

**CAUSES AND TRENDS IN SHORELINE CHANGE IN THE  
WESTERN REGION OF GHANA**



**DEPARTMENT OF MARINE AND FISHERIES SCIENCES**

**UNIVERSITY OF GHANA**

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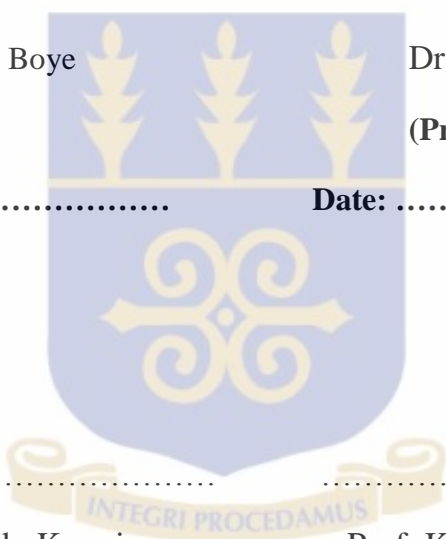


**This thesis is submitted to the University of Ghana, Legon in partial fulfilment  
of the requirement for the award of PhD Oceanography degree**

**MARCH, 2015**

## DECLARATION

I declare that this thesis is the result of a research work undertaken by Mrs Cynthia Borkai Boye in the Department of Marine and Fisheries Sciences of the University of Ghana under the supervision of Dr. George Wiafe, Dr. Appeaning Addo Kwasi and Prof. Komla Dzigbodi-Adjimah.

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## ABSTRACT

Shoreline change is an issue of concern to most coastal managers because the coastal zone is home to over 60% of the world's population. In Ghana, shoreline change has been associated with loss of economic lands and properties. Previous researches have shown that the Ghana coastline is eroding at variable rates; the Eastern and Central Zones are receding while the Western zone is thought of as stable. This opinion, however, contrasts field observations and interview with local coastal community members. This research therefore sought to determine the shoreline change trends in the study area through modelling the driving and resistive factors along the shores. The factors investigated are sea-level rise, wave impact, sediment supplied by rivers, resistance of coastal material and human impact. Multi-temporal spatial datasets, hydrodynamic datasets, geological map of the area and systematically sampled field measurements were used. Standard procedures were employed to compute values for the eight variables that were selected as proxies for the driving and resistive variables. Analysis was carried out in short-term (1974-2005) and long-term (1895-2005) change categories in shoreline trends. Average short term change rate of  $-4.18 \pm 0.10$  m/year and long term change rate of  $-7.25 \pm 0.11$  m/year were obtained for the entire study area. The results revealed that the strength of hard shore outcrops, the shear strength of the soil, the sediment supplied by rivers and human impact contributed significantly to variations in the shoreline change trends along the study area. It was identified that shoreline change trends observed in the study area is mainly caused by physical processes of wave action, which is modified by the characteristic features along the shores, and aggravated by human impact. The shoreline change trends reflect the coastal material resistance at the various sections along the coastline; this

is attributed largely to the formation history of the coast. It was, however, found out that the effect of sea level rise on the shoreline trends was minimal. The Western Section of the study area was found to be more vulnerable to erosive forces relative to the Eastern Section. It is recommended that a non-linear model be employed for confirmation of the findings.



## DEDICATION

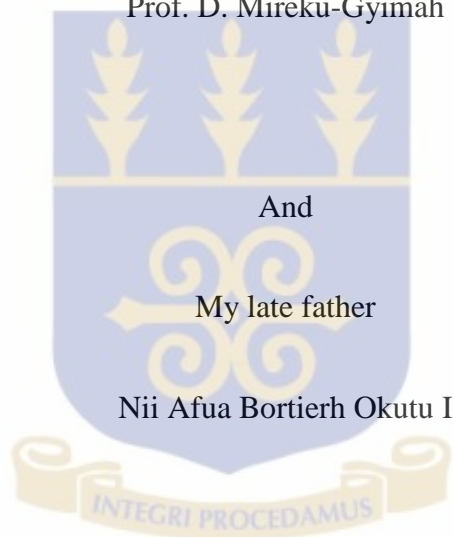
This work is dedicated to all researchers in the field of oceanography and its related fields, stakeholders of the coast and to the following who have played a pivotal role in my academic pursuits:

Dr. George Wiafe,

Dr. K. Appeaning Addo

Prof. K. Dzigbodi-Adjimah

Prof. D. Mireku-Gyimah



**And God is able to make all grace abound unto you, so that in all things at all times, having all that you need, you will abound in every good work.**

**II Corinthians 9:8**

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## LIST OF ABBREVIATIONS

|        |   |   |
|--------|---|---|
| AESC   | - | Australian Earth Science Convention                                     |
| AHP    | - | Analytic Hierarchy Process  |
| AoR    | - | Average of Rates  |
| ARIWA  | - | Atlas on Regional Integration in West Africa                            |
| ASTM   | - | American States Transport Manual  |
| CERC   | - | Coastal Engineers Research Centre                                       |
| CSIR   | - | Council for Scientific and Industrial Research                          |
| CRCFN  | - | Coastal Resources Centre / Friends of the Nation                        |
| CVI    | - | Coastal Vulnerability Index   |
| DPT    | - | Dynamic Cone Penetrometer   |
| DCPT   | - | Dynamic Cone Penetrometer Test  |
| EPA    | - | Environmental Protection Agency   |
| EPR    | - | End Point Rates   |
| GPA    | - | Global Programme of Action  |
| HWL    | - | High Water line   |
| IADC   | - | International Association of Dredging Companies                         |
| ICFG   | - | Integrated Coastal and Fisheries Governance                             |
| IPCC   | - | Intergovernmental Panel on Climate Change                               |
| IRTCES | - | International Research and Training Centre on Erosion and Sedimentation |

|        |   |  |
|--------|---|--|
| LST    | - | Longshore Sediment Transport   |
| MCDA   | - | Multi-Criteria Decision Analysis                                       |
| MRA    | - | Multiple Regression Analysis   |
| MWL    | - | Mean Water Line  |
| NICMMN | - | National Institute of Coastal and Marine Management of the Netherlands |
| NOAA   | - | National Oceanic and Atmospheric Administration                        |
| RMSE   | - | Root Mean Squared Error  |
| SCAPE  | - | Soft Coast And Platform Erosion  |
| UNESCO | - | United Nations Education, Scientific and Cultural Organization         |
| UCS    | - | Unconfined Compressive Strength  |
| UEMOA  | - | West African Economic and Monetary Union                               |
| UNEP   | - | United National Environmental Programme                                |
| UNPD   | - | United Nations development Programme                                   |
| USACE  | - | United States Army Corp of Engineers                                   |
| WHOI   | - | Wood Hole Oceanography Institutes                                      |
| WLC    | - | Winsconsin Legislative Council   |

## CHAPTER 1

### GENERAL INTRODUCTION

#### 1.1 Background

Shoreline change is the movement in the land-sea interface for a given coastline (Boak & Turner, 2005). The occurrence of this phenomenon leads to inundation and/or coastal erosion (Zhang *et al.*, 2004). Shoreline change usually serves as a good indicator of coastal erosion/accretion (Srivastava *et al.*, 2005). The shoreline is dynamic and it is influenced by several oceanographic and geomorphic stresses as well as anthropogenic factors. The shoreline feature is most commonly indicated on maps and aerial photos as the visible High Water Line (HWL) along the coast (Boak & Turner, 2005; Crowell, Leatherman, & Buckley, 1991 ; Galgano & Douglas, 2000), other datum based indicators such as the Mean Water Line (MWL) or the Mean High Water Line (MHWL) may also serve as proxy for the shoreline on maps (Boak & Turner, 2005; Mague & Foster, 2008; Moore *et al.*, 2006).

The coastal areas serve as preferred home to between 23% and 60% of the world's population (Al-Tahir & Ali, 2004; Church *et al.*, 2006; Hinrichsen, 1998). This is probably due to food security, ocean transportation and modified atmospheric weather and climate along the coast (Stewart, 2008). Coastal areas are, however, facing a global challenge of erosion or inundation (this phenomenon shifts the shoreline landwards) with about 70% of the world's sandy beaches eroding (Bird, 2008). Some consequences of coastal erosion include loss of valuable and economic lands, destruction of natural coastal

defences which results in flooding of the hinterlands, and damage of artificial coastal defences, which is likely to bring about increase in flood risks (Alexandrakis *et al.*, 2008).

Shoreline change is caused by various factors, but the three key drivers are sea-level rise (Bray & Hook, 1997; Kumar *et al.*, 2003; Nicholls *et al.*, 2007), change in storm climate (BeachMED, 2008; E. Bryant, 2001; Vassie *et al.*, 2004; Woodroffe, 2003) and human interference with the coastal processes (Ly, 1980; Mensah, 1997; Zhang *et al.*, 2004). Other factors influencing the spatial location of the shoreline include differences in alongshore sediment supply (Woodroffe, 2003), fluvial sediment supply (Al-Hatrushi *et al.*, 2005; Ly, 1980), offshore bathymetric changes (Cooper & Navas, 2004), beach composition (EUROSION, 2004), angle between approaching wave and shoreline (Ashton *et al.*, 2001), coastal material behavior (Beyeler & Sklar, 2010; Sallenger *et al.*, 2002) and platform slope (Kamphuis, 1987).

The factor of safety of the shoreline is presumed to be a function of the coastal erosive forces and the resistance offered by the coastal material (Sunamura, 1992). The specific combination of the coastal destabilising forces responsible for shoreline change pertaining to any given coastline and the corresponding shoreline responses vary from region to region. This is partly determined by the inherent characteristics of the coastal material and the extent of exposure of the coastline to erosive stresses. Each of these factors contributes differently to the total shoreline migration. The cause-effect relationship between the trigger and shoreline response is important (Allan *et al.*, 2003), as they give clues for predicting future trends. Trends in shoreline position change are usually achieved through modeling the interaction between the trigger and the response

variables. It is therefore imperative that investigations are carried out for each coastal zone so as to understand the shoreline change trends, identify the dominant factors causing its migration and possibly develop testable models that will enable future predictions (Fletcher *et al.*, 2003). Findings of this nature could inform coastal managers, thereby minimising losses due to coastal erosion.

## **1.2 Statement of Problem**

The shoreline in Ghana, like other West African coastal states, is receding at variable rates along most parts of the entire coastline (Ibe & Awosika, 1991). Population distribution in Ghana is skewed towards the coast with about 25% of the total population living along the coastal zone. About 80% of the industries in Ghana are established in the coastal zone (Wiafe *et al.*, 2013). Erosion of the Ghanaian coastline is usually associated with loss of valuable land and properties of coastal dwellers (Appeaning Addo *et al.*, 2008). An earlier research by Ly (1980) asserted that the Western Zone of the Ghanaian coastline is stable; however, field observations of eroded coastal structures, uprooted coastal trees (Figure 1) coupled with the numerous sea stacks (Figures 2a & 2b) formed along some portions of the coast contrast Ly's assertion. Again interview with local coastal community members (ICFG, 2010) confirmed that the shoreline had moved landwards, with loss of some human habitation as well as open spaces previously used as playground for the youth. For instance, Adjan, a town near Axim has lost some significant tracts of its sandy beach to the sea while the more consolidated rocky portion is gradually being engulfed by the sea (Figures 2a & 2b). Evidence of past erosion is also observed by the presence of groynes erected along some portions of the sandy coast (Figure 3).

These proofs of shoreline migration landwards call for a scientific investigation into the shoreline status of the coast so as to advise prospective coastal developers and the local authorities for effective planning.

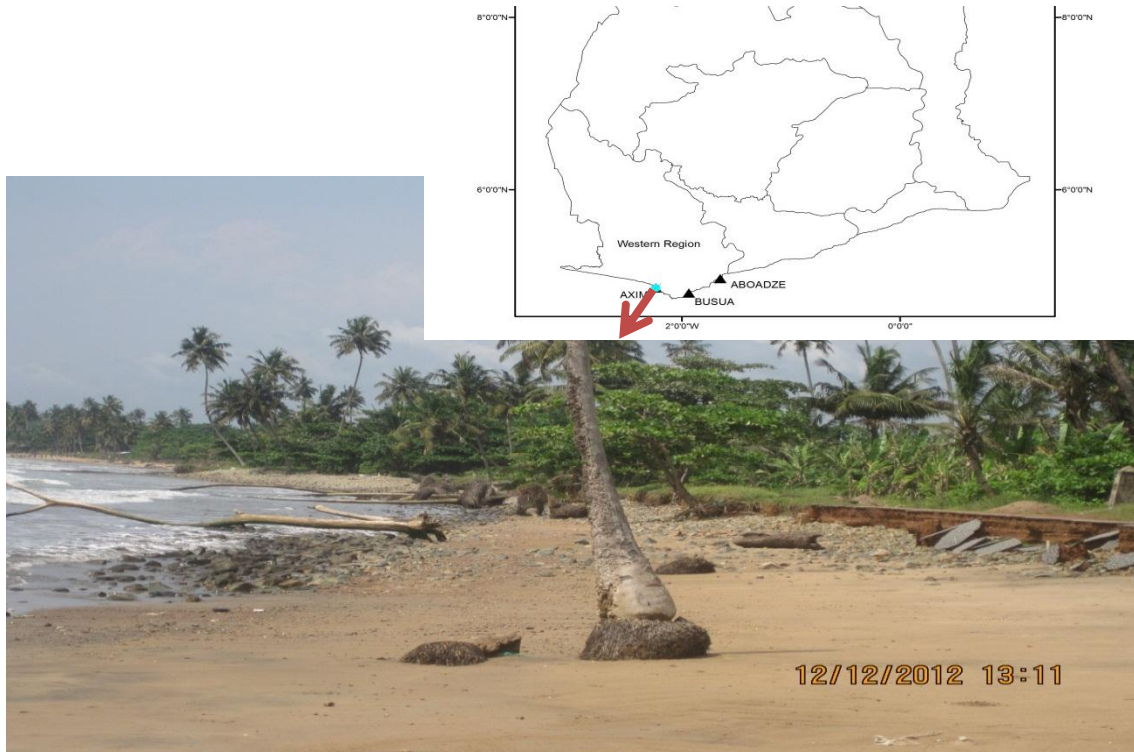


Figure 1: Destruction of Some Coastal Trees and Road by Erosion at Akyenim (near Axim)

Shoreline change investigations, like other feature change studies, require that the feature under study is detectable, measurable quantitatively and its pattern determinable to enable future predictions using modelling techniques. Investigation of the shoreline change in the Western Region could be achieved through the use of a viable quantitative prediction approach for modelling the shoreline vulnerability. Such an approach must be applicable to both the ‘soft’ and ‘hard’ coastal systems pertaining.



Figure 2a: Sea Stack Being Formed off Aboadze Beach

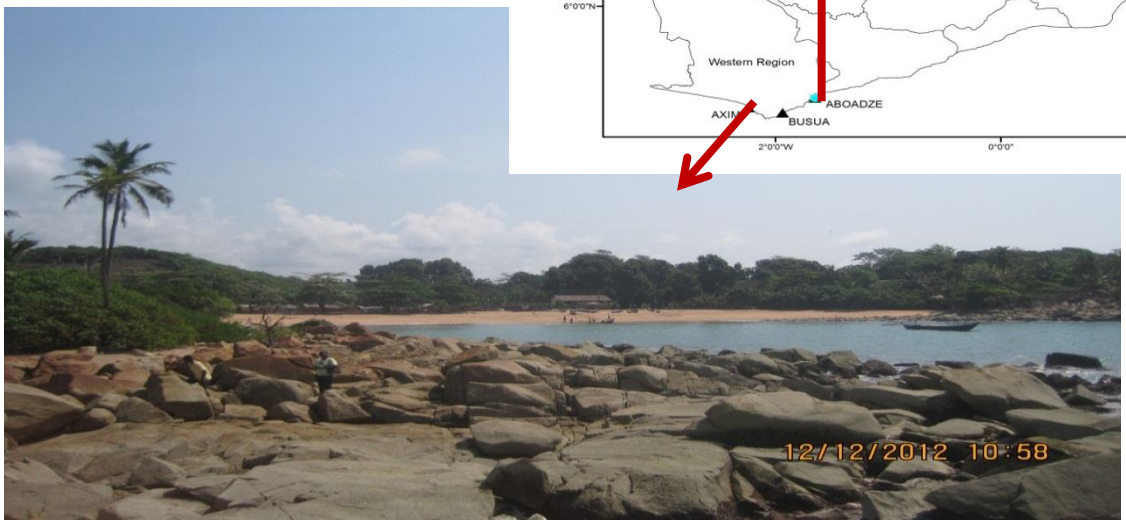


Figure 2b: Sea Stack Being Formed at Adjan (near Axim)

in the study area and must take into account the erosive and resistive factors pertaining at the shore (Wiafe *et al.*, 2013). There are however, few such viable quantitative predictive approaches, possibly because of the interplay between the various factors driving the

shoreline change phenomenon (Cooper & Pilkey, 2004). The only reliable source of information for shoreline change prediction remains current and historic shoreline data. The commonly used shoreline recession models such as End Point Rates, Average of Rates and Linear Regression by least square approaches (Dolan *et al.*, 1991; Foster & Savage, 1989) produce reliable results for soft coasts. These recession methods may yield erroneous result where the coast is non-homogeneous due to the assumption of uniform coastal material behaviour. Besides, the limitation of linear models such as the Linear Regression method to depict the cyclical trend of the shoreline renders different change rates for the same segment of the shoreline by different researches (Galgano, 2008). More so, analysis of historic shoreline data alone does not provide a comprehensive understanding of shoreline change trends (Wiafe *et al.*, 2013).

Other shore prediction models, such as that proposed by Sunamura (1992) establishes a mathematical relation between long term average rate of cliff recession as a ratio of average destructive force of waves and the average strength of the rock mass. The model, however, is applicable to shore platforms and not relevant for other coastal systems such as sandy beaches.

