

ASSESSMENT OF SHORELINE MORPHOLOGICAL CHANGES IN
BRASS (NIGER-DELTA, NIGERIA)



A THESIS SUBMITTED TO THE DEPARTMENT OF MARINE AND FISHERIES
SCIENCES OF THE UNIVERSITY OF GHANA, LEGON



IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF

MASTER OF SCIENCE

IN

COASTAL ZONE MANAGEMENT

JULY, 2015

DECLARATION

This is to certify that this thesis is the result of research undertaken by Opuene Azibanato Olali towards the award of the Master of Science in Coastal Zone Management in the Department of Marine and Fisheries Sciences, University of Ghana, under the supervision of Dr. Kwasi Appeaning- Addo and Mr. S. D. Ababio. I hereby declare that except for references to work of other scholars that have been duly cited, this thesis is entirely my original research which has neither been presented in whole nor in part to any other university for the award of a degree.

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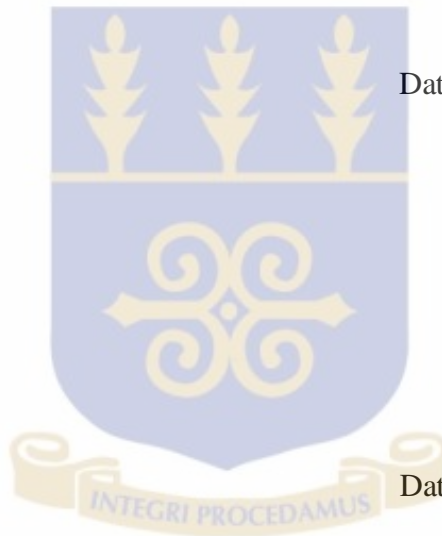
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Date.....

Date.....

Date.....

DEDICATION

This study is dedicated to the struggle for the development of the Niger Delta and its people and in loving memory of my mum, Madam Ada C. Opuene Jnr (Nee Obiajulu).



ACKNOWLEDGEMENT

I would like to acknowledge most sincerely my supervisors, in particular Dr. K. Appeaning Addo for his motivation and contributions. I am grateful to Prof. Elvis Nyarko for kick starting the process and to Mr. Jason Quashigah for his availability and patience.

Sincerest appreciation to Mrs. Grace Bitrus and the office of the Surveyor- General of Nigeria, the Department of Geography and Resource Development University of Ghana for giving me access to data.

My gratitude also goes to Dr. (Mrs.) Angela Lamptey and Mr. A.K. Armah for their concerns and directions.

I offer my special gratitude to my Dad, Hon. O. M. E. Opuene Jnr. for making funds available during the course of this research and most importantly to God Almighty for his courage, wisdom and protection.

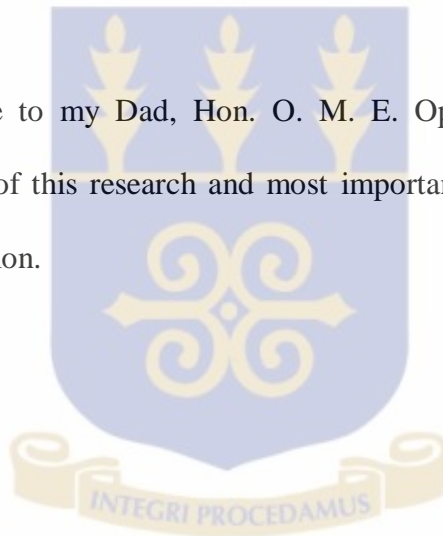


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ABSTRACT

Assessment of shoreline morphological changes provides information about the historical, present and future shoreline positions. Such information is essential to coastal planning and managing natural coastal environments and human communities. Oil exporting facilities which are vital to the economy of Nigeria are located on the Okpoama- Brass shoreline in the Niger delta. The shoreline experiences morphological changes caused by natural and anthropogenic factors. Recent studies on shoreline morphological change in some parts of the Niger delta indicate that shoreline erosion is dominant over accretion. However, they did not provide information for the entire coastline of the Niger Delta. Approximately 551 transects were cast along the entire shoreline at 50m interval and rates of change statistics were calculated using the End Point Rate, Linear Regression, and Weighted Linear Regression methods. The estimate of shoreline position error for the extracted shorelines was 1m. The study reveals that in the long term, accretion is the dominant trend with overall mean shoreline change rate of + 0.1 m/yr \pm 1m (meso accretion). However in the short term, the study revealed that erosion was dominant with overall mean shoreline change rate of - 0.42 m/yr \pm 1m (meso erosion). Some transects revealed erosion rate as high as 7.03 m/yr \pm 1m (extreme erosion). The study also forecasted the future shoreline position in fifty (50) years, which reveals erosion and minimal accretion. This study will serve as a guide in the planning and management of the natural environment and communities in the study area. The methodology used for this study can also be replicated in other selected areas along the coastline of the Niger Delta in Nigeria.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Assessment of morphological changes in shoreline position is necessary for managing natural coastal environments and human communities (Anderson *et al.*, 2014). The coastal zone has been observed to be a zone of transition between the land and sea and is dynamic in nature (Dora *et al.*, 2012). The resultant effect of the dynamic nature of the coastal zone is changes in shoreline morphology (Obowu and Abam, 2014), as the shoreline adjusts itself to maintain equilibrium with changes in the land and marine processes (Sankar *et al.*, 2014). Changes in morphology of shoreline can also be attributed to the continuous interaction between the land and sea in response to both natural and anthropogenic factors in different spatial and temporal scales (Wiafe *et al.*, 2013). The natural and anthropogenic drivers of change cause impacts ranging from erosion to expansion of the built environment and inundation due to sea level rise (Luisetti *et al.*, 2011).

The most natural factors that influence the morphology of the shoreline include winds, storms, near shore currents (wave induced and/or tidal currents), relative sea-level rise and slope processes (Bonetti *et al.*, 2013). Anthropogenic drivers of change in the shoreline morphology include construction of navigation works leading to a reduction in sediment delivery to the coast and subsidence induced by ground fluid extraction (Dean *et al.*, 2013).

The shoreline position changes continually through time due to cross-shore and alongshore sediment movement in the littoral zone and especially due to the dynamic nature of water levels at the coastal boundary due to waves, tides, storm surge, etc. (Boak and Turner, 2005).

Erosion of beach sand leads to destruction of the coastal environment and properties (Bonetti *et al.*, 2013). This vulnerability is vectored by the changing shorelines. Shorelines, especially sandy shoreline, tends to change rather quickly due to the influences that can either deposit sand on the beach or erode it away (Gao, 2013) than rocky shorelines.

Coastal ecosystems such as wetlands, estuaries, and deltas provide goods and services, such as natural protection and flood control, shoreline stabilization, sediment retention and cycling, recreation provision and cultural heritage (Brown, 2013). Utilization of the coast increased dramatically during the 20th century and this trend is virtually certain to continue through the 21st century (Nicholls, 2007). Hence, coastal areas host significant populations and provide important socio-economic activities for regions worldwide (Birkmann, 2010). Although the low elevation coastal zone accounts for only about 2 per cent of the world's land area, about 10 per cent of the world's population and 13 per cent of the world's urban population live in the zone (McGranahan *et al.*, 2007). It is estimated that 50 percent of the world's population will live within 100 km of the coast by 2030 (Small, 2003).

With the threat of accelerating global sea level rise, burgeoning coastal populations worldwide, as well as growing pressures on social and social systems, it is important to assess risk to the coastal environment (Kearney, 2013). Much of the West African coast is threatened by erosion. In the Gulf of Guinea region, the Niger Delta is at risk, as is the coast extending westwards along the coast to Ghana. These populations are currently dominantly rural, but this is likely to change and each of the deltas is associated with at least one large and rapidly growing megacity. Thus even as a result of urbanization alone, the delta populations are likely to grow much further (Brooks, 2006).

In order to plan and implement effective beach erosion control, flood zone delineation and ecosystem protection, coastal managers and scientists need information on long term and short term changes taking place along the coast (Klemas, 2013). Also, decision makers are to develop policies that best address present and future coastal development (Kearney, 2013). In assessing the shoreline morphodynamics, data from archival sources present information on where the shoreline was in the past, while data from current sources indicate the present position of the shoreline. Combining shoreline data from the two sources present a unique opportunity to trace how the shoreline has evolved over the period to its present position. This provides the baseline information to analyze the cyclic behavior of the shoreline in the short and long term and how other factors influence the lateral morphological change as well as estimate the shoreline's historic rates of change that enables the prediction of the future position of the shoreline using various modeling techniques (Apeaning- Addo and Lamptey 2013).

There are a number of remote sensing techniques that are commonly used to detect and monitor shorelines such as aerial photographs, visual interpretation and on-screen digitization, however the accuracies of the different techniques are directly related to their spatial resolution. While the vertical accuracy might vary considerably, the horizontal accuracy, which actually determines the location of the shoreline, is typically of the same order of magnitude as the spatial resolution of its source data (Gens, 2010). Information about where the shoreline is located, where it has been in the past, and where it is predicted to be in the future is fundamental to a broad range of investigations undertaken by coastal scientists, coastal engineers, and coastal managers (Boak, 2005).

Previous studies of the shoreline morphology of Brass were conducted by Ibe and Anita (1983), Adegoke (2010), and Obowu and Abam (2014). The study of Ibe and Anita (1983) was aimed at making a scientific input into long term and large scale coastal management planning, thus providing preliminary results and interpretations based on beach profiling and littoral environment observation. The work done by Adegoke (2010) was an attempt at filling the gap caused by the dearth of studies into recent shoreline changes using Satellite imagery processed in a GIS environment (Erdas Imagine Version 8.7 and Arc Info 9.1.). In the work carried out by Obowu and Abam (2014), the research focused on coastline change detection and vulnerability assessment to coastline changes using remote sensing and geographical information system.

1.2 Aim and Objectives of Study

The aim of this research was to assess the rate of shoreline change in the Brass shoreline located in the Niger Delta coastline. Specific objectives include the following:

1. To identify the shoreline changing trend
2. To predict future changing trend in shoreline position
3. To recommend appropriate coastal erosion management strategies

1.3 Justification of study

Important Oil industry infrastructures and facilities critical to the foreign exchange earnings of Nigeria are located along the Brass shoreline. The information on shoreline morphological changes in this location needs to be periodically updated so as to provide coastal managers and scientists, information on long term and short term changes taking place along the coast in order:

- to plan and implement effective beach erosion control measures to protect vulnerable infrastructure along the Brass shoreline
- to effectively manage and plan the natural coastal environment and communities in the study area due to the rapidly increasing economic activities and its consequent urbanization.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Coastal Zone

The coastal zone is a dynamic environment made up of beaches, dunes, and coral reefs, coastal floodplains, estuarine swamps, coastal forests called mangroves, marshes, tideflats (coastal areas affected by the rise and fall of the tide), as well as marine fisheries (Liz, 2003). The land and the sea continuously interact within the coastal zone in response to both natural and anthropogenic factors in different spatial and time scales. As a morphodynamic system with various components, there is an energy component (wind, tide and wave) and the material component (rock and sediment) which interact to evolve the coast and generate morphological change. The interactions between coastal materials and the forcing factors (waves, tide, current, and wind) that shape coastline are interconnected. Therefore any change in the coastal materials (input and output) could have significant impacts on the forcing factors and vice versa (Wiafe *et al.*, 2013).

The resources and amenities of the coastal zone are crucial to our societal needs as they represent about 12 percent of the world's surface (Costanza *et al.*, 1987). Population densities in coastal areas are three times higher than the global average and it is estimated that 50 percent of the world's population will live within 100 km of the coast by 2030 (Small, 2003). It has been estimated that by 2025, the coastal zone from Accra to the Niger Delta could be an unbroken chain of cities with a population of 50 million along the 5000 km of coastline (ACOPS, 2003). As coastal populations continue to grow, their impacts in terms of the development of coastal habitats can be expected to grow as well (Burke *et al.*, 2001). The

combined effects of booming population growth and economic and technological development are threatening the ecosystems that provide these economic benefits (Liz, 2003).

Coasts have been changing physically at local to global scales because of diverse natural processes and human induced coastal degradation (Sertel and Seker 2013). Threats to the coastal environment have reached an alarming proportion where it is estimated that about 38 percent of Africa's coastal ecosystem is highly threatened (FAO, 1998). The recognition of the economic value of nature and the services it provides to humanity has become increasingly essential in the context of coastal zone management (Luisetti *et al.*, 2011). With the coastal zone as an important economic, social and environmental resource, one of the principal problems that coastal managers frequently have to deal with is the erosion of the shoreline (Archetti and Lamberti, 2008). As the erosion front moves along the shore, the volume of beach sand decreases and shoreline retreats landward constituting a hazard to coastal infrastructure (Finkl and Makowski, 2013).

In order to plan sustainable coastal development and implement effective beach erosion control, food zone delineation and ecosystem protection, coastal managers and scientist need information on long-term and short-term changes taking place along the coast, including changes in beach profiles due to erosion (Klema, 2013). Collaboration among scientists, coastal engineers, coastal managers, and practitioners of monitoring and information technology will be needed to develop the information base and linkages necessary to fully assess the condition of coastal environments (Burke *et al.*, 2001).

2.2 Vulnerability of the Coastal Zone

Vulnerability as a concept represents a potential damage and it is conditional upon the possibility of a hazard. Thus a system is said to be vulnerable when it has a high susceptibility to the effects of a hazard, and is unable to cope, recover or adapt (Balica *et al.*, 2013). Vulnerability levels vary within a system therefore indicators are used to determine and measure it; indicators can be ecological, political, technological and socio-economic factors of a system (Musa *et al.*, 2014).

For coastal systems, risk is heavily influenced by environmental and geographical factors such as elevation above mean sea level, distance from the shoreline, and the effectiveness of artificial coastal defenses or natural barriers such as wetlands, dunes, coral reefs or mangroves which can dissipate the energy of hazards such as storm surges (Brooks *et al.*, 2006). Coastal zone ecosystems are impacted by dynamic environmental change that occurs both ways across the land-ocean boundary. The natural and anthropogenic drivers of change cause impacts ranging from erosion to expansion of the built environment and inundation due to sea level rise (Luisetti *et al.*, 2011). Coastal wetland ecosystems, such as salt marshes and mangroves, are especially threatened where they are sediment starved or constrained on their landward margin. Degradation of coastal ecosystems, especially wetlands and coral reefs, has serious implications for the well-being of societies dependent on the coastal ecosystems for goods and services. Increased flooding and the degradation of freshwater, fisheries and other resources could impact coastal communities, and socio-economic costs on coasts will escalate as a result of climate change (Nicholls *et al.*, 2007).

Deltas, some of the largest sedimentary deposits in the world, are widely recognized as highly vulnerable to the impacts of climate change, particularly sea-level rise and changes in runoff,

as well as being subject to stresses imposed by human modification of catchment and delta plain land use (Parry *et al.*, 2007). Most deltas such as Ganges-Brahmaputra, Indus, Mississippi, Niger, Nile, Volta, and Zambezi are already undergoing natural subsidence that results in accelerated rates of relative sea-level rise above the global average. Many are impacted by the effects of water extraction and diversion, as well as declining sediment input as a consequence of entrapment in dams (Nicholls *et al.*, 2007).

Land subsidence lowers the topography of delta areas with respect to the sea and makes the relative sea level rise to be high. For coastal areas, the relative sea level rise value is much more important than the eustatic sea level rise. Compared to the global average eustatic SLR of 3mm/yr^{-1} the relative sea level rise in the Niger delta is between $25\text{--}125\text{mm/yr}^{-1}$, which makes it highly vulnerable to river floods due to the effects of sea level rise (SLR) (Musa *et al.*, 2014). Land subsidence has increased in the Niger Delta as a result of the extraction of oil and gas with subsidence values estimated to range from $25\text{--}125\text{mm/yr}^{-1}$ (Syvitski, 2008).

2.3 The Niger Delta and Sea Level Rise (SLR)

Since the emergence of concerns about human-induced global warming in the 1980s, Sea-level rise and its impacts on the coastal areas have attracted considerable concern. The large and growing concentration of people and assets in coastal areas mean that the potential impacts are high (Nicholls *et al.*, 2011). The dominant driver of sea-level change is sea and air temperature with an estimated rise of $0.6\text{ }^{\circ}\text{C}$ in the average global sea surface temperature during the 20th century and a further predicted rise of between $1.5\text{ }^{\circ}\text{C}$ and $4.5\text{ }^{\circ}\text{C}$ over the next 100 years (Houghton *et al.*, 2001).

