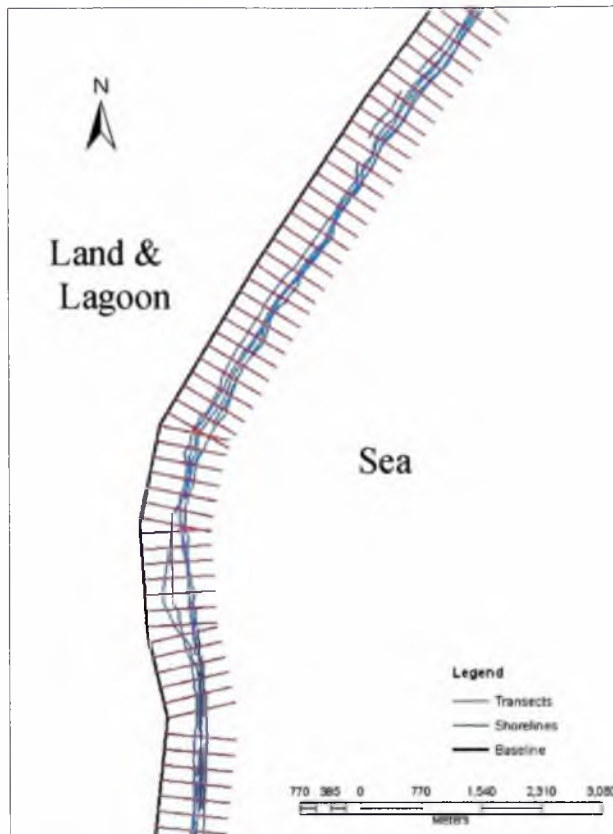


Figure 4.3 Transects and Baseline

4.5.4 Uncertainty Quantification

For this study, uncertainties were quantified using estimates based on studies such as Crowell et al. (1991) and Moore (2000) and Hapke et al., (2010). Additional errors, which were associated with the imagery used for this study, were estimated. Four main sources of error were identified to account for the uncertainties. Errors resulting from image registration, digitization of the shoreline, position of HWL and differences in resolution were considered. As discussed in section 4.3, resampling the 1986 and 1991

images from 30m to 15m did not add any spatial information. A pixel with the same spatial information is split into four to get 15m.

The uncertainty estimates for this study are displayed in Table 4.2. The tidal range (1m) of the area was negligible and therefore was not accounted for as a source of uncertainty due the resolution of the imagery used.

A total shoreline positional error for each epoch (E_x) was therefore calculated using the following equation:

$$E_x = \sqrt{(E_s^2 + E_p^2 + E_r^2)}$$

where E_s is the error occurring from scale difference, E_p is the photogrammetric error and E_r is the registration error. This approach carries the assumption that component errors are normally distributed (Dar and Dar, 2009).

The total uncertainties were used as weights in the shoreline change calculations. The values were annualised to provide error estimation for the shoreline change rate at any given transect and expressed as:

$$E_a = \frac{\sqrt{(E_1^2 + E_2^2 + E_3^2 + E_4^2 + E_5^2)}}{T}$$

where E_1, E_2, E_3, E_4 and E_5 are the total shoreline position error for the various years and T is the 25 years period of analysis.

4.6 Change Rate Calculation

For this study the WLR was used since there were more than two shoreline positions and uncertainties were also quantified. The NSM which reports the distance between two shoreline positions was also used for accuracy assessment purposes.

For the purpose of assessing accuracy of the mapped shoreline positions (discussed in section 4.6) the net shoreline movement was used to determine the distance between the 2010 satellite image extracted shoreline and 2011 GPS mapped shoreline, a period less than a year. The distance between where the two shoreline positions intercept with a transect is reported as the net shoreline movement taking into consideration uncertainties. This distance was used as measure to determine the ability of mapping the shoreline at 15m resolution (see section 4.7).

The EPR was employed where only two shoreline positions were available as was the case for the period between 2001 and 2007. The distance between the two points where the shoreline intercept a transect was calculated and this distance was divided by the number of years that elapsed in this case 7years, to give the end point rate. This was done along all transects and the EPR was reported for all.

For the entire period under study five shoreline positions were available (i.e. 1986, 1991, 2001, 2007 and 2011) and uncertainties were also quantified. WLR method was therefore used for calculating the rates. The method was also used to calculate changes for shorter periods thus between 1986 and 2001 (period before the KSDP) and between 2001 and 2011 (the period during and after the KSDP). Both periods had three shoreline positions mapped.

Here shoreline positions with smaller positional-uncertainty values had more influence in calculating the regression. The slope of the regression line between the shoreline positions at each transect was reported as the rate of change. This method proved to produce better rates of change statistics.

4.7 Accuracy Assessment

To assess the accuracy of the band ratio at mapping the water/land boundary, the extracted shorelines were overlaid on the colour composites and visually interpreted. The 1986 and 2011 shoreline positions were also overlaid on the 2010 image to further assess their accuracy through visual interpretation.

Furthermore, the accuracy of mapping the shoreline at 15m resolution was also assessed by comparing the 2010 November shoreline to the January 2011 shoreline positions. This covers a period of only three months and little change was expected for the shoreline positions aside from tidal effects which for the area is only about 1m.

The 2010 shoreline was then compared with the 2011. The movement between the November 2010 and June 2011 '*b*' was taken as a short term movement of the shoreline position in the study area. This was then subtracted from the movement between the November 2010 and the January 2011 '*a*'. The result was assumed as the error at mapping the shoreline using 15m resolution imagery. Thus:

$$a - b = x$$

where *x* is the resulting error in meters

The change between these two dates was considered as an error for mapping the shoreline at 15m resolution.

CHAPTER FIVE

RESULTS

5.1 Introduction

This chapter discusses the results from the shoreline mapping and change analysis, looking at the pattern of change and the rates of accretion and erosion along this coast. Changes are presented for the period before the KSDP thus from 1986 to 2001 and the period after thus from 2001 to 2011. Overall changes were presented for the 25 years period thus between 1986 and 2011. Results for a shorter period between 1986 and 2007 were also presented as well as results for the accuracy assessment.

5.2 Extracted shorelines

A total of 6 shorelines were extracted from satellite imageries and additional shorelines from GPS field survey were used for shoreline analysis and accuracy assessment. The shoreline positions were for 1986, 1991, 2001, 2007, 2010 and two shoreline positions for 2011 as shown in Figure 5.1. The shoreline positions from satellite imagery for 2007 and 2011 had gaps.

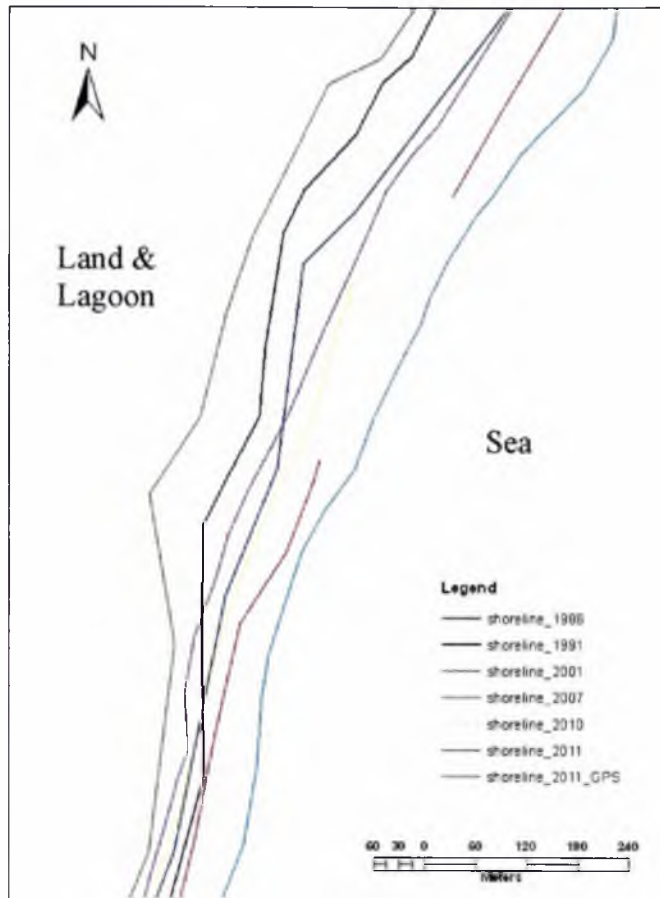


Figure 5. 1 Extracted Shorelines for a Section of the Coast

5.2 Overall Changes

Change rates were calculated for the period between 1986 and 2007 (Figure 5.2a) and then for 1986 to 2011 (Figure 5.2b). This was to cross the check the effects of the gaps in the 2011 image on the rates. The results show that there have been significant changes along the entire coast for the 25 years period under study. For the period between 1986