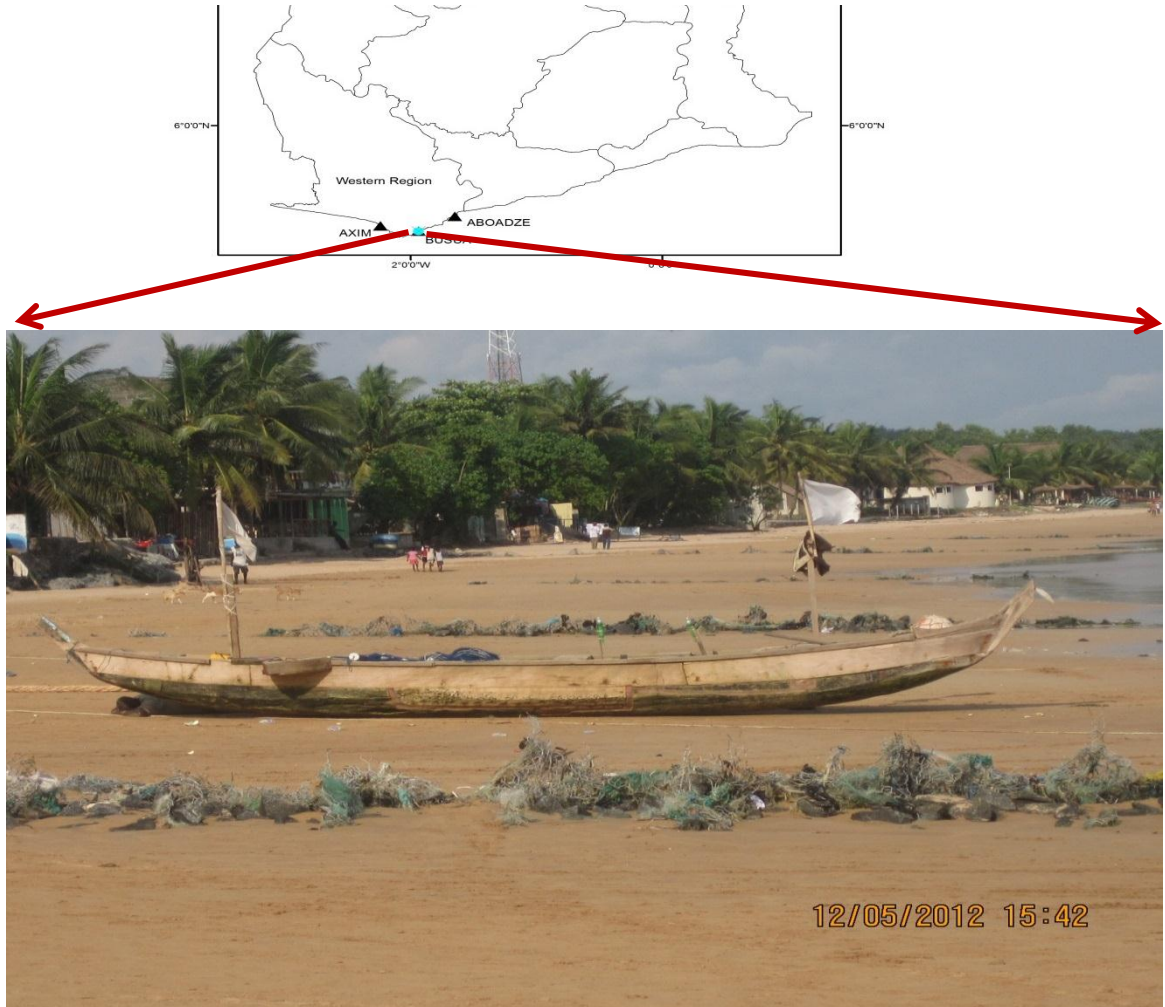


Figure 3: Beach Protected from Erosion at Busua

Again, the Soft Coast and Platform Erosion (SCAPE) model (Walkden & Hall, 2005) which is a numerical geomorphological model was formulated for future prediction of eroding 'soft' and beach shores. Application of the SCAPE model may yield erroneous results for 'hard' portions of the shore as prevails in the Western Region of Ghana. Another commonly used method of estimating coastal zone vulnerability to sea-level rise is the Coastal Vulnerability Index (CVI) (Alexandrakis *et al.*, 2008; Appeaning Addo, 2013; Shaw *et al.*, 1998; Thieler & Hamma-Klose, 1999). CVI is a relatively simple

functional method developed to estimate the vulnerability of any coastal zone to erosion in relation to future sea-level rise. Two main sets of variables are used: the geological variables and the marine process variables. The former encompasses the geomorphology, historical shoreline change and the regional coastal slope, whereas the latter includes the relative sea level rise, the mean significant wave height and the tidal range. These six variables influencing the CVI are determined and their values assessed based on existing information which are combined and interrelated spatially (Alexandrakis *et al.*, 2008). CVI is, however, an index and not a predictive tool of the future position of coastline, but provides a rank based vulnerability assessment so as to identify high risk zones.

It is in the light of these limitations of existing prediction models that this research is formulated to determine shoreline change through modelling of the geological, marine and human impact variables that drive the shoreline dynamics in the study area using Multiple Linear Regression techniques.

### **1.3 Research Aim and Objectives**

To address the problems that have been outlined (taking into consideration all the speculated factors influencing the migration of the shoreline at the Western Region of Ghana) the following aim, objectives and research hypothesis have been suggested. The overall aim of the research was:

To determine the shoreline change trends through modelling the dynamics of the driving forces.

To achieve the overall aim of this research, specific objectives were formulated through which the individual forces at play were addressed. The specific objectives were to:

- determine changes in the shoreline over short term and long term periods;
- determine how the resistivity of coastal materials influence shoreline evolution;
- assess the effect of sediment supplied along the littoral zone on the coastline responses; and
- use Multiple Regression technique to predict future shoreline positions.

In order to provide a scientific basis for the research and a speculative expected outcome, the following hypotheses were formulated:

- the shoreline change trend reflects the magnitude of the erosive forces and the corresponding resistances offered by the coastal system at each site; and
- the shoreline change trend is a function of all the driving erosive and resistive variables.

#### **1.4 Research Approach**

The research was conducted in four phases: Preliminary Work, Data Collection, Data Analysis and Impact Assessment as shown in the flowchart in Figure 4.



### Phase I (Preliminary Work)

The first phase of the research covered a review of relevant material, collection of historic ortho-rectified aerial photographs as well as topographic and geological maps of the study area. Other data acquired include recorded hydrodynamic data comprising of water surface oscillations measured offshore and tide gauge records measured at the Takoradi Harbour close to the study area. River flow data measured along the three major Rivers (Pra, Ankobra and Butre) that contribute sediment to nourish the coastline of the study area was also acquired. The shoreline change rates which served as the dependent variables were computed as well as variables understood to influence shoreline change trends identified for the study area. Finally the sampling procedure was designed.

### Phase II (Data Collection)

The second phase of the study was field measurements of the independent variables and the collection of rock and soil samples for laboratory investigations. The field measurements included distance of the exposed beach and the beach profiles. Measurements of the coastal rock outcrop rebounds and the penetration resistance connoting the compressive strength of the shore surface rocks as well as the shear strength of the soil were also recorded. Again soil and rock samples were taken at selected sample locations where practicable.

### Phase III (Data Analyses)

The data was analysed in line with the study objectives. The sea-level rise effects at the various sampled locations were evaluated for correlation and quantification. The resistance of the coastal material to erosive forces were also analysed. This was achieved by relating the compressive strengths of the rocks outcrops and the shear strength of coastal soils to their respective shoreline change rates at the different sampled locations. The effects of sediment supplied by the Rivers and those supplied along the shores by currents generated by breaking waves were analysed for correlation. Finally, stepwise multiple regression analysis was carried out to determine the contribution of identified independent variables on observed shoreline change rates.

### Phase IV (Assessment Phase)

The fourth phase of the research assessed the accuracy of the models developed by determining correlation between the shoreline change rates and a coastal vulnerability status generated from the developed models.

## **1.5 Justification of Study**

The aim of the study allowed for inclusion of key geological, marine and human induced factors in the determination of the shoreline change at spatial and temporal scales.

The specific objective one allowed for historic information of the shoreline change to be captured into the model developed. The consideration of shoreline change trends in the

short term (<60 years) and long term (>100 years) provided understanding of the seasonal fluctuation of the shoreline position as well as either the long term recession or static possibility of accretion of the shoreline. The duration for the short and long term periods were adopted from Crowell (1993) and Galgano, (2008) and in line with the hypothetical change in shoreline position that is cyclic over 100 year period as modified by Dolan (1991) and as stated in Doeke (1995). Analysis of shoreline change in short and long term allows both the linear and non-linear behaviour of shoreline change variability to be understood in spatial and temporal scales that facilitate future shoreline prediction (Stewart, 2008).

Objective two enabled the acquisition of field data on the coastal material resistance to deformation. By interrogating with the ‘hard’ shore and the ‘soft’ dune soil using appropriate equipment, such as the Dynamic Cone Penetrometer, their respective responses to deformation (strengths) were measured and fed into the model. Measurements of the coastal material resistance were carried out at the sampled locations so as to obtain accurate information about each site. The coastal dune assumed to extend at least 100 m into the hinterland from the back beach was investigated (at 50 m intervals) since the dune forms the second line of defence to wave attack especially during storm events. The strengths of the coastal cliffs were determined since the presence of these rock outcrops is indicative of the formation history of the coast which in turn influences the geomorphic processes of the coast (Granja, 2004).

Objective three allowed for sediment transported along the shore by longshore currents to be quantified within the surf zone and its correlation with the shoreline change rates

determined. The continuity of shoreline change through time is blamed on sediment transportation within the near shore zone along and across the shore (Boak & Turner, 2005). The effect of waves on shoreline change is realised through sediment erosion, transportation and the deposition of sediment entrained. Fluvial sediment brought in by rivers is conceived to contribute between 80 and 95% of the total sediment supplied to coastal beaches (Milliman *et al.*, 1995; Walling, 2006). Deficiency of fluvial sediment is blamed for higher recession rates at the Central and Eastern Zones of the Ghanaian coast (Ly, 1980). It was therefore important to investigate the effect of sediment transport on the study area.

Objective four enabled the integration of numerical modelling techniques, research hypotheses and data to enhance understanding into the shoreline evolution trends. The model enabled variables which satisfy the condition of correlation and statistical significance to be selected as driving shoreline change along the study area.

## **1.6 Thesis Structure**

This thesis is composed of six (6) chapters, list of references and appendices.

Chapter 2 presents reviews of literature on the topic and the factors driving shoreline change. Review of the methods available for modelling shoreline change, determining the trends and the techniques applied for modelling and predicting future shoreline positions are considered.

Chapter 3 comprises of the relevant information about the study area, procedures, computations and the analysis involved in shoreline change statistics, sediment supplied by rivers and along the shores by currents using hydrodynamic dataset and mean coastline orientation. In addition, procedures involved in computing shoreline change rates as dependent variables and the driving variables as predictor variables are recorded. The chapter further discusses the procedures and computations involved in measuring the surface and subsurface strength of coastal materials using the Schmidt's hammer and the Dynamic Cone Penetrometer Device respectively. Finally, methods adopted in Stepwise Linear Multiple Regression modelling and prediction equations generated for the study are documented in the chapter.

Chapter 4 consists of the results obtained from the research. It comprises of laboratory analysis, shoreline change rates considered in short and long term categories. The outcome of the Stepwise Linear Multiple Regression analysis for the entire study area, the Eastern and Western Sections of the study area are also presented in the chapter.

Chapter 5 is composed of discussion on the observed shoreline change trends in the short and long terms for the study area. Also, the identified variables controlling the shoreline change trends are discussed in line with the research specific objectives. The effects of human impact, the coastal material resistance, coastal wave impact and the effects of sediment supply by rivers and the vulnerability of the coastal dune soil are discussed. The effect of the formation history of the coast and the behaviour of the coastal material pattern are deliberated upon.

Chapter 6 presents a brief summary of the research objectives, methods employed, major findings and conclusions drawn from the research. It also contains recommendations made for future research.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

Shoreline change trends and their associated effects on coastal lands have been an issue of concern to coastal managers (Boesch *et al.*, 1994). As such, various scientific research efforts have been carried out to investigate the factors driving these change trends. This is because a clear understanding of the factors influencing shoreline change is required before appropriate solutions could be obtained. The specific factors destabilising the shoreline pertaining to any given coast and the corresponding responses from the coastal material vary in spatial and temporal scales. The stretch of coastline usually exposed to high intensity of erosive forces is more vulnerable to shoreline change particularly in areas where the coastal material exhibit low resistive characteristics. Portions of the shoreline exposed to medium to low erosive attack tends to be more resilient especially in the case where the coastal material have high resistive properties (Briaud, 2005; Sunamura, 1992).

Some research efforts including those conducted in the study area are reviewed in this section. These research works are directed toward understanding the causes of shoreline change, determining the interaction and interdependence among the agents driving the phenomenon and possibly predicting future trends.

In a research along Massachusetts (North-East of the United States) shore by the Wood Hole Oceanography Institutes (WHOI, 2014), the quest to understand the shoreline change phenomenon within the region was achieved using spatial datasets spanning 140

years. The study which covered a stretch of 1000 miles of shore identified relative sea level rise as the key driving force causing the shoreline change in the area. Results of the research revealed that erosion caused by relative sea level rise was far greater in the area than erosion caused by wave action. Shoreline recession rates recorded ranged between 0.18 m/year and 4 m/year. The research further identified vulnerable zones subjected to both short and long term erosion within the study area.

Morton (1977), carried out a research along the Texas Gulf (South-Central of the United States) coast using charts, aerial photographs and other datasets spanning 125 years. The investigation revealed that both accretion and erosion of the shoreline are taking place in the region. This observation is believed to be a reflection of changes in the littoral drift cells. Reduction in sediment supply and continuing relative sea level rise, including compaction subsidence, were also identified to be responsible for shoreline change in the area. The research also projects that most parts of the Texas coast will continue to retreat landwards as part of the long term erosion trends. Short term shoreline change trend was identified to be caused by complex interaction of climate change, sediment budget, coastal processes, sea level rise and human activities (Morton, 1977).

Investigation carried out along the Hawaii (Northern Island of the United States) coast by Romine *et al.*, (2013) with the aim of determining the causes of shoreline retreat along that coast revealed that sea level rise is the principal cause of shoreline retreat in Hawaii. Relative sea level rise along the coast of Hawaii was attributed to variation in island subsidence. Other factors found to be influencing shoreline change in the study area included waves, sediment supply and littoral processes, and anthropogenic interferences.

Shoreline change rates recorded range between 0.3 m/year – 1.3 m/year (Romine *et al.*, 2013).

In a research conducted along the shores of Puerto Rico Island (North-Eastern Caribbean) (Thieler *et al.*, 2007) the researchers sought to understand how the physical, oceanographic, geomorphic and anthropogenic variables contributed to coastal erosion in the study area. This effort was to provide the information needed for management of coastal resources. The research enabled a geomorphic model to be developed for the study area and other Caribbean Island coastal areas. The methods employed included classification of the study site, and the determination of shoreline change rates at selected sites. These were combined with beach profiles, image analysis and sediment data, from which wave regime, shelf morphology and coastal lithology parameters were used to determine the natural beach processes along the coastal site.

Dehouch, (2004) monitored the shoreline change along an 8 km sandy coast at the entrance of the English Channel, West Brittany (North-west France). Near-vertical aerial photographs taken between 1952 and 2000 were used for the study. This enabled knowledge of the shoreline dynamics along the study area to be acquired. The evolution of the beaches are believed to be driven by sea level rise due to high tidal regimes (7.5 m spring tides), moderate changes in the wave climate and anthropogenic factors. The results of the research revealed that shoreline variability along that coast experienced erosional periods from the early 1950s to the beginning of the 1990s (0.2 – 2.0 m/year). This period of erosion was followed by a period of recovery which took place along larger portions of the coast from the 1990s to 2000 with accretion recorded (0.2 – 3.3 m/year).

Corbella & Stretch (2012) researched along the Eastern Coast of South Africa to determine trends in shoreline or beach evolution and the causative factors. Beach profiles and tide gauge records spanning a 37 year period taken in three time histories, and wave datasets taken over a period of 18 years were used for the study. Under the assumption that waves, tides, sea level, wind and anthropogenic influences are the causative factors, the effects of proxies of these factors namely maximum significant wave height, average wave direction, peak period, and storm frequencies, were analysed against the measured erosion rates. The results indicated an average erosion rate of  $1.97 \text{ m}^3\text{m}^{-1}\text{yr}^{-1}$  and a projected rate of  $2.06 \text{ m}^3\text{m}^{-1}\text{yr}^{-1}$ . Of all the assumed contributors evaluated, only the peak period and wave directions showed statistical significant influence on shoreline or beach evolution. Changes observed in the shoreline or beaches were attributed to sea level rise and reduction in sediment supply to the beach.

An earlier study carried out along the coast of the Nile Delta in Egypt in 2003 to determine beach responses to rising sea levels. It was revealed that the 35 km stretch of the coast between Alexandria and Port Said is vulnerable due to the effect of a combination of sea level rise and other factors such as river sediment deficiency and local subsidence rate (Frihy, 2003). A follow-up study to determine the extent of vulnerability of the coast to erosion due to sea level rise integrated multiple criteria techniques to identify three factors which significantly influence shoreline change in the study area (Agrawala *et al.*, 2004). This aided in the categorisation of the coast based on its susceptibility to erosion due to sea-level rise.

Shoreline change and its associated coastal erosion are recognised as a crucial issue along the coast of West Africa as it is reported that erosion rates ranging between 23 and 30 m annually are recorded along some areas (Ibe & Queleennac, 1989). The Intergovernmental Panel on Climate Change (IPCC) indicated that the west coast of Africa is pounded by storm surges and it is at risk from erosion, inundation and extreme storm events (IPCC, 2007).

Allersma, (1993) also reported of potential increase in tidal waves, storm surges, and hazards along the West African coast which may modify littoral transport. It is also reported from environmentalist's point of view that coastal erosion along the West African coastline is due to sea-level rise resulting from global warming, the construction of ports and hydropower dams and sand mining among others. It is thought that the construction of ports and harbours perpendicular to the littoral zone causes acute down-drift erosion as experienced in Benin, Côte d'Ivoire, Ghana, Liberia, Nigeria and Togo (Wellens-Mensah, 1994; UNEP, 1999). The ever increasing human population along the coast, over dependency of coastal material for domestic and industrial use from estuaries and beaches coupled with the oceanographic influences pose some stresses along the shores rendering them vulnerable.

In Ghana, shoreline change in the Eastern and Central zones of the coastline has been reported to be associated with past and present human interventions on coastal processes (Boateng, 2009; Ly, 1980; Mensah, 1997). Ly (1980) opinion that sediment deficit to the coast, aftermath of the damming of the Volta River at Akosombo (1961-1965), contributed significantly to shoreline recession rates recorded along the Eastern zone of

the Ghanaian coast (e.g. Keta and Ada) is confirmed (UNEP, 1999). Again shoreline recession rates recorded within portions of the Central Zone are thought of as emanating from interference of coastal processes due to the construction of the Tema Fishing Harbour.