To appreciate how rising sea levels will affect the coastal zone, it is important to consider relative sea level change – the combination of eustatic sea level change and local vertical movements of land as this is what produces impacts and requires a response (Brown *et al.*, 2013). Local relative sea level change is caused both by global sea level change and local ground motion and is estimated by subtracting local ground motion (subsidence having a negative sign) from global sea level rise. Local ground motion can be produced by tectonic activity, Glacial Isostatic Adjustment (GIA), subsidence from consolidation of soft sediments, groundwater extraction and other effects (Houston, 2013). River delta regions around the world are sinking due to ground subsidence, causing local relative sea level to rise faster than the global average (Houston, 2013).

The need for humans to achieve their socio-economic objectives causes them to locate their socio-economic activities near to the resources supporting those objectives (Darwin *et al.*, 2001). Therefore, much of human activities tend to be near coasts that provide among other things; proximity to seafood sources, mineral resources, transportation opportunities, and many other socio-economic opportunities provided by coastal regions (Payoyo, 1994). Coastal zones are of great importance as zones of settlement and play a vital role in the economic well-being of many nations. Sea level rise (SLR) will have profound implications for many coastal populations and the systems on which they depend (Brooks *et al.*, 2006).

The Niger Delta coastline is generally protected from the ocean by a chain of natural barriers. However, the narrow sandy beach ridge of the barrier islands and the coastal beach ridges are of relatively low elevation. This implies that significant rise in sea level could inundate this zone, which inhabits some of the settlements. The physical and socio-economic implications in terms of physical infrastructure and land loss, as well as demographic inconveniences

arising from sea-level rise are obvious (Obowu and Abam, 2014). Satellite altimetry measurements (1993 to 2010) over the Niger delta coast show eustatic sea-level rise rates of 3.03–3.39mm/yr⁻¹ (Rosmorduc, 2012). In addition the Niger delta is subsiding at a rate of 25–125mm/yr⁻¹, which classifies it as a very high relative SLR (Musa *et al.*, 2014). The Niger Delta could lose over 15000 Km² of land by the year 2100 with a one meter rise in sea level (Awosika *et al.*, 1992). Moreover, it is predicted that Nigeria will lose about \$9 billion as a result of the sea level rise while at least 80% of the people of the Niger Delta will be displaced due to the low level of the region (Awosika *et al.*, 1992).

The problems of land loss in the Niger Delta will be compounded by local subsidence and sediment starvation. The Niger delta is economically highly at risk mainly due to infrastructure related to the oil industry as conventional protection with sea walls would be impossible without a very large investment and the application of new technology (Nicholls and Mimura, 1998). This will also accelerate the associated inundation, increase problems of floods, intrusion of sea-water into fresh water sources and ecosystems destroying such stabilizing system as mangrove, and affecting agriculture, fisheries and general livelihoods (Okali and Eleri, 2004). In addition to the direct threat of inundation where coasts are not defended, SLR will increase the exposure of coastal populations to storm surges and storm waves. The destructive power of such events will increase as a consequence of higher mean sea-level: higher waves will be capable of reaching the original shoreline (defined as the shoreline prior to the rise in sea level) and areas further inland will become exposed to wave action (Jiménez and Sánchez-Arcilla, 1997). The actual retreat at any level within the limits of wave action is composed of both erosion and the inundation by rising water (Walkden and Hall, 2005).

2.4 Shoreline Retreat/Erosion in the Niger Delta

The shoreline is defined as the line of contact between land and a body of water. Although easy to define it is difficult to capture, since the water level is always changing (Michalis *et al.*, 2007). Shoreline changes often result in erosion of coastal areas or accretion of sediments, depending on the dominant processes acting on the Shoreline. Coastal erosion is the process of wearing away material from a coastal profile due to imbalance in the supply and export of material from a certain section. It takes place in the form of scouring in the foot of the cliffs or dunes or at the sub-tidal foreshore. It also exposes new sections of the upland areas to wave attacks, through increased water depths, that allow larger wave attack and erode, hence shifting the littoral system landward (Wiafe *et al.*, 2013).

The rate of erosion is correctly expressed in volume/ length/time, e.g. in $m^3/m/year$. However, erosion rate is often used synonymously with Shoreline retreat, and thus expressed in $m/year$ (Mangor, 2004). The rates of shoreline migration often change irregularly alongshore or compose a spatial quasi-sinusoidal, periodic wave phenomena with oscillations of 2.5-7 km. Most shoreline rate estimation methods assume that shoreline change is linear through time. However shorelines do not change uniformly (Douglas *et al.*, 1998). Short-term shoreline variability is higher in areas of low beach slopes and abundant near-shore bars, because of dynamic positional shifts. Shoreline changes of less than 0.1 m/yr are regarded as being micro and shoreline migration rates of 0.1-0.9 m/yr as being meso while shoreline migration rates >1 m/yr are regarded as being high to extreme (Bowman and Enzo, 2008). The spatial erosion rates become progressively smoother as longer time spans are used. Increased time spans help to filter out short-term fluctuations (Crowell *et al.*, 1993).

Cyclic sedimentation patterns occur on the Niger Delta. This process is active on the delta with the eastern side of the delta generally being erosional, marine dominant (destructive); the western side of the delta is depositional, fluvial dominant (constructive). These cycles of sedimentation affect the present-day morphology and sediment character of the beaches of the delta (NEDECO, 1961). Erosion is already ravaging the Niger Delta (NDRMP, 2004). Coastal vegetation especially the mangroves have been lost to coastal erosion (Awosika *et al.*, 1992). Settlements in the Niger Delta have been uprooted by coastal erosion (Awosika, 1995). The result of the analyses from recent studies of the Niger Delta coastline indicates among other things that the rate of coastline erosion was dominant over accretion of sediment deposition (Adegoke *et al.*, 2010). However, quantitative measurement and analysis showed that for most of the coast line sections, there have been period of erosion and accretion, only very few sections show consistent erosion or accretion over the years (Obowu and Abam, 2014).

Nigeria's economy depends on Oil and gas extraction from the Niger delta as the main source of foreign exchange (Baghebo & Atima, 2013). Over 500 Oil wells located onshore (Syvitski, 2008); Oil and gas facilities such as the AGIP Brass terminal, Shell Forcados terminal, Olokola LNG and their associated facilities located along the coastlines are highly vulnerable (Obowu and Abam, 2014). In some places, especially in Forcados, some oil wells have been lost to the ocean due to erosion (Awosika, 1995).

2.5 Shoreline Monitoring/Assessment

Monitoring in this regard can be defined as the systematic measurement of abiotic parameters of the coastal environment, with a predefined spatial and temporal schedule, having the

purpose to produce datasets that can be used for application of assessment methods and derive credible conclusions on whether the desired state or target is achieved or not and on the trend of changes for the coastal area concerned (UNEP MAP, 2014).

Shoreline monitoring involves the collection and recording of information about the shore area which is used for assessing past changes as well as predicting future changes. Information collected is basically about the physical characteristics including shoreline position, sediment movement, defense structures, beach profile, littoral drift, and tide level. It takes place across coastal process littoral cells and sub-cells at local and trans-boundary scales (Wiawe *et al.*, 2013). The monitoring of beach evolution plays a fundamental role in all territorial policies along the coast, being subject to morphological variations that can alter the protective function it provides to the hinterland as well as the potential use for tourism and recreation (Lupino *et al.*, 2004).

Beach management, control of coastal erosion, the design of artificial nourishment projects, the construction and monitoring of defense structures, management of natural hazards as well as the definition of a set-back line for development and of the risk zone, are typical coastal management problems all requiring an accurate evaluation of coastal morphodynamic evolution (Cicin-Sain, 1998). The rate of shoreline change is one of the most common measurements used by coastal scientists, engineers, and planners to quantify historical rates of change and indicate the dynamics and hazards of the coast (Dolan *et al.*, 1991). The assessment of variations in shoreline position is one of the most important components of Integrated Coastal Zone Management (ICZM), both for monitoring erosion processes and evaluating the efficiency of shore protection projects (Pranzini and Simonetti, 2008).

Mapping shoreline position is therefore essential for coastal planning and management, for establishing building setback lines and for designing coastal defense as shorelines may migrate due to various factors and controlling processes (Bowman and Pranzini, 2008). How far shoreline change, reflect trends in the coastal sedimentary budget (Battiau-Queney *et al.*, 2003). The knowledge of trends in shoreline displacement is therefore fundamental for coastal management (Stauble, 2003), since it allows estimation of the magnitude and direction of sedimentary transport, monitor the changes caused by a coastal engineering structure, establish flood zones and set-back lines for erosion as well as verify numerical models on changes to shoreline position (Byrnes *et al.*, 2003). However, many developing countries are not able to map their shorelines on a frequent basis due to limited resources (Faduhunsi *et al.*, 2013).

Shoreline change monitoring is an issue of concern in coastal management (Moran, 2003) in which the Niger Delta area is not exceptional. In the Niger Delta, there are also a number of reported shifts in shoreline position around coastal communities. These changes have significant consequences on the sustainability of the daily livelihood of coastal communities and also on the safety and integrity of oil and gas production facilities which face the Niger Delta coastline (Obowu and Abam, 2014). When there is no room to accommodate change, coastal erosion becomes a problem. Knowing the natural behavior of the coast enables the, formulation of a sustainable, economically rational and socially acceptable coastal management strategy (Marchand, 2010).

2.5.1 Shoreline Data processing techniques

To guarantee the systematic monitoring of the shoreline it is however necessary to use an image processing procedure that is less bound to subjective variables, in order to optimize

processing times and to enable measurements to be made autonomously by operators not highly specialized but employed in the sphere of territorial management (UNEP MAP, 2014).

Shoreline mapping is commonly achieved through the application of different techniques and remote sensing data varies from fine to moderate spatial resolution (Dewidar and Frihy, 2010). These include land based, aerial/space based and sea based surveys. The factors to consider when monitoring are: cost, data needs and site accessibility (Wiafe *et al.*, 2013). Land-based topographic surveying has been widely used in monitoring shoreline changes because of its accuracy in information provided (Graham *et al.*, 2003). Multispectral remote sensing images and remote sensing techniques are a suitable instrument for identifying shoreline variations in order to examine causes and put forward possible evolution (Favretto *et al.*, 2004).

With the use of high-resolution images it is possible to define the shoreline with accuracy sufficient to guarantee a medium-term monitoring of beaches that have a moderate slope and low-reflectivity sand like using Landsat-TM images to measure the shoreline, based on the different spectral response of water and sand. Correct monitoring should therefore be based on the acquisition of archive images after having checked sea conditions in order to prevent the over-estimation or under-estimation of variations (Giovanni *et al.*, 2008).

Where available, aerial photography is the most common data source for determining past shoreline positions, the need for ground control points decreased with the increasing accuracy of this technique (Boak and Turner 2005). Aerial imagery in the form of digitized aerial photography is commonly analyzed to qualitatively and quantitatively study the evolution of coastal landforms on spatial scales (Zarillo *et al.*, 2008). Beach profiles are important tools

for elucidating long-term trends, such as erosion and accretion, and for predicting the future evolution of coastal landforms (Dora *et al.*, 2012).

Landsat imagery of multispectral datasets is readily available at no cost for many coastal areas around the world. Other considerations for Landsat imagery include the satellite revisit cycle, the ease of public access to archives and its absolute calibration (Faduhunsi *et al.*, 2013). Light Detection and Ranging or LIDAR is a method used inter alia in hydrographic surveys to measure distance or depth by analyzing pulses of laser light reflected off an object. These survey systems are typically aircraft-mounted and provide seamless coverage between land and sea. Bathymetric LIDAR is used to acquire data in areas with complex and rugged shorelines (UNEP MAP, 2014).

The sensors of new-generation commercial satellites currently make it possible to obtain multispectral images having a high spatial resolution: Ikonos and Quickbird images (which have a spatial resolution of 4 m and 2.44 m respectively in the multispectral and 1m and 0.61m respectively in the panchromatic) appear to be particularly useful not only for distinguishing the shoreline but also for classifying the vegetation of coastal zones (Fromard *et al.*, 2004). They provide not only high-resolution and multi-spectral data, but also the capability for stereo mapping. Because of their high resolution and their short revisit rate (3 days), Ikonos and Quickbird satellite images are very valuable for shoreline mapping and change detection, therefore their data have been used in several past studies (Michalis *et al.*, 2007).

The use of remote sensing and GIS for mapping and analyzing shoreline changes over a period of time has gained prominence in recent years as high resolution satellite data have become more readily available (Adegoke *et al.*, 2010). Geographic information systems

(GIS) provide the platform for information integration, analysis and dissemination. Image processing systems are specialized tools to manipulate satellite data (UNEP MAP, 2014). Images can be analyzed visually or quantitatively using machine assisted algorithms to extract information from the imagery in an automatic way (Deichmann *et al.*, 2011). However, Shoreline positions should be monitored under calm conditions. Random errors which are derived from shoreline interpretation, from surveying, digitations and storm induced erosion can be minimized under calm conditions (Leatherman, 2003).

2.5.2 Shoreline Detection and Analysis Techniques

Analysis of shoreline variability and shoreline erosion-accretion trends is fundamental to a broad range of investigations undertaken by coastal scientists, coastal engineers, and coastal managers (Boak and Turner, 2005). Procedures to measure, compile and analyze shoreline position may vary according to personal experience and the scope of the study. Some of the methodological difficulties include the identification of time scales, the selection of an adequate indicator and the choice of a method for determining shoreline position (Lupino *et al.*, 2004).

The shorelines derived from LIDAR data are truly referenced to the statistically established tidal datum surface and therefore overcome the problems associated with the use of wet/dry beach line on aerial photographs as the shoreline proxy. The wet/dry line detected is subject to tidal effect and wave action at the time of aerial photograph acquisition. In addition, airborne LIDAR data provide detailed information about near-shore bathymetry and beach topography over a broad region. The data allow analysis of beach and dune micro topography and repeat data allow quantification of local sediment budgets through three-dimensional volumetric change analysis (Lui *et al.*, 2007)

The AMBUR (Analyzing Moving Boundaries Using R) package for the R software environment provides a collection of functions for assisting with analyzing and visualizing historical shoreline change. The package allows import and export of geospatial data in ESRI shape file format, which is compatible with most commercial and open-source GIS software. The baseline and transect method is the primary technique used to quantify distances and rates of shoreline movement, and to detect classification changes across time (Chester *et al.*, 2011).

Shorelines extracted for the same area over different times can be compared and changes detected. Various approaches are available for change rate estimation. Software such as ArcGIS, AMBUR and Matlab are readily available for the implementation of such analysis. However, they come at a relatively high cost. There is open source software (free) such as ILWIS, OSSIM and QGIS for data processing but these require considerable expertise (Wiafe *et al.*, 2013). Shoreline change analysis is one of the important means for understanding the evolution of the subaerial delta. Recent advances in remote sensing and geographical information system (GIS) techniques have enabled the acquisition of high-accuracy shoreline information and shoreline analysis on finer spatial and temporal scales (Li *et al.*, 2014).

2.6 Data for Monitoring Shoreline Evolution

The modeling of shoreline changes may be derived from the historical data that include topographical maps, aerial photographs and satellite images. These data can easily be combined and processed with the use of geographical information system (GIS), suggesting that shoreline change is best studied using GIS because of its ability of combining and comparing satellite images of different time (years) of the same area (Fabiya, 2002). Data also

include ground survey of the shoreline by manual systems (GPS) and collection of photographs from the ground (UNEP MAP, 2014).

If sufficient beach profiling data are available for a specific site, tidal datum-based shorelines, such as MHW, are easily and accurately determined. A shoreline can be compiled by interpolating between a series of discrete shore-normal beach profiles. Over the last decade, a range of airborne, satellite, and land-based remote sensing techniques have become more generally available to the coastal scientist, coastal engineer, and coastal manager. Where it is available, aerial photography is the most common data source for determining past shoreline positions (Boak and Turner, 2005).

For the selection of images to be used, multispectral images should be preferred, even though spatial resolution is lower. The normalized ratio between the infrared and red bands (NDVI) has indeed proved to be particularly suitable for the identification of the water/sand interface. This ratio, furthermore, makes it possible to compare images taken at different times, since it minimizes the effects caused by different atmospheric conditions on sand radiance, as ascertained from spectro-radiometric measurements in situ and in the laboratory (UNEP MAP, 2014).

2.6.1 Shoreline Indicators for Monitoring Shoreline

Due to the dynamic nature of the idealized shoreline boundary, the use of shoreline indicators has been adopted for coastal studies. A shoreline indicator is a feature that is used as a proxy to represent the true shoreline position (Gens, 2010). The horizontal position of a natural shoreline may vary according to the indicator chosen (Graham *et al.*, 2003). Indicators can be

morphological (beach scarp, berm crest, vegetation line, dune toe, dune crest) or non-morphological, based on the water level (Parker, 2003).