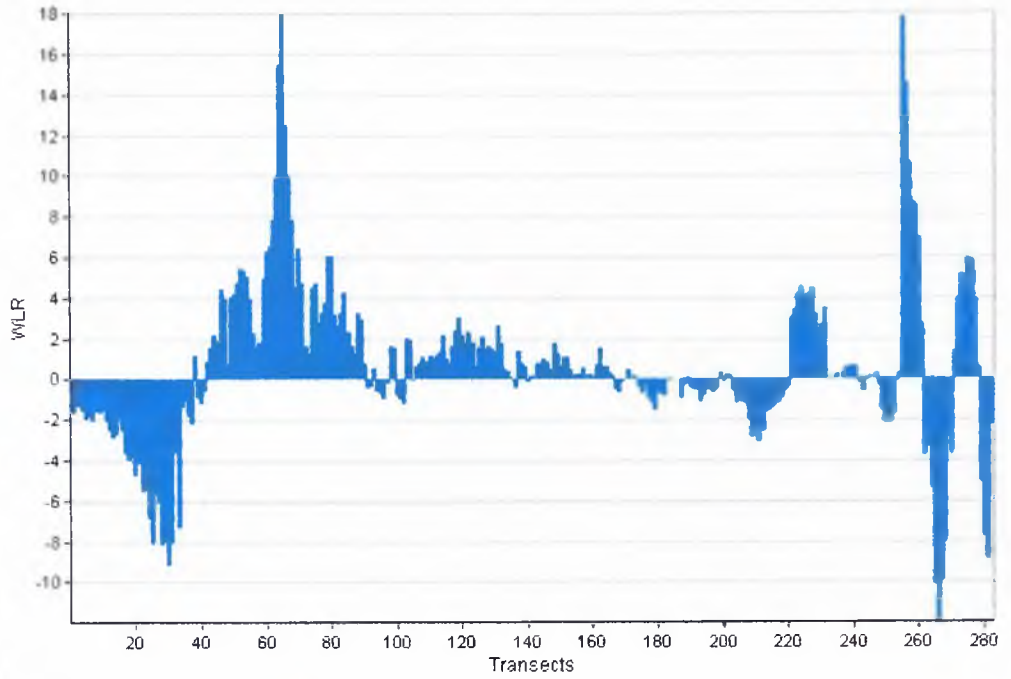
and 2011, about 40% of transects were ignored due to the gap in the 2011 shoreline positions. This affected change rates especially near the estuary. However, overall rates were not much affected, showing little variation in rates of changes. The averages of the calculated rates are shown in Table 5.1.

Table 5. 1 Average Erosion and Accretion Rates

Period	Erosion Rate Ave(m/year)	Accretion Rate (m/year)
1986-2011	1.91	2.04
1986-2007	2.38	2.77
1986-2001	3.10	5.17
2001-2011	4.52	5.59
2001-2007	4.68	10.04

Overall rates per transect varied from between -12m/year to 18m/year where negative values represent erosion and positive values represent accretion (Figure 5.2). Using the 1986 to 2007 results as a reference, about 45% of the entire shoreline experienced erosion while the remaining have mostly accreted. No change was recorded for only one transect. Accretion rates per transect ranged from 0.1m/year to 19m/year with an average 2.5m/year while erosion rates were between 0.1 to 9.3m/year with an average of 2.38m/year. Both rates were significantly high for the area.

(a)



(b)

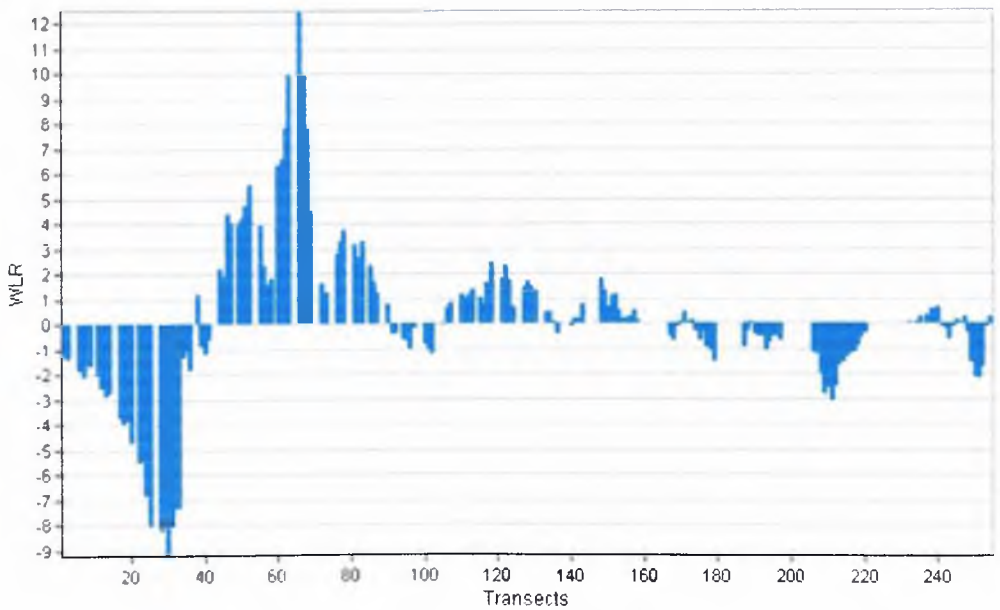


Figure 5. 2 Overall Erosion and Accretion Rates.

The Keta area, as shown in Figure 5.3 (a) has seen much of accretion with rates reaching about 18m/year while the area between Keta and Adina (Figure 5.3 b) has seen much erosion with rates at an average of 3.5m/year with some sections recording as high as 9m/year. Near the estuary there are extreme cases of erosion and accretion over the period (Figure. 5.3c) and rates are as high as -11m/year and 17m/year respectively. For the entire shoreline erosion and accretion rates averaged at 2m/year.