Furthermore, shoreline recession in parts of the coast of Ghana is attributed to *ad hoc* methods of intervention usually adopted in the country. The technology of using 'hard' coastal material to protect sections of eroding coast results in shifting the erosion downstream. Boateng (2009) recommended the adoption of an integrated shoreline management approach in solving coastal erosion issues in Ghana.

Armah (1991) concluded that shoreline change in Ghana is as a result of anthropogenic factors and local and global sea-level rise effects due to climate change. (Appeaning Addo *et al.*, 2011) in their study along the shores of Dansoman, a suburb of Accra, declared the area to be vulnerable to flooding due to rising sea levels. Their study further claimed that about 650 000 people living in about 1 000 coastal buildings would be affected by 2100. Olympio and Amos-Abanyie (2013) studied on the effects of shoreline change on coastal infrastructure along Nkontompo in Western Ghana recorded high recession rates of about 2 m/year. The study recommended a new legislation that will create a setback line for coastal development to be enacted so as to reduce the losses caused by coastal erosion. The proposed setback distance should be based on the current shoreline recession rates and the 60 year average life span of buildings (Ranson, 1987). The stresses exerted on the coast due to rising coastal population which stands at population growth rate of 3%,

coupled with the recession of the shoreline renders the coast vulnerable (Apeaning Addo *et al.*, 2011).

Though increasing coastal population is perceived to have some effect on shoreline change, the extent to which the shoreline is affected by growing coastal population is unclear and often not easy to quantify (Boesch *et al.*, 1994). It was also reported (Mensah, 1997) that sand mining along the coast to support the construction industry is prevalent along portions of the Ghanaian coast in varying proportions more especially within section of the Western zone of the Ghanaian coast.

The coast of the Western Region of Ghana (which lies within the Western and Central portions of the Ghanaian coast) has increased demand for land for establishment of oil companies and plants, and that requires resettlement of local communities as a result of the discovery of crude oil off its continental shelf (Otoo, 2013; Planitz & Kuzu, 2014). Scores of investors in the oil companies are operating within the Region's territorial waters and require coastal lands for developmental projects. Some of these companies may embark upon on-land loading and oil processing plants which are likely to be sited along the coast. Again, the tourist industry is likely to invest into new hotel facilities to accommodate the increasing number of tourists, foreign immigrants and investors visiting the Region. This is because the oil industry is capital intensive and therefore requires highly skilled labour most of who are expatriates or from the country's capital, Accra (Otoo, 2013). Since few extensive scientific investigations have been carried out on the shoreline change phenomenon, it is imperative that research efforts be invested along this coast to inform developers of future shoreline trends.

## 2.2 Natural Factors Influencing Shoreline Change

Shoreline change is a product of coastal landforms, a process influenced by both natural and anthropogenic factors. Coastal landforms are usually initiated by geologic activities but often modified by both oceanographic and geomorphic factors, prominent among these are land and sea level changes, waves, tides, wind and currents.

### 2.2.1 *Land and Sea level Changes*

Shoreline position varies in spatial and temporal scales as a result of the land and sea level change. Changes between land and sea levels emanates from two sources: relative levels between land and sea, and changes in the sea levels. The former may come about due to tectonic movement of the earth resulting in uplift or subsidence of the land in which case the land-sea boundary are dictated by the landform pertaining to the area. This situation may occur in areas of known history of tectonic activities or areas liable to earth quakes (Bird, 2008).

On the other hand, changes in sea levels may be due to variation in the sea level. Changes resulting from actual rise or fall of sea levels may be attributed to variations in temperature, pressure and/or the volume of the ocean basin. Eustatic movement usually occurs as a result of imbalances in the distribution of solar energy round the globe which create pressure differences causing increases or decreases in the volume of water in the oceans (Church *et al.*, 2001).

Rising sea levels may be partly attributed to climatic change and global warming due to greenhouse effect (Nerem *et al.*, 2010). Global warming causes general rise in the average

temperature of the oceans leading to melting of glaciers in some temperate but non-polar regions (Church *et al.*, 2001) which consequently causes rise in the water levels. Irrespective of what initiates changes in the land-sea levels, relative sea level rise is the resultant of these land and sea changes.

Sea levels relative to land elevation is understood to have changed over several geologic periods with relative height difference ranging from negative 130 m to a few meters, according to the Late Pleistocene and Holocene Sea level Curve (Imbrie & Imbrie, 1979). In the past six thousand years, however, most of the world's coastline has experienced a phase of stand-still, and the sea has remained at its present relative level (Lambeck *et al.*, 2002). During the last decades of the 20<sup>th</sup> century, nonetheless, attention was drawn to global warming because of evidence that the industrial age and human activities are producing a significant influence on climate (Barth & Titus, 1984). Climate change models now project between 1.5°C to 2.5°C increases in global temperatures during the 21<sup>st</sup> century (IPCC, 2007). Rise in temperature of this magnitude could lead to sea level rise between 18 cm to 59 cm above the 2000 levels by 2100 (IPCC, 2007). A global sea level rise of 10 to 25 cm was recorded over the last century. The forecast for the global sea level rise for the next century varies considerably; however, the central estimates are 0.2 m and 0.6 m at the middle and end of the 21<sup>st</sup> century, respectively, according to Intergovernmental Panel on Climate Change (IPCC, 2007).

Sea level rise according to some researches (Group, 1998; Zhang *et al.*, 1997; 2000) is one of the key factors to shoreline change. Sea level rise causes changes in the position of the shoreline that commensurate with the mean slope of the beach profile. As sea levels

rise, the shoreline migrates landward; with gently sloping coastal areas experiencing significant change in shoreline whereas steep sloping coastal areas experience minimal change in shoreline (Nicholls *et al.*, 2007). For instance, for low-lying regions such as marshes, an increase in the sea level much beyond a few millimetres per year may result in destruction of plants such as mangroves (Zhang *et al.*, 2004) and coral reefs (Wielgus *et al.*, 2010). It is anticipated that one centimetre rise in sea level may cause a corresponding horizontal displacement of one metre of the shoreline (BeachMED, 2008). It is also opined that as the water levels increase, storm climate may change influencing sediment budget within the littoral area (Nicholls *et al.*, 2007). A relation developed between shoreline change due to sea level rise, beach slope and rising water levels (Allan *et al.*, 2003) was explored in this present research, to assess the effect of sea level rise on shoreline change for the study area.

### 2.2.2 Wave Action

Apart from sea level rise, another school of thought opined that a potential consequence of climate change is an alteration in the frequency of extreme storm surge events that could cause shoreline change (Zhang *et al.*, 2004). The storm events could impact the coast causing erosion and inundation (Lowe *et al.*, 2001). Changes in the wave climate significantly influences the occurrence of coastal erosion (Bryant, 2001; Vassie *et al.*, 2004; Woodroffe, 2003) thereby affecting shoreline position. Waves, which are the vertical motions of the ocean surface, are basically caused by disturbances of the equilibrium state by prolonged strong winds (Gill, 1982). Waves propagate energy through the water body over long fetch distances and time much larger than the characteristic

wave lengths and periods of the disturbances (Garrison, 2013). As waves travel their intensity is influenced by their wave height, wave steepness and velocity of waves (Bird, 2011).

Large variety of waves is found on the ocean (trans-tidal waves, tides, seiches and wind generated waves) with each category identified by their characteristic wave lengths and periods (Holthuijsen, 2007). Waves with the longest wave lengths are the trans-tidal waves, which are generated by low-frequency fluctuations in the Earth's crust and atmosphere. Tides, which have slightly shorter wave lengths, are generated by the interaction between the Earth and the Moon on one hand and earth and the Sun on the other hand. The period of tides range from a few hours to a little more than a day and their wave lengths accordingly vary from a few hundred to over thousand kilometers (Holthuijsen, 2007). Seiches or storm surges have wavelengths and periods usually slightly shorter than those of tides. A storm surge is described as the large scale elevation of the ocean surface in severe storm, generated by low atmospheric pressure and high wind speeds in the storm (Holthuijsen, 2007). The intensity of a storm surge is directly related to the space and time scale of the generating storm. Wind generated surface waves are the type that occur both at the oceans and coasts all over the world. Wind-generated waves have shorter periods than 30 seconds. When dominated by gravity (periods longer than 1/4 seconds), the waves are referred to as surface gravity waves. When generated by the local winds, the waves are irregular and short-crested, and often called wind-sea. When they leave the generation area, the waves take on a regular and long-crested appearance and are called swell. These types of waves are the dominant waves considered

in this research based on the characteristics of off shore wave data procured for the research.

Waves approaching the continental shelf of the Ghanaian coast and the West African sub-region as a whole originate from the South Atlantic Ocean (Hopsch *et al.*, 2007). They travel over long fetches and approach the coast uninterrupted by any land mass. These waves arrive at the coast as swells, mixed with waves generated by local winds (seas). The seas are generated by the prevailing south-westerly winds, while the waves are produced by storms south of the trade wind belt (AESC, 1988).

Waves are observed to be responsible for causing geomorphic changes along most open-coast shores (Hapke *et al.*, 2006). This is because waves of greatest energy are produced over long fetches as winds blow continuously in a specific direction over open oceans (Morton *et al.*, 2004). Large ocean waves formed in the open ocean continue to grow as they absorb energy from the wind until their wave height to length ratio equals one seventh ( $1/7$ ) when they decay making white caps (Garrison, 2013). This process is repeated for other waves within the train; as they get closer to the shore most large waves break down in size and speed. According to Thornton (1983), the largest waves tend to break farthest offshore and the small waves closer to the shore.

This notwithstanding, waves arriving at the shore possess inherent energy which they transmit from the generating source over long distances with minimal energy losses until obstacles are encountered. At this point, they break and dissipate their energy (Holthuijsen, 2007). Waves usually break as they travel from deep water to the surf zone.

This results in energy conversion with subsequent turbulence and generation of other forms of energy. This phenomenon which is associated with wave breaking greatly influences both the behaviour of sediment on the beaches and the magnitude of the forces experienced by coastal structures (Hedges, 1976). Wave breaking within the surf zone mostly occurs due to unstable wave steepness and bottom friction (Fredsoe & Deigaard, 1992; Hinrichsen, 1998; Thornton & Guza, 1983). Along the coast of Ghana, the principal cause of wave-energy dissipation is conceived to be bottom friction due to the broad width of the continental shelf (Apeaning Addo, 2011). There is, therefore, considerable reduction in the amount of energy produced from offshore waves as they approach the country's coast.

Other forms of energy generated after wave decays produce currents capable of moving sediment. Sediment movement takes place due to the intensity of turbulence produced by breaking waves coupled with the shallowness of the water which makes it easy for sediment to dislodge from the bottom by the disturbed water (Kumar *et al.*, 2003). The amount of sediment transported by breaking waves is dependent on the wave energy at breaking, which is also influenced by the wave height at breaking point and the intensity of the current produced within the surf zone (Fredsoe & Deigaard, 1992; Masselink & Hughes, 2003).

Some mathematical equations have been formulated by Mitchell (1893) to determine wave energy at breaking point as follows:

$$[aK]_{max} = 0.44 \quad (2.1)$$

where  $a$  is the wave amplitude (m) and  $K$  the wave number (cycles per unit time).

Mitchell (1893) was the first to suggest that a monochromatic wave has a limiting steepness expressed as Equation 2.1. The limiting steepness expresses the wave height to length ratio beyond which waves break and dissipate or convert their energy into other forms.

Later, Longuet-Higgins (1977) and Fox (1978) developed a simple model for wave breaking which is still used for prediction purposes (Lin & Liu, 1998). An advanced form of the Wave Analysis Model (WAM) was formulated in 1988 which is capable of calculating the spectral wave breaking based on modern formulation. The input variables in the WAM formulae are based on the mean wave steepness, mean phase velocity and energy density in the frequency and direction domain. However, using these formulae may not be reliable since wave breaking is more affected by individual wave characteristics rather than the mean wave properties (Lin & Liu, 1998).

As individual waves in trains move from deep water into shallow waters, friction generated between the approaching waves and the bottom of the sea bed cause the waves to break. Waves usually break in shallow waters when the ratio of the height to local water depth is as expressed in Equation (2.2) (Fredsoe & Deigaard, 1992).

$$\frac{\text{Wave height } (H)}{\text{local water depth } (D)} = 0.8 \quad (2.2)$$

Apart from local water depth and wave height, the slope characteristic of the beach also controls wave breaking patterns in the surf zone. Three types of wave breaking occur based on the slope characteristics of the beach, namely spilling, plunging and surging breakers (Holthuijsen, 2007). Spilling breaker often happens where the beach slope is flat, while plunging occurs on steep beach slopes, and beaches with characteristic steep beach slope. Galvin (1968) established a relationship between the wave geometry and the breaker type. The relationship was expressed in terms of the waves' characteristic surf similarity parameter  $\xi$  as expressed in Equation (2.3)

$$\xi = \frac{\tan\beta}{\sqrt{\frac{H}{L}}} \quad (2.3)$$

Where the  $\tan\beta$  is the beach slope and  $H/L$  is the wave steepness. The wave steepness is usually calculated from deep water (o) or at breaking (b). Range of values of the waves surf similarity parameter  $\xi$  for different types of breaking waves are:

Spilling breakers;  $\xi_o < 0.5$  or  $\xi_b < 0.4$

Plunging breakers;  $0.5 < \xi_o < 3.3$  or  $0.4 < \xi_b < 2.0$

Surging breakers;  $3.3 < \xi_b$  or  $2.0 < \xi_o$

Anderson (1983) developed an empirical relation for the determination of water depth at wave breaking point as follows:

$$\frac{H}{D} = 0.5 + 0.3 \exp\left(-0.11 * \frac{\Delta x}{D_b}\right) \quad (2.4)$$

Where  $\Delta x$  is the distance inshore at the breaker point  $H_b$  and  $D_b$  is the water depth at the breaker point.

Assuming breaking waves can be described under the linear shallow water wave theory then the wave height at breaking can be estimated from the deep water condition. Supposing the wave height and length at deep water are  $H_o$  and  $L_o$  respectively, then:

$$L_o = \frac{g}{2\pi} T^2 \quad (2.5)$$

where  $T$  is the measured wave period and  $g$  acceleration due to gravity.

The speed or celerity  $C_o$  of waves in deep water and at breaking point  $C_b$  in shallow water respectively under the linear wave theory are as follows:

$$C_o = \sqrt{\frac{gL_o}{2\pi}} \text{ and } C_b = \frac{gL_o}{2\tau} \tanh \left[ 2\tau \frac{d}{L_o} \right] \quad (2.5a)$$

Where  $d$  is the water depth of the shallow water.

Assuming no energy losses occur between the deep water and breaking point, then the shore-normal energy flux at deep water  $E_{fo}$  is equal to the energy flux at breaking  $E_{fb}$ . By the deep water and shallow water linear wave theory respectively and Equation 2.5a:

$$E_{fo} = \frac{1}{16} * \rho g H_o^2 C_o = \frac{1}{16} * \rho g H_o^2 \frac{g}{2\pi} T \quad (2.6)$$

and

$$E_{fb} = \frac{1}{8} * \rho g H_b^2 C_b = \frac{1}{8} * \rho g H_b^2 \sqrt{g D_b} \quad (2.7)$$

Where  $C_o$  and  $C_b$  are the celerity of waves offshore (deep water) and at breaking point respectively.

Equating Equations (2.7) and (2.8) and substituting Equation (2.6) into the ensuing result yields:

$$\frac{H_b}{H_o} = \left[ (2\sqrt{2.5\pi}) \sqrt{\frac{H_o}{L_o}} \right]^{\frac{2}{5}} \quad (2.8)$$

Therefore

$$\frac{H_b}{H_o} = 0.5 * \sqrt{\frac{L_o}{H_o}} \quad (2.9)$$

Equation 2.9 is applicable to swell waves which travel through deep water with minimal energy losses until they reach shallow water where they experience friction at the bottom. As the wave approaches the shore, the speed reduces and finally it breaks dissipating part of its energy while the remaining is used to transport sediment back and forth the shore. This happens especially where the wave approaches the shore at an oblique angle. The movement of sediment by breaking waves (erosion and deposition) is a natural factor driving coastal erosion together with other driving factors such as tides and currents. Equations (2.5) – (2.9) are employed for the transformation of measured offshore directional wave data to near shore conditions at breaking point. This is used for the computation of sediment transported by breaking waves in this research.

### 2.2.3 *Tidal Effects on Shoreline Change*

Tide is the periodic rise and fall of the sea level. This usually occurs on average, every 12 hours and 26 minutes (Holmes, 1978). Tides are caused by differential gravitational attraction between the earth and the moon on one hand, and the earth and the sun on the other hand, as the moon and earth rotate about the earth and sun respectively about their barycentre. The effect of the attraction of the earth to the moon is much greater than that between the sun and the earth as a result of the relatively shorter distance between the moon and the earth. When the positions of the earth, moon and sun are aligned in a straight line a maximum tide occurs. This is referred to as spring tides. Conversely, neap tide occurs when the position of the moon and sun are at right angles relative to the earth. Generally, the amount of tide experienced at any given coast varies depending on the position of the moon and sun relative to the earth, and also the configuration of the coastline.

According to Davis (1973) a third of the world's coasts experience minimal tide i.e. *micro* tides with tidal range between 0 and 2 m; these coasts usually occur along open oceans of the world. Coasts along open oceans or enclosed basins such as around the Mediterranean or the Black sea (Holmes, 1978) are some examples of coasts exposed to micro tides. The next third proportion of the world's coasts experience intermediate tides i.e. *meso* tides (2 - 4 m) while the remaining third of the coasts have tides exceeding 4 m. Macro tides coasts are usually along shallow seas especially where the tide is concentrated between converging shores. For instance, around the British Isles, tidal ranges between 6 – 9 m are common (Holmes, 1978). According to the NOAA (2014), the highest tides in the world

are recorded in Canada at Bay of Fundy in Nova Scotia (16.3 m), followed by Alaska (USA) where a tidal range of 12.2 m has been recorded.

It is important to note that tides in themselves do not move significant amount of sediment to cause shoreline change, but the currents they generate in constricted bodies of water. Tides on open coasts tend to control the water level at which waves strike the shore. The near shore bathymetry and the shape of the coast also influence the storm tides (surge) flowing higher into shallow embayment (Kim, 2010).