Shoreline indicators are categorized in three groups: visible discernible features, tidal datum based indicators and indicators based on the processing technique to extract the shoreline. A visually discernible indicator is a feature that can be physically seen, for example, a previous high-tide line or the wet/dry boundary. In contrast, a tidal datum– based shoreline indicator is determined by the intersection of the coastal profile with a specific vertical elevation, defined by the tidal constituents of a particular area, for example, mean high water (MHW) or mean sea level. Recently, a third category of shoreline indicator has begun to be reported in the literature, based on the application of image processing techniques to extract proxy shoreline features from digital coastal images that are not necessarily visible to the human eye (Boak and Turner, 2005). Of all the shoreline indicators, the high water line (HWL) is the widely used shoreline indicator, because it is easily field-located and photo interpreted (Leatherman, 2003).

2.6.2 High Water Line (HWL) as Shoreline Indicator

Some morphological indicators are linked to oceanographic characteristics of the study area and seasonal variability in wave energy may reduce their efficacy at shorter time scales. These difficulties can be solved with the use of an indicator that is based on the water level, a vertical datum (Lupino *et al.*, 2004). The most common proxy for shoreline position is the high water line (HWL), it is the wet/dry line (which often exists just seaward of the berm, where present); this shoreline indicator should not be confused with the water saturated zone, which occurs much further down the beach profile and varies in position with each wave generated swash (Zhang *et al.*, 2002).

The HWL can be approximated by vegetation, driftwood, discoloration of rocks and tonal contrasts in air photos between the dry and the wet beach (Carli *et al.*, 2008). Daily variations of the HWL on gently-sloping beaches can be significant. HWL does not represent an intersection of any water surface. It is the manifestation of different water levels and run ups rather than an actual coastal morphology (Liu *et al.*, 2007).

2.7 Historical and Future Prediction of Shoreline Position

The assessment of variations in shoreline position is one of the most important components of Integrated Coastal Zone Management (ICZM), both for monitoring erosion processes and evaluating the efficiency of shore protection projects (Pranzini & Simonetti, 2008). Analysis of shoreline changing trend, under the influence of both climatic and anthropogenic forcing, is hampered by the availability of archival time series data, especially in developing nations where there is scarcity of data. However, the novelty/innovation is the coupling of these archival data with remotely sensed data in data starved nations, especially developing nations, to obtain reliable information for developing shoreline management strategies (Apeaning-Addo and Lamptey, 2013).

Forecasting considers uncertainties from different sources and of different nature. The method must be capable of stating this uncertainty. Models and other forecasting tools must be chosen within a forecasting window; forecasting must be probabilistic (and not deterministic) and research must use all resources possible, such as field trips, laboratory, numerical modeling, and model behavior assessment (De Vriend, 2003). Several sources of uncertainty (positional uncertainty and measurement uncertainty) impact the accuracy of historical shoreline positions and the final shoreline change rates. Positional uncertainty is

related to the features and phenomena that reduce the exactitude of defining the true shoreline position in a given year. Influences on position include the stage of tide, the recent incidence of storms and the seasonal state of the beach. The measurement uncertainty is related to operator- based manipulation of the map and photo products (Fletcher *et al.*, 2003).

Accurate detection of shoreline positional change through time and quantification depends on the methods adopted to map the shoreline position and accounting for uncertainties (Wiafe *et al.*, 2013). One of the simplest approaches that has been widely used to project future shoreline position is based on the principle of conservation of mass and assumes that a similar cross-shore profile will be maintained as the shoreline migrates landwards (Brown *et al.*, 2013).

The AMBUR (Analyzing Moving Boundaries Using R) package (Chester *et al.*, 2011) and Digital Shoreline Analysis System (DSAS) can be used to calculate rate of change using linear regression, end point, average of rates, jackknife and weighted linear regression methods. The Linear regression method is the most statistically robust method and widely accepted by coastal researchers for computing long term rates of shoreline change since it consistently gives better long term forecasting results than other techniques (Dean and Dalrymple, 2002).

2.8 Measures for Shoreline Stabilization

Generally speaking, the preferred order of measures is to define set-back lines, apply soft nourishment to restore the sediment balance, and implement hard engineered structures if no other options are possible. A combination of these measures often provides the best results (Marchand, 2010).

A setback line is normally defined as the landward limit of a buffer zone along the coastline where building restrictions or prohibitions are applied. The width of this buffer will depend on the associated physical, environmental and socioeconomic criteria (Marchand, 2010). The use of setback lines is basically a tradeoff between coastal development on the one hand and prevention of an unacceptable risk due to coastal erosion on the other. This should be based on scientific knowledge of natural processes, information on ecological and landscape values and an analysis of the costs of implementation under local circumstances (Winckel *et al.*, 2007).

The modern concept of coastal defense is based on developing compromises among the competing considerations of safety, landscape, ecology, and attraction to the water. Coastal defense should be achieved based on analysis of near-shore hydrodynamics, sediment transport, coastal process, and the natural features of a beach (Hsu *et al.*, 2008). A beach can be rebuilt by beach nourishment combined with coastal structures that do not disrupt the natural environment, when the sand or gravel is mined at deep-water sites or from some accumulated places in which engineering costs are considerable. However, it is recognized that these new coastal defenses are sustainable and attempts have been made to maintain a beach with a natural appearance to prevent beach erosion (Hsu *et al.*, 2008).

Groynes are long (up to 300 m), narrow structures perpendicular or slightly oblique to the shoreline extending into the surf zone (generally slightly beyond the low water line) to reduce the longshore currents and hence the littoral drift in the inner surf zone, to retain the beach sand between the groynes, to stabilize and widen the beach or to extend the lifetime of beach fills. A series of similar groynes (groyne field) may be constructed to protect a stretch of

coast against erosion. These structures are known as beach groynes. An example is the Keta Sea defense project in Ghana (Van Rijn, 2013).

Revetment is a sloping feature which breaks up or absorbs the energy of the waves but may let water and sediment pass through. The older wooden revetment consists of posts fixed into the beach with wooden slats between. Modern revetments have concrete or shaped blocks of stone laid on top of a layer of finer material. Rock armor or riprap consists of layers of very hard rock with the largest, often weighing several tonnes, on the top. Riprap has the advantage of good permeability and looks more natural (Marchand, 2010).

Seawalls, sea-dikes and revetments are shore-parallel structures armoring the shore to protect the land behind it against episodic storm-induced erosion and/or long-term chronic erosion by the sea. These structures (vertical, concave or sloping) are built along a limited section of the shoreline as a last defense line against the waves, when natural beaches and dunes are too small or too low to prevent erosion due to high waves (Van Rijn, 2013).

Bulkheads and seawalls protect banks and bluffs by completely separating land from water. Bulkheads act as retaining walls, keeping the earth or sand behind them from crumbling or slumping. Seawalls are primarily used to resist wave action. Design considerations for these types of structures are similar. These structures do not protect the shore in front of them, however (Marchand, 2010).

Various methods including soft solutions and hard structures should be considered based on the study of hydrodynamics, sediment transport, and physiographic features for each site (Kim *et al.*, 2013).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

Assessment of trends in shoreline evolution is necessary for managing the coastal environment (Tiffany *et al.*, 2014). Within the coastal zone, scientists carry out research in the shoreline evolution trend to determine its potential impacts on coastal resources and to assist with policy-making decisions (Chester *et al.*, 2011). Among the many questions for research, there are four central questions for a research analysis: (1) How far has the shoreline moved? (2) How fast did the shoreline move? (3) How variable is the shoreline's movement? (4) Where is the shoreline going to be in the future? (Chester *et al.*, 2011)

There are a number of remote sensing techniques that are commonly used to detect and monitor coastlines. The accuracies of the different techniques are directly related to their spatial resolution. While the vertical accuracy might vary considerably, the horizontal accuracy, which actually determines the location of the shoreline, is typically of the same order of magnitude as the spatial resolution of its source data (Gens, 2010).

The Analyzing Moving Boundaries using R (AMBUR) package for the R programming environment (R Development Core Team, 2011) provides a collection of scripts to assist with shoreline change analysis that takes advantage of R's statistical, graphical, and geospatial capabilities, while allowing the freedom to choose any commercial or open-source GIS software for editing, preparing, and viewing shapefiles. The method is typically GIS-based (Chester *et al.*, 2011).

3.2 Site Description

Okpoama- Brass is a community located in Brass Local Government of Bayelsa State at the southernmost tip of the Niger Delta coast of Nigeria and within the eastern side of the Arcuate Delta. It is bounded by the Brass River in the Northwest, the St. Nicholas River to the East and the Atlantic Ocean to the South. The Brass and St. Nicholas Rivers are part of 16 major river mouths/tidal inlet that intersect the coast. The study area extends along the Brass coastline spanning from a point at Okpoama community $04^{\circ}17'30.6''$ N, $006^{\circ}16'31.5''$ E to $04^{\circ}18'58''$ N, $006^{\circ}24'32.7''$ E (Figure 1). The relief is nearly flat and beach slope measured at intertidal beach face has an average of elevation of 0.5m above sea level. It is characterized by a west to east long shore current direction (Adegoke *et al.*, 2010) measuring 0.5m/sec and wave height of 1.2m (Sexton and Murday, 1994).

The geology of the area is comprised of alluvial sedimentary basin and basement complex with mean grain size of 2.5mm – 3.0mm (Sexton and Murday, 1994). Noticeable concentrations of dark-colour heavy minerals were found along the upper reaches of the active beach (Plate 1). The vegetation found in this area is comprised mostly of mangrove swamps; light rain forest and thick mangrove forest. The most common coastal plant found was the creeping vine *Impomoea aquatica* (Plate 2).

The tides occur with a period of approximately 12 hours and 25 minutes, and with amplitude that is influenced by the alignment of the sun and moon and the shape of the earth. The wind direction is dominantly in a southwesterly direction. The study area experiences two high and two low tides per day, with a tidal range which varies across the Niger Delta and has average value of 1.8 m (Obowu and Abam, 2014). The difference in tidal amplitude is accentuated because of the low volumes and frequency of freshwater discharge at the sub deltas on the

eastern side of the Arcuate Delta thereby allowing the marine processes to play a more active role in shaping the sub delta morphology.

It is generally erosional as compared to the more depositional active Western Delta shoreline. This can be attributed, primarily, to the configuration of the active river systems on the delta's surface. Oil and gas facilities such as the AGIP's major exporting terminal and other associated facilities are located along the vulnerable shoreline. The estimated population is in the region of 100, 000 and is likely to increase on the commencement of the LNG project. Retreat of the shoreline threatens coastal settlement, loss of recreational grounds and oil export handling facilities.

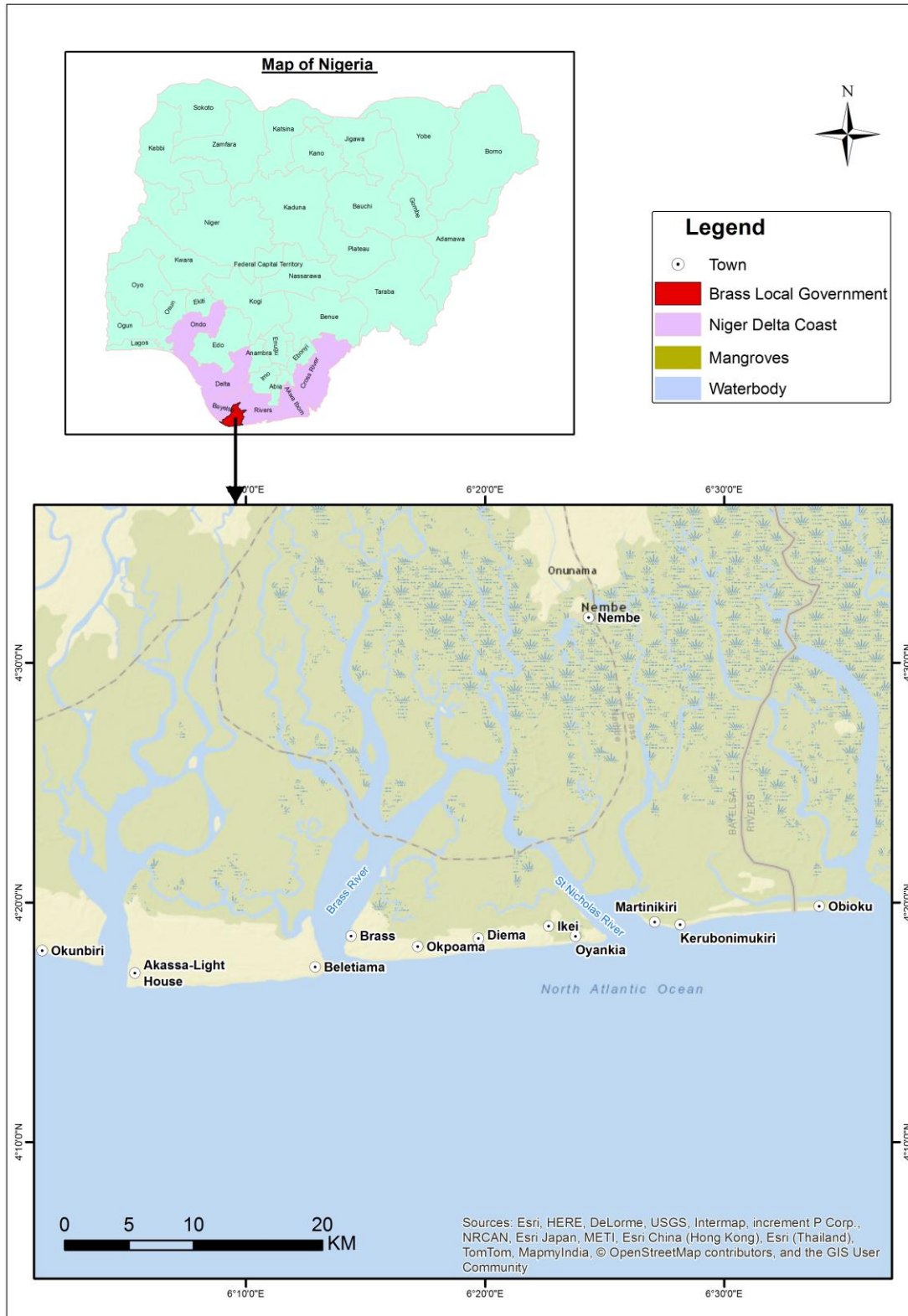


Figure 1: Map of Study Area



Plate 1: Uprushing and backwash of water at the beach face concentrate dark minerals between ripple crests



Plate 2: The most common coastal plant found along the shoreline is the creeping Impomoea aquatica at the berm

3.2 Materials

A mix scale approach involving the integration of primary and secondary data provided through government sources and data bases from other organizations. The raw spatial data and satellite images used in the research were procured through the United States Geological Survey (USGS) and the GIS laboratory of the Department of Geography and Resource Development, University of Ghana.

Hard copy map of federal surveys, Nigeria of 1974 (1.500/620/9-74) with scale 1:50,000 and soft copy of map of federal surveys, Nigeria of 1974 (1.500/620/9-74) with scale 1:50,000 obtained from the office of the Surveyor-General, Nigeria.

The data sets used include three Landsat images covering the study area for period spanning twenty-eight (28) years, satellite images for three different years of 1987, 2002 and 2013. Landsat Thematic Mapper (LTM) of 1987, 2002 and 2013 of 30 X 30 meters ground resolution were acquired from the United States Geological Surveys (USGS) and actually used for the various analyses carried out.

3.3 Method

The method is typically GIS-based and involves a number of steps. A historical shoreline database of Brass was created using ESRI ArcGIS. Database for Brass contains 3 historical shorelines spanning the time period from 1987 to 2013. Timing is a primary aspect in shoreline monitoring, both to collect data that actually represent the time interval under study (which can be short for single event analysis, or longer in order to retrieve a secular trend), and to meet the need for cost effectiveness (Beachmed, 2005).

The long-term shoreline variation was defined as the period (twenty-six years) necessary to relatively minimise the short-term changes and delineate the true long-term trend while the short-term shoreline variations was defined as the period (ten to fifteen years) necessary to capture shoreline changes due to possible storm events, seasonality of the wave climate, longshore migration of sand bodies or impacts of engineering activities like beach nourishment.

Each shoreline was digitized from Landsat images in a polyline shapefile using ArcGIS to confirm the shoreline position. The shoreline proxy was boundary between the dry and wet sand seen in the Landsat images. The other digitized shorelines were appended on the recent Landsat image hence creating historical shoreline positions.