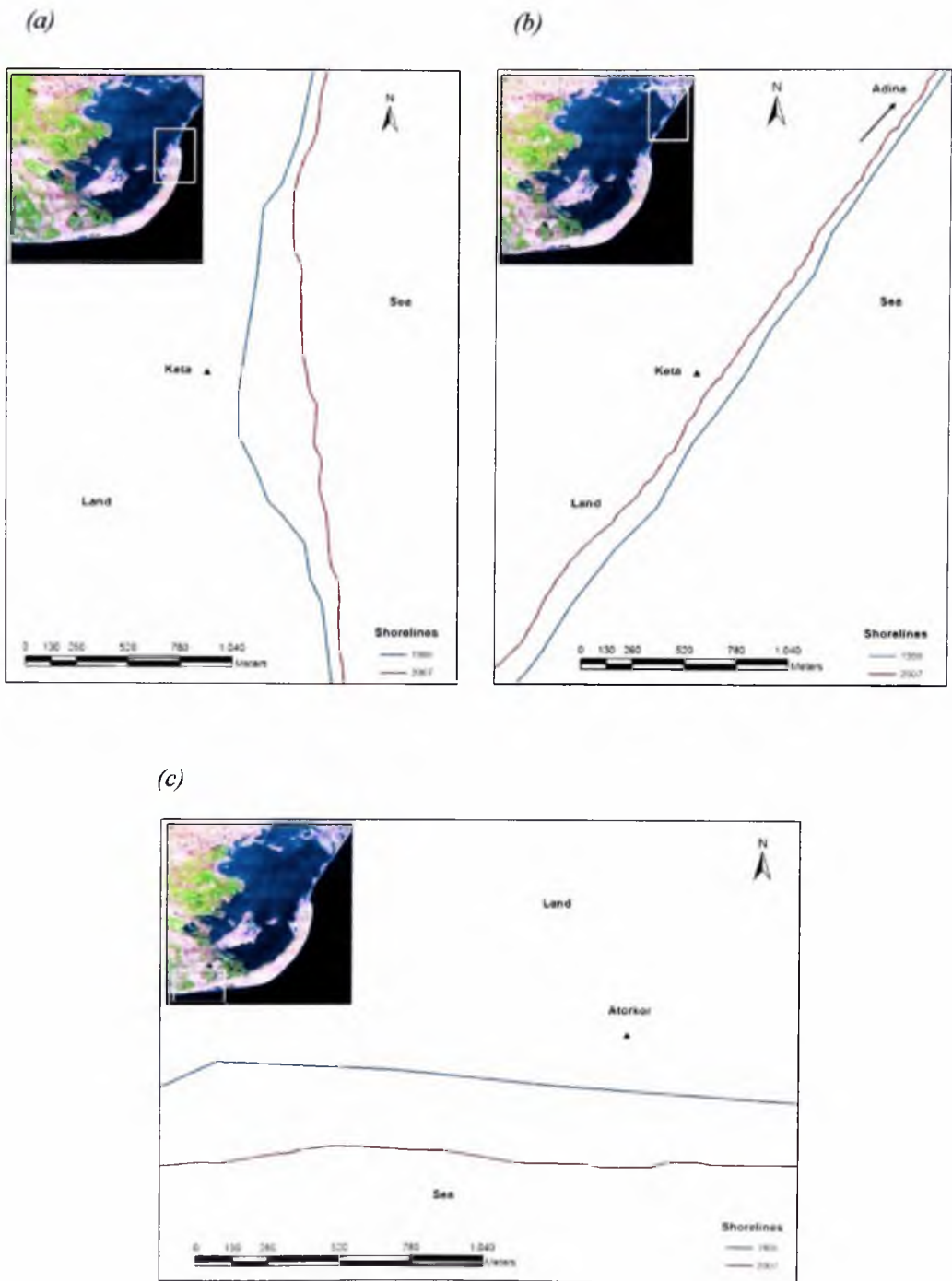


Figure 5. 3 Areas of Erosion and Accretion

5.3 Shoreline Change between 1986 and 2011

This period revealed that erosion dominates the entire shoreline (Figure. 5.4) with about 70% of the cast transects recording erosion. Erosion rates ranged from 0.1 to 15.4 m/year with an average of 3m/year and accretion rates ranging from 0.1m/year to 21m/year with an average of 5.90m/year. The higher erosion rates occurred between Keta and Adina and Atorkor and Anyanui while the area between Keta and Anloga experienced significant accretion.

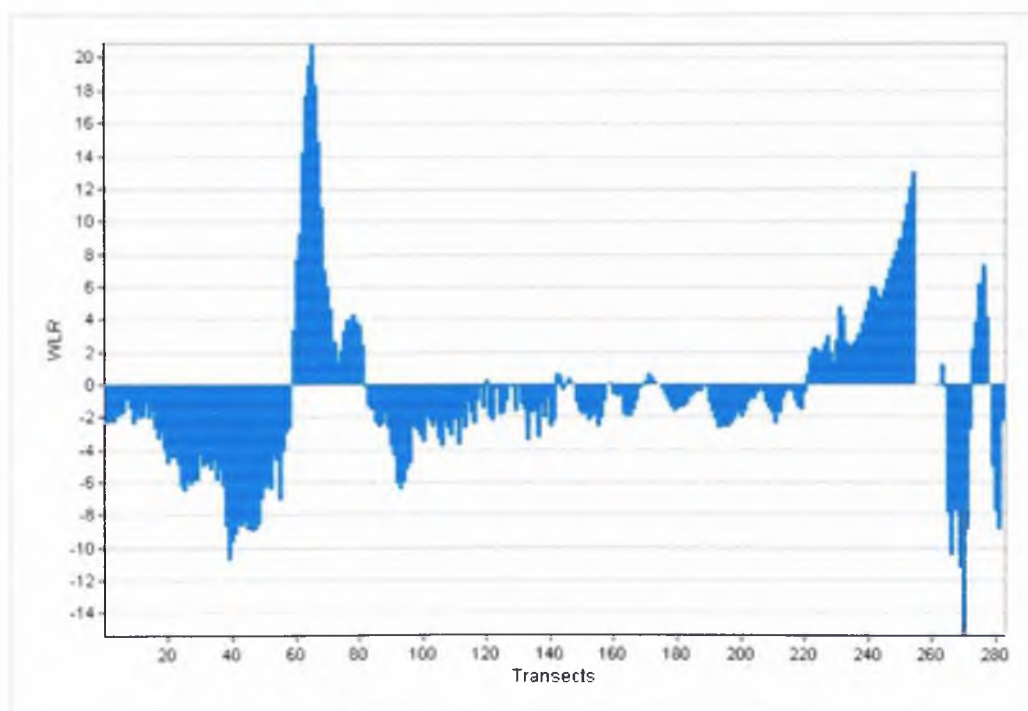


Figure 5. 4 Erosion and Accretion Rates between 1986 and 2001

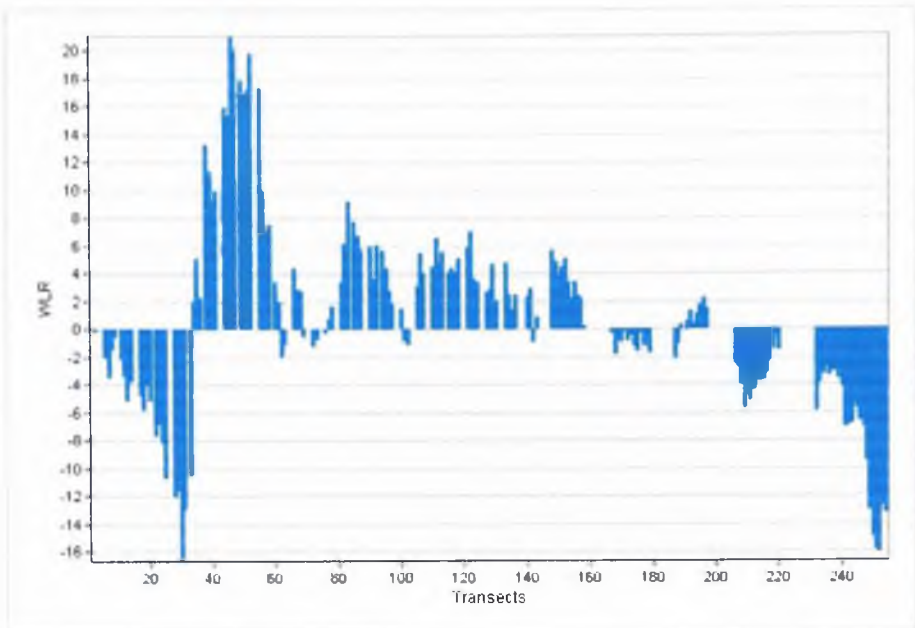
Close to the estuary there is evidence of both erosion and accretion over the period. Here erosion rates were as high as 15m/year and accretion rates also at a high of 14m/year.

5.4 Shoreline Change between 2001 and 2011

The period between 2001 and 2011 showed a reversal of situations with the entire coast experiencing more accretion (about 80%) than erosion (Figure 5.5). However, erosion rates remained high, ranging from 0.1 to 17m/year with an average as high as 4.5m/year. Accretion rates also were high ranging from 0.1 to 26m/year and an average of 5.6m/year. The area between Keta and Blekusu and the area near the estuary remained high points of erosion over this period with rates reaching as high as 16m/year. Figure 5.6 shows the impacts of the high erosion rates around Blekusu and Atorkor.

It is also evident that most areas that experienced erosion between 1986 and 2001 had accreted between 2001 and 2007. The immediate vicinity of the Keta Township continues to accrete as well as areas around the estuary with values reaching 17m/year. Most portions of the Cape have also accreted.