Oftentimes, tide and wave energies combine in shaping coasts. Depending on the significant energy source driving the formation of coasts, a coast may be classified as tide-dominated, wave-dominated or mixed-energy (Hayes, 1979). Sedimentary coasts are more susceptible to erosion with time (Masselink & Hughes, 2003) and are thus more liable to geomorphic processes. Where tides along sedimentary coasts are low, the coastline tends to be more linear in shape as beaches are formed by waves. Under such scenario, the beaches are aligned in the direction of incoming wave crests (Hayes, 1979). In situations of high tide range, waves tend to have less time to work at perpendicular levels; rather they breaks up any shore parallel bars or barrier islands into more perpendicular features (Short, 2013). Intermediate to the two ends of the spectrum of wave-dominated or tide-dominated is a mixed energy coast, where waves and tides combine to control the shape of the shoreline. This information was employed to assess the type of coastline within the study area.

#### 2.2.4 *Currents*

Currents, in general are fluids in motion from a region of higher concentration to one with lower concentration. They are the sum of the entire horizontal or vertical movements of fluids (water) seen along both surface and deep water throughout the world's oceans. Currents are masses of streams, flowing rivers that circulate water and heat around the oceans persistently. An ocean current is a continuous, directed movement by the forces acting upon it. These forces may be due to tides, winds, waves or by differences in temperature, salinity etc. The configurations and interaction with other currents influence a current's direction and strength (Garrison, 2013).

Currents normally move in a specific direction and aid significantly in the circulation of the Earth's moisture, the resultant weather, and water pollution (Garrison, 2013). Oceanic currents are found all over the globe and vary in size, importance, and strength.

The world's ocean currents may be grouped into two namely, the uppermost currents, and the under currents. The uppermost currents constitute about 10% of the total and it is referred to as surface currents. They are initiated by thermal expansion and contraction, stress of winds blowing over a body of water and by density differences in the water layers. Temperature differences between tropical waters and polar or temperate waters (which receive varying proportions of the solar energy) result in increased water volumes of the former. Thus tropical waters have relatively higher water level compared to polar waters. This phenomenon generates elevation differences between waters of the warmer equatorial regions and that of the cooler polar or temperate waters which further creates pressure differences resulting in the horizontal movement of air masses. Horizontal

currents of water of this nature also flow -far off the coast- from regions of higher water level to lower water levels within the ocean

Vertical flow of currents may also occur in response to wind blowing near the oceans or seas. In general, ocean current originates from the sun and winds, and they are sustained by gravity and the ensuing surface tension created. The flow of ocean currents is directed and controlled by secondary factors such as Coriolis effects, gravity, friction and the shape of the oceanic basin (Holthuijsen, 2007).

In the near shore zone, the major current components include wave-induced current, tidal currents, wind driven currents, and river flow (near the mouths of rivers). These current components act together with the dynamics morphology and generate complicated near shore current circulation patterns (Pruszek *et al.*, 2002). Longshore current is a current in the water beyond the influence of the waves where material is carried in suspension (mud and clay) along the coast in the direction of the prevailing wind. This provides information on the effect of sediment transported along the shore on shoreline change as applied in this research.

### **2.3 Anthropogenic Factors Influencing Shoreline Change**

Human factors influencing shoreline change is synonymous to human impact on coastal processes. It is the third candidate assumed to be driving shoreline change. Human interference with coastal process obstructs the natural flow of sediment within the coastal system. Some ways by which human interfere with coastal processes include the anthropogenic interventions on natural sediment transport processes along the coast

(Doeke, 1995), blocking of sediment supplied by rivers from reaching the coasts (Walling, 2006), removal of beach material, and stresses imposed on the coast by human population.

Human efforts to develop the coastal area turn to adversely affect the natural processes along the coast. For instance the construction of coastal structures such as breakwaters end up interrupting the progress of waves to the beach, weakening the alongshore current and allowing sand to accumulate there (Garrison, 2013). Again, the diversion or damming of rivers which discharge their sediment load into the sea lead to sediment starvation along the coast causing severe erosion (Milliman *et al.*, 1995; Walling, 2006). Moreover, high human population along the coast and the mining for coastal material, typically sand, for construction purposes poses a threat to the shoreline position.

### *2.3.1 Human Influence on Natural Sediment Transportation*

Wave breaking and the subsequent sediment movement within the surf zone contribute significantly to the dynamics of the coast (Fredsoe & Deigaard, 1992). Sediment within the surf zone aids in the dissipation of wave energy thus reducing the extent of geomorphic work carried out along the surf zone. The construction of artificial structures along the coast has tremendous impact on beaches by altering the natural pattern of ocean waves, currents and littoral transport along the shore. Examples of these artificial structures are harbours, seawalls, groynes and jetties. Although they are intended to moderate condition along portions of the coastline by redirecting rivers and streams, often they cause downstream erosion problems (Airoldi *et al.*, 2005) with associated cost exceeding the construction cost of the structures originally being protected.

Construction of artificial harbours required building of series of breakwaters and jetties. When these are built in areas subjected to high energy wave action, they interrupt littoral drift resulting in severe erosion downstream. This is particularly true where the harbours are designed such that the direction of net wave approach is not perpendicular to the shore. Jetties, like groynes, interrupt and redirect longshore current causing accumulation of sand upstream at the expense of the downstream thereby creating permanent disruption of the equilibrium system of the beach. The equation of the effects of humans on shoreline change was derived and included in the modelling processes in this research.

### 2.3.2 *Beach Sediment Blockage*

Beaches are the dynamic piles of sediment mostly sand at the coast. Sediment, which refers to solid material recently moved and deposited along the coast, form an integral part of any coastal environment. Beach sediment originates from diverse sources such as disintegration of parent rocks (Gilbert, 1877), fluvial (Al-Hatrushi *et al.*, 2005; Bittencourt *et al.*, 2005; Ly, 1980), erosion of cliffs, alongshore drift and from constructive waves and currents which bring material up the beach from the sea. Strong winds blowing parallel to the coast generate local waves and currents which erode and deposit sediment along the coastline.

Sediment is typically transported due to a combination of the force of gravity acting on it, and or the movement of the fluid in which the sediment is entrained. The force of gravity moves such particles due to the sloping nature of the ground on which they lie. Air, water or ice (glacier) is means by which sediment movement occurs. Sediment from terrestrial rivers is known to be the main source of sediment supply to the coast (Bittencourt *et al.*,

2005). These rivers nourish the coast with their load of sediment transported from the hinterland (Milliman *et al.*, 1995; Walling, 2006).

Dams constructed across natural river courses for the generation of hydroelectric power ends up blocking river sediment from reaching the coasts. Apart from the ecological disturbances caused by damming of rivers, sediment deficiency is created within the respective coastal sediment cells leading to coastal erosion. Dams hold back sediment, especially the heavy gravel and cobbles which are more resilient to coastal erosive forces, from reaching the coast.

Damming of rivers has adverse effects on many coasts worldwide especially coasts which were hitherto nourished by very long rivers which contribute large amounts of sediment to the coast. For instance, studies (IRTCES, 2011; Pottinger, 1996) show that the construction of the Aswan High Dam across the Nile River has dwindled sediment supplied by the river to the sea by 98% resulting in serious coastal erosion along the shore. Similarly, the Eastern zone of the Ghanaian coast previously nourished with lots of sediment from the Volta River- records serious shoreline recession after the construction of the Akosombo Dam (IRTCES, 2011; Ly, 1980). The Akosombo Dam has cut off the supply of sediment to the Volta Estuary, affecting neighbouring Togo and Benin, whose coasts are now being eroded away at a rate of 10–15 meters per year (Pottinger, 1996). Again, it is reported that the damming of the tributary rivers to the Mississippi River over the past 60 years has reduced sediment supplied to the Louisiana's wetlands by 50% thus worsening its condition (IRTCES, 2011). Severe shoreline recession caused by preventing river sediment from reaching the coast is a common phenomenon observed from one coast

to another. When natural processes are interfered with, the natural supply of sand is interrupted and the beach changes shape or can disappear completely. The sediment supplied by the rivers to the sea were evaluated and included as a dependent variable in this research.

### 2.3.3 *Sediment Mining along the Coast*

Coastal sand mining is a practice where sand is extracted from beaches, inland dunes dredged from ocean and river beds. Sand mining from coastal river channels and around the surf zone contributes immensely to shoreline change and the subsequent erosion of the coast. Although sand mining has been practised over several years and often backed by legislation in some locations, it is prohibited in many places yet it is still practiced.

Some companies, such as Frac Sand Mining (WLC, 2013) and Monterey Sand Co. have legal permission to mine sand from the surf zone of Winsconsin with restrictions. In the United States of America, Marina and Sand City are licenced sand mining companies whose operations are regulated by the State Lands records (Magoon *et al.*, 1972). Records from the State Lands Lease reconciled with the company records revealed that a total annual amount of sand mined is between 75-230 km<sup>3</sup>/year with a mean of 150 km<sup>3</sup> yearly. This figure is thought to be linked with the high recession rates in the southern Monterey Bay (i.e. 0.5-2 m/year) which is the highest rate in California (Hapke *et al.*, 2006; Thornton *et al.*, 2006). In Ghana sand mining along the coast is prohibited by legislation, however, some citizens have devised a strategy of moulding cement blocks along the coast using the sand from the beaches. This practice is observed along the entire coastline of Ghana, except for isolated sites where strict law enforcement is adhered. Ly (1980), in his

research attributed the high recession rates of the Eastern and Central Zones of the Ghanaian shoreline to sediment deficiency.

The practice of sand mining along the coast is an issue subject to debate (Thornton *et al.*, 2006). The school of thought in support of coastal sand mining activities along the coast argue that proper dredging of sand from the sea keeps the bed at the desired level especially close to harbours. Again, it is claimed that sand mining from coastal rivers and the sea in particular reduces the bed depth thus preventing flooding which may result in loss of properties (IADC, 2012). It is also argued that high demand for coastal sand for construction purposes (and sometimes used to replace eroded coastline) makes sand mining from the coast a lucrative business. Those who oppose sand mining from the coast argue that removal of coastal sand, which serves as a natural protection for the coast against impounding erosive forces, exposes the coast to direct erosion (Thornton *et al.*, 2006; UNEP, 2014; USACE, 1983).

#### 2.3.4 *Evaluation of Human Impact on Shoreline Change*

Various methods have been adopted to determine the effect of these coastal destabilising factors on shoreline change through modelling. However, the effect of human impact on coastal process which translates into shoreline position change has not been evaluated. In this research, human impact was considered as a Multi-Criteria Decision Analysis (MCDA) and Saaty (1980) Analytic Hierarchy Process (AHP) technique was employed to rank the selected evaluation parameters.

#### 2.3.4.1 Analytic Hierarchy Process (AHP)

AHP is one of the best known and most widely used approaches (Forman & Gas, 2001). The process allows decision makers to evaluate the relative weights of the multiple criteria decision in an intuitive manner. Where quantitative rating is unavailable, AHP allow decision makers to recognise whether one criterion is more important than another. Pairwise comparisons of AHP are attractive to use, and offers a consistent manner of converting such pairwise comparisons into set of numbers representing the relative priority of each criteria (Forman & Gas, 2001).

AHP was first proposed by Saaty in the 1970s but has been modified since (Saaty, 1994). The technique assists decision-makers discovery the best decision taking into account the goal and understanding of the problem on hand. It is capable of handling multifaceted problems especially when the criteria involved are in different units or difficult to quantify (Forman & Gas, 2001) as pertains in assessing human impact on coastal processes. The technique is based on well-defined mathematical structure of consistent matrices and their associated right eigenvector's ability to generate true or approximate weights (Merkin, 1979; Saaty, 1980).

Application of AHP in solving complex problems involves three main steps: declaration of the problem, selection of the criteria to be used for the evaluation and choosing the different alternatives available for the criteria evaluation process. The information is then organised in a hierarchical tree structure. The information is then synthesized to determine the relative rankings of the alternatives. Expert judgement is used to determine the ranking of the criteria by means of pairwise comparison using a nine level scale of comparison

(Table 1). Pairwise comparison allows the relative importance of one criterion over the other to be expressed. The pairwise comparisons are turned into matrices. Each matrix generated from the pairwise comparison is squared, normalised and their Eigen vectors determined. The process is iterated until convergence occurs i.e. difference between computed values and the successive values are negligible. The resulting Eigen vector gives the relative ranking of the criteria.

Again, pairwise comparisons of the alternatives express the preference of one alternative over the other. Eigen vectors for the pairwise comparisons of the alternatives express the relative ranking of the alternatives in each criterion. AHP then combines all the information (both qualitative and quantitative) to produce the hierarchy tree with all its weights. This technique has been adopted to evaluate human impact on shoreline change in terms of the population, sand mining activities along the coast, and distances off coastal obstructing structures along the coast. AHP was used because it is widely applied; it provides a logical and intuitive solution to complex problems (Forman & Gas, 2001).

Table1: The Fundamental Scale of Absolute Numbers

| Intensity of Importance | Definition  | Explanation  |
|-------------------------|---|--|
| 1                       | Equal Importance  | Two activities contribute equally to the objective   |
| 2                       | Weak or slight  |  |
| 3                       | Moderate importance   | Experience and judgement slightly favour one activity over another                               |
| 4                       | Moderate plus   |  |
| 5                       | Strong importance   | Experience and judgement strongly favour one activity over another                               |
| 6                       | Strong plus   |  |
| 7                       | Very strong or demonstrated importance  | An activity is favoured very strongly over another; its dominance demonstrated in practice       |
| 8                       | Very, very strong   |  |
| 9                       | Extreme importance  | The evidence favouring one activity over another is of the highest possible order of affirmation |
| Reciprocals of above    | If activity $i$ has one of the above non-zero numbers assigned to it when compared with activity $j$ , then $j$ has the reciprocal value when compared with $i$ | A reasonable assumption  |

Source: Saaty (1980)

## **2.4 Response of Coastal Materials to Shoreline Change**

Coastal materials are the natural unconsolidated and or consolidated landforms found between the surf zone and the back beach along the coast (BeachMED, 2008). They may be grouped into soft (coastal sediment) and hard (rocks) coastal materials.

### *2.4.1 Soft Coastal Material*

Soft coastal material is the beach which serves as a buffer zone between the sea and the coastal land. They are usually composed of sediment. They are usually formed when strong winds blowing parallel to the coast generate local waves and currents which erode and deposits sediment along the shore.

#### *2.4.1.1 Sediment Supplied by Rivers to the Sea*

According to Walling (2006) sediment supplied by rivers constitutes between 80 and 95% of total sediment deposited at the coast worldwide. These rivers go through natural processes of eroding soil and rock particles along their channels, transporting and depositing them at the coast either through estuaries, deltas or into lagoons. River sediment load deposited in lagoons is often redeposited into the sea during high tide periods. Depositions of river load recharge the respective shores within their catchment area with sand required for normal coastal processes. This occurs particularly where coastal cell boundaries clearly and distinctly exist (Cooper & Pethick, 2005). Segments of the coast where sediment loads received at the shores exceed the sediment transported away from it records growth in the beach, while beach losses are observed where more sediment are transported away from the shore than received.

Sediment load reaching the coast may be in two categories namely, suspended load and bed load. Suspended load are the particle held in suspension because of the turbulence in the water; these include suspended material such as silt, clay and sand. The amount of suspended load in a stream is directly proportional to the turbulence (Anderson & Fredsoe, 1983) and mainly originates from erosion of the bed and banks of the river as well as sediment by runoff into the rivers. In many rivers, suspended sediment form most of the load transported. Bed load on the other hand, comprises stony material such as gravels and cobbles that move by rolling along the bed of a river. These are heavier and cannot be carried in suspension by the river current. Bed load is usually only transported during periods of extreme high discharge and in landscape of large topographic relief, where river gradient is steep. For the purpose of the research only suspended sediment discharge is considered.

#### *2.4.1.2 Methods of Quantifying Sediment Load Discharge*

Methods of quantifying river sediment discharge involve collection of representative suspended-sediment samples, measurement of discharge and calculation of instantaneous suspended sediment discharge. Representative samples are usually obtained from continuous collection of aliquot of water and sediment which is mostly acquired from specialised installations (Barnes & Frevert, 1954; Brown *et al.*, 1973). Where suspended sediment concentration collection is not from a continuous sampling source, the sediment load computed is not a true representative of the total suspended sediment load but rather an indicative sample of the river under consideration (Landers, 2010). This results in aberration in the estimated sediments load. Due to scarcity of continuously recorded

suspended sediment and daily flow data, instantaneously (discrete) measured data are often used subject to some modifications (Nittrouer & Viparelli, 2014; Walling, 1977). The discrete data is fed into a power regression relation developed using continuous data to derive a sediment rating curve, which depicts the statistical relation between suspended sediment concentrations and discharge (Walling, 1977):

$$C_s = aQ^b \quad (2.10)$$

Where  $C_s$  is the instantaneous sediment concentration (mg/l),  $Q$  is the instantaneous water discharge ( $m^3/s$ ) and  $a$  and  $b$  are the sediment rating coefficient and exponent respectively.

The correlation between instantaneous sediment concentration  $C_s$  and instantaneous discharge  $Q$  are statistically significant. These inform researchers about the extent of correlation between suspended sediment concentration and the discharge by means of the determination coefficient. In some rivers, there is a moderately good relationship between suspended sediment concentration and discharge (Milliman *et al.*, 1995; Walling, 2006). The collections of the instantaneous daily measurement over a period is an expensive and high logistics support intensive venture and it is usually undertaken by recognised organisation such as the Research Institution, eg, USGS (Nittrouer & Viparelli, 2014) and the Water Research Institute – (CSIR) in Ghana (Akrasi, 2011 ). The suspended sediment concentration and the discharge for important rivers having large basins are often determined and published.

In southern Ghana, for instance, measurements of suspended sediment transport for 21 monitoring stations were used as sample sites to collate sediment yield data in south-

western and coastal basin systems. Regression analysis was used to establish a relationship between specific suspended sediment yield with the mean annual runoff and with the drainage basin area (Akrasi, 2011).

Although the study developed a simple model to estimate suspended sediment yields of the catchment area within the south-western and coastal basins, and the models could be used to estimate the total sediment load being discharged into the sea; only rivers with large basins were considered. The large scale analysis of the sediment load discharged into the sea make it difficult to evaluate in detail sediment supplied by smaller basin rivers to the shores. Besides, rivers with relatively smaller drainage basins can be just as important as those with large drainage basins (Milliman & Syvitski, 1992). Smaller basins have less area for sediment storage and therefore their sediment yield increases as much as sevenfold for each magnitude decrease in basin area (Milliman, 1990). Small basin streams will be considered in this research.