A baseline polyline shapefile was created and the outer offshore baseline constructed by hand through digitizing a line onscreen in Arc GIS and estimating a preferred location by eye in order to obtain desired transect orientations across the historical shorelines and parallel the general orientation of the historical shorelines in the GIS. Following the creation of the baseline, transect lines are cast perpendicular to the baseline at a 50m spacing and transect length of 1000m spacing along the baseline. Transect lines are intersected with the historical shorelines to produce a database of points, which record the locations of historical shoreline positions along each transect through time (Figure 2). The estimate for shoreline position error is set at 1m.

Statistics were calculated for transects in the AMBUR (Analyzing Moving Boundaries Using R) software and stored in a data table with the confidence level calculated for linear regression set at 95 %. Analysis was done for the entire stretch of the Brass shoreline as well as the study area. Subsequently, a projection of future shoreline positions based on calculated

shoreline rate-of-change statistics. The area of accretion or erosion was also measured using a polygon shapefile.

Ground truthing on the entire study area was conducted for one week. The aim was to gather information from the field and interview the people from the study area (Plate 2). The persons interviewed were asked about the status of the shoreline in relation to previous years. Their responses agreed well with the GIS analytical findings. A number of photographs were also taken of the study site using a digital camera in order to capture the area's current appearance.



Plate 3: Interaction with a resident of Okpoama community along the Brass Shoreline

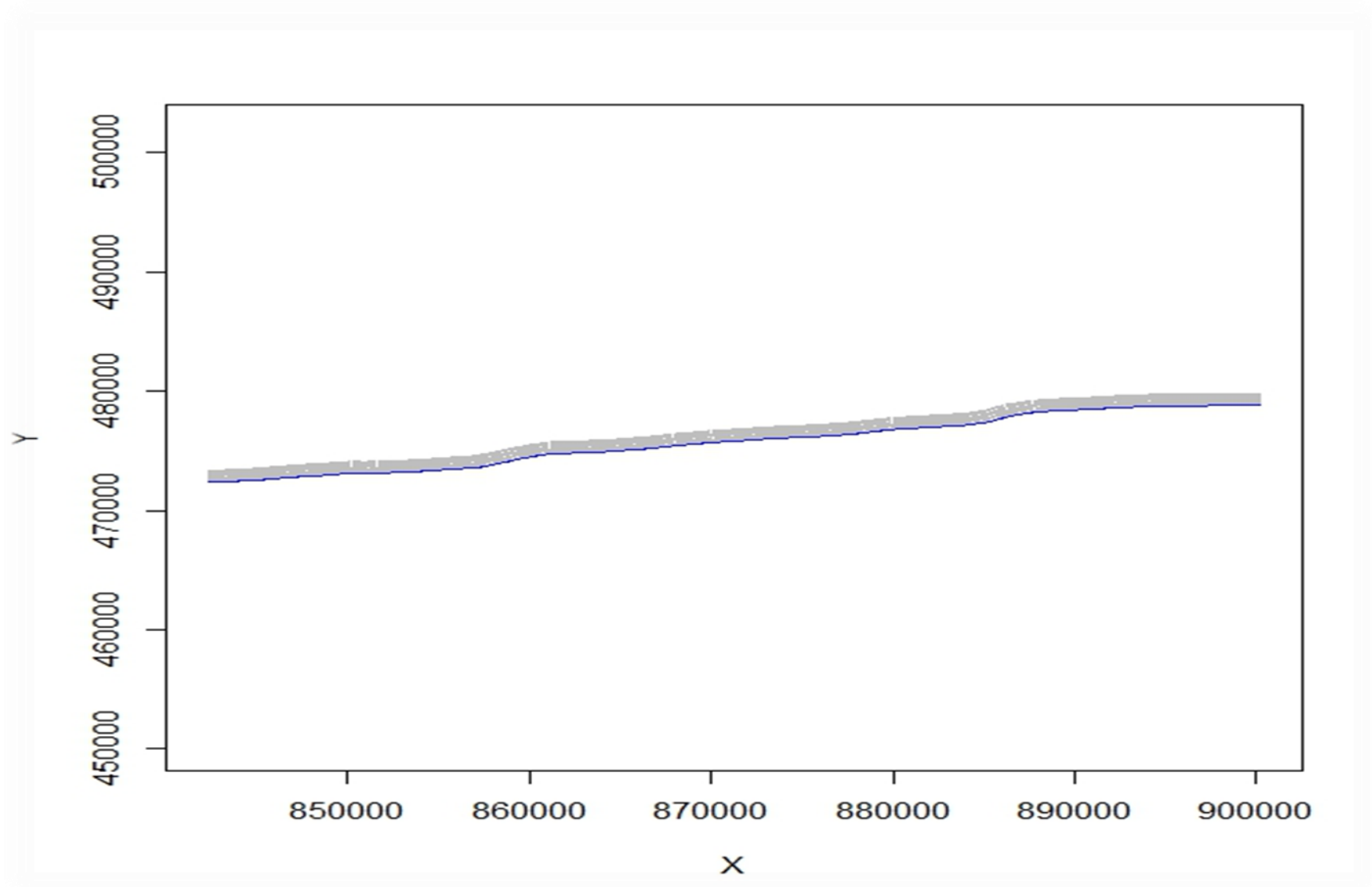


Figure 2: Casted transect for the Entire Brass Shoreline as produced in AMBUR software

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction

The Brass shoreline is made up of three (3) sections which are the Beletiamia- Akassa lighthouse section on the west, Okpoama- Brass section and Martinikiri- Obioku section on the east. There are a total of 551 transects (1 – 1215) cast, however the study area is between transects 366 and 787 (i.e. the Okpoama- Brass section). Shorelines digitized and extracted show changes in the morphology of the shorelines over time as shown in Figure 3. . The results from the analyses also revealed remarkable changes in the shoreline with the rate of change (EPR) measured as shorelines End-point change rate between oldest and youngest shorelines (see Table 1 and 2). It also revealed the dominant shoreline trend that occurred between the spatial scales of each available image, as well as future predictions of the shoreline position considering the area to be eroded.

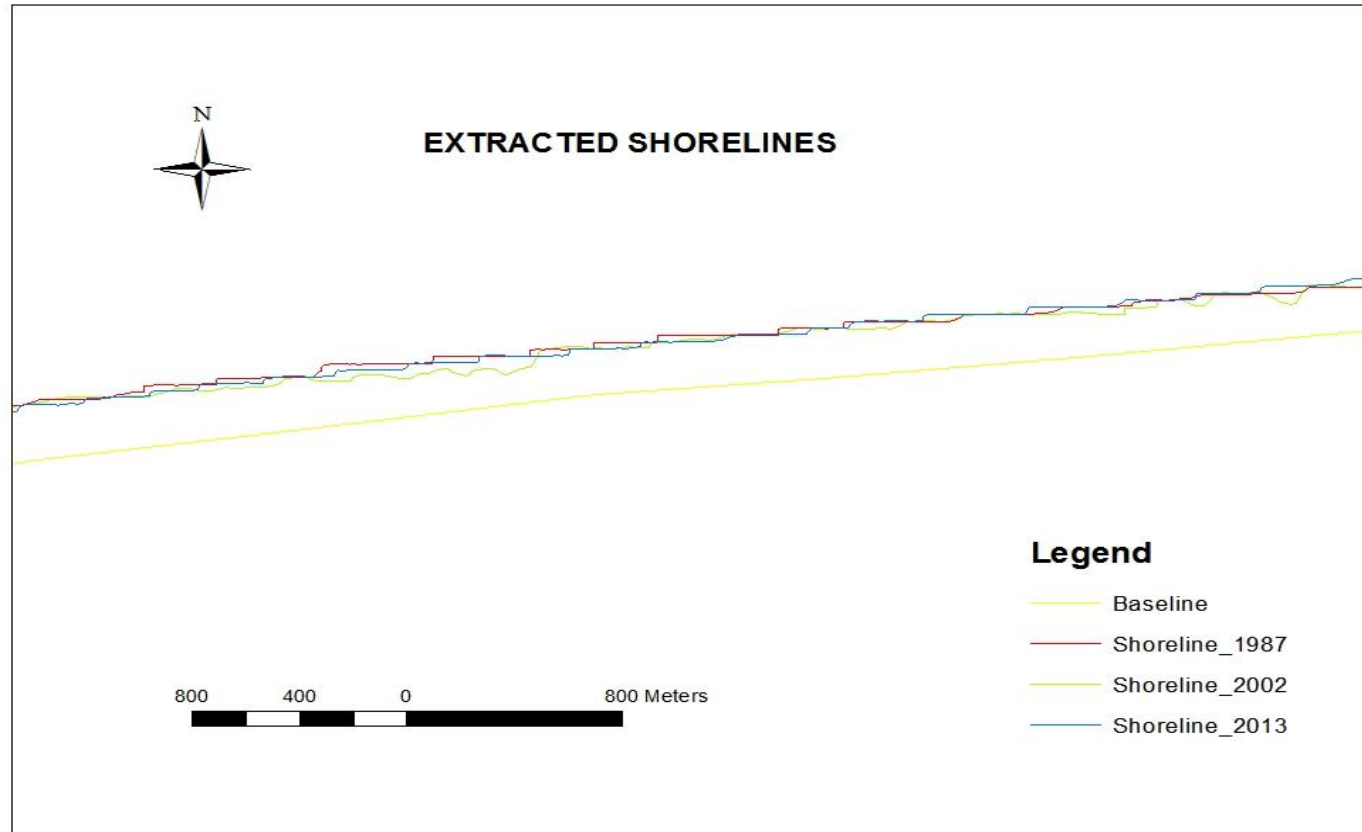


Figure 3: Section of the extracted Shorelines and Baseline

4.2 Short term Shoreline Changes

1987 - 2002 (Changes observed along the Brass Shoreline within the period)

There was a total of 551 transects (439 accretion transects and 109 erosion transects) and 3 flagged transects. The erosion areas were found in transects 367-372, 440-450, 453-454, 509-527, 549-552, 567, 590, 604, 607-609, 615-619, 622-623, 647-654, 659-665, 669-678, 691-694, 702-707, 716, 722-725, 733-735, 745-747, 750, 868-875, and 898-948 approximately (see Appendix iv). Approximately 80 % of the erosion transects were found in the Okpoama- Brass section. The highest erosion rate was observed in transect 910 while the highest accretion rate was observed in transect 313.

For the entire shoreline, approximately 80 % of the shoreline revealed accretion. The mean shoreline change rate for all transects (accreting and eroding) measured 3.93 m/yr (high accretion), maximum accretion rate and maximum erosion rate measured 20.82 m/yr and 18.36 m/yr respectively while the mean accretion rate and mean erosion rate measured 5.48 m/yr and 2.32 m/yr respectively (see Appendix v).

In the Okpoama- Brass section, accretion was also dominant with approximately 30 % of the shoreline revealing erosion. Maximum accretion rate and maximum erosion rate measured 12.86 m/yr and 3.10 m/yr respectively, while the mean accretion rate and erosion rate measured 3.36m/yr and 0.82 m/yr (meso erosion) respectively (see Appendix v). The mean shoreline change rate for all transects (accreting and eroding) measured 2.1 m/yr (high accretion).

2002 – 2013 (Changes observed along the Brass Shoreline within the period)

There was a total of 551 transects (439 accretion transects and 109 erosion transects) and 3 flagged transects. The erosion areas were found in transects 2-27, 29, 32-63, 308-313, 367-386, 391, 399-400, 403-414, 426-435, 530-533, 538-542, 556-585, 610-620, 624-639, 640-660, 664-667, 679-696, 708-713, 719-720, 721-735, 734, 740-747, 768- 771, 777-787, 878-913, 933-1029 and 1037 approximately (see Appendix vi). The highest erosion rate was observed in transect 375 while highest accretion rate was observed in transect 783.

For the entire shoreline, approximately 60 % of the shoreline revealed accretion. The mean shoreline change rate for all transects (accreting, stable and eroding) measured 0.02 m/yr (micro accretion), maximum accretion rate and maximum erosion rate measured 49.12 m/yr and 36.76 m/yr respectively while the mean accretion rate and mean erosion rate measured 4.60 m/yr and 5.96 m/yr respectively (see Appendix vii).

In the Okpoama- Brass section, erosion was also dominant with approximately 55 % of the shoreline revealing erosion. Maximum accretion rate and maximum erosion rate measured 6.04 m/yr and 7.03 m/yr respectively, while the mean accretion rate and erosion rate measured 2.32m/yr and 2.74 m/yr respectively (see Appendix vii). The mean shoreline change rate for all transects (accreting, stable and eroding) measured 0.42 m/yr (meso erosion).

4.3 Long Term Shoreline Changes

1987 – 2013 (Changes observed along the Brass Shoreline within the period)

The analysis was characterized by accretion for most transects in the study area. There was a total of 551 transects (394 accretion transects and 157 erosion transects) and 5 flagged transects. The erosion areas were found in transects 2-7, 38, 366-381, 466-448, 533-541, 552, 566-567, 585, 590, 604, 611-620, 623-633, 638-725, 728-747, 868-876, 878-913 and 930-993 approximately (see Appendix viii). The highest erosion rate was observed in transect 910 while highest accretion rate was observed in transect 1211.

For the entire shoreline, approximately 70 % of the cast transects recorded accretion. The mean shoreline change rate for all transects (accreting, stable, and eroding) measured 2.32 m/yr (high accretion), maximum accretion rate and maximum erosion rate measured 49.12m/yr and 26.15m/yr respectively while the mean accretion rate measured 4.09m/yr and 2.14m/yr respectively (see Appendix ix).

Most of the erosion transects were found in the Okpoama- Brass section. In the Okpoama-Brass section, maximum accretion rate and maximum erosion rate measured 7.57 m/yr and 4.40 m/yr respectively, while the mean accretion rate and erosion rate measured 2.43m/yr and 0.89 m/yr respectively (see Appendix ix). The mean shoreline change rate for all transects (accreting, stable, and eroding) measured 0.1 m/yr (meso accretion).

Table 1: Summary of shoreline rate of change over the different periods under investigation in the Entire Brass Shoreline

Period	Maximum Accretion rate (m/yr) \pm 1m	Maximum Erosion rate (m/yr) \pm 1m	Rate of change (EPR)	
			Mean Accretion rate (m/yr) \pm 1m	Mean Erosion rate (m/yr) \pm 1m
1987 – 2013	49.12	-26.15	4.09	-2.14
1987 – 2002	20.82	-18.36	5.48	-2.32
2002 – 2013	49.12	-36.76	4.6	-5.96

Table 2: Summary of shoreline rate of change over the different periods under investigation in the Okpoama– Brass section

Period	Maximum Accretion rate (m/yr) \pm 1m	Maximum Erosion rate (m/yr) \pm 1m	Rate of change (EPR)	
			Mean Accretion rate (m/yr) \pm 1m	Mean Erosion rate (m/yr) \pm 1m
1987 – 2013	7.57	-4.40	2.43	-0.89
1987 – 2002	12.86	-3.10	3.36	-0.82
2002 – 2013	6.04	-9.73	2.32	-2.74

4.4 Future Prediction

The forecast of the shoreline position at 50 years showed the dominant trend for the Beletiamama- Akassa Lighthouse section of the Brass shoreline to be erosion and that a total area of 3.5 Km² would be eroded (Plate 4). The Okpoama-Brass section will also experience erosion and slight accretion. The erosion areas measured 0.2 Km², 0.5 Km², and 0.5 Km² respectively (Plate 5). At the Martinikiri- Obioku section of the Brass shoreline, the forecast measured area for erosion as 0.1 Km² and 2 Km² respectively while accretion area measured 0.1 Km² and 0.3 Km² respectively (Plate 6).