(a) 2001 to 2011



(b) 2001 to 2007

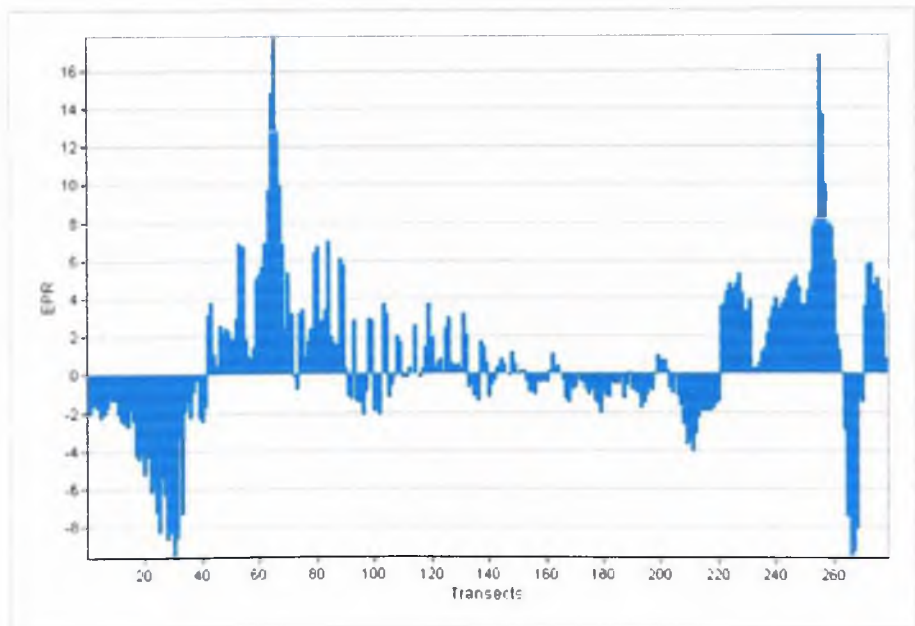
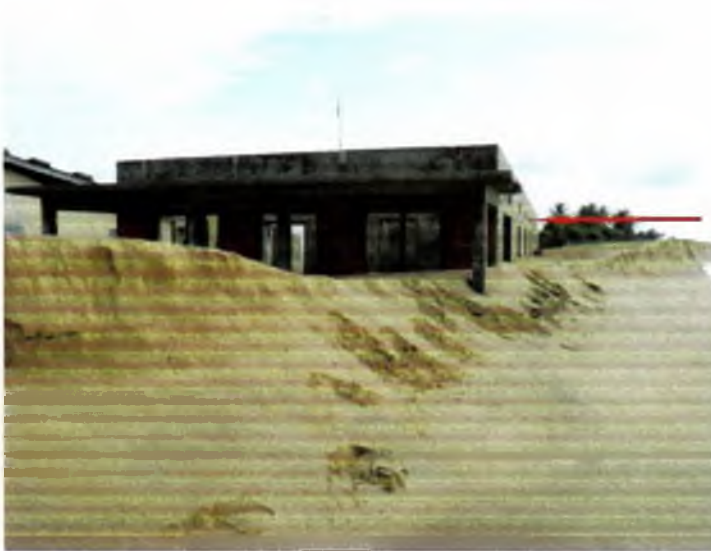


Figure 5. 5 Erosion and Accretion Rates for 2001 to 2011

(a)



(b)



Figure 5. 6 Destruction by Erosion at (a) Blekusu and (b) Atorkor

5.5 Accuracy Assessment

Visual interpretation of the overlay of the automatically extracted shoreline positions (Figure 5.7) show that the method was efficient in delineating the water land boundary. Additionally, three of the extracted shorelines were used for accuracy assessment thus the 2010 and the two 2011 shoreline positions. The average of the NSM between the November 2010 and June 2011 shoreline positions was 20.12m while that of November 2010 and January 2011 was 31.43m (Table 5.2).

From the application of the method discussed in section 4.7, the total error for mapping the shoreline at 15m resolution was estimated to $\pm 11.31\text{m}$.

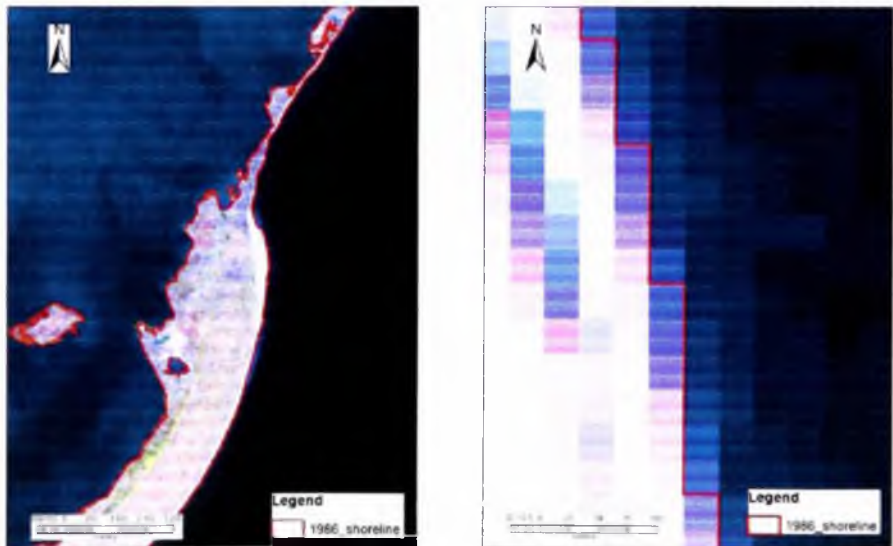


Figure 5. 7 Overlay of 1986 Vector Shoreline on Original Image

Table 5. 2 NSM Results used for Accuracy Assessment

TransectID	NSM (m)	
	(11/10/2010-01/10/2011)	(11/10/2010-06/06/2011)
109	29.43	31.53
110	39.53	32.32
111	17.25	28.77
112	17.86	25.51
113	22.74	10.48
114	29.47	10.78
115	33.73	6.83
119	21.48	1.90
120	16.93	4.33
121	21.88	0.53
122	16.20	1.13
212	66.52	42.26
213	75.54	41.32
214	92.20	44.00
Average	31.43	20.12

Based on estimates (Table 5.3) the maximum annualized uncertainty for this study is $\pm 0.44\text{m/year}$.

Table 5. 3 Uncertainty levels

Shoreline Year	Registration Uncertainty	Digitizing Uncertainty	HWL Uncertainty	Scale Uncertainty	Total Uncertainty
1986	-	$\pm 1.00\text{m}$	$\pm 4.5\text{m}$	$\pm 3\text{m}$	$\pm 5.5\text{m}$
1991	-	$\pm 1.00\text{m}$	$\pm 4.5\text{m}$	$\pm 3\text{m}$	$\pm 5.5\text{m}$
2001	-	$\pm 1.00\text{m}$	$\pm 4.5\text{m}$	-	$\pm 4.61\text{m}$
2007	$\pm 0.35\text{m}$	$\pm 1.00\text{m}$	$\pm 4.5\text{m}$	-	$\pm 4.62\text{m}$
2011	-	$\pm 1.00\text{m}$	$\pm 4.5\text{m}$	-	$\pm 4.61\text{m}$
Annualized Transect Error (Ea) (m/year)				$\pm 0.44\text{m}$	

Furthermore, visual interpretation of the overlay of the 1986 and 2011 shoreline positions on the 2010 high resolution imagery revealed a fairly accurate mapping of the shoreline

by the 15m resolution imageries. As shown in Figure 5.8, the area covered by circle 'B' was a large creek which was still part of the shoreline during the late 1980 and early 1990's as confirmed by community members. The circle 'A' also shows part of the community around the Roman Catholic church which was also affected around the same time. The 2011 shoreline position was also approximately in line with the 2010 one which is a period of about only three months.