To determine the quantity of sediment load discharge into the sea per year by the smaller basin rivers the widely used method for computing maximum discharge that is the rational method was employed. This method was used because it offers a simple technique for estimating discharge of small drainage basins (Cleveland *et al.*, 2011). The estimated total flood discharge for each of the drainage areas were expressed in terms of the Rainfall Intensity of the region and the Time of Concentration.

$$\text{Total flood discharge } Q_{\max}=0.277CAI \quad (2.11)$$

where  $Q_{\max}$  is the total flood discharge ( $\text{m}^3/\text{s}$ ),  $C$  the runoff coefficient of the region,  $A$  the catchment area ( $\text{km}^2$ ) and  $I$  is the mean intensity of rainfall in  $\text{mm}/\text{h}$  during the time of concentration

The rainfall intensity  $I$  is computed from the depth duration equation (Watkins and Fiddes, 1984):

$$I = \frac{a}{(b + T_c)^n} \quad (2.12)$$

where  $a$ ,  $b$  and  $n$  are constants, and the Time of Concentration  $T_c$  is the time required for the most distant part of the catchment area to contribute to the outflow of the rivers.

$$T_c = 2.8 * \left( \frac{L}{\sqrt{S}} \right) \quad (2.13)$$

Where  $L$  is the length of the main stream ( $\text{km}$ ) and  $S$  is the main stream slope.

For the purpose of the study, the respective drainage basins were delineated and their catchment areas determined from a topographic map of the study area at a scale of 1:50 000.

#### *2.4.2 Sediment Transportation along the Surf Zone*

Sediment along the surf zones are constantly moved by waves and currents due to the turbulence generated by breaking waves. These coupled with the shallowness of the bottom (which makes it easier for sediment dislodge) results in the formation of various landforms (Al-Hatrusi *et al.*, 2005). Currents generated from wave breaking processes along the surf zone play a key role in the transportation of sediment along the shore (Güner *et al.*, 2011; Voulgarisa & Collins, 2000), some of which are deposited along beaches. The

transportation of sediment entrained within the surf zone and the deposition of such sediment near or further from the shore constitutes erosion which reflects in shoreline position change. Sediment movement and depositional pattern significantly influence shoreline dynamics within any coastal environment.

There are existing methods for computing sediment transport current along the near shore. Sediment transport along the shore is referred to as alongshore sediment transport whereas littoral transport across the shore is termed cross-shore transport. Littoral transport results from the interaction of winds, waves, currents, tides, sediments and other phenomena in the littoral zone (EUROSION, 2004).

#### 2.4.2.1 Sediment Transport Rate Formulae

Sediment transport is defined as the product of instantaneous concentration of particles in the fluid and the instantaneous velocity of the fluid in which the particles are engrossed (Fredsoe & Deigaard, 1992). Generally, the sediment transport through a plane of unit width and height equal to the water depth is denoted by Equation (2.14) (Van Rijn, 2007).

$$q_s = \frac{1}{t'} \int_0^{h+\eta} \int_0^{t'} c(z, t) u(z, t) dt dz \quad (2.14)$$

where  $q_s$  is the sediment transport rate ( $m^3/ms$ ),  $t'$  is the integration period (s),  $h$  is the local water depth (m),  $\eta$  is the instantaneous water surface elevation (m),  $c(z, t)$  is the instantaneous concentration of material,  $u(z, t)$  is the instantaneous velocity component (m/s),  $z$  is the elevation above the bed level (m),  $t$  is the time (s).

For waves approaching a shoreline at an angle, alongshore sediment transport takes place. Equation (2.14) for the alongshore sediment transport can therefore be reduced to a much more convenient (i.e. Equation 2.15).

$$q_s = \frac{1}{t'} \int_0^{h+\eta} u(z) dz \quad (2.15)$$

where the velocity,  $u$ , is taken equal to the alongshore velocity,  $V$ .

The velocity  $V$  is practically independent of time, because the waves, causing the time dependent velocity component, are assumed to act almost perpendicularly to the coast and thus to the alongshore velocity direction. Because the velocity  $u(z,t)$  is almost independent on the time, as  $u(z,t)$  approaches  $u(z)$  the time averaged concentration  $c(z)$  could be used instead of the instantaneous concentration  $c(z, t)$ .

Equation (2.15) for longshore sediment transport is similar to the sediment transport formulas used for rivers (Fredsoe & Deigaard, 1992). Principally both types of transport formulae are the same, so it is possible to use these transport formulae also for a current alone situation.

The methods used for calculating sediment transport, i.e. the velocity and the concentration, however, are different in each case. The velocity depends on the generating forces and on the bottom shear stress. The bottom shear stress is influenced by the wave action. The sediment concentration along the coast is often much higher than in a river because wave action stirs up a lot of material from the bottom and the current transports it (van der Velden, 1989). Alongshore transport has an average net direction parallel to

the shoreline. Sediment, moved by alongshore transport, will generally not return to the same area.

When waves break in the surf zone momentum is released, giving rise to a radiation stress. The cross-shore component of the radiation stress forces water onshore and causes a set-up of the water level, which rise in the onshore direction above the still water level. The water surface slope that is produced balances the cross-shore gradient of the shore-normal component of the radiation stress. For waves incident obliquely on the shoreline there is also an alongshore component of the radiation stress, whose gradient gives rise to a longshore current within the surf zone which is balanced by friction with bed. This in turn drives sediment longshore as a longshore sediment transport.

#### *2.4.2.2 Longshore Sediment Transport Formula*

The most widely used model for estimating total Longshore Sediment Transport (LST) rate is the Coastal Engineers Research Centre (CERC) formula which is based on field measurements and is often applied to calculate the total LST rate (USACE, 1984). Accuracy of the CERC (1984) formula is estimated to be  $\pm 30\text{-}50\%$  at best. Several parameters that logically might influence LST are excluded in the formula, such as breaker type and grain size (USACE, 1990).

The model is based on the assumption that the total longshore sediment transport rate is proportional to longshore energy flux, is given as:

$$Q = \frac{K}{16\sqrt{\gamma_b}} \rho g^{\frac{3}{2}} H_{sb}^{\frac{5}{2}} \sin(2\theta_b) \quad (2.16)$$

where  $Q$  is the total immersed weight LST rate,  $K$  is an empirical coefficient,  $\rho$  is density of water,  $g$  is acceleration due to gravity,  $H_{sb}$  is significant wave height at breaking,  $\gamma_b$  is the breaker index, and  $\theta_b$  is wave angle at breaking.

Breaker index is often assumed to be 0.78, although it is a function of wave height, wave period, and beach slope (Rattanapitikan *et al.*, 2000; Smith, 2009). Although improved methods for estimating breaker index have been developed (USACE, 2002), the value of 0.78 is used in calculations of Equation (2.18) for simplicity in the present study. The *Shore Protection Manual* recommends a value of  $K$  of 0.39, which is derived from the original field study of Komar (1970) using sediment tracers. The CERC (1984) formula in Equation (2.16) is adopted for the research because it provides accurate results ( $\pm 30$ -50% at best) (USACE, 1984) since the model is based on field measurements and it is widely used for estimating the longshore sediment transport rates.

## 2.5 Coastal Systems

Coastal (or beach) systems are coastal features which are influenced by both oceanographic and geomorphic conditions. Some of the coastal features manipulated by these conditions include: the beach, the coastal dune, and the shore face. The erosive forces driving the geomorphic work within the coastal system are generally identified as waves, tides, and currents. However, the specific causes are to be determined in this research. According to Sunamura (1992), the net erosive force that controls the dynamics of the coastal system is a ratio of the erosive force and the material resistance. In this research, the erosive force is assumed to be responsible for sediment transportation

whereas the material resistance is considered as the coastal material resistance to erosion and transportation of sediment.

### 2.5.1 *Erosive Forces Driving Shoreline Change*

The dynamics of the coastal system is caused by eroding forces specifically currents generated from breaking waves, tides and winds (Zhang *et al.*, 2004). Notwithstanding the eroding forces, the resilience of the coastal material determines the shoreline changes trends recorded at any spatial location in time. Sunamura (1992) observed a relationship between eroding forces, shoreline resistance and slope as expressed in Equation 2.17. He postulated that the erosion vulnerability of a rock shore can be expressed through a safety factor:

$$\text{Rock Shore factor of safety} = \frac{\text{Erosive Forces } (F_W)}{\text{Material Resistance } (F_R)} \quad (2.17)$$

Although the equation is widely used, different authors assign different physical properties for the Erosive forces and the Material resistance.

Mano (1999) studied erosion of soft cliffs at Fakashima coast in Japan, and represented the  $F_W$  by wave energy flux at the breaking point and  $F_R$  by the cliff height and Young's Modulus. Trenhaile (1983), in a study on erosion development of shore platform in hard rock cliffs, defined  $F_W$  as the wave energy required to cut a notch in a unit length. In another study on shear strength and exposure to wave attack of soft glacial cliffs around Thompson Island in Boston Massachusetts, Jones (1993) revealed that cliffs with low shear strength and high exposure to wave attack are likely to experience high recession.

Wilcock (1998) studied the Maryland coast in the USA and defined relative wave strength as a ratio of wave pressure (T) to the cohesion strength (S). It is observed that area with high T/S ratio experienced the highest erosion rates. The topography of the platform on the breaker shape, and the impact load and erosion rates were acknowledged to be important (Wilcock, 1998). Budetta (1999) also define mathematically the destructive force  $F_w$  of waves in terms of water density  $\rho$ , acceleration due to gravity  $g$  and wave height,  $H$ , as in Equation (2.18).

$$F_w = A\rho gH \quad (2.18)$$

where  $A$  is a non-dimensional constant reflecting the effect of beach sediment acting as abrasive.

The wave height,  $H$ , in Equation (2.18) is time dependent on the swell characteristics, currents, winds and approaching bathymetry and therefore  $F_w$  would not be a constant value. In another study, the evolution of the shoreline geometry was related to lithology and the surrounding wave regime (Granja, 2004). Other factors driving the cliff retreat are the internal rock structure, stream channels, water seepage, and hill slope processes. According to Sunamura (1992), the rate of cliff retreat on receding coastlines varies greatly with rock type. In general, softer rock types with less shear strength erode faster than those with higher strength, and stronger rocks support much steeper cliff formation. Similarly, shoreline that is exposed to higher wave energy erodes faster, and are less likely to have sediment deposition taking place.

To enable rock strength to be quantified, Budetta (1999) proposed a simple model of rock strength as in Equation (2.19):

$$F_R = B \sigma_c \quad (2.19)$$

Where  $F_R$  is the strength of the rock mass,  $\sigma_c$  is the rock compressive strength and  $B$  is a non-dimensional constant reflecting the presence of joints in the rock face.

The value of  $B$  was assumed to be unity for the Santa Cruz Island, although different rock types have different values of  $B$ .

For the purpose of this research, Sunamura (1992) relation for rock shore safety factor was adopted by representing the erosive force,  $F_w$ , as the wave force at breaking and the material resistance,  $F_R$ , as sum of the compressive strength of the ‘hard’ shore rock and or the shear strength of the dune ‘soft’ shore rock. To enable explanation of shoreline change along the different rock types, petrographic studies were carried out to support the analysis so as to enable detail description of the rocks in terms of their mineral content and their texture relationships.

### 2.5.2 *Material Resistance to Shoreline Change*

The resistances offered by each of the coastal features under consideration are presented in this segment. Stephenson (2000) in their study on shore platform of the Kaikoura peninsula in New Zealand concluded that the passage of waves across the platform reduces the wave energy by as much as five orders of magnitude. Shih (1994) also

recognised a relation between cliff retreats and run up, which is controlled by the topography and the beach.

#### *2.5.2.1 The Beach*

Beaches are accumulations of unconsolidated sand or gravel that extend from mean low tide to the uppermost extent of wave impact (Komar, 1998). Beaches serve as buffer zones or shock absorbers that protect the coastline, sea cliffs or dune from direct wave attack. According to Davies (2011), the presence of wide sandy beaches provides a buffer to keep waves action away from coastal properties. Beaches usually develop best on low lying alluvial coasts, but they are not restricted to these areas. In some locations, beaches have thin slivers of sand in front of coastal cliffs whereas other parts have broad features backed by wide dune fields and coastal marshes. Beaches may be categorised based on the characteristics of the materials that they are composed of, or by the features found in their profiles. These include:

- Texture that form the beach;
- Composition of the particles; and
- Slope of the beach.

The texture of beach sediments provides a means of describing different beaches. The main distinction is between gravel or sand beaches, but further distinctions are made in terms of grain sizes such as fine, medium, or coarse-grained sand beaches (see Table 2). Gravel beaches may result from high wave energies, or may be lag gravel left behind as a coastline containing gravels is eroded. These are formed because wave energy removes

sand and fines (silt and clay) as erosion proceeds, leaving gravel debris behind. For sandy beaches, the size of the sand is determined from two factors: the energy (height) of the waves, and the size of the material furnished to the beach (Briaud, 2005). Other factors being equal, the higher the average waves on a beach, the coarser the sand. This is because higher waves tend to move the smaller grains offshore to quieter water. Dune sand is consistently finer grained than the adjacent beaches although the dune sand is derived from winds blowing across the beach.

Categorisation of beaches in terms of beach slope and grain characteristics allows beaches to be described as dissipative or reflective beaches (Wright & Short, 1983). Dissipative beaches develop under high wave conditions when there is an abundant supply of medium to fine sand. Dissipative beaches have the largest fore dunes because their width allows drying of the upper beach face resulting in maximum potential sand transport by onshore winds during low tide. On a reflective beach, sand transport is minimal due to the usual presence of wet sand and swash. Only on the back beach, which is generally removed from wave influence, is the sand dry enough for grain movement by wind action. For the purpose of this research, the width and slope of the beach at the sample locations were measured to explore their correlation and statistical significance with the shoreline change in the study area.

#### *2.5.2.2 The Shore Platform and Dune*

The inherent resistive properties of the shore platform, which forms a boundary between the beach and the coastal dune, influence the resistivity of the coastal feature to erosive forces. In this vein, the coasts are described as either ‘hard’ or ‘soft’ based on the material

composition of the platform; in another vein, coasts are distinguished on the basis of the topographic elevation of the coastal platform such as sea cliffs or plains.

Cliff coasts are classified as “hard” as they are formed from resistant materials such as sedimentary or volcanic rocks (Emery & Kuhn, 1982). This type of coast typically has a short shore platform that is usually exposed during neap tide (Griggs & Trenhaile, 1994). Natural erosion is attributable to slope instability, weathering and wave action that leads to regression of the shoreline. Where cliff coasts consist of cohesion soils and often have a nearly vertical banks ranging from one to five meters, they are categorised as ‘semi-hard’. The rate of erosion is relatively high compared to the ‘hard’ coast because it is composed of weaker and less resistant material (Sunamura, 1992).

Soft coasts may be categorised into two as fine-grained sedimentary deposits and unconsolidated material predominantly sand with some pebbles and shells. Fine-grained sedimentary deposits comprise mainly silt, and clay that come from rivers. The unconsolidated sandy material has a gentle seaward slope and its profile depends on wave form and energy and wind direction. Hence, profiles can be adjusted (during beach nourishing) to provide the most efficient means of dissipating incoming wave energy. Sandy shores (or beaches) make up two-thirds of the world’s ice-free coasts. Sandy beaches are composed of two main material types namely, quartz (silica) and carbonates; the former originates from the terrain and is transported by rivers to the sea, whereas the latter is of marine origin. Sandy beaches are made up of several different sizes of particle diameters which are grouped into the following (Table 2) generic names for easy identification and analyses.

Table 2: Sediment Particles Diameters and Generic Names

| Generic Name | Particle Diameter (mm) |
|--------------|------------------------|
| Very coarse  | 1.0 to 2.0             |
| Coarse       | 0.50 to 2.0            |
| Medium       | 0.25 to 0.50           |
| Fine         | 0.125 to 0.50          |
| Very Fine    | 0.0625 to 0.125        |

(Source: Sutton, 1992)

### 2.5.2.3 Methods of determining the strength of 'hard' coastal material

Coastal erosion is a worldwide menace affecting several sandy shores as well as some rocky shores, particularly, along shores where the parent rocks are relatively weak or have numerous discontinuities. Coastal areas underlain by relatively hard rocks tend to have higher resistance to erosion (Trenhaile, 1983), thus slowing down the geomorphic processes. Pressures from breaking waves, on coastal rock masses generally dislodge sediments from locations of least strength such as within discontinuities, or weak rocks or weathered material. The physical and chemical properties of coastal bedrocks or soil in a locality greatly determine the severity of coastal erosion in the area. For instance, the strength of rocks exposed along the coast is a critical parameter in determining the erodibility of the coast (Benumof, *et al.*, 2000). Stronger rocks form prominent headlands that resist erosion and often form natural boundaries to littoral and aeolian transport. Weaker rocks erode more quickly and form embayment, where coastal sediment may accumulate.

The rock properties may be viewed from two perspectives namely, geological and geomechanical (or geotechnical). The geological aspect is more qualitative and deals

primarily with the origin and distribution of earth materials such as the chemistry and orientation of the underlying rocks while the geomechanical aspect (which is also influenced by the geological properties) is more quantitative and comprises structural features such as discontinuities within the rock mass and strength. Where engineering parameters are required, it is possible to translate and quantify geological data (Koloski *et al.*, 1989).

Rocks are generally composed of minerals which are inorganic solids with specific internal structure and a definite chemical composition that varies only within a narrow range. The composition of rocks helps in the description and classification. It also influences permeability, porosity and relative susceptibility of the rock to erosion. Earth materials in geotechnical terms are composed of rocks or minerals, water and air. Their structural properties are mapped based on the rock type, orientation of their discontinuities and their potential for weathering. Sections of rock masses with discontinuities become more vulnerable to erosion particularly during inundation.

The resistance of coastal rocks to hydraulic pressure from the turbulence of breaking waves may best be determined by performing elaborate tests considering the chemical composition of the lithological types and the disposition and strength under both field and laboratory conditions. However, estimations of intact strength are good for examining relative erosion susceptibility in a more efficient manner (Whipple *et al.*, 2000). The intact rock strength is a major property which determines the strength of the intact rock block material and as such governs partially the strength of a rock mass. Estimation of the intact rock strength may be determined by means of the following:

- Unconfined Compressive Strength (UCS) tests,
- Point Load Strength tests,
- Schmidt hammer tests, or
- Simple mechanical means (geological hammer and hand crushing).

The use of UCS involves the definition of rock strength and using strength values based on laboratory UCS tests. UCS test is the geotechnical property that is most often quoted in rock engineering practice. It is widely understood as a rough index which gives a first approximation of the range of issues that are likely to be encountered in a variety of engineering problems (Hoek, 1977). The UCS includes discontinuity strength for rock masses with small discontinuity spacing. The challenge is that the UCS test sample is most often about 10 cm long and if the discontinuity spacing is less than 10 cm the core may include some defects. Again, samples tested in laboratories tend to be of better quality than the average rock because poor rock is often disregarded when drill cores or samples break (Laubscher, 1990), and do not meet the standard test specification.