Plate 4: Forecast area of the Beletiamama- Akassa section of the Brass shoreline



Plate 5: Forecast of the Okpoama- Brass section of the Brass shoreline

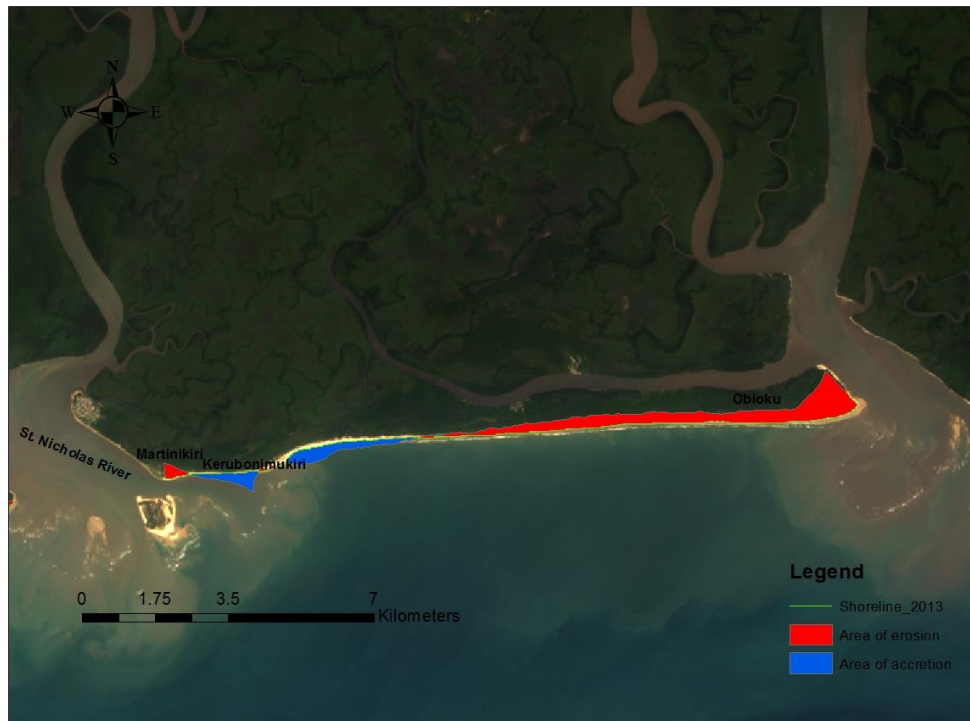


Plate 6: Forecast of the Martinikiri- Obioku section of the Brass shoreline

CHAPTER FIVE

5.0 DISCUSSION

5.1 INTRODUCTION

From the three (3) shoreline positions extracted for morphological change detection, shoreline changes were analyzed for short term and long term changes. The short term necessary to capture shoreline changes due to possible storm events, seasonality of the wave climate, longshore migration of sand bodies or impacts of engineering activities like beach nourishment while the long term necessary to relatively minimize the short-term changes and delineate the true long-term trend. Analysis for short term changes (1987 - 2002, 2002 - 2013); long term changes (1987 - 2013), future predictions of the shoreline position considering the area to be eroded and possible causes of erosion are also discussed.

5.3 Short Term Shoreline Changes

1987 – 2002 (Changes observed along the Brass Shoreline within the period)

The period between 1987 and 2002 revealed that accretion dominates the entire shoreline. Approximately 80 % of the cast transects recorded accretion while erosion recorded approximately 20 %, however, 80 % of the erosion transects were found in the Okpoama-Brass section. Accretion rates range from 0.1 to 20.82 m/yr with an average of 5.48 m/yr and erosion rates ranging from 0.1m/year to 18.26 m/yr with an average of 2.32 m/yr. The highest accretion rate was observed at Beletiamama in the Beletiamama– Akassa Lighthouse section at the western end of the entire shoreline while the highest erosion rate was observed in Kerubonimukiri at the Martinikiri- Obioku section.

In the Okpoama- Brass section, accretion rates range from 0.1 to 12.86 m/yr with an average of 3.36 m/yr while erosion rates ranging from 0.1m/year to 3.10 m/yr with an average of 0.82 m/yr. The highest accretion rate was observed close to the St. Nicholas River mouth while the highest erosion rate was observed around Ikei. In areas around the Agip Oil Company export handling facility, Okpoama and Diema high accretion rates were also observed, however the shoreline trend was cyclic. Overall, the mean shoreline change rate of 2.1 m/yr (accretion) observed confirms the effort at stabilizing the shoreline by AGIP Oil Company as was reported by Ibe & Anita, 1983.

2002 – 2013 (Changes observed along the Brass Shoreline within the period)

The period between 2002 and 2013 revealed that accretion dominates the entire shoreline with about 60 %. It further reveals that for the entire shoreline, the accretion rates range from 0.1 m/year to 49.12 m/year with an average accretion rate of 4.60 m/year while the erosion rates range from 0.1 m/year to 36.76 m/year with average erosion rate of 5.96 m/years respectively. The highest accretion and erosion rates were observed at Obioku and Kerubonimukiri within the Martinikiri- Obioku section of the shoreline. The mean shoreline change rate of + 0.02 m/yr however revealed that the morphological change was micro.

In the Okpoama- Brass section, the accretion rates range from 0.1m/year to 6.04 m/year with average accretion rate of 2.32 m/year while erosion rates range from 0.1m/year to 9.73m/year with average erosion rate of 2.74 m/year. The dominant morphological trend was observed to be erosion as the mean shoreline change rate revealed that the Okpoama- Brass section was eroding at the rate of 0.42 m/yr (meso erosion). The highest erosion rate was observed around the Brass River, close to the AGIP Oil Company export handling facility. Other areas of high erosion include Okpoama, Diema and Oyankia around the St. Nicholas River. The erosion

observed can be attributed to the 2012 flooding which inundated most parts of the shoreline and led to the destruction of trees within the period, further exposing the coastal communities to erosion as shown Plates 7.



Plate 7: Destroyed trees along the Brass shoreline near the St. Nicholas River mouth at the easternmost part of the Okpoama- Brass section

5.2 Long Term Shoreline Changes

1987 – 2013 (Changes observed along the Brass Shoreline within the period)

This period covers twenty-six years. The analysis revealed that the entire stretch was characterized by approximately 70% accretion. The accretion rates range from 0.1 m/year to 49.12 m/year with an average of 4.09 m/year while erosion rates were between 0.1 to 26.15 m/year with an average of 2.14 m/year. The highest accretion and erosion rates were

observed at Obioku and Kerubonimukiri respectively in the Martinikiri- Obioku section of the Brass shoreline. It further revealed that the entire stretch of the shoreline was accreting at the rate of 2.32 m/yr in the long term.

In the Okpoama– Brass section, the analysis revealed approximately an equal percentage of erosion and accretion transects, however the highest accretion and erosion rates was 7.57 m/yr and rate 4.40 m/yr respectively. For the Okpoama- Brass section, the accretion rates range from 0.1m/year to 7.57 m/year and the erosion rates range from 0.1 m/year to 4.40 m/year. The highest erosion rate was observed close to the Brass River mouth while the highest accretion rate was observed around the AGIP Oil Company export handling facility. The high accretion rate observed around the facility can be attributed to the previous intervention carried out by the company. Erosion was however observed around Okpoama, Diema, and Oyankia and can be attributed to downdrift resulting from the earlier intervention around the export handling facility at the western end of the section. Such an intervention tends to stabilize the shoreline at the eroding area but shifts the problem elsewhere along the shoreline. Erosion was also observed around the St. Nicholas River mouth. This reveals that on a long term there is almost a balance between the rates of accretion and erosion in the Okpoama- Brass section of the shoreline, although it is more accretion than erosion. However, it must be noted that the accretion observed can be attributed to the depositional season during which the satellite image was acquired.

Generally, it is evident that some areas that experienced accretion between 1987 and 2002 have experienced erosion between 2002 and 2013 while some areas have experienced steady accretion. The Beletiamama – Akassa Lighthouse section of the Brass shoreline has been experiencing accretion while the Okpoama- Brass section, particularly around Okpoama,

Diema and Oyankia has been eroding. The Eastern part of the Brass shoreline around Martinikiri and Kerubonimukiri experience erosion while Obioku continues to accrete.

5.4 Shoreline Position Forecast

The forecast of the shoreline at 50 years was very helpful in understanding how the coast could change and which areas are prone to have severe changes. In the Beletiamama- Akassa Lighthouse section of the Brass shoreline, severe erosion is expected to occur and a total of 3.5 Km² will be the area lost. At the Okpoama – Brass section of the shoreline around Agip Oil Company, the area to be lost to erosion measures about 0.2 Km² while the area to be lost around Okpoama measures about 0.5 Km². The shoreline seemed to stay technically stable around Diema with slight accretion around Ikei but will erode around Oyankia where area to be lost to erosion measures about 0.2 Km².

In the Martinikiri- Obioku section of the Brass shoreline, there will be both accretion and erosion. The area to be eroded around Martinikiri close to the estuary mouth will be approximately 0.1 Km² while accretion is expected around Kerubonimukiri close to Martinikiri and will measure approximately 0.3 Km². Around Obioku, there is also expected to be an area approximately measuring 2 Km² to be eroded.

5.5 Possible Causes of Erosion

It is evident from the study that erosion is still prevalent in the Brass shoreline. A number of factors are however responsible for this trend. These include:

- (a) Sea-level rise: causes a range of impacts for coastal areas, including submergence/increased flooding, and increased erosion (Nicholls *et al.*, 2011), rising sea

level generally has clear effects, in terms of a landward translation of shoreline. It is reasonable to assume that all low lying deltas, including the Niger Delta, will be affected by global sea level rise. Satellite altimetry measurements (1993 to 2010) over the Niger delta coast show eustatic sea level rise rates of $3.03\text{--}3.39\text{mmyr}^{-1}$. In addition the Niger delta is subsiding at a rate of $25\text{--}125\text{mmyr}^{-1}$, which classifies it as a very high relative SLR (Musa *et al.*, 2014).

(b) High intensity of wave action: values obtained from NIOMR (2010) give wave heights of 0.5–1.5m at the eastern end of the Niger Delta. The transport or drift, of beach sediments along the shoreline is caused primarily by the action of waves and tidal currents (Obowu and Abam, 2002). The south-south westerly waves strikes the coast obliquely to generate strong longshore currents which have a dominant eastward drift everywhere along the coast (Ibe and Anita, 1983). Longshore current is primary responsible for the distribution of sediments along the coast. A combination of high tide and strong winds pushes up the sea water level, exposing the beach and dunes to heavy attack by the incoming waves, usually resulting in erosion.

(c) The diurnal tides: tidal forces play a significant role with respect to determination of deposition or erosion (Obowu and Abam, 2002). The tides occur with a period of approximately 12 hours and 25 minutes, and with amplitude that is influenced by the alignment of the sun and moon and the shape of the earth. The tides approach the coast from a south-south westerly direction; create reversible semi- permanent currents which occur at high angles to the coast, carrying sediments away from the shore (Ibe and Anita 1983).

(d) Construction of dams: damming in the upper and lower River Niger system has a strong impact on sediment transport and deposition as river discharge is altered. With the

construction of dams on many rivers which drain the hinterland and hitherto brought sediments to the coast, the contribution of sediments to the beaches from fluvial sources which constitute one of the main sources of sand supply have been reduced hence accelerating erosion.

(e) Elevation of the terrain: the nearly flat coastal terrain makes it easily susceptible to breaking waves and their actively eroding rising back wash. A remarkable observation is the unusually high erosion rate on the estuary fronts. Estuaries are typically areas of active sedimentation. This deviation results because the estuaries are obstructed seawards by sandy mouth bars standing within the reach of waves. Where tidal waves are channeled, currents are strengthened and may locally exceed normal open ocean tidal currents. In the Niger Delta, ebb tidal flows attain maximum velocity of about 60 – 280 cm/sec compared with 30 – 150 cm/sec for flood currents (Ibe and Anita, 1983). Such acquired strength results in erosion of the beaches on the estuary front and the net transport of sediments out to the sea.

(f) The impacts human activities: activities on the delta such as dredging of river mouths, shore protection and heavy marine transport equipment are most prominent in the Brass River and are closely related to the activities of oil and gas exploration companies. All these human activities alter the natural fluvial and marine processes that model the coastline. While some of these activities induce accretion, others induce erosion.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Results of this study have been useful in revealing the recent morphological changes along the Brass shoreline while zooming into the Okpoama- Brass section. This study has been able to ascertain that through satellite remote sensing and GIS techniques, the morphological changes on the Brass shoreline can be monitored. The use of remote sensing techniques and applications like AMBUR creates more analyses and graphs in approximately two to three minutes thus facilitating the process of obtaining data as it is accessible and cost-efficient.

Erosion areas identified along the Brass shoreline include areas around the Agip Oil Company export handling facility, Okpoama, Diema, Oyankia, Martinikiri and Kerubonimukiri. From the forecast severe erosion is expected to occur along the Beletiamā– Akassa Lighthouse section of the Brass shoreline, erosion is also expected around the NLNG Brass Terminal while the shoreline is expected to stay technically stable around Diema but will erode around Oyankia. Although the Okpoama- Brass section reveals erosion in the short term, it is much slower than recorded in the early 80's. This may be as a result of the efforts of Agip Oil company to check the massive erosion previously experienced in the area.

Limitations for this project may include the spatial resolution of the satellite imagery used; therefore the introduction of errors in the digitalization of the shoreline is possible. To further enhance the project, high-resolution images of the study area may be used to increase the accuracy of measurements of shoreline changes. Due to lack of time and sufficient funds, ground truthing was limited to the Okpoama- Brass section; also the area around the Agip Oil

Company was inaccessible for ground truthing due to the uncooperative attitude of security operatives stationed at the sites.

6.2 Recommendations

Beach nourishment as a control measure with due regard to or understanding of the factors and processes occurring in the coastal morphodynamic; the pattern of change; the source of sediments, the paths of sediment flow and the quantities involved over a period of time is recommended. Such knowledge enables the effects of the control measure to be predicted and offset or allowed for, in engineering works.

Compared with other coastal protective measures, the method of beach nourishment is very effective, natural, and cheap. Beach nourishment is mainly used to compensate local erosion in regions with relatively narrow and low dunes (in regions where coastal safety is critical) or when the local beach is too small for recreational purposes. Beach nourishment has to be repeated every six to seven (6-7) years to keep the coastline unchanged.

If there is a substantial loss of sediment over a period of five (5) years, nourishment of the area with a sediment volume equal to the observed volume loss may be considered. It is a soft protective and remedial measure that leaves the coast in a more natural state than hard structures and preserves its recreational value. The method is relatively cheap if the borrow area is not too far away (<10 km) and the sediment is placed at the seaward flank of the outer bar where the navigational depth is sufficient for hopper dredgers.

Afforestation of the estuary front is also recommended. Vegetation plays an important role in the shaping of depositional forms within estuaries and on tidal shores where estuarine conditions are found. For instance, the introduction of the vigorous hybrid, *Spartina*

townsendii would help to build up marshland at a rapid rate thereby stabilizing and reclaiming coastal land as happened in Britain, Australia, New Zealand and the Netherlands. Other vegetation types such as carpets of algae (e.g. *Enteromorpha*) marine grasses (e.g. *Zostera*), plants like *Spartina* or *salicornia* and shore rush such as *Juncus maritimus* have also proved effective in checking erosion. Aesthetically, this might not be the best solution but marshlands have other advantages that outweigh any aesthetic considerations.

Also recommended is the creation of a delineation zone. This zone may not be less than 100 meters in width; this common method should be based on scientific knowledge of natural processes, information on ecological and landscape values and an analysis of the costs of implementation under local circumstances. This information should be combined with the perceptions and views of stakeholders at the local level in a process of open communication and discussion. The outcome of this participatory process should be used to make a final decision on a setback line that is scientific valid, socioeconomically defensible and broadly acceptable to the public. This requires an assessment of the risk from coastal erosion as well as a procedure how to incorporate this risk into an economic cost benefit analysis. Furthermore, also ecological values and social motives, such as public access to the beach, can be included in the rationale for defining set back lines.

Finally, there is a need for a formulation of an integrated coastal management program that will help in the design of an intersectoral- intergovernmental coordinating mechanism for the coastal management to ensure effective interagency coordination. This coordination is generally required in two dimensions; horizontally among various sectorial agencies (fisheries, land use, coastal erosion management, oil and gas, etc.) and vertically among

various levels of government (federal, state and local government) with the aim of harmonizing the policies and activities of the separate line agencies.