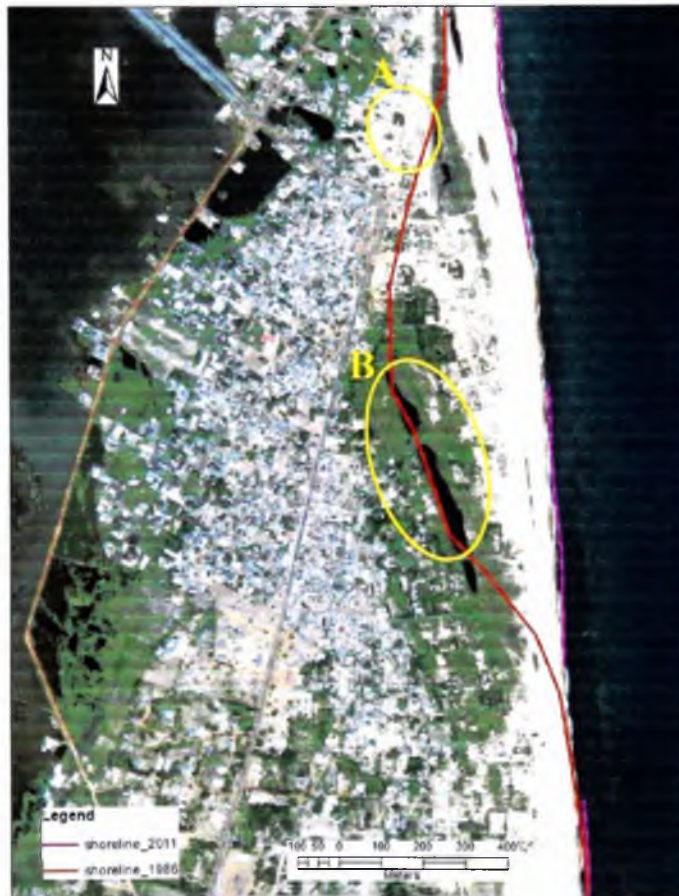


Figure 5. 8 Overlays of 1986 and 2011 on 2010 Imagery

CHAPTER SIX

DISCUSSION OF RESULTS

6.1 Introduction

Shoreline change is evident along the entire coastline of Keta and various factors contribute to such change. This chapter discusses the erosion and accretion trends and the possible factors that are influencing the observed trends along this coast with emphasis on erosion. Natural factors including wave and current actions, shoreline orientation as well as anthropogenic factors including land, soil mining and mangrove harvesting as well as the influence of Keta Sea Defence Project is discussed.

6.2 Erosion Trends

According to Ly (1980), erosion rates along the eastern coast have increased after the construction of the Akosombo Dam in 1962. The rates reached as high as 8m/year as compared to the 4m/year high rates before the construction. The result of this study revealed high rates of erosion along the entire coast for the period under study from 1986 to 2011 thus an average rate of about 2m/year ± 0.44 m. The period before the construction of the KSDP marked intense erosion along the entire coast with rates reaching as high as 15m/year and an average of about 3.10m/year for the area near Keta and the Volta estuary. This has led to destruction of many coastal facilities and homes especially at

Keta (see section 3.4). It also confirms the assertion that the Cape has been retreating since the construction of the Akosombo Dam (Boateng, 2009).

As part of efforts to curb the situation, the Keta Sea Defence project was initiated in 2001. Thereafter, the rates indicate more accretion to the west of the site and erosion to the east. Erosion rates remain high, averaging 4.52m/year while accretion rates were also as high as 5.5m/year. Currently, the people around Keta are relieved as the shoreline has been stabilized and the community protected from the impacts of erosion. However, high erosion rates in the east have led to the destruction of houses at Blekusu and its surrounding communities. This situation is responsible for the generally higher erosion rates recorded after the KSDP.

Further down to the west (near the estuary) erosion rates had also increased leading to the destruction of homes and schools. As well the road linking Anyanui in the far west to Keta was completely cut off at Atorkor. Efforts are underway to protect this area from further erosion.

Previous studies estimated erosion rates at 1.13m/year \pm 0.17 for the Accra shoreline (Apeaning et al., 2008) and Ly (1980) estimated for the eastern coast between 4-8m/year. The current rates reflect this general trend.

6.3 Factors Influencing Erosion

Natural factors continue to be a major contributor to shoreline change. Climate change which leads to sea level rise, wave, current, tides and shoreline orientation influence the movement of shoreline at any point in time. However anthropogenic influences such as construction of harbours, dams and coastal Defence works greatly affect coastal processes. A combination of these factors is responsible for shoreline change along the Keta coast.

6.3.1 Waves Currents and Tides

As discussed in section 3.5, waves are active in the study area and it is considered a high energy beach. The prevailing southwesterly wind causes an oblique wave approach to the shoreline. This wave approach generates an eastward littoral transport. Shoreline retreat is therefore due to removal of sand from the unconsolidated Quaternary sediments exposed at the shoreline to the littoral zone to compensate the sand loss caused by longshore transport. Since there are no major headlands to act as obstacles to the littoral transport rates of retreat along this coast is high (Ly, 1980; Boateng, 2009). Furthermore, due to the generally sandy nature of the Keta beach, there is accelerated coastal erosion since mobile sand presents less resistance to wave action. The sand is easily removed from the coast and carried away by the drift. Reduction in sediment supply from other sources such as the Volta River to compensate for this loss increases the risk of erosion along this coast (Ly, 1980).

According to Manu et al. (2005) recent mapping of the sea bed topography of the estuary area reveals the presence of numerous canyons (valleys) from the shelf all the way to the deep water. Waves reaching this point may behave as in deep waters. The waves will therefore break at a higher speed on suddenly reaching the shoreline. The impact is stronger and may partly explain the high erosion rates along the Keta shoreline.

6.3.2 Construction of the Akosombo Dam

Sediment supply to the region from the Volta River is important. According to Ly (1980), prior to the construction of the Akosombo Dam sediment supply from the Volta River was estimated to be 71 million m³/a. This was carried along the wave-induced littoral drift to the east. In effect there was natural accretion at Cape St. Paul. With the construction of the Dam, this supply reduced to only 7 million m³/a leading to shortage of littoral sediment and hence reduction in accretion along the eastern strip since the late 1960s (Boateng, 2009). Accretion was now occurring further west of the Cape near the estuary (i.e. Atiteti) as a result of reduced ebb tidal energy from the Volta which is caused by the reduction of the flow of the river.

Further away from the estuary the shortage of sediment supply has led to the removal of sediments from the shoreline to compensate for this loss leading to increased erosion. Ly (1980) confirmed that this reduction led to an increase in erosion rates from an initial high of 4m/year to 8m/year. As confirmed by the results of this study, erosion dominates this shoreline prior to the construction of the Keta Sea Defence. The erosion rates have remained fairly high.

6.2.3 Sea Level Rise

Rising sea levels as a result of climate change in concert with coastal erosion is contributing to gradual submergence of communities along the West African nation's coast. Coastal systems react to changes in mean sea level by redistributing sediments. As supply of sediments reduce along this coast the shoreline retreat (Allersma and Tilsman, 1993). Keta has been identified as highly vulnerable to increased erosion associated with sea level rise (Boateng, 2009).

For the coast of Ghana, the local sea level is rising in conformity with the global trend at a historic rate of approximately 2 mm/yr. This is expected to increase, potentially up to as much as 6 mm/yr (Appaning Addo, 2009). Higher sea levels exposes previously out of reach land to waves and currents increasing the vulnerability to erosion. This partially explains the high erosion rates found in this area. It has been identified that all the frontage of the Keta strip could be submerged by 1m rise in sea level, and 2m rise may result in inundation of the whole frontage (Boateng, 2009).

6.2.4 Shoreline Orientation

Cape St. Paul is a dominant feature along this coast projecting seaward and giving a convex shaped coastline. The shoreline roughly runs in the south-east direction (Figure 6.3). As sediments are supplied and transported from the Volta estuary greater part is deposited between its mouth and a point eastward of Cape St. Paul, where the littoral

transport almost ceases. This is because the south-westerly waves cannot reach this area. Active erosion occurs here (point A, Figure 6.3), where the transport capacity increases and feeds the coast further east (Allersma and Tilsman, 1991).



Figure 6. 1 The Shoreline Showing the Cape (Google Earth)

This phenomenon is responsible for accretion around the Cape St. Paul prior to the construction of the Akosombo Dam. As discussed in section 6.2.2 the construction of the Dam reduced sediment supply to this coast. The less sediment depletes quickly before reaching the Cape leading to the removal from the Cape onwards to compensate for the loss, hence the recession of the Cape after the construction of the Dam.

6.2.5 The Keta Sea Defence Project (KSDP)

As discussed in section 3.4, various attempts were made to halt the shoreline recession in the Keta area. The KSDP was the largest and was aimed at intercepting the reduced yet significant present littoral sediment drift (Boateng, 2009). The effect of this project on shoreline change was determined by comparing shoreline change before and after the construction. Prior to the construction of the Sea Defence, erosion was dominant along the entire coast especially around Keta.