Furthermore, the intact rock strength measured depends on the sample orientation. If the intact rock exhibits anisotropy, variable values will be obtained depending on direction of penetration. In such situations, other alternatives to testing intact rock strength of a rock mass by UCS testing are employed. Notable among these are the Point Load strength test or hammer tests using different means, example the Schmidt hammer or by combination of geological hammer and hand crushing.

The Schmidt hammer (also called the ‘rebound’ hammer) is another alternative to the UCS testing. It has been used worldwide as an index test for a quick rock strength and deformability characterisation due to its rapidity and ease in execution, simplicity, portability, low cost and non-destructiveness. The device was invented by Ernest Schmidt in 1948 for measuring the elastic properties or the strength of rocks or concrete mainly by their surface hardness or penetration resistance. The hammer measures the rebound of a piston activated by a spring loaded mass impacting against the surface of the rock sample. The hammer hits the sample with a defined energy and its rebound which is dependent on the hardness of the rock under consideration is measured and recorded. The rebound value measured on the rock surface is correlated to intact rock strength using a conversion chart. Schmidt hammer values are, however, influenced to a fairly large depth, by the material behind the surface tested.

The intact rock strength is a major property which determines the strength of the intact rock block material and as such governs partially the strength of a rock mass. Hack and Huisman (2002), revealed that in many cases, an estimation of intact rock strength by ‘simple means’ such as the use of the Point Load test, Schmidt hammer tests and coupling geological hammer and hand crumbing, are more representative for establishing the strength of a rock mass than establishing the intact rock strength by more elaborate testing. The Schmidt’s technique was adopted following the American Society for Testing Material (ASTM D5873) procedure since it provides a quick, non-destructive test results; it also yields better estimates representative of the material compressive strength determined as compared to the other elaborate laboratory tests such as the UCS. The

rebound strength of outcrops measurement within their elastic limits enables the compressive strength of rock masses to be determined using a conversion chart as shown in Appendix I. For the purpose of this research, the field measurements of rebound strength were complimented by collection of rock samples for UCS testing at the laboratory for validation purposes.

#### *2.5.2.4 Measurement of shear Strength of Dune Soil*

Unlike coastal beaches that are exposed to direct currents of water generated from breaking waves, coastal dunes are often exposed to currents of winds associated with the oceanographic environments. Dune sand is consistently finer grained than sand on adjacent beaches as the dune sand is derived from winds blowing across the beach. The differences in size is due to the fact that winds generally only pick up and carry the finer grains of beach sand and leave the heavier, larger sand grains behind. The inherent resistance of coastal dune soil to erosive forces (such as winds and rains) determine the practical limit of stability of the dune and therefore the shore. Soil investigations to evaluate the strength of the soil underlying the coastal dune may provide the meaningful explanation to the shoreline change variability.

The principal properties of interest in this study are the strength and deformation characteristics of the coastal dune soil. Soil may be described as either cohesive (e.g. clay and silt) or cohesion less (e.g. sands and gravel) based on inter particular bonding among the particles constituting the soil. The most important engineering properties of soil required for this research is the shear strength of the soil. Shear strength of a soil mass is the internal resistance per unit area that the soil mass can offer to resist failure and sliding

along any plane inside it. Shear strength is a term in soil mechanics that describe the magnitude of the shear stress that a soil can sustain. Shear resistance of a soil on the other hand, is a result of friction and interlocking of particles, and possibly cementation or bonding at particle contacts. Due to interlocking, particulate material may expand or contract in volume as it is subjected to shear strains.

Mohr (1900) presented a theory for rupture in materials that contended that materials fail because of a critical combination of normal stress and shearing stress, and not from either maximum normal or shear stress alone. Thus the functional relationship between normal stress and shear stress on a failure plane may be expressed as in Equation (2.20):

$$\tau_f = f(\sigma) \quad (2.20)$$

The failure envelope defined by Equation (2.20) is a curved line. For most soil mechanics problems, it is sufficient to approximate the shear stress on the failure plane as a linear function of the normal stress (Coulomb, 1776). This linear function may be written as in Equation (2.21).

$$\tau_f = c + \sigma \tan\phi \quad (2.21)$$

where  $c$  is the cohesion,  $\phi$  is the angle of internal friction,  $\sigma$  is the normal stress on the failure plane, and  $\tau_f$  the shear strength.

Equation (2.21) is referred to as the Mohr-Coulomb failure criterion. In saturated soil, the total normal stress at a point is the sum of the effective stress ( $\sigma'$ ) and pore water pressure ( $\mu$ ), or:

$$\mu = \sigma' + \sigma \quad (2.22)$$

The effective stress  $\sigma'$  is carried by the soil solids. The Mohr-Coulomb failure criterion expressed in terms of effective stress is of the form in Equation (2.21) as shown in Equation (2.23):

$$\tau_f = c' + \tan \phi' \quad (2.23)$$

Where  $c'$  is the cohesion and  $\phi'$  the friction angle, based on effective stress.

Thus, Equations (2.20) and (2.21) are expressions of shear strength based on total stress and effective stress. For normally consolidated sand,  $c'$  can be approximated to zero.

Good estimates of soil properties for cohesive soils can be made by laboratory tests on undisturbed samples which can be obtained with some difficulty. It is nearly impossible to obtain a truly undisturbed sample of soil; so in general usage the term "undisturbed" means a sample where some precautions have been taken to minimise disturbance or remoulding effects. In this context, the quality of an "undisturbed" sample varies widely between soil laboratories (Herrick *et al.*, 2001). The following are the major field tests available for determining the shear strength of soils (Terzaghi *et al.*, 1996):

- Vane shear test (VST).
- Standard Penetration Test (SPT).
- Dynamic Cone Penetration Test (DCPT).
- The Borehole Shear Test (BST).
- The Flat Dilatometer Test (DMT).
- The Pressure-meter Test (PMT).
- The Plate Load Test (PLT)

The shear strength of the dune soil was measured using a standard procedure ASTM D 1586 that is the Dynamic Cone Penetrometer test (DCP). DCP test is one of the in-situ penetration tests widely used for site investigation in support of analysis and design (Salgado & Yoon, 2003). The standard penetration test (SPT) and the DCPT are two typical *in-situ* penetration tests. While the SPT is performed by driving a sampler into the soil with hammer blow, the DCPT is a quasi-static procedure. DCPT was developed in Australia by Scala (1956). The current model was developed by the Transvaal Roads Department in South Africa (Luo *et al.*, 1998).

The DCPT equipment was simple, portable, easy to operate and allows quick processing of the test results (Luo *et al.*, 1998); it is also known to be the versatile, rapid *in-situ* evaluation device currently available for testing soil (Farshad, 2003). The equipment, consists of a 10 kg weight (hammer) falling under gravity on an anvil through a distance 0.5 m and determines the shear strength of soil at given depth by virtue of the number of blows required to move the piston of the device through depth of 0.1 m. The *in-situ* measurement and computed shear strength of the coastal soil at varying depths were determined by employing Prandt (1921) method for plastic deformation. The shear strength soil  $S$  is expressed as follows:

$$S = \frac{nmgh}{\Delta sA} * \frac{1}{N} \quad (2.24)$$

where  $n$  is the total number of blows causing penetration through depth of  $\Delta s$  for a hammer of mass  $m$  falling through height  $h$  of a dynamic cone penetrometer with a cone of cross sectional area  $A$  and a coefficient  $N$  which depends on the geometry of the cone

and surface it penetrates (Sutton, 1992). This method was adopted in the computation of the shear strength of the dune soil in this research.

### 2.5.3 *Coastal Vulnerability*

Susceptibility of the coast to erosive forces as expressed by Sunamura (1992) is a function of erosive forces and the material resistance. Material vulnerability is evident in the erosion or accretion recorded in the coastal systems under study. Erosion of beach material, the shore platform or sediment from the foreshore constitutes losses which reflect in shoreline change (Blott & Pye, 2001). Changes in the shoreline position connote coastal vulnerability status of the coastal system.

#### 2.5.3.1 *Mapping Shoreline Change*

Mean shoreline position usually changes marginally over several period of time under climate change conditions except for instances of unusual storm conditions. Under such exceptional conditions the physical effects of sea level rise can include shoreline displacement landwards, and inundation of low-lying coastal areas, and these effects may be magnified by increased storm events (Cowart *et al.*, 2010). Due to the high positional accuracy required for shoreline mapping and modelling, only spatial datasets derived from high spatial resolution sources such as aerial photography (Dolan *et al.*, 1991) and field survey measurement are recommended for the extraction of the shoreline positions for all the given time series datasets.

In the absence of a viable quantitative prediction approach for modelling shoreline vulnerability that is applicable to most coastal systems (and also takes into accounts the

erosive and resistive factors) the only reliable source of information for shoreline change prediction remains current and historic shoreline data (Wiafe *et al.*, 2013). It is, therefore, imperative that imperfection emanating from source data, measurement and computations are minimized.

Aside errors associated with source data, reliability of shoreline trends is dependent on measurement errors, sampling errors and statistical errors related to compilation and comparison of shoreline positions (Anders & Byrnes, 1991; Crowell *et al.*, 1991; Moore, 2000; Ruggiero *et al.*, 2003) Considerable amount of positional errors in shoreline measurement have been attributed to scales and inaccuracies in the original survey (Apeaning Addo *et al.*, 2008; Thieler & Danford, 1994). The limitation of linear models (such as the Linear Regression method (Crowell, 1991; Morton, 1997)), depict the cyclical trends of the shoreline evolution, as a result, different change rates are obtained for the same section of the shoreline by different researches (Galgano, 2008). Oftentimes, analysis of both long term (>100 years) and short term change (<60 years) trends (Galgano, 2008) are carried out to capture shoreline movement from which predictions are made. This is to enhance understanding of shoreline change trends since they could be unidirectional and constant, or cyclic with acceleration and decelerations (Dolan *et al.*, 1991; Galgano & Douglas, 2000; Galgano *et al.*, 1998).

#### *2.5.3.2 Coastline Orientation and Classification*

The general orientation of a shoreline to a large extent determines the magnitude of the erosive forces exposed to it (Cooper *et al.*, 2004). The alignment of the shore in relation to the direction of propagation of approaching waves control the gross or net sediment

transport along the shore. Where the direction of approaching wave's propagation makes oblique angle with the mean coastline, long shore transport of sediment is recorded (USACE, 2002). Locations along the shore that are prone to high incidence of longshore sediment transport are likely to erode faster if sediment from other sources (such as fluvial sediment) is unavailable to make up for the sediment lost from that vicinity. Shoreline orientation forms an integral part of classification parameters employed along different coastlines (Mendoza Ponce, 2008).

The classification of coastline is also useful in most shoreline management planning systems, where coastlines with similar features are grouped together (Ihl, *et al.*, 2006; Shepard, 1973). Various coastline classification schemes exist, but for the purpose of this study, commonly used schemes are discussed. These are based on coastline formation origin, tectonics, sediment-budget, and dominant process.

Coastline formation origin classification is also referred to as the Shepard (1973) classification. This has been modified by Ihl *et al.* (2006) to reflect the coastal processes and the geologic history of the coast. The Shepard's classification scheme distinguishes between primary and secondary coasts depending on whether it was formed by a non-marine agent or by natural sources. According to the classification primary coastlines exist in their geological framework, not modified significantly by the marine agents such as waves, tides and currents. In the same vein, secondary coastlines are formed just like the primary coastline but have been changed depending on the marine agent prevalent in the coastlines under consideration.

Tectonic classification scheme relates coastal landforms and processes to the proximity of active tectonic boundary to a coast. This scheme is applicable for large-scale coastal classifications and distinguishes between coastline based on whether they have a broad continental shelf or plate trailing edge. Two types of coastal margins are distinguished in this classification as active or passive coastal margins. Active coastal margins coasts are in close proximity to active plate boundaries and hence earthquakes and deformation of the crust are common. They usually have a continental shelf which tends to be narrow (<20 miles). Passive coasts, on the other hand, rarely experience earthquakes and crustal deformation activities. The nearest active plate boundary is farther (>200 miles) from the coast. The continental shelf tends to be very wide (50 – 100 miles) across.

Sediment Budget classification relates to the coastal landforms either erosional or depositional processes, which ever dominates along a given shoreline. Erosional coasts experience vigorous wave and current activities, with sediment removal being much more than the sediment being deposited. Depositional coasts, on the other hand, tend to have moderate wave and current activities with fluvial process bringing more sediment than is removed by the erosional processes.

Dominant Process classification scheme is somehow similar to the Sediment Budget classification scheme and it is based on the predominant natural activity in a coastal zone. A coastal zone, under this classification, could be wave-dominated or tide-dominated or both. Wave-dominated coasts have wave activity as the main agent of coastal erosion or deposition providing energy for near shore currents and sediment distribution. In tide-dominated coasts, tides serve as the dominant agent influencing coastal landforms - erosion

and deposition of coastal sediment. The Wave and or Tide dominated coastline classification scheme is a special case of the Shepard's secondary coasts class where the marine agents under consideration are waves and or tides.

Where the coast is dominated by the effect of waves shaping the coastline to be aligned at right angles with the direction of approaching wave crest, such coasts is designated as Wave-Dominated coasts. On the other hand, where the effect of waves are minimal often obliterated by tides and the coastline formation is influenced significantly by the tides are termed as Tide-dominated coasts (Hayes, 1979). In cases where the contributions of both waves and tides cause appreciable modification of the coastline, then the coast are referred to as Wave-Tide dominated coast.

For the purpose of this research, coastlines are classified based on geological formation according to the modified Shepard's scheme, together with geomorphological processes and variability within the coastal material.

The physiographic variability within the coastal material and the environment is also used to classify coastlines based on their orientation relative to the grid north direction. Other factors considered are the presence or absence of coastal cliffs within a given stretch of the coastline. According to Emery and Kuhn (1982), cliffs are strongly influenced by the geology of coastal regions, particularly the structure and the lithology of the rock formation that outcrop on the coast and their response to weathering and erosion processes.

## 2.6 Modelling

Modelling in this context refers to the development of mathematical expressions that describe (in some sense) the behaviour of a random variable of interest (Rawlings *et al.*, 1989). Shoreline positions like other natural coastal landforms are dynamic systems which change in form and pattern both in space and time in response to environmental influences. Coastal destabilising factors originate from two main sources, namely oceanographic and geomorphologic factors. Each of these stresses may be further reduced to a number of identifiable causative dynamic variables so as making modelling of shores a complex system.

### 2.6.1 Existing Techniques for Modelling the Shoreline Change

Existing modelling techniques employed for shoreline systems include: Static Models, Physical models, stochastic models and Process-based models.

#### 2.6.1.1 Static Models

Static models are models employed in coastal systems which are based on equilibrium conditions. A classic example is the parametric equilibrium model which is based on attainment of equilibrium of the shape of the coastline. Parametric equilibrium models represent the shape of the coastline or its response to external forces by means of simple equations that have been derived through a mixture of curve-fitting and theoretical considerations. The models are simple, and quick to apply. They have been proposed for coastal areas where hydrodynamic forces are responsible for the transportation of sediment. The best known model relates shoreline retreat to increase in sea level and was

proposed by Bruun (1962). Bruun's study on beach profiles in Denmark and California revealed that the cross-shore profile in the vertical may be expressed as in Equation (2.25) (Bruun, 1954).

$$h = Ay^{2/3} \quad (2.25)$$

where  $h$  = water depth,  $A$  is a sediment scale parameter and  $y$  is the cross-shore distance from the shoreline.

A careful examination of the results of Bruun's study by Dean (1977) led to the conclusion that equilibrium beach profiles would take the form indicated by Bruun if the dominant destructive force was wave energy dissipation per unit volume (Dean & Dalrymple, 2002). Equilibrium beach profiles are, however, less suitable for making predictions since calibration tend to be more site-specific (Dean & Dalrymple, 2002). The main challenge with the equilibrium beach profile is that the slope is infinite at the water line and it does not allow for bars.

Bruun (1962) later proposed the following equation for the equilibrium shoreline retreat,  $R$ , of sandy coasts that will occur as a result of sea level rise,  $S$ :

$$R = \frac{SL}{h+B} \quad (2.26)$$

where  $L$  is the cross-shore width of the active profile,  $h$  is the closure depth and  $B$  is the elevation of the beach or dune crest.

The equation balances sediment yield  $R(h + B)$  from the horizontal retreat of the profile with sediment demand,  $SL$ , from a vertical rise in the profile (Dean & Dalrymple, 2002). The magnitudes of  $h$  and  $B$  are difficult to determine and the actual seabed will need time to respond to a change in sea level.

Bruun rule does not depend on a particular coastal profile, but does assume that no sediment is lost from the coastal system (which is likely to happen if there are fine soil in the area eroded). It assumes a coast of unconsolidated sediment, mainly sand, with a coastal dune and it makes no allowances for gradients in the longshore or cross-shore transport of sand. Although Bruun rule is a very simplistic analysis tool yet it is difficult to validate.

#### *2.6.1.2 Physical Models*

Unlike static equilibrium models which are feature shape-dependent, physical models are based on laboratory experimental simulation and may be required on small sites to determine external parameter such as the wave climate. Physical models are well established procedures for the analysis of wave propagation and breaking effects. They are useful in analysis of the effects of structures on the wave field and probably the only dependable method for estimating wave fields. Physical models are, however, rarely used due to scaling limitations and cost (Frostick *et al.*, 2011).

### 2.6.1.3 Stochastic models

Stochastic models are deterministic models that represent aspects of geomorphic systems in terms of probability and statistics. Two main approaches to modelling shorelines under this category are discussed. They are the erosion based methods and the recession based methods.

#### *Shoreline Erosion Based Prediction Models*

The erosion based models depend on sediment mass conservation and attempt to balance volume of sediment within the littoral zone in order to predict the shoreline change. A typical model was proposed by United States Army Corps of Engineers (USACE, 1992).

The equation is as follows:

$$\frac{\Delta x}{\Delta t} + \frac{1}{D_B + D_C} * \left( \frac{\Delta Q}{\Delta y} \pm q \right) = 0 \quad (2.27)$$

where  $\Delta x$  is the change in shoreline perpendicular to the shore;  $\Delta t$  the time interval of the analysis;  $\Delta Q$  the rate of sediment transport;  $\Delta y$  is the length of the shoreline under consideration;  $D_B$  and  $D_C$  are offshore closure depth and berm crest elevation respectively. Sand mining is considered through term  $q$  in the equation.