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APPENDIX I

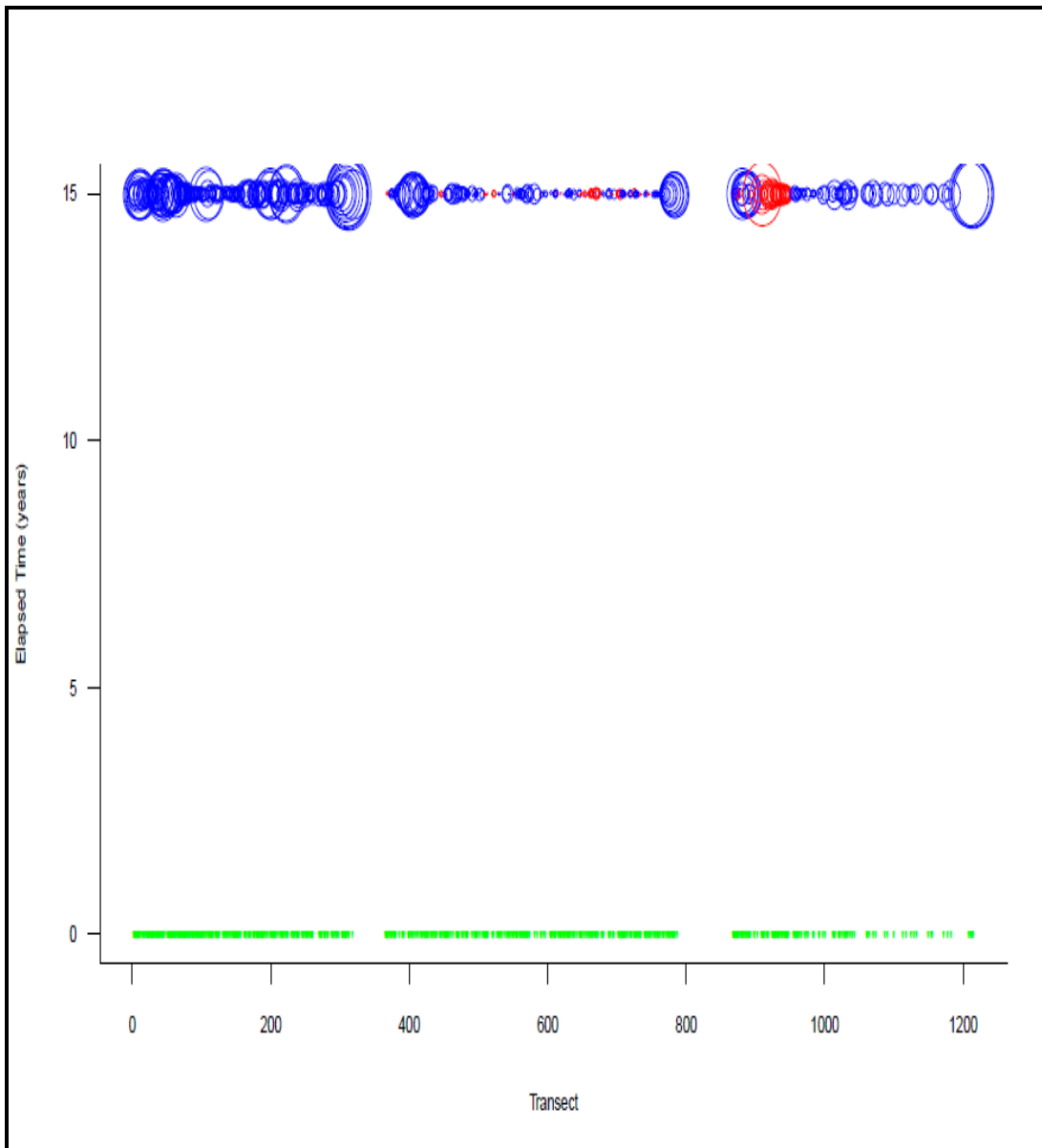


Figure 4: Graph of Shoreline cumulative change for 1987 - 2002

APPENDIX II

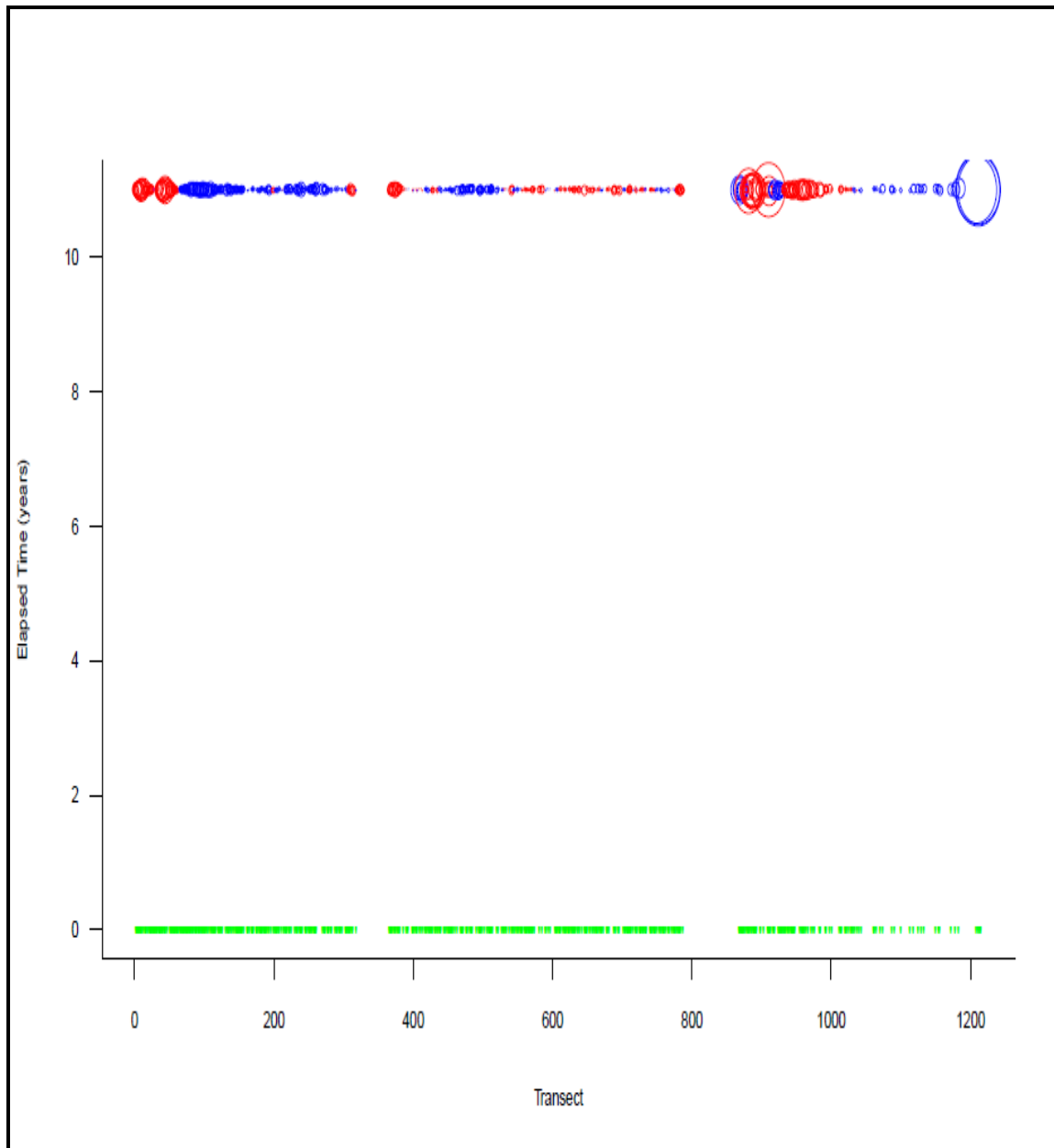


Figure 5: Graph of Shoreline cumulative change for 2002 – 2013

APPENDIX III

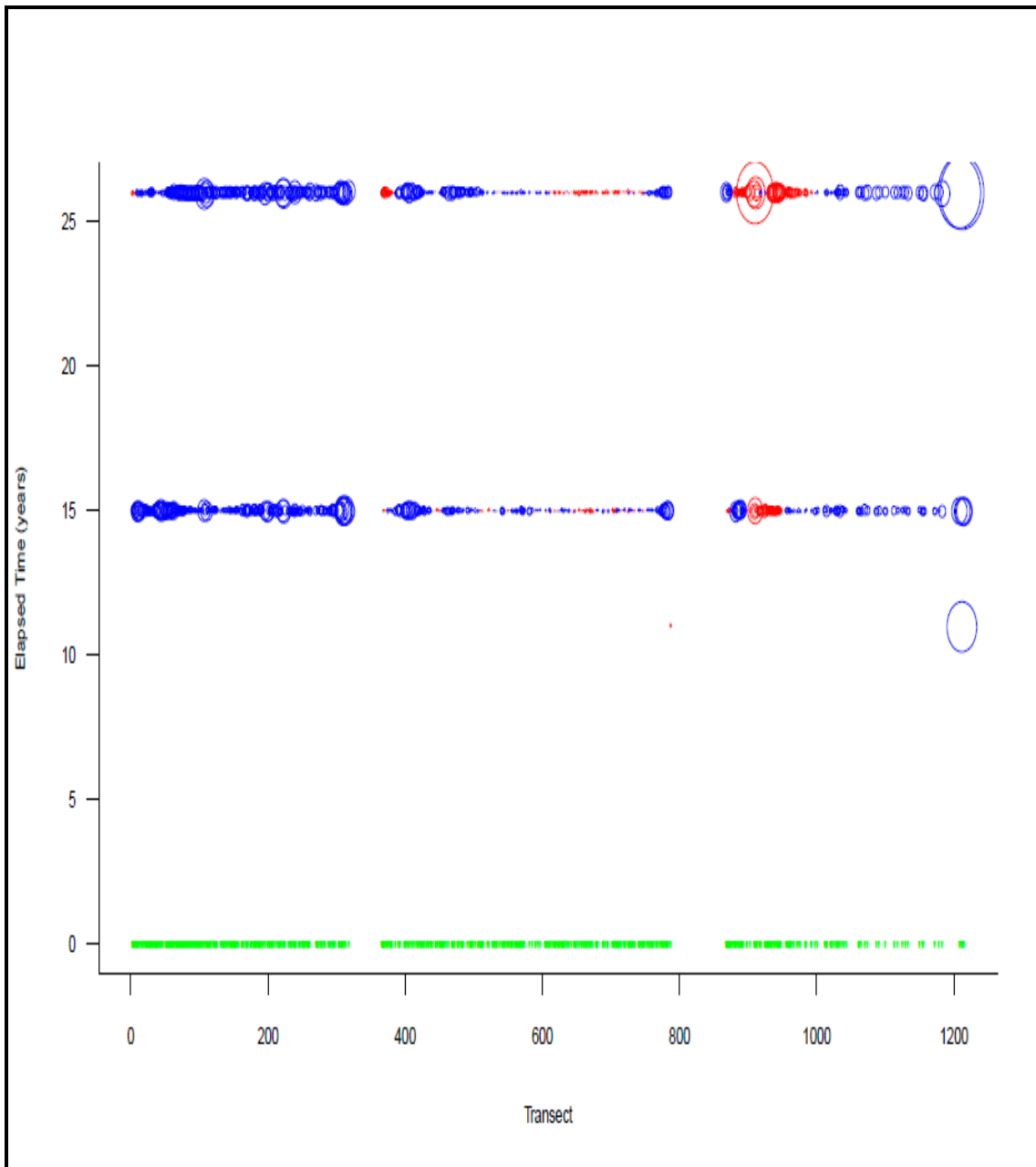


Figure 6: Graph of Shoreline cumulative change for 1987 – 2013

APPENDIX IV

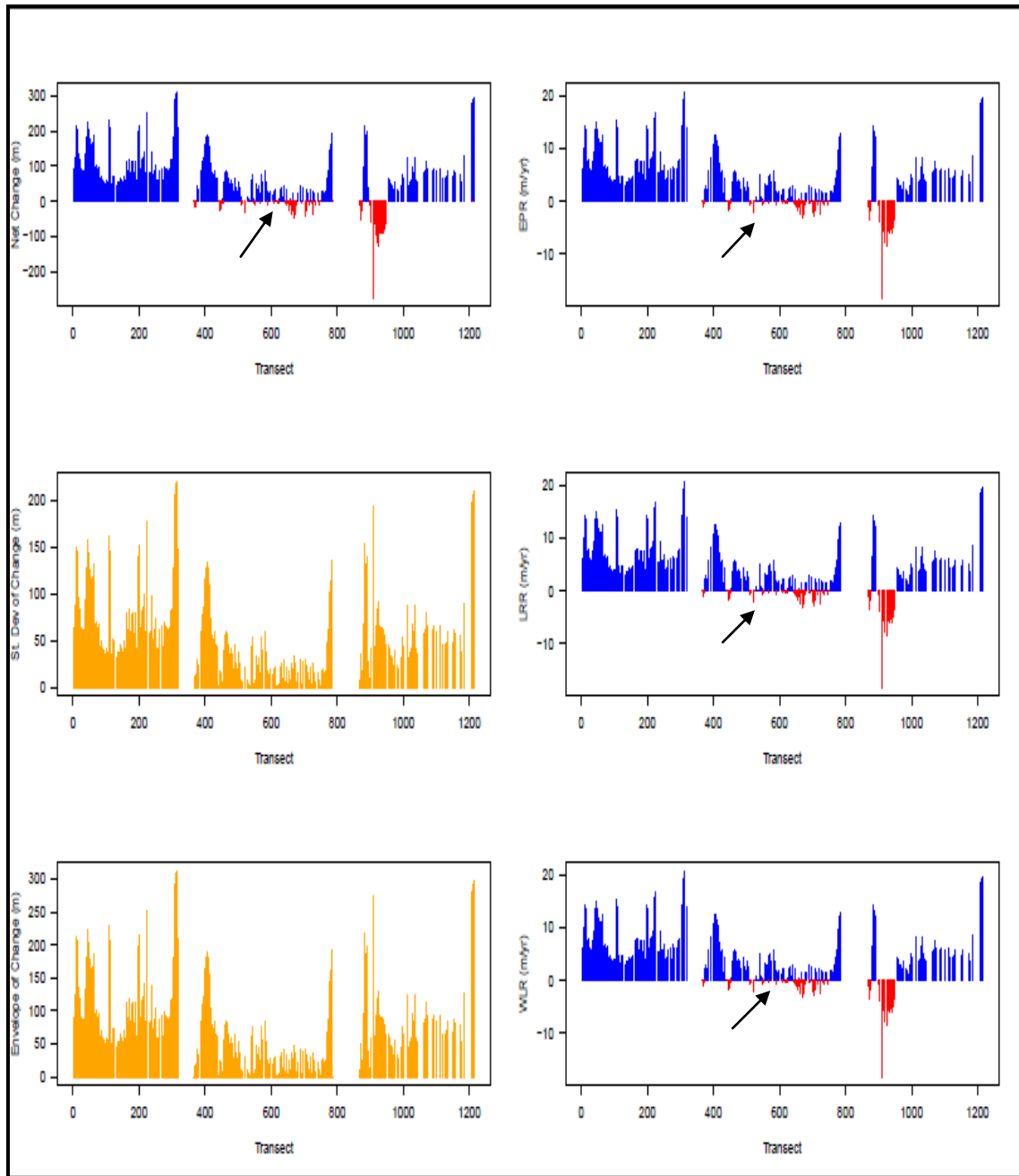


Figure 7: Graph plots of shoreline Analysis 1987 - 2002

APPENDIX V

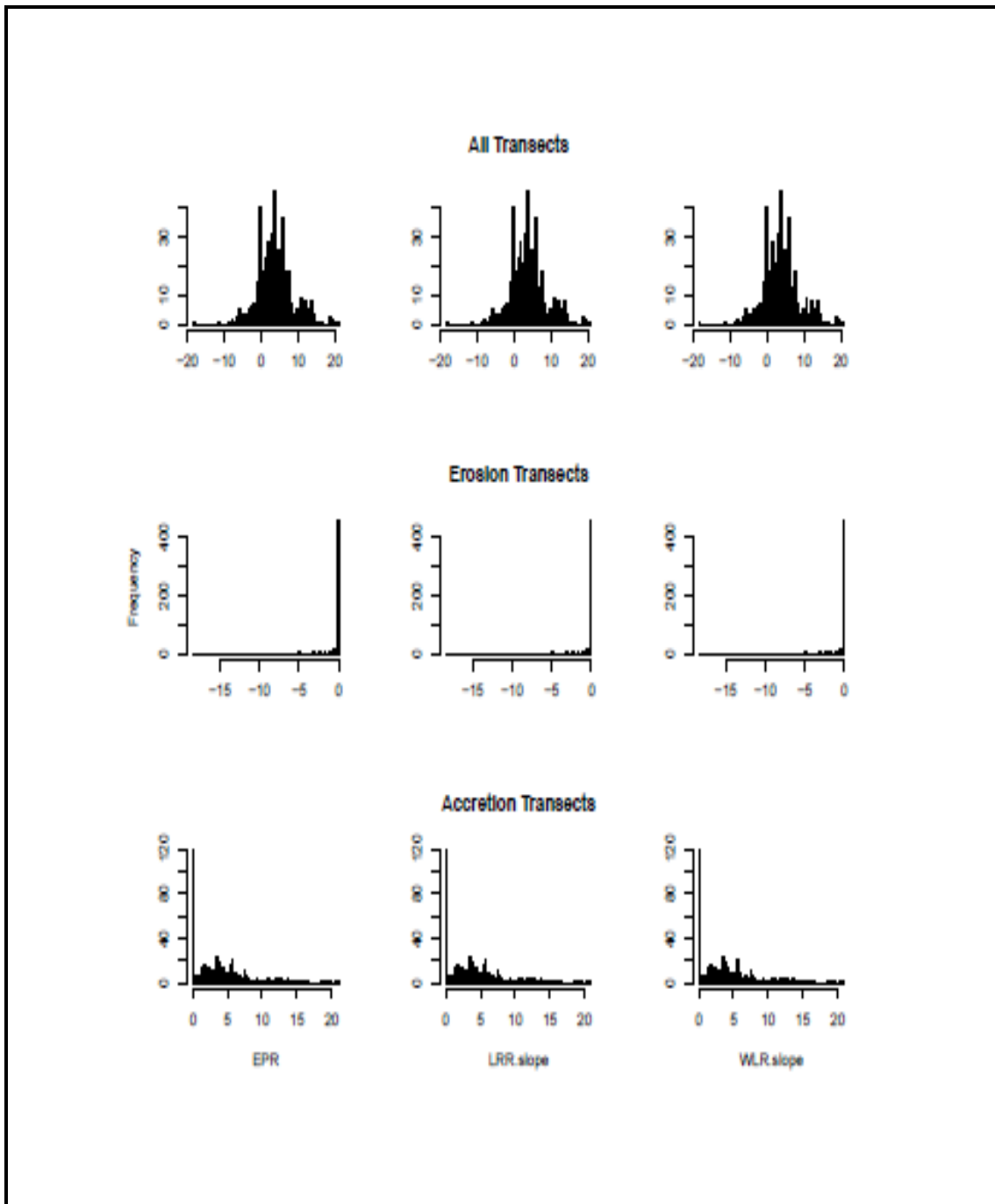


Figure 8: Histogram of Shoreline Transects 1987 - 2002

APPENDIX VI

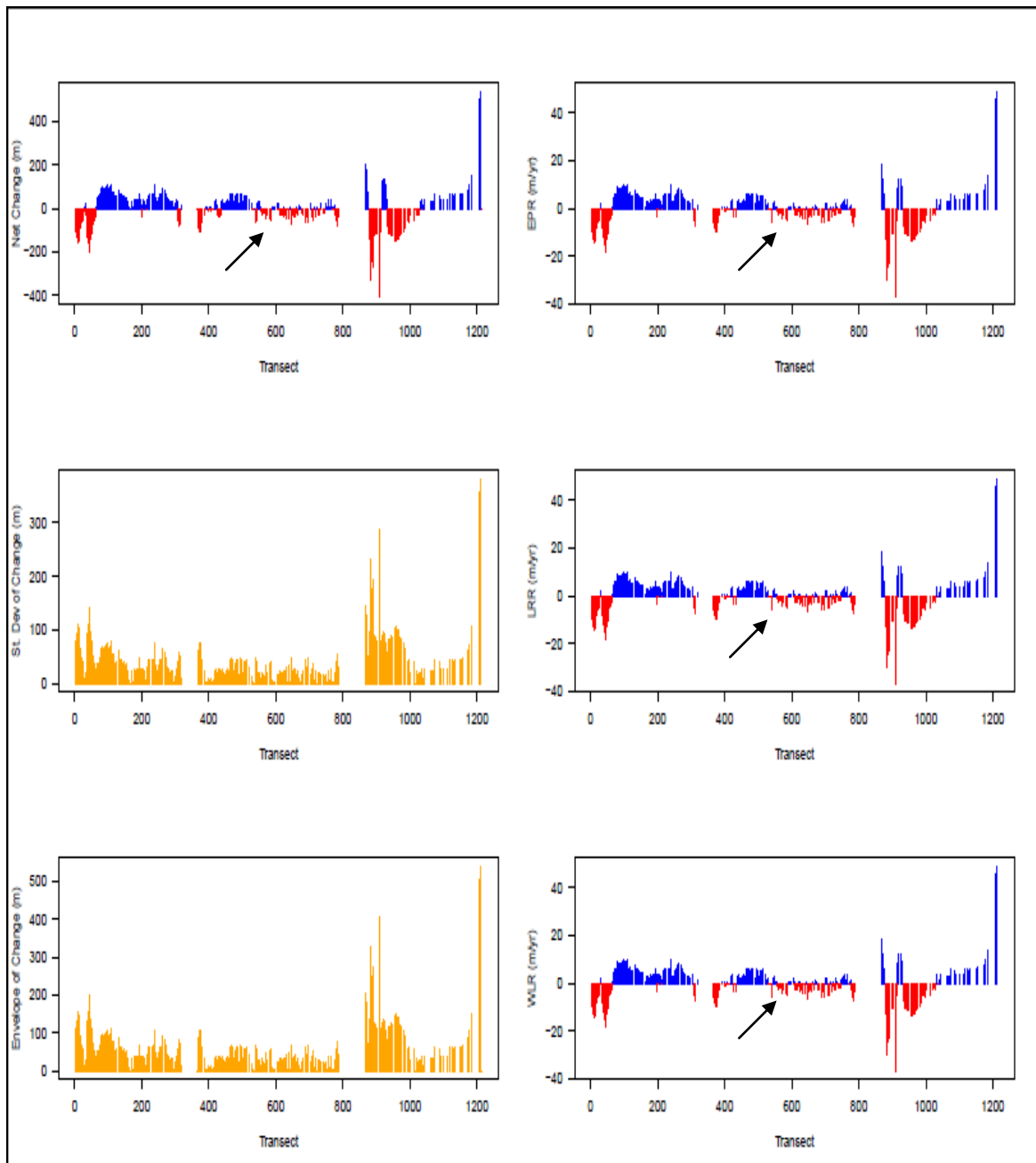


Figure 9: Graph plots of shoreline Analysis 2002 - 2013

APPENDIX VII

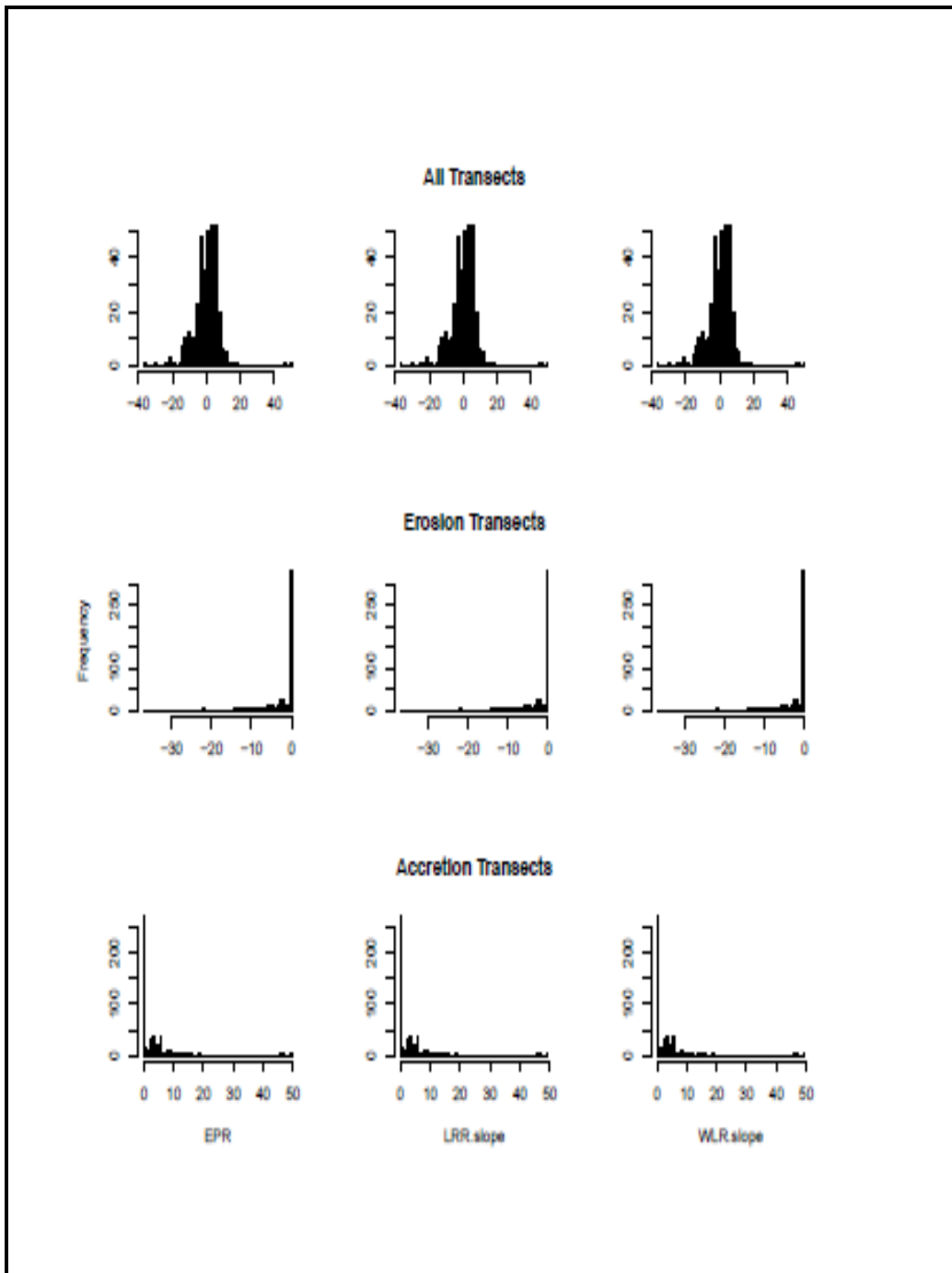


Figure 10: Histogram of Shoreline Transects 2002 – 2013

APPENDIX VIII

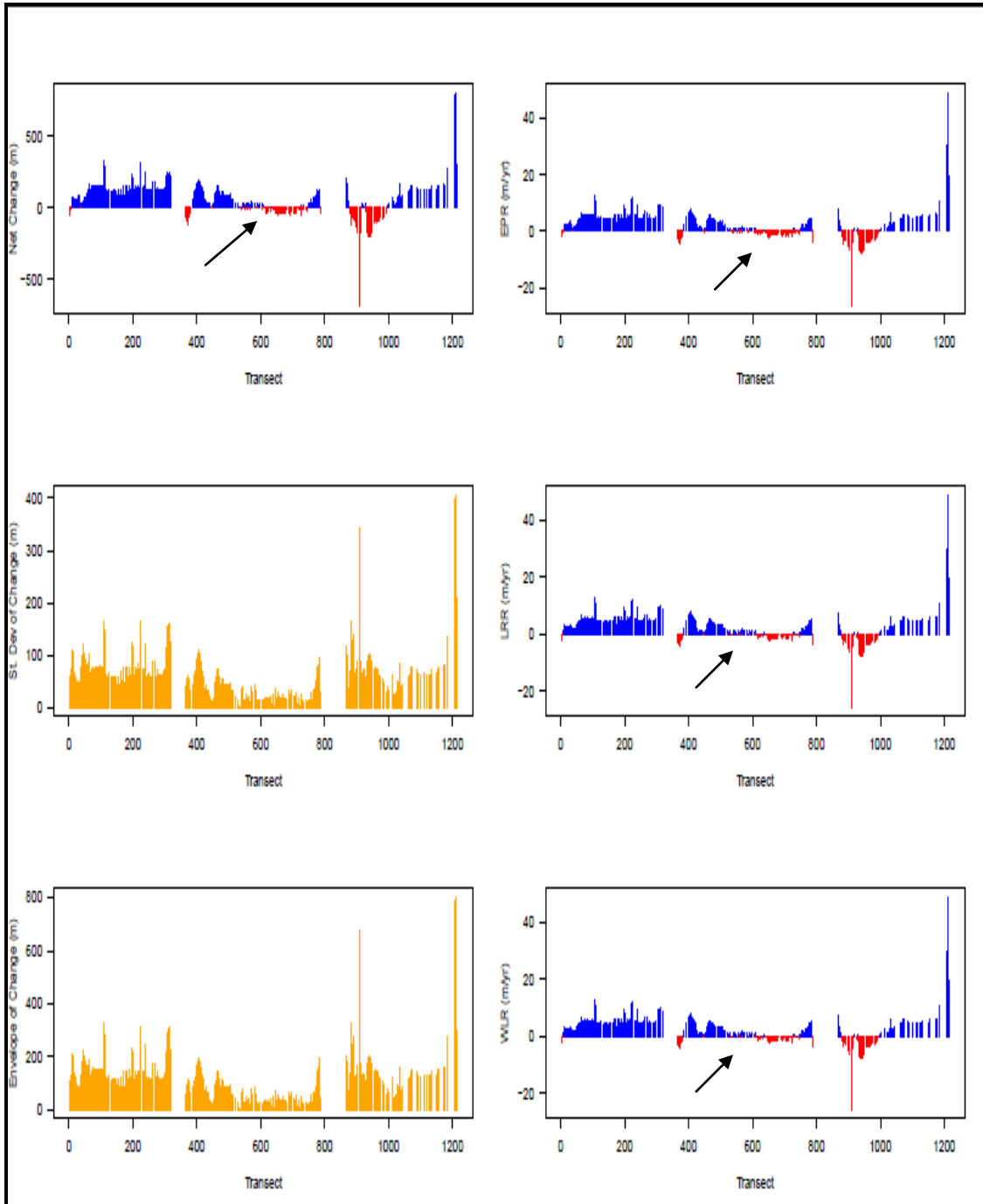


Figure 11: Graph plots of shoreline Analysis 1987 - 2013

APPENDIX IX

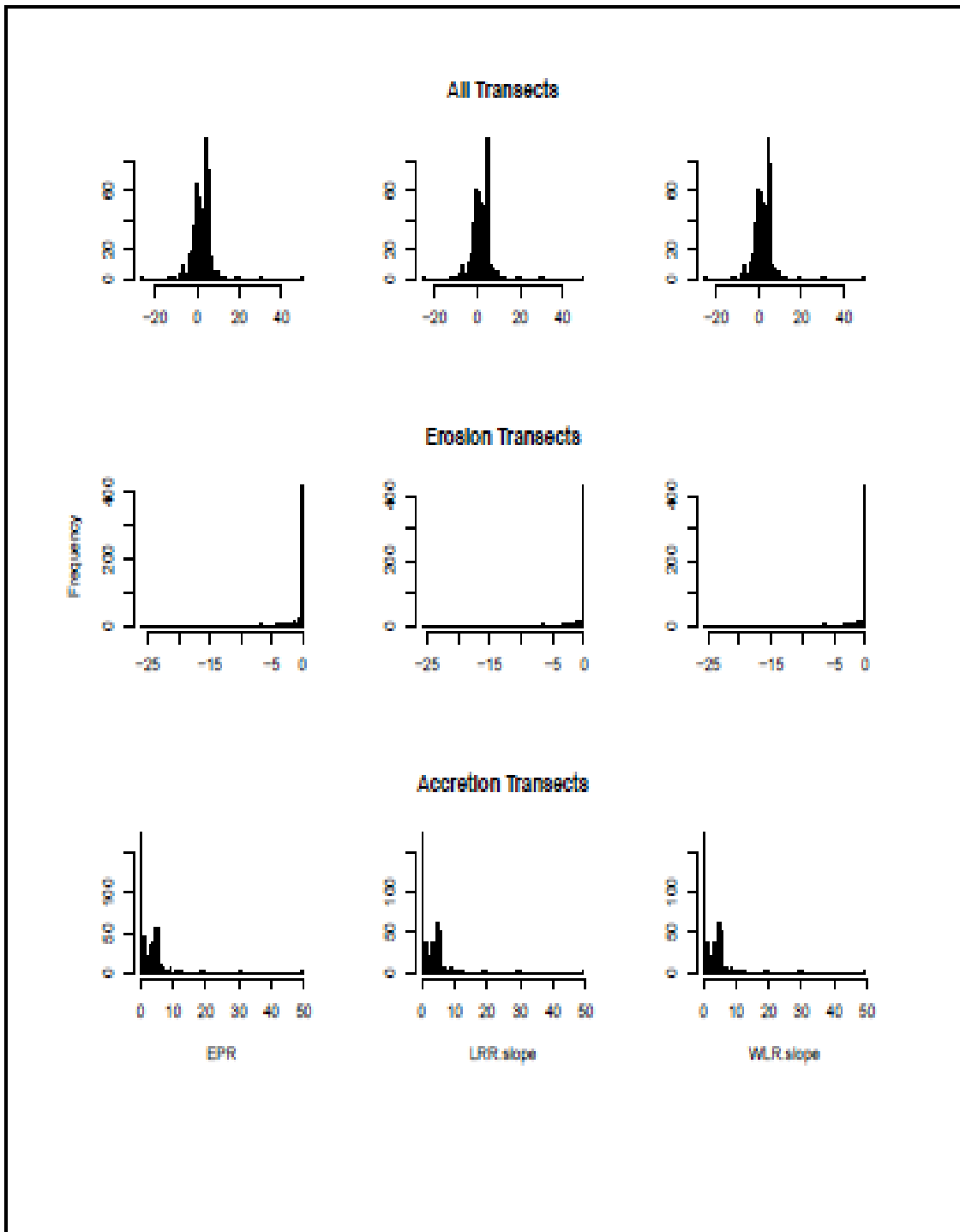


Figure 12: Histogram of Shoreline Transects 1987 - 2013

APPENDIX X

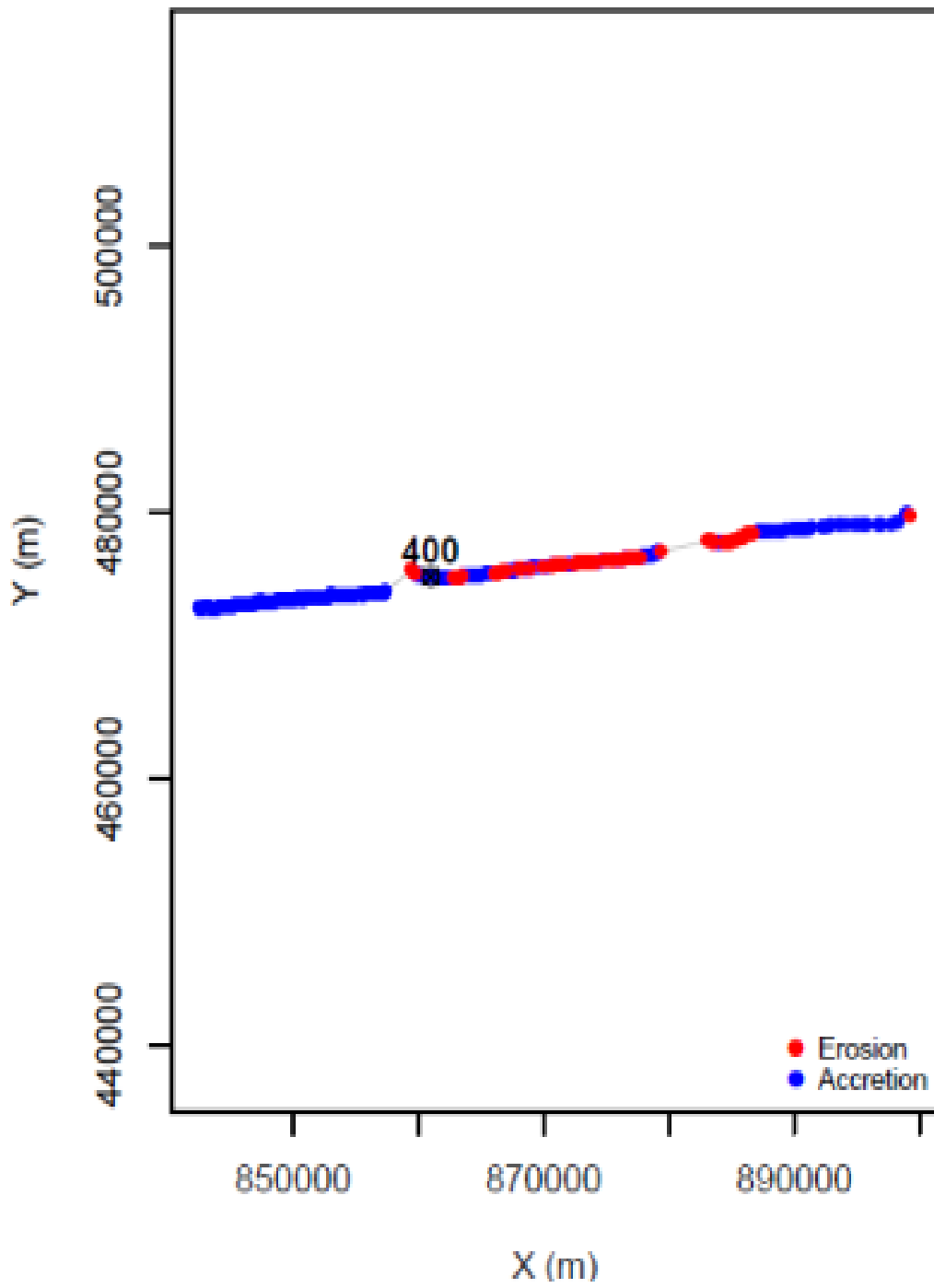


Figure 13: Range of Shoreline variation (1987 - 2002)

APPENDIX XI

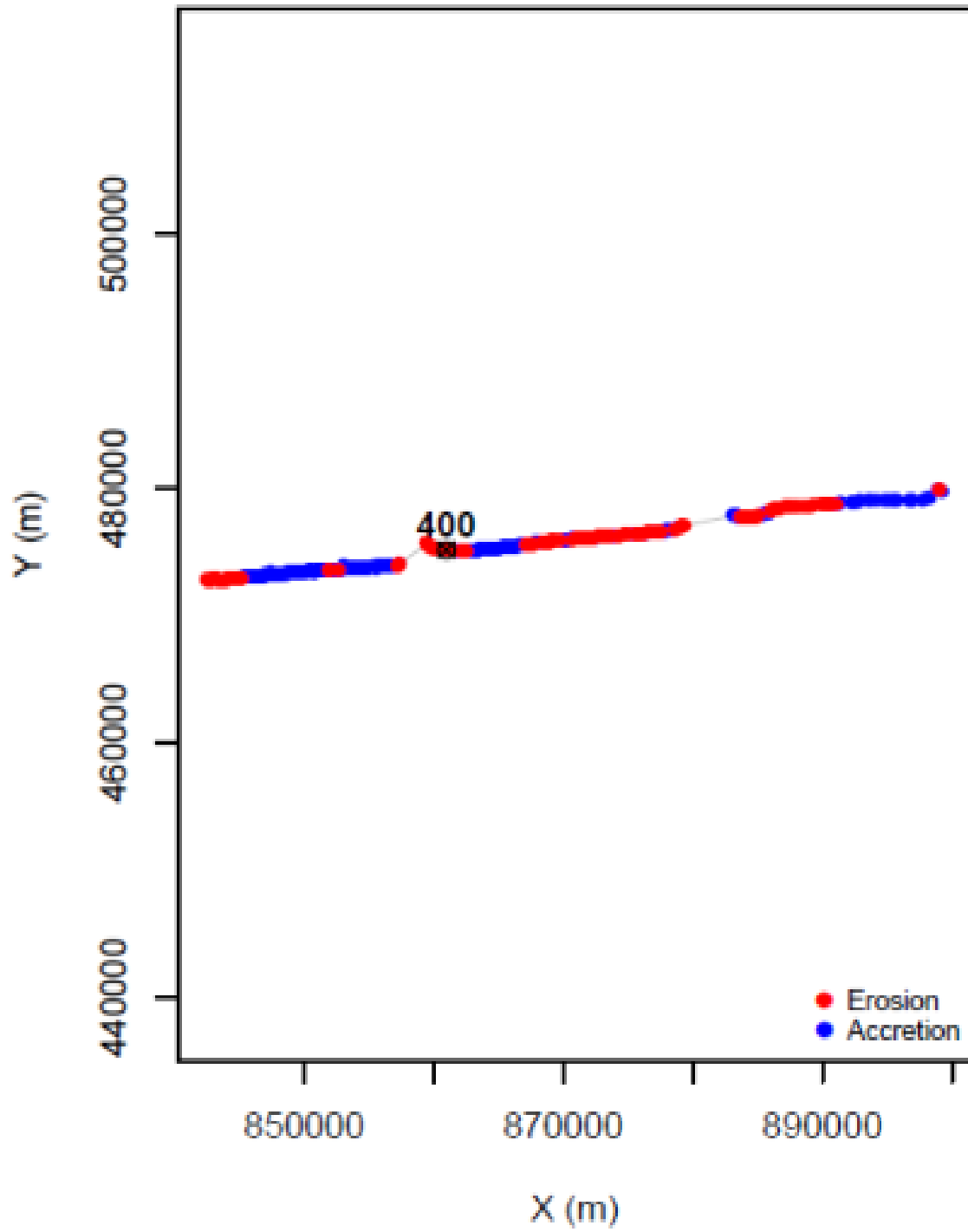


Figure 14: Range of Shoreline variation (2002-2013)

APPENDIX XII

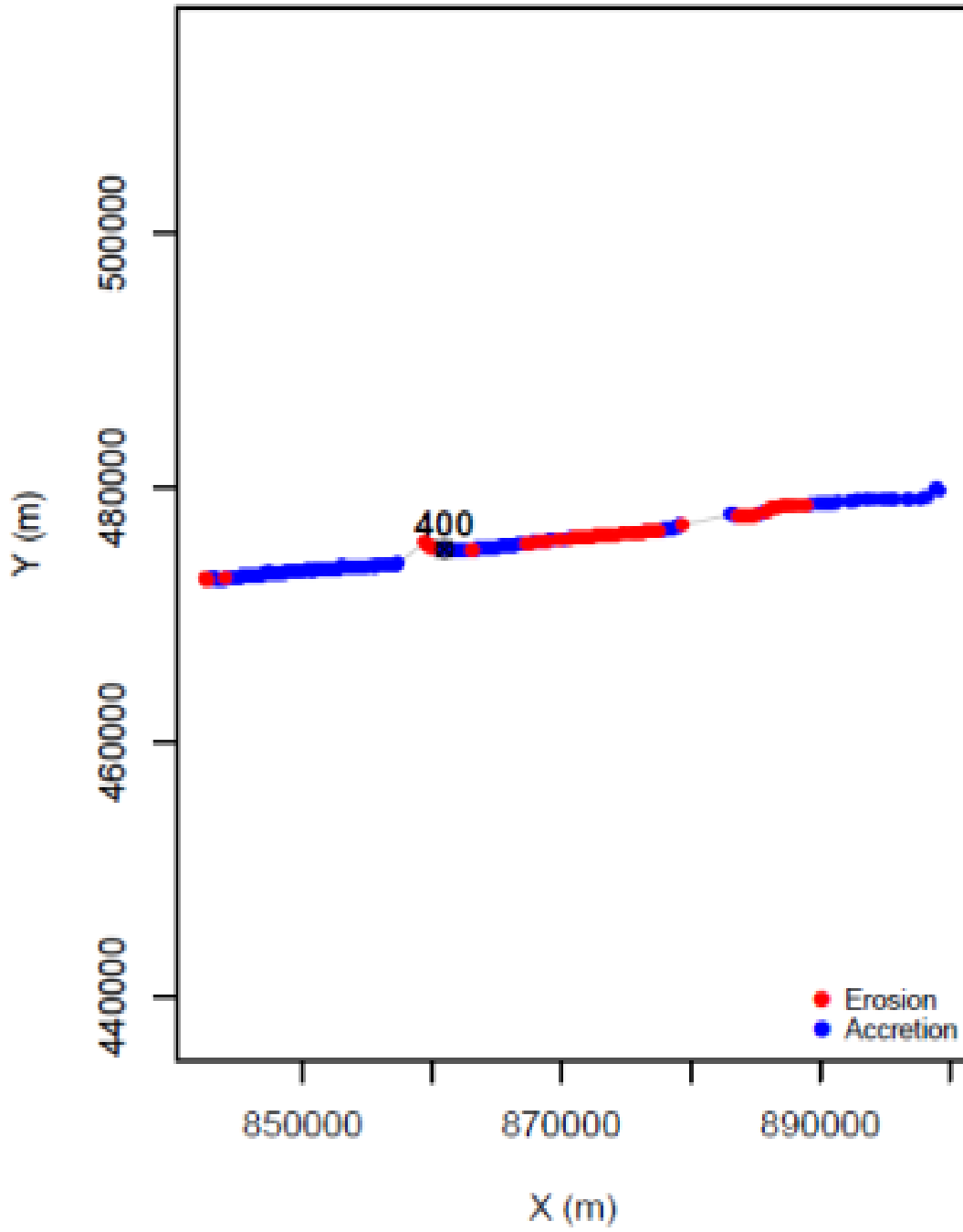