With the completion of the project in 2004, erosion was greatly reduced as the shoreline between Keta and Havedzi was stabilized. There is evidence of accretion along most sections of the coast especially west of the defence between 2001 and 2007 as a result of the construction. However, the construction of site specific hard structures such as the Keta Sea Defence tends to stabilise a specific section of the coastline and cause a “knock on effect” down drift (Boateng, 2009). As confirmed by this study, to the immediate east of the Sea Defence erosion is occurring at high rates leading to the destruction of properties.

Furthermore there is increased erosion closer to the Volta estuary leading to massive destruction of coastal establishments. As part of efforts to curb the current situation, 2.5km long gabion revetment structure is being constructed along the shoreline at Atorkor as well as the reconstruction of the road linking the community. About 500m of the revetment has been constructed and the rest will be completed by the end of the year

2011 (Ayivor, 2011). This is expected to stabilize the shoreline around this area but may shift focus to another point. As discussed in section 2.6, there is the need for the development of SMPs for the management of Ghana's shoreline.

6.2.6 The Land Squeeze Factor

Land use patterns have significant influence on erosion patterns. Increase in population along the coast puts much pressure on the natural land, making it more vulnerable to erosion. Rapid development along the coast of Ghana has been identified as a driving force for coastal erosion in Ghana. As discussed in section 3.8, land is, and remains a scarce commodity in the Keta area and as a result there high pressure on existing land. The sandbar on which the Townships are located is barely more than 2.5km at its widest point. The land is bounded in north by the Keta Lagoon and the south by the Gulf of Guinea.

According to Schlepner (2008), coastal development prevents coasts from adapting to increased erosion rates by shifting landward. Since the sandbar is limited in the north by the lagoon, developments cannot be moved further inland. As well, the land cannot adapt to sea level rise by migrating inland. In effect the available land is competed for by wave action as well as developments leading to squeeze situation. Furthermore, most of the settlements, historic and tourism sites and industries are within 200m radius from the shoreline. The impact of erosion is therefore felt in this area (Boateng 2006).

6.2.7 Sand mining and Mangrove Harvesting

As discussed in section 3.7 sand mining even though banned is being carried out in the area. Mensah (1997) has established that sand mining plays an important role in coastal erosion. The sand deposit ensures that sediment is available for littoral transport. Its removal reduces the beach volume and hence increases erosion. This has been identified as a major contributor to erosion along the Keta coast especially near Atorkor, Dzita, Dzelokope and Woe.

Also, mangroves prevent erosion by stabilising sediments with their tangled root system and also trapping sediments originating from inland thereby stabilising the shoreline. Over exploitation of mangroves has also been identified as a driving factor in increased coastal erosion. The intensified harvesting of red and white mangroves growing around Anyanui, Atorkor and Salo for domestics and commercial use has further aggravated the soil erosion problem (Keta Municipal Assembly, n.d.).

CHAPTER SEVEN

CONCLUSION

7.1 Introduction

The main objective of this study used medium resolution multi-temporal and multi-spectral remote sensing data to extract and detect shoreline changes from 1986 to 2011 and discussed the possible underlying factors, particularly the influence of the KSDP and the implications of such changes for the management of the zone. It involved the extraction of historical and current shoreline position, shoreline change analysis and assessment of factors influencing the changes observed. This chapter summarizes the approach to the study, the results and draws conclusions. Recommendations are then made both for further research and for policy formulation and management of the area.

7.2 Data Source and Approach to Study

The data used for this study were from different satellite sensor platforms including WorldView-2, Landsat TM and ETM+ and ASTER, with resolution varying from 2m to about 30m. All data, except the high resolution were re-sampled to 15m resolution. A total of seven shoreline positions were extracted using semi-automatic and manual methods. The extracted shorelines represented the wet/dry boundary for 1986, 1991, 2001, 2007, 2010 and 2011. Both the semi-automatic and the manual delineation proved efficient at extracting this boundary.

Uncertainty values for the shoreline positions used vary $\pm 4.1\text{m}$ to $\pm 8.8\text{m}$. These were used as weights in linear regression analysis. The NSM, EPR and the WLR methods available in the DSAS were used change analysis and rate estimation. NSM results were used for assessing the accuracy of mapping the shoreline at 15m. The EPR was used to calculate the rate of change when only two shoreline positions were available while the WLR was used when more than two shoreline positions were available. Rates were calculated along a total of 283 transects cast at right angles to the constructed baseline. Overall rates of change for the entire period (25year) were calculated as well as for the periods 1986 to 2001 (period before the KSDP) and 2001 to 2011 (the period after the KSDP).

7.3 Summary of Results

Overall the average rate of erosion along the coast was estimated at 2m/year. The area east of the KSDP site, between Keta and Blekusu have experienced high erosion over the entire period. Near the estuary, there is the evidence of accretion and erosion with the area recording the highest rates. The area immediately south of the KSDP has seen much accretion. The middle section around the Cape St. Paul changes has not been that abrupt with evidence of accretion and erosion.

Prior to the inception of KSDP, erosion was dominant on the entire coast with average rate of 3m/year. Since the completion of the project there has been evidence of accretion

dominating the shoreline. Change around the Cape St. Paul has not been that abrupt. Results show that the Cape was retreating gradually prior to the Sea Defence. After the construction of the Sea Defence the entire Cape accreted at an average rate of 5m/year. However, erosion rates for the entire shoreline remained high (4.5m/year).

7.4 Conclusion

Results of this study have been useful in revealing the trends in shoreline change both erosion and accretion along the coast of Keta. Although aerial photographs are traditionally the main sources of data for shoreline monitoring, the study has shown that medium resolution multi-spectral satellite imagery can be used to map and monitor the large and dynamic shoreline of Keta. Though the study was only for the Keta coast, it is clear the methodology can be applied elsewhere.

The first objective of the study was to identify change in shoreline positions from 1986 to 2011. To achieve this shoreline positions was extracted from the images for 1986, 1991, 2001, and 2011. The extracted shoreline positions were overlaid and visually interpreted to identify the changes that have occurred. The results indicated significant variations in the positions of the shoreline over the period. Hence the first objective was achieved.

Using the extracted shorelines, the DSAS was used in calculating the shoreline rate of change. The rates were calculated along transects that were cast along the entire shoreline using weighted linear regression. The findings generally confirmed the high rates

reported for this area after the construction of the Akosombo Dam. Average erosion rates were estimated to be 2m/year with the sections to the extreme east and west experiencing higher rates. The effect is the destruction of infrastructure along the coasts as evident at Atorkor and Anyanui. The second objective was hence achieved.

Natural factors including wave action, sea level rise and shoreline orientation are major contributors to shoreline change. The comparison of rates before and after the KSDP as discussed in section 6.2.5 has shown that, the structure is currently playing a major role in the erosion and accretion patterns in the area. Erosion is now taking place down drift (Blekusu and beyond). The shoreline around Keta and Cape St. Paul has been experiencing accretion since the completion of the KSDP. Other factors such as increasing pressure on the scarce land in the area, sand mining and mangrove harvesting in the area have been blamed for making the coast more vulnerable to erosion. The third objective has thus been achieved.

7.4 Recommendations

Based on the results obtained from this study, the area east of the KSDP (Blekusu) and near the estuary (Atorkor) were identified as hotspots for coastal erosion. The timely intervention for a sea defence structure at Atorkor is therefore justified and timely. However further east, the Blekusu stretch is also eroding very fast and there is the need for assessment and intervention.

Since high resolution images are expensive and lack very large coverage's, medium resolution such as used for this study can be used for assessing overall changes in shoreline for the entire eastern coast of Ghana and better still the entire coastline of Ghana to assess current trends and target intervention.

There is the need to study sediment budgets in the area to further understand the patterns of shoreline change in the area especially near the estuary. There is also the need for further research on the tidal conditions as well as the local influence of sea level rise on erosion in the area. These were outside the scope of this study.

As has been indicated by this study, the implementation of hard structures such as the KSDP leads to knock off effects in other areas which also then need other forms of intervention. There is therefore the need for integrated shoreline management for the entire shoreline of the Country so as to reduce these effects. There is the need for policies by the local and municipal Assembly to completely halt sand mining and mangrove destruction near the estuary. Development along the coastal margin also needs to be properly planned to reduce the impacts of erosion.