#### *Shoreline Recession Based Models*

These are empirical models that deal only with the shoreline geometry and do not involve any information regarding the causal interactive factors of the coastal erosion processes.

This approach calculates changes in the shoreline over a length of time. Shorelines are identified in increasing order of time and then the relationship between the shoreline position changes and the time are analysed by numerical method. The shoreline position changes are measured from extracted shorelines plotted from historic topographic maps, aerial photographs and GPS ground survey sources. Then choosing a baseline on shore or off shore, the distance between shoreline positions are measured. From the measured data the rate of change is calculated as follows:

The rate of shoreline change

$$= \frac{\text{Measured movement of shoreline}}{\text{Specified length of time}} \quad (2.28)$$

Positive values of the rate of shoreline change indicate recession landwards whilst negative figures indicate accretion seaward. Commonly used transect based recession (numerical) methods include: End point rate, Average of Rates and Linear regression by least squares.

#### *End Point Rates (EPR) Method*

End Point Rates method derives a linear equation from two shoreline points available, the slope of which gives the recession rate. The advantage of this model lies in its simplicity. It, however, yields misleading results if inaccurate shorelines are used in the computation. Again useful information on intermediate shoreline morphology is missed out in the model (Dolan *et al.*, 1991).

*Average of Rates (AoR) Method*

This method defines a minimum time criterion to provide more accurate shoreline position data and magnitude of the rate of change (Foster & Savage, 1989; Thieler *et al.*, 2001). The minimum time criteria defines a time  $T_{\min}$  which represents the minimum time that must elapse between measured shorelines in order to ensure that the average rates calculation produces results that exceed measurement error. The time  $T_{\min}$  require the End point rates for all the pairs of shorelines available as input (Dolan *et al.*, 1991).

$$T_{\min} = \frac{\sqrt{E_1^2 + E_2^2}}{R_1} \quad (2.29)$$

Where  $E_1$  = measurement error in the first shoreline point

$E_2$  = measurement error in the second shoreline point, and

$R_1$  =end point rate of the longest time span from the transect

The main disadvantages are that the accuracy of the model is dependent on the minimum time span (Equation (2.29)), and the sensitivity of the result to the values used in the measurement error values. Again, some results are produced as end point rates if only two points are available (Thieler *et al.*, 2001). Another method free of these limitations is the linear regression with errors handled by least square approach.

*Linear Regression Method*

Multiple regression analysis, which is one of the most powerful tools that is widely used for studying the relationship between a dependent variable and two or more independent

variables for the purposes of predicting, explaining and building theory was employed (Rawlings *et al.*, 1989). The Multiple Regression Model requires one dependent variable (response) and two or more independent (predictor) variables which are dynamic variables from the external environment and the Sample size of at least fifty ( $\geq 50$ ) (at least 10 times as many cases as independent variables) (Cohen, 1988).

The Multiple Regression Model operates under the following assumptions about the data used:

- **Independence**, which implies that the measured or observed values of any particular variable are independent of the measured or observed values of all other variables.
- **Normality**, which implies that the population, the measured or observed values on the dependent variable are normally distributed for each of the possible combinations of the level of the X variables; each of the variables is normally distributed.
- **Homoscedasticity**, which means that in the population, the variances of the dependent variable for each of the possible combinations of the levels of the X variables are equal.
- **Linearity**, which implies that in the population, the relation between the dependent variable and the independent variable is linear when all the other independent variables are held constant.

This method uses a minimum of four shorelines and measures the slope of regression line obtained by fitting a line which minimises the squares of the error terms in all shorelines points for a particular transect. The advantage of this method is that all the data are used regardless of the changes in the accuracy. It also offers rigorous solution and it is capable of assessing the accuracy of the line of best fit. The method may be used where data is

noisy since least squares adjustment is capable of reducing the noise during the analysis (Frazer *et al.*, 2009; Galgano & Douglas, 2000). The disadvantage is that it assumes normal distribution of the shoreline points (constant slope of the shore) which technically is incorrect because linear regression fails to recognise the probable temporal differences in the trends and acceleration or deceleration (Morton, 1991). This approach was adopted in the computation of initial shoreline change rates employed in this research where the required minimum number of shorelines was available.

#### *Numerical Shoreline Excursion Predictive Model*

Another shoreline evolution numerical predictive model was derived by Allan *et al.* (2003). The method measures the shoreline variability using water level change and the beach slope Equation (2.30).

$$\text{Shoreline excursion (SE)} = \frac{\text{vertical change in water level (VC)}}{\text{Average slope of beach (S)}} \quad (2.30)$$

Although these statistical models are used extensively, they can only predict behaviour under certain conditions that are well represented in historic records (Dolan *et al.*, 1991 ; Hall *et al.*, 2002) .

#### *2.6.1.4 Process Based Models*

Process-based models are based on simulation of processes that are thought to operate in reality. Coastal systems are dynamic systems undergoing adjustments of form and process at different time and space scales in response to oceanographic and geomorphic factors

(Cowell *et al.*, 2003). Coastal systems response to variations in the external conditions as well as changes triggered from their internal thresholds. The challenge is to determine whether or not observed changes from external factors exceed internal threshold values. Process-based models take into consideration practically all the morphodynamics (i.e. form and process dynamics) pertaining to a particular coastal system under study. A typical example of process-based model is the Soft Cliff And Platform Erosion (SCAPE) model (Walkden & Hall, 2005). The model is a generic tool which allows coastal modelling in terms of shore platform, beach, tide range, wave transformation, cliffs and rock debris. The SCAPE model is a classic process-based geomorphic model which addresses issues related to quantitative predictions of the effects of natural and anthropogenic changes that cannot be predicted by statistical analysis of historic data alone (Walkden & Hall, 2005). The model enables predictions over timescales of decades; it may also be used to explore the dynamics of retreating soft shore profiles and predict future behaviour. However, material strength, an important factor controlling shore platform vulnerability (Sunamura, 1992), is not captured explicitly in the model. Besides, the model was formulated for soft shore profiles and may not be applicable to shore profiles possessing heterogeneous coastal material like the Western Region of Ghana.

#### *Multiple Regression Analysis as a Process-Based Modelling Technique*

Regression analysis is a statistical tool that utilises the relation between two or more quantitative variables so that one variable can be estimated or predicted from another. Regression analysis serves three purposes, namely Description, Control, and Prediction. Regression enables an expectation of real world i.e. theory to be linked with data

(Rawlings *et al.*, 1989). Where the relation is a linear function, the resulting function is referred to as a simple linear regression model expressed as Equation (2.31).

$$Y = \beta_0 + \beta_1 X + \epsilon_i \quad (2.31)$$

In this model  $\beta_0$ ,  $\beta_1$  and  $\epsilon_i$  are parameters and  $Y_i$  and  $X_i$  are measured values. Data for the regression analysis may be either observational or experimental. Higher order models can be generated in which case the parameters and the independent variables are polynomials.

To estimate the regression function, least square is often employed due to its ability to minimise the error term in Equation (2.31) and expressed as Equation (2.32).

$$\hat{Y}_i = b_0 + b_1 \hat{X}_i \quad (2.32)$$

where  $\hat{Y}$  is the predicted value by the regression model,  $\hat{X}$  is the corresponding independent value,  $b_0$  and  $b_1$  are constants representing the Y-intercept and the slope of the line of regression using the methods of least squares. Ordinary least squares technique was adopted because it provides estimates that are unbiased and have minimal variance among all unbiased linear estimators and also minimise the sum of squared errors. Stepwise multiple regression also referred to as statistical regression, is a way of computing ordinary least squares regression in stages.

## CHAPTER 3

### MATERIALS AND METHODS

#### 3.1 Description of the Study Area

The coastal zone in Ghana is defined as the area extending landwards from the shoreline to the 30 m contour, and stretching seawards to a coastal offshore shelf area to the 200 nautical mile depth (Wiafe *et al.*, 2013). The Ghanaian coastal zone constitutes 6.5% of the total land area of Ghana. The coastline of Ghana stretches for approximately 550 km and it is composed of about 70% sand beaches and about 30% of rocky coastline (Armah, 1991). Based on the geomorphology, Ly (1980) the coastline of Ghana has been zoned into three (Figure 5), as follows:

- a. The Western Zone, i.e. west of Cape Three Points: a flat and wide beach, backed by coastal lagoons marks this coast. Wave height is generally low.
- b. The Central Zone, i.e. between Cape Three Points and Tema: this section is of an embayed coast of rock headlands and sandbars or spits enclosing coastal lagoons. The surf zone is a medium to high-energy environment with wave heights often exceeding one (1) metre. The south westerly prevailing winds cause oblique wave approach to the shoreline, which generates an eastward littoral sediment transport.
- c. The Eastern Zone, i.e. east of Tema: the shoreline is sandy and is characterised by the eroding Volta delta. Wave and sediment dynamics are similar to those between Cape Three Points and Tema.

The Western Region is an administrative region in Ghana. The coast of the Region falls within the Western Zone (labelled a in Figure 5) and part of the Central Zone (labelled b in Figure 5) of the coastline of Ghana. The wave and sediment dynamics within the Region is a good representation of the entire coastline of Ghana. This is because the part of the Central Zone falling within the Western Region possesses wave and sediment dynamics similar to the Central and Eastern Zones of Ghanaian coastline while the Western zone differs in their characteristics (Ly, 1980).

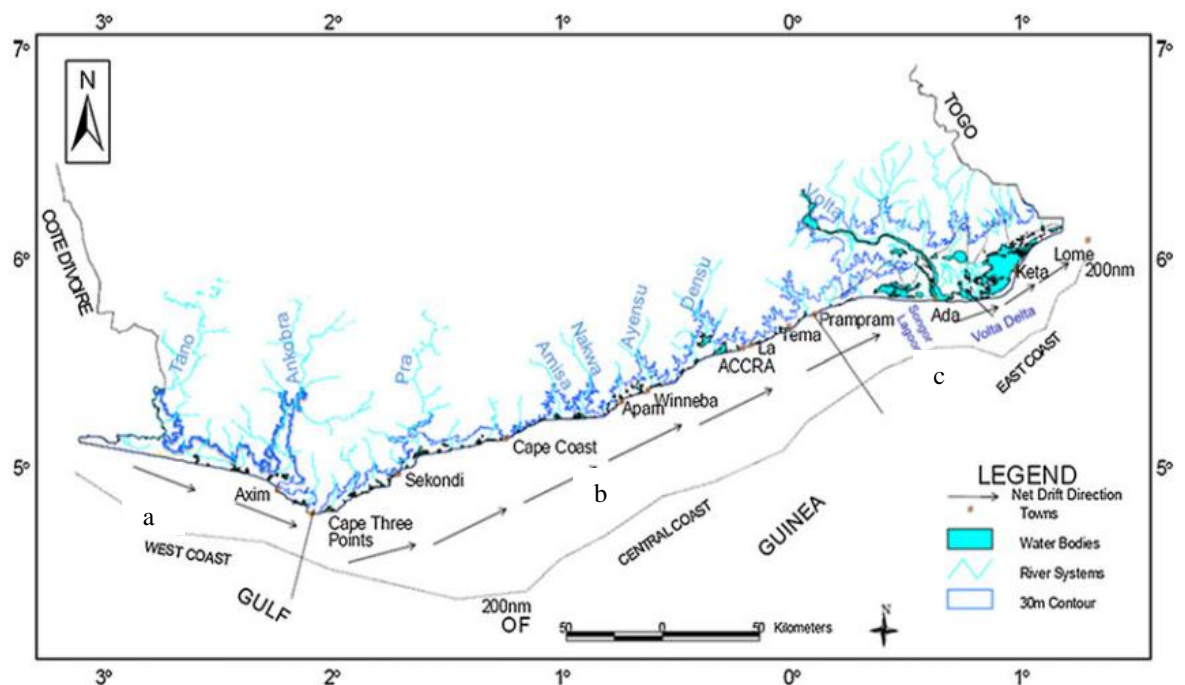


Figure 5: Map showing the Three Stretches of the Coastal Zones of Ghana (Source: Boateng, 2009)

### 3.1.1 Study Location and Geology of the Coast of the Western Region of Ghana

Ghana is a West African country bordered by Togo to the East, Cote d'Ivoire to the West, Burkina Fasso to the north and the Gulf of Guinea (Atlantic Ocean) to the south. The

Ghanaian coastline stretches about 550 km and it is zoned into three, namely, the Eastern, Central and Western Zones. The Western Region of Ghana lies within latitudes 4°40' and 5°10' north and longitudes 3°07' and 1°40' west (Figure 6). The coastline of the Region stretches to about 192 km constituting about 35% of the Ghana coastline. The coast is generally low lying with topographic elevation not exceeding the 30 m contour above mean sea level (Boateng, 2009). The coast has a wide continental shelf with the 200 nm extending to about 80 km off Cape Three Points.

The Region covers about 2 391 km<sup>2</sup> (about 10%) of the total land area of Ghana (GSS, 2012). The coastal material is composed of about 60% sandy beaches and 40% composite rock/sandy beaches (rocky headlands alternating with sandy bays).

Coastal materials within the study area may be described as heterogeneous with coastal rock types ranging from granitoids, through shales, sandstones to soils (Kesse, 1985). Portions of the study area are bounded by outcrops of high resistant rocks forming promontories giving the coast a characteristic curvilinear shape of headlands inter-spaced with embayment along the eastern portion of the study area. Prominent among the headlands is the Cape Three Points (most southern part of the country) which protrudes into the sea with an elevation of about 30 m above mean sea level. The western part of the study area has homogeneous coastal materials which stretch to about 100 km (Ankobra River Estuary – New Town) and it is characterized by purely sandy beaches occasionally intersected by some lagoons and estuaries (Loh & Hirdes, 1999). The Western Region, which lies within the Tano Basin, is underlain by Eocene and Cretaceous Appolonian sediments. The Appolonian consists of rapidly alternating sands and clays

with occasional thin beds of gravel and fossiliferous limestone. The sands and clays are more compact at depth and pass into sandstones and shales. Nodules of pyrite or marcasite are common in the clays and shales, and muscovite is common in some of the sand beds. The rocks strike in the west-northwest direction and most parts dip at very low angles (see Figures 6 & 7) (Kesse, 1985).

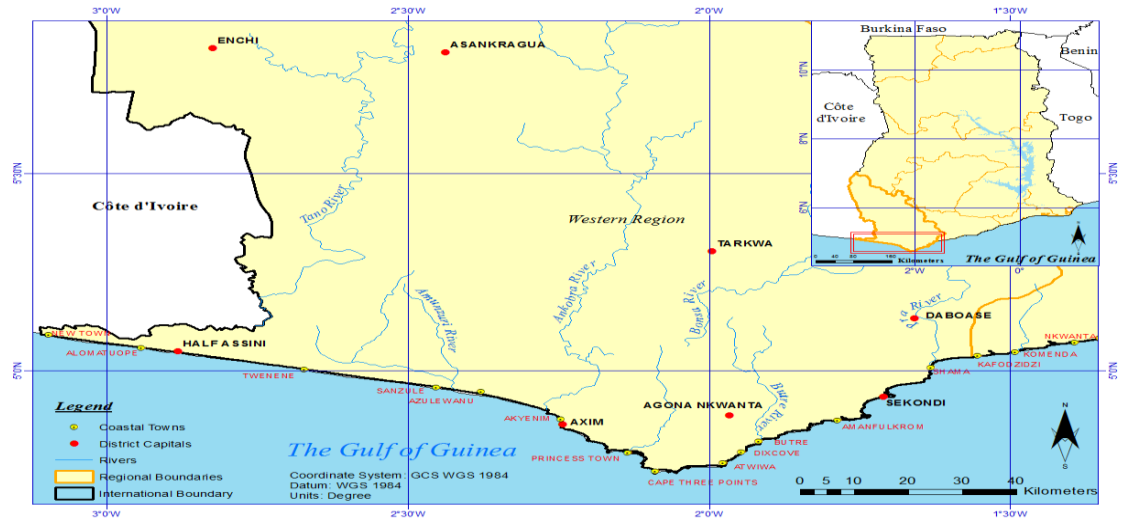


Figure 6: Map of the Coast of the Western Region of Ghana (source: SMD, Lands Commission, Ghana)

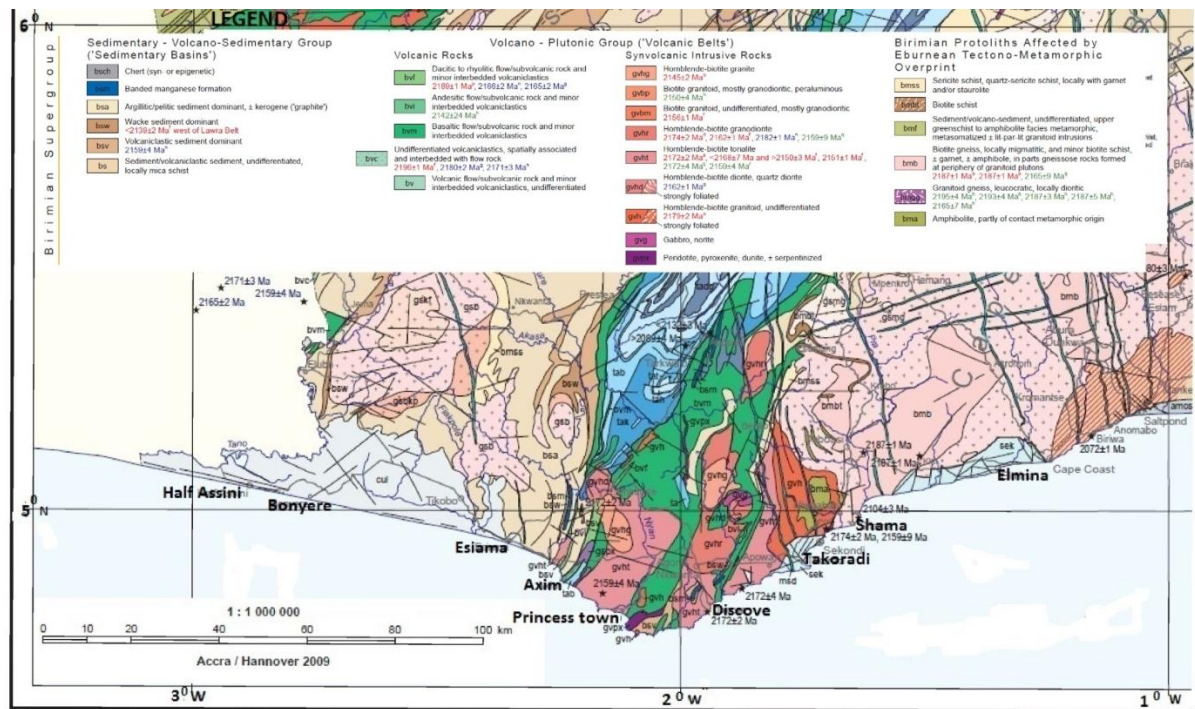


Figure 7: Map showing the Geology of the coast of the Western Region of Ghana (source: Ghana Geological Survey, 2009)

### 3.1.2 Climate and Hydrology of the Western Region Coast

The climate within the coast of the Western Region shows an average significant wave height of about 1.2 m and a relative wave period between 10 s and 12 s (AESC, 1980). Prevailing wave direction approaches the coastline from south-south west with a local sea level rise rate of about 3 mm/year (Apeaning Addo *et al.*, 2008). Relatively low tides are observed in the area with the neap and spring tidal ranges recorded as 0.53 m and 1.3 m respectively (Wiafe *et al.*, 2013) and a mean tide range of 0.6 m (AESC, 1980).