Figure 15: Range of Shoreline variation (1987 – 2013)

APPENDIX XIII

AMBUR SUMMARY REPORT	
AMBUR v.1.1.6 (20130916)	
Oldest Date:	1987-12-01 00:00:01
Youngest Date:	2002-12-01 00:00:01
Number of transects:	551
Erosion transects:	109
Accretion transects:	439
Flagged transects:	3
Maximum Erosion (m):	-275.45
Mean Erosion (m):	-34.88
Maximum Erosion Rate (m/yr):	-18.36
Mean Erosion Rate (m/yr):	-2.32
Maximum Accretion (m):	312.35
Mean Accretion (m):	82.16
Maximum Accretion Rate (m/yr):	20.82
Mean Accretion Rate (m/yr):	5.48
Overall Mean Change (m):	58.56
Overall Mean Rate (m/yr):	3.93
Analysis Date:	2015-07-03 16:29:28
Analyst:	Opuene
File:	
C:/Users/Opuene/Desktop/shorelines/AMBUR_capture2015-07-03 16_22_03 shorepts/shore_pts.shp	
Results:	
me/Desktop/shorelines/AMBUR_capture2015-07-03 16_22_03 shorepts/AMBUR_results/2015-07-03 16_29_28 ambur	
Transect Spacing:	50
Confidence Interval:	95%

Figure 16: Brass Shoreline summary report 1987 - 2002

APPENDIX XIV

AMBUR SUMMARY REPORT	
AMBUR v.1.1.6 (20130916)	
Oldest Date:	2002-12-01 00:00:01
Youngest Date:	2013-12-01 00:00:01
Number of transects:	551
Erosion transects:	240
Accretion transects:	308
Flagged transects:	3
Maximum Erosion (m):	-404.4
Mean Erosion (m):	-65.52
Maximum Erosion Rate (m/yr):	-36.76
Mean Erosion Rate (m/yr):	-5.96
Maximum Accretion (m):	540.31
Mean Accretion (m):	50.6
Maximum Accretion Rate (m/yr):	49.12