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APPENDICES

Appendix 1: WLR Change Rate Calculation Output for the entire Period (1986 to 2011)

TransectId	StartY	EndX	EndY	Azimuth	WLR	WR2	WSE	WC195
2	664183.93	284167.72	663647.24	126.61	-1.25	0.66	2.11	1.63
3	664023.38	284048.46	663486.69	126.61	-1.37	0.77	1.78	1.38
6	663541.73	283690.66	663005.04	126.61	-1.85	0.94	1.10	0.85
7	663381.19	283571.40	662844.49	126.61	-2.08	0.85	2.04	1.58
8	663220.64	283452.14	662683.95	126.61	-1.58	0.84	1.64	1.27
9	663060.09	283332.87	662523.40	126.61	-1.65	0.74	2.33	1.80
11	662738.99	283094.34	662202.30	126.61	-2.06	1.00	0.32	0.25
12	662578.44	282975.08	662041.75	126.61	-2.54	0.95	1.42	1.10
13	662417.89	282855.81	661881.20	126.61	-2.91	0.85	2.91	2.25
14	662257.34	282736.55	661720.65	126.61	-2.77	0.93	1.81	1.40
17	661775.70	282378.75	661239.01	126.61	-3.72	0.90	3.01	2.33
18	661615.15	282259.49	661078.46	126.61	-3.97	0.90	3.08	2.38
19	661454.60	282140.22	660917.91	126.61	-3.84	0.95	2.04	1.58
20	661294.05	282020.96	660757.36	126.61	-4.75	0.93	3.07	2.37
22	660972.95	281782.43	660436.26	126.61	-5.55	0.87	5.04	3.89
23	660812.41	281663.16	660275.71	126.61	-5.45	0.81	6.20	4.79
24	660651.86	281543.90	660115.16	126.61	-6.83	0.89	5.79	4.47
25	660491.31	281424.63	659954.62	126.61	-8.08	0.91	6.08	4.70
28	660009.66	281066.84	659472.97	126.61	-8.21	0.90	6.38	4.94
29	659849.11	280947.57	659312.42	126.61	-8.02	0.88	6.96	5.38
30	659683.73	280863.89	659187.97	123.42	-9.21	0.82	10.24	7.92
31	659516.81	280753.72	659021.05	123.42	-8.08	0.86	7.74	5.98
33	659182.97	280533.38	658687.21	123.42	-7.33	0.88	6.33	4.89
34	659016.04	280423.21	658520.29	123.42	-1.34	0.10	9.42	7.28
35	658849.12	280313.04	658353.36	123.42	-1.03	0.07	8.92	6.89
36	658682.20	280202.88	658186.44	123.42	-1.86	0.33	6.24	4.82
38	658348.36	279982.54	657852.60	123.42	1.16	0.03	16.35	12.64
39	658181.43	279872.37	657685.68	123.42	-0.91	0.02	16.35	12.64
40	658014.51	279762.20	657518.75	123.42	-1.21	0.04	14.01	10.83
41	657847.59	279652.03	657351.83	123.42	-0.62	0.01	14.27	11.03
44	657337.89	279357.81	656877.27	120.78	2.24	0.09	16.67	12.88
45	657166.07	279255.44	656705.45	120.78	1.91	0.06	17.52	13.54
46	656994.25	279153.08	656533.63	120.78	4.42	0.19	21.65	16.73
47	656822.43	279050.72	656361.81	120.78	3.99	0.18	20.55	15.88
49	656478.79	278846.00	656018.17	120.78	4.03	0.23	17.46	13.50
50	656306.97	278743.64	655846.35	120.78	4.20	0.25	17.25	13.33

51	656135.15	278641.28	655674.53	120.78	4.73	0.26	19.08	14.75
52	655963.33	278538.92	655502.71	120.78	5.54	0.31	19.73	15.25
55	655423.57	278402.50	655241.23	101.69	3.96	0.21	18.14	14.03
56	655227.72	278361.98	655045.38	101.69	2.32	0.19	11.25	8.70
57	655031.87	278321.45	654849.53	101.69	1.57	0.13	9.61	7.43
58	654836.02	278280.93	654653.67	101.69	1.85	0.22	8.24	6.37
60	654444.31	278199.89	654261.97	101.69	6.32	0.86	5.95	4.60
61	654246.14	278208.98	654302.28	86.42	6.58	0.84	6.79	5.25
62	654046.53	278221.45	654102.67	86.42	7.83	0.69	12.55	9.70
63	653846.92	278233.93	653903.06	86.42	9.96	0.77	12.92	9.99
66	653248.09	278271.35	653304.23	86.42	12.54	0.89	10.49	8.11
67	653048.48	278283.83	653104.62	86.42	9.94	0.88	8.90	6.88
68	652852.16	278297.57	653054.53	77.01	7.86	0.86	7.67	5.93
69	652657.28	278342.54	652859.65	77.01	4.53	0.54	9.93	7.68
72	652072.64	278477.46	652275.02	77.01	1.63	0.18	8.23	6.36
73	651877.76	278522.43	652080.14	77.01	1.24	0.10	9.08	7.02
76	651281.40	278481.39	651186.19	96.07	2.82	0.38	8.52	6.58
77	651082.52	278460.23	650987.31	96.07	3.28	0.52	7.51	5.80
78	650883.64	278439.08	650788.44	96.07	3.75	0.62	6.98	5.40
81	650287.01	278375.61	650191.80	96.07	3.19	0.47	8.00	6.19
82	650088.13	278354.45	649992.93	96.07	2.69	0.29	9.95	7.69
83	649889.25	278333.29	649794.05	96.07	3.29	0.31	11.60	8.97
85	649503.14	278201.32	649253.35	106.11	2.33	0.13	14.32	11.07
86	649310.99	278145.81	649061.21	106.11	1.68	0.07	14.96	11.56
87	649118.85	278090.31	648869.06	106.11	1.26	0.04	14.03	10.85
90	648542.42	277923.78	648292.64	106.11	0.79	0.01	15.24	11.78
91	648350.28	277868.27	648100.49	106.11	-0.46	0.01	13.57	10.49
92	648158.14	277812.77	647908.35	106.11	-0.36	0.00	14.24	11.01
94	647783.35	277608.63	647361.51	117.95	-0.62	0.02	11.97	9.25
95	647606.68	277514.89	647184.84	117.95	-0.68	0.02	12.02	9.29
96	647430.01	277421.15	647008.17	117.95	-1.00	0.03	12.56	9.71
97	647253.35	277327.40	646831.50	117.95	-0.17	0.00	10.99	8.49
100	646723.34	277046.18	646301.49	117.95	-0.84	0.03	10.87	8.41
101	646546.67	276952.43	646124.82	117.95	-1.00	0.06	9.50	7.35
102	646370.00	276858.69	645948.15	117.95	-1.20	0.07	10.60	8.20
105	645839.99	276577.46	645418.14	117.95	-0.03	0.00	10.16	7.86
106	645668.28	276440.12	645186.14	122.39	0.69	0.02	12.08	9.34
107	645499.40	276332.97	645017.26	122.39	0.84	0.05	8.56	6.62
110	644992.77	276011.54	644510.62	122.39	1.18	0.11	8.16	6.31
111	644823.89	275904.40	644341.74	122.39	1.06	0.07	9.12	7.05
112	644655.01	275797.25	644172.86	122.39	1.20	0.13	7.23	5.59