Mean Accretion Rate (m/yr):	4.6
Overall Mean Change (m):	-0.25
Overall Mean Rate (m/yr):	-0.02
Analysis Date:	2015-07-03 16:34:18
Analyst:	Opuene
File:	
C:/Users/Opuene/Desktop/shorelines/AMBUR_capture/2015-07-03 16_22_03 shorepts/shore_pts.shp	
Results:	
m/Desktop/shorelines/AMBUR_capture/2015-07-03 16_22_03 shorepts/AMBUR_results/2015-07-03 16_34_18 ambur	
Transect Spacing:	50
Confidence Interval:	95%

Figure 17: Brass Shoreline summary report 2002 - 2013

APPENDIX XV

AMBUR SUMMARY REPORT	
AMBUR v.1.1.6 (20130916)	
Oldest Date:	1987-12-01 00:00:01
Youngest Date:	2013-12-01 00:00:01
Number of transects:	551
Erosion transects:	157
Accretion transects:	394
Flagged transects:	5
Maximum Erosion (m):	-679.85
Mean Erosion (m):	-55.4
Maximum Erosion Rate (m/yr):	-26.15
Mean Erosion Rate (m/yr):	-2.14
Maximum Accretion (m):	803.17
Mean Accretion (m):	103.47
Maximum Accretion Rate (m/yr):	49.12
Mean Accretion Rate (m/yr):	4.09
Overall Mean Change (m):	58.2
Overall Mean Rate (m/yr):	2.32
Analysis Date:	2015-07-03 16:23:08
Analyst:	Opuene
File:	C:/Users/Opuene/Desktop/shorelines/AMBUR_capture/2015-07-03 16_22_03 shorepts/shore_pts.shp
Results:	m/Desktop/shorelines/AMBUR_capture/2015-07-03 16_22_03 shorepts/AMBUR_results/2015-07-03 16_23_08 ambur
Transect Spacing:	50
Confidence Interval:	95%

Figure 18: Brass Shoreline summary report 1987 - 2013