113	644486.13	275690.11	644003.98	122.39	1.36	0.11	9.30	7.19
115	644177.31	275327.98	643553.77	133.85	1.03	0.16	5.61	4.34
116	644033.09	275189.41	643409.55	133.85	0.79	0.09	5.88	4.54
117	643888.87	275050.85	643265.33	133.85	1.66	0.22	7.39	5.71
118	643744.65	274912.28	643121.11	133.85	2.47	0.39	7.41	5.73
121	643311.99	274496.59	642688.44	133.85	1.85	0.24	7.86	6.08
122	643167.76	274358.02	642544.22	133.85	2.33	0.25	9.63	7.44
123	643023.54	274219.46	642400.00	133.85	1.78	0.32	6.17	4.77
124	642879.32	274080.89	642255.78	133.85	0.66	0.05	7.16	5.54
127	642446.66	273665.20	641823.12	133.85	1.52	0.20	7.31	5.65
128	642302.44	273526.63	641678.90	133.85	1.69	0.16	9.33	7.21
129	642158.22	273388.07	641534.67	133.85	1.50	0.14	8.71	6.73
130	642037.68	273110.83	641311.03	143.84	1.32	0.14	7.64	5.91
133	641683.67	272626.39	640957.02	143.84	0.50	0.02	8.03	6.21
134	641565.67	272464.91	640839.01	143.84	0.46	0.03	6.50	5.02
135	641447.66	272303.43	640721.01	143.84	0.10	0.00	6.41	4.95
136	641329.66	272141.96	640603.01	143.84	-0.42	0.02	6.96	5.38
140	640864.58	271483.13	640132.22	144.46	-0.12	0.00	5.40	4.17
141	640748.33	271320.39	640015.97	144.46	0.21	0.01	4.74	3.66
142	640659.49	270819.40	639781.34	167.35	0.22	0.03	2.99	2.31
143	640615.68	270624.26	639737.53	167.35	0.81	0.60	1.57	1.22
148	640396.64	269648.55	639518.50	167.35	1.85	0.39	5.52	4.27
149	640352.83	269453.40	639474.69	167.35	1.28	0.24	5.44	4.21
150	640309.03	269258.26	639430.88	167.35	0.68	0.11	4.51	3.49
151	640265.22	269063.12	639387.07	167.35	1.12	0.21	5.24	4.05
152	640221.41	268867.97	639343.27	167.35	1.15	0.18	5.82	4.50
153	640185.17	268607.79	639295.13	171.47	0.52	0.05	5.17	4.00
154	640155.50	268410.00	639265.46	171.47	0.20	0.01	4.95	3.83
155	640125.83	268212.21	639235.79	171.47	0.24	0.01	5.79	4.48
156	640096.17	268014.42	639206.12	171.47	0.25	0.01	5.63	4.35
157	640066.50	267816.64	639176.45	171.47	0.55	0.07	4.65	3.59
158	640036.83	267618.85	639146.79	171.47	0.18	0.02	2.95	2.28
167	639769.82	265838.76	638879.77	171.47	-0.49	0.13	3.03	2.35
168	639740.15	265640.98	638850.11	171.47	-0.68	0.17	3.58	2.77
169	639710.48	265443.19	638820.44	171.47	-0.14	0.01	3.20	2.47
170	639681.60	265194.02	638785.36	174.76	0.06	0.00	4.10	3.17
171	639663.33	264994.86	638767.09	174.76	0.48	0.18	2.40	1.85
172	639645.05	264795.70	638748.82	174.76	0.10	0.01	2.40	1.85
173	639626.78	264596.53	638730.55	174.76	0.17	0.02	3.19	2.47
174	639608.51	264397.37	638712.27	174.76	-0.32	0.07	2.68	2.08
175	639590.24	264198.21	638694.00	174.76	-0.68	0.23	2.94	2.27

176	639571.97	263999.04	638675.73	174.76	-0.30	0.06	2.94	2.27
177	639553.69	263799.88	638657.46	174.76	-0.93	0.35	3.01	2.33
178	639535.42	263600.72	638639.19	174.76	-1.10	0.53	2.46	1.90
179	639517.15	263401.55	638620.91	174.76	-1.51	0.62	2.79	2.16
187	639370.98	261808.24	638474.74	174.76	-0.95	0.28	3.59	2.78
188	639352.70	261609.08	638456.47	174.76	-0.31	0.08	2.53	1.95
189	639334.43	261409.92	638438.20	174.76	0.11	0.02	1.96	1.51
190	639316.16	261210.75	638419.92	174.76	-0.45	0.04	5.04	3.89
191	639297.89	261011.59	638401.65	174.76	-0.48	0.07	4.31	3.33
192	639279.62	260812.43	638383.38	174.76	-0.47	0.07	4.04	3.12
193	639261.34	260613.26	638365.11	174.76	-1.10	0.28	4.17	3.22
194	639242.25	260422.63	638346.83	174.22	-0.78	0.14	4.60	3.55
195	639222.10	260223.65	638326.68	174.22	-0.51	0.07	4.25	3.29
196	639201.95	260024.66	638306.53	174.22	-0.47	0.08	3.71	2.87
197	639181.80	259825.68	638286.38	174.22	-0.68	0.18	3.44	2.66
206	639000.45	258034.84	638105.03	174.22	-1.12	0.41	3.21	2.48
207	638980.30	257835.86	638084.88	174.22	-1.18	0.26	4.71	3.64
208	638960.15	257636.88	638064.73	174.22	-1.95	0.33	6.64	5.13
209	638940.00	257437.89	638044.58	174.22	-2.85	0.41	8.12	6.28
210	638919.85	257238.91	638024.43	174.22	-2.54	0.44	6.77	5.23
211	638905.00	256957.70	638005.05	179.44	-3.10	0.53	6.88	5.32
212	638903.06	256757.71	638003.10	179.44	-2.52	0.47	6.42	4.96
213	638901.12	256557.72	638001.16	179.44	-1.63	0.20	7.86	6.08
214	638899.18	256357.73	637999.22	179.44	-1.55	0.20	7.38	5.71
215	638897.24	256157.74	637997.28	179.44	-1.35	0.17	7.20	5.56
216	638895.29	255957.74	637995.34	179.44	-1.20	0.13	7.53	5.82
217	638893.35	255757.75	637993.40	179.44	-1.16	0.11	7.73	5.97
218	638891.41	255557.76	637991.45	179.44	-0.89	0.06	8.73	6.75
219	638889.47	255357.77	637989.51	179.44	-0.54	0.02	9.84	7.61
220	638887.53	255157.78	637987.57	179.44	-0.36	0.01	9.77	7.55
232	638864.23	252757.90	637964.27	179.44	0.10	0.00	9.77	7.56
233	638862.85	252508.17	637963.78	182.61	0.05	0.00	9.33	7.22
234	638871.96	252308.38	637972.90	182.61	0.08	0.00	9.99	7.72
235	638881.07	252108.59	637982.01	182.61	0.28	0.00	10.91	8.43
236	638890.19	251908.79	637991.12	182.61	0.01	0.00	13.23	10.23
237	638899.30	251709.00	638000.23	182.61	0.32	0.00	14.77	11.42
238	638908.41	251509.21	638009.35	182.61	0.61	0.01	16.21	12.53
239	638917.52	251309.42	638018.46	182.61	0.63	0.01	18.28	14.13
240	638926.64	251109.63	638027.57	182.61	0.64	0.01	20.22	15.63
241	638935.75	250909.83	638036.68	182.61	-0.08	0.00	23.33	18.03
242	638944.86	250710.04	638045.80	182.61	-0.18	0.00	24.46	18.91

243	638953.98	250510.25	638054.91	182.61	-0.61	0.00	24.64	19.05
244	638963.09	250310.46	638064.02	182.61	-0.08	0.00	25.98	20.08
245	638972.20	250110.66	638073.13	182.61	0.14	0.00	26.99	20.86
246	638981.31	249910.87	638082.25	182.61	0.06	0.00	28.09	21.72
247	638990.43	249711.08	638091.36	182.61	0.30	0.00	29.65	22.92
248	638999.54	249511.29	638100.47	182.61	-0.37	0.00	31.86	24.63
249	639008.65	249311.49	638109.58	182.61	-1.55	0.01	35.09	27.12
250	639017.76	249111.70	638118.70	182.61	-2.13	0.02	37.37	28.88
251	639026.88	248911.91	638127.81	182.61	-2.17	0.02	38.60	29.84
252	639034.19	248796.62	638135.24	177.23	-1.75	0.01	39.77	30.74
253	639024.52	248596.86	638125.58	177.23	-0.13	0.00	38.93	30.09
254	639014.86	248397.09	638115.91	177.23	0.30	0.00	40.68	31.44

Appendix 2 Field Pictures



Recording Readings



Asistant at Field



Kedzi After the KSDP



Destruction at Atorkor



Discussion with James-Ocloo



Remains of Fort Prinzenstein

Appendix 2 Field Pictures



Recording Readings



Asistant at Field



Kedzi After the KSDP



Destruction at Atorkor



Discussion with James-Ocloo



Remains of Fort Prinzenstein