The marine environment, like other parts of the Ghana, is characterised by two seasonal upwelling namely major and minor. A major upwelling, which occurs from either late June or early July to late September or early October, and a minor upwelling, which occurs

between January and March. These upwelling have considerable influence on both the local and sub-regional fisheries (Armah & Amlalo, 1998).

The climate along the coast of the Western Region like other parts of the country's coastal zones is described as equatorial with significant variation in spatial distribution in precipitation. The region records the highest rainfall values in Ghana with mean annual rainfall of 2083 mm which explains the relatively lush green vegetation found in the region. Mean annual temperature range along the coast is narrow ( $26^{\circ}\text{C}$ – $28^{\circ}\text{C}$ ) but shows strong seasonal differences ( $21^{\circ}\text{C}$ – $22^{\circ}\text{C}$ ) in August and  $24^{\circ}\text{C}$ – $28^{\circ}\text{C}$  in April.

The area is well drained by numerous rivers; prominent are the Pra, Ankobra, and the Tano. The spatial location of Pra River in the east and Tano River in the west partly forms the western regional boundary. Ankobra, which flows to the west of Pra, has a relatively small drainage basin. It rises in the hilly region of Bibiani and flows in a southerly direction to enter the Gulf of Guinea just west of Axim. Ankobra river is navigable for a stretch of approximately eighty (80) kilometres inland from its mouth – it has been used as means of transport of machinery to gold-mining areas in the vicinity of Tarkwa. The Tano, which is the westernmost of the three rivers, rises near Techiman in the centre of the country. It also flows in a southerly direction, but it empties into a lagoon in the southeast corner of Côte d'Ivoire. Navigation by steam launch is possible on the southern sector of the Tano for about 70 kilometres (Loh & Hirdes, 1999).

The shores of the Western Region are nourished by the numerous rivers of different sizes which deposit their sediment load to recharge the beaches. Akrafi (2011) in his study

determined the sediment load deposited by each of the major rivers for the southern part of Ghana. The coastal basins were, however, considered on a large scale hence the finest details of the sediment load deposited were difficult to estimate on the small scale applied in this study.

### *3.1.3 Districts and Demography of the Western Region*

The Western Region has an estimated population of 2 376 021, making up about 9.6% of the total population of Ghana with an annual population growth rate of 2% with 13 Administrative districts (GSS, 2012). It is the second most densely populated region in Ghana next after Greater Accra with a population density of about 79 person's per-square kilometer and 63% of the region is rural (GSS, 2012). The principal economic activities include agriculture (cash crops and food crops), fishing (commercial and subsistence), mining and manufacturing. The main exportable produce are cocoa, timber, copra, coffee, rubber/latex, gold, manganese, bauxite and petroleum.

The region is endowed with considerable natural resources, which gives it a significant economic importance within the context of national development. It is the largest producer of cocoa, rubber and coconut and one of the major producers of oil palm. Its rich tropical forest makes it one of the largest producers of raw and sawn timber as well as processed wood products. A wide variety of minerals, including gold, bauxite, iron, diamonds and manganese are either exploited or are potentially exploitable. The region's total geological profile and mineral potential are yet to be fully determined (Loh & Hirdes, 1999).

### 3.1.4 *Classification of the Coast of the Western Region of Ghana*

Classification of coasts is the first step in most shoreline management planning systems, where coasts with similar features are grouped together. For the purpose of this study, the coast is classified based on the formation which ties in well with the geological framework according to the modified Shepard's scheme (Ihl *et al.*, 2006), the geomorphological processes and the variability within the coastal material.

On the account of the geomorphic processes, the area was initially grouped into three geomorphic sections based on the topographic relief and the hydrological flow pattern. However, the surface characteristics of the coastal material place the study area into two categories, the Western Section (New Town - Ankobra Estuary) and the Eastern Section (Ankobra Estuary – Shama). In this vein, the presence or absence of coastal cliffs along a given stretch of the coastline was considered. This is in line with Emery and Kuhn, (1982) assertion that coastal cliffs are strongly influenced by the geology of the coastal region and therefore it is conceivable to have similar responses to weathering and erosion processes. It is on these grounds that the study area was divided into two: the Western and the Eastern Sections for effective analysis of the coastal system characteristics.

## **3.2 Materials and Methods Used**

The methods adopted in the study comprised of the selection of a sampling technique, laboratory testing and analysis, geo-referencing of digital images, extraction of shorelines and the computation of change statistics, measurement of beach profiles and width, measurement of strength of coastal rock outcrops using the Schmidt's Hammer and the

measurement of coastal soil resistance to penetration. Other methods employed include computation of longshore sediment transport, estimation of rates of sediment deposition by rivers into the sea, development of a Multiple Regression Model for future shoreline prediction, and testing of the prediction model generated. The methodology used to achieve the set out objectives are in four components. They include:

- Extraction of shoreline information from available historic, topographic and ortho-rectified aerial photographs by digitising, from which a geospatial database in ArcGIS environment was created. Then the determination of the shoreline change rates for 100 m intervals of orthogonal transects along the study area by applying the Average of Rates and the Linear Regression by least square algorithms using Digital Shoreline Analysis Systems (DSAS) extension of ArcGIS.
- Analysing coastal material to determine their strength against erosive forces. Systematic collection of soil samples from the study area for laboratory testing using the Sieve Analysis method and measurement of the rebound strength of the coastal rocks. Where practicable, rock samples were also collected and their compressive strength determined using Unconfined Compressive Strength test to validate the field measurements. Strengths of coastal material (hard and soft), texture of coastal material and the thickness of the overburden were evaluated for correlation analysis.

- Computation of potential sediment transport along the shore of the study area, and sediment supplied by coastal rivers to nourish the beach were evaluated to assess their relationship with the computed shoreline change. Evaluation of human impact on the coast by the AHP, and the effect of sea level rise on the shoreline for correlation analysis.
- Creation of a numerical model realised through multiple regression model and feeding of the model with data so as to determine variables significantly influencing shoreline change in the study area.
- Computation of sea level rise effect on shoreline change along the study area.

Secondary data used in the study were acquired from diverse sources and these have been shown in Table 3

**Table 3 Secondary Data used**

| <b>Data Type</b>  | <b>Year</b> | <b>Source</b>                       | <b>Scale</b> | <b>Remarks</b>                   |
|---|-------------|-------------------------------------|--------------|----------------------------------|
| Digital Topographic Map of the Gold Coast Colony and Neighbouring Territories | 1895        | British Council Library, UK         | 1:506 880    | Image Format                     |
| Geological Map of Gold Coast  | 1955        | Geological Survey Department, Ghana | 1:1000 000   | Image Format                     |
| Digital Topographic Map of Ghana  | 1974        | SMD, Lands Commission, Ghana        | 1:50 000     | National Mapping Agency in Ghana |
| Digital Topographic Map of Ghana  | 1984        | SMD, Lands Commission, Ghana        | 1:50 000     | National Mapping Agency in Ghana |
| Digital Topographic Map of Ghana  | 1994        | SMD, Lands Commission, Ghana        | 1:50 000     | National Mapping Agency in Ghana |
| Ortho Rectified Aerial Photographs  | 2005        | CTK Ghana Ltd                       | 1:10 000     | Mapping Consultants, Ghana       |
| Measured Tide Data  | 1965-1992   | SMD, Lands Commission, Ghana        |              | Ghana Port & Harbour             |
| Measured Offshore Wave Data   | 2010        |                                     |              | University of Ghana              |

### 3.2.1 Sampling

A systematic sampling strategy was adopted in this study. This approach allows gridding of the coastline at regular intervals of about two kilometres along the shore and 50 m across the shore into the coastal hinterland up to 100 m with the grid intersections serving as the sample locations. The technique offers ease of drawing samples locations, an unbiased sample estimator of the population and yields more precise sampling compared to other methods such as the non-probabilistic, stratified random or the clustering sampling approaches (Gundersen *et al.*, 1999). A total of 282 sample locations were established, however, 6.4% of this figure was inaccessible.

The following data were collected at each of the sample locations:

- i. The geographic location coordinates;
- ii. The penetration resistance for every 10 cm depth;
- iii. The Schmidt Hammer rebound value of the coastal rock outcrops where applicable;
- iv. The attitude of the coastal rock where outcrops were seen;
- v. The profile of the exposed beach;
- vi. The width of the exposed beach.

Representative intact rock samples were collected, labelled and bagged in transparent polythene material. Similarly, sufficient quantities of undisturbed soil samples were taken at measured depths, labelled and transported to the laboratory.

### 3.2.2 Laboratory Analysis

Samples taken were tested in the laboratory to validate the properties of the soil and rocks that were sampled *in situ*. Sieve analysis was also carried out on the soil samples for their respective particle size distributions.

#### 3.2.2.1 Particle Size Distribution Test

The particle size distribution was determined for each soil sample using the wet sieving method to enable classification of the soil according to the Unified Soil Classification System. In this test, a known mass of the soil sample was run through a series of sieves nested in decreasing order of aperture size ranging from 2.8 mm to 0.063 mm.

Mass of the particles retained on each sieve size was expressed as a percentage of the original mass of sample used. The quantity that passed the 0.063 mm size was assessed and if found to be significant, the sedimentation test was run so as to determine the clay and silt size proportions.

The percentage of particles passing a given size of sieve P% is given as follows:

$$P\% = \frac{M_i}{M_w} * 100 \quad (3.1)$$

where  $M_i$  = the mass of the soil sample passing through a given sieve size, and

$M_w$  = mass of the total soil sample.

The percentage particles passing each sieve size were plotted against their corresponding sieve sizes to give the grading curve of the soil.

### 3.2.2.2 Compressive Strength of Intact Rock Samples

The compressive strengths of the intact rock samples were determined as follows:

The intact rock samples were cut into cubes of about 5 cm<sup>3</sup> by means of a diamond saw blade and subjected to compression in the Compression testing machine to failure. The stress at failure ( $\sigma$ ) was computed by dividing the maximum load attained by the cross-sectional area of each specimen as shown in Equation (3.2).

$$\sigma = \frac{\text{Load (kN)}}{\text{Area (m}^2\text{)}} \quad (3.2)$$

The test was performed on two or three specimens and the mean value of each of the samples was determined and compared with the in-situ strength determined using the Rebound hammer.

### 3.2.3 Geo-referencing of Digital Images

The 1895 and 1955 topographic maps were geo-referenced by extracting coordinates of clearly visible geographic grid intersections points. The extracted geographic coordinates of the six grid intersection points were transformed into plane Cartesian Coordinates System (Ghana Metre Grid in metres) by applying the Transverse Mercator configuration using the Spectrum Survey GPS processing software and applying the prescribed parameters. These coordinates, which served as control points, were entered in Microsoft Excel and imported into Arc GIS software. The map in image format was also loaded in the Arc GIS environment and the coordinates of each grid intersection point on the image was mapped onto the coordinates of the corresponding transformed Cartesian Coordinates, after which the geo-referencing was updated. To ensure accurate geo-

referencing, the Root Mean Squared Error (RMSE) of the geo-referencing was calculated and the level of certainty determined.

### *3.2.4 Extraction of Shorelines and Computation of Shoreline Change Rate Statistics*

Available historic topographic maps of 1895, 1955, 1974 and 1994 all of which share a common datum (Clarke 1880 modified RGS spheroid) and projection (Transverse Mercator) were integrated in an Arc GIS environment. The shoreline positions within the study area were extracted from geo-referenced ortho-rectified aerial photographs taken in 2005, and the High Water Line (HWL) proxy was used to extract the shoreline position from the photograph. The same procedure was used to define all the shoreline positions for all the topographic maps considered. HWL proxy was used because it is easily identified in the field and on aerial photographs and often used to represent the shoreline position on historical maps (Thieler *et al.*, 2009). The shorelines were therefore compatible and ready for the change detection and comparison. A geodatabase was created where all the shoreline features were stored after keying in specific attributes as prescribed by the DSAS extension before appending all the shorelines. A baseline feature was created and transects cast at interval of 100 m to cross all the shoreline after which the shoreline change statistics were computed using the Average of Rates (AoR) and the Linear Regression (Dean & Dalrymple, 2002) methods respectively. These methods were used by virtue of their simplicity, accuracy and popularity.

### 3.2.5 *Measurement of Exposed Beach Profiles and Widths*

Beach levels were measured from the dune to the shore-face so as to depict the longitudinal section of the beach at that chainage; this enables the beach slope to be determined and the corresponding shoreline excursion due to rising sea-level to be computed. Beach width was measured since this parameter is assumed to correlate with wave energy dissipation within the littoral zone. Spirit levelling technique was adopted due to its high accuracy and flexibility (Ceylan & Baykal., 2006). To ensure reliability of the instrument used, a prior two-peg-test was conducted by assessing the staff reading values when the level instrument was equidistant from two temporary fixed staves' positions, and then when the instrument was closer to one of the staves. The results obtained suggested no collimation error in the level instrument used.

Now setting the instrument within the working area the staff was first placed on a permanent feature of known elevation (above mean sea level) and the staff reading was recorded and added to the reduced level of the point to obtain the height of collimation for the set position. By subtracting the staff reading at any staff position along the beach from the collimation height computed, the reduced levels of the various staff positions set-out at about three (3) metre intervals were calculated. To ensure positional accuracy of the staff locations along the beach, Garmin GPS receiver was used to record the location coordinates. A standardised linen tape was also used to measure the beach width at four different locations at each shore chainage and the mean values determined. Table 4 illustrates profile and beach width sample data collected in the field.

To investigate and quantify the shoreline response to sea-level rise, the method of Allan *et al.*, (2003), derived to measure shoreline variability using water-level change and beach slope was employed. Historic tide gauge readings measured from the study area was analysed using Linear

Regression analysis. The slope so determined gave the local rate ( $r$ ) of sea-level rise per year. Assuming that sea-level rise is the only factor contributing to shoreline position, the shoreline position for a given rise in sea-level depends on the shore slope obtained from the beach profiles (see Figure 8).

**Table 4: Sample Field Data Recorded on Beach Width and Profile**

| Exposed Beach width (m) | Back sight | Inter sight | Fore sight | Latitude    | Longitude   | Remarks            |
|-------------------------|------------|-------------|------------|-------------|-------------|--------------------|
| 18.20                   | 0.31       |             |            | 4° 54.138'N | 1°44.793 'W | Concrete slab      |
| 18.00                   |            | 1.33        |            |             |             | Edge of Shore back |
| 17.30                   |            | 2.55        |            |             |             |                    |
| 18.65                   |            | 3.26        |            |             |             | P9 New Takoradi    |
|                         |            | 2.94        | 3.19       | 4° 54.136'N | 1°44.779 'W | Shore face         |

The shoreline excursion  $SE$  proposed by Allan *et al.*(2003), could be expressed in terms of the Sea-Level Rise Rate ( $r$ ) and the beach slope  $S$  as follows:

$$SE = \frac{VC}{S} = \frac{SL_1 - SL_0}{t} * \frac{t}{S} = \frac{r*t}{S} \quad (3.3)$$

where  $t$  is the duration (years) for sea-level to rise from  $SL_0$  to  $SL_1$ . The shoreline position change  $SE$  exclusively caused by sea-level rise is the product of the sea level rise rate and the duration (eg. 110 years *i.e.* 2005-1895) divided by the beach slope. For the long term analysis in this study, for instance, the shoreline was obtained by multiplying duration (110 years) by the rate of sea level rise (3 mm/year) divided by the mean shore slope (0.22).

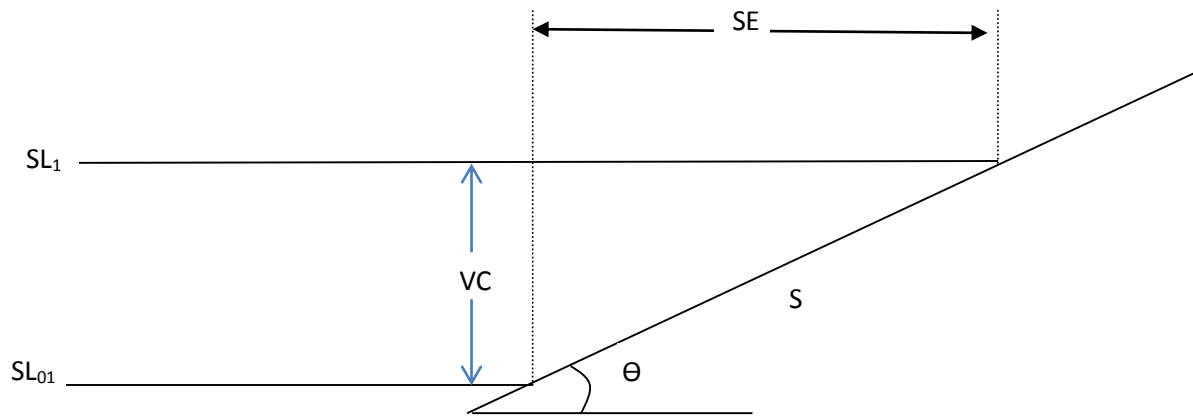


Figure 8: Shoreline Excursion due to Sea-Level Rise Rate

### 3.2.6 Measurement of Coastal Rock Outcrop Strength

Rock exposures within the study sites were identified, and their surface hardness measured as an indicator of their resistance to coastal erosion. The internal resistance of the rocks to externally exerted stress (which is a measure of their strengths) were measured by means of a Schmidt or Rebound hammer. The hammer was applied at right angles to the rock surface, and a piston within the hammer driven by a spring loaded mass impacted against the rock surface with a definite energy, thus causing a rebound from the rock. The rebound value is indicated on an index scale on the hammer. The test was performed at 15 different locations on each outcrop and the rebound value at each location recorded (see Appendix X & Figure 9). The mean values and the standard deviations for the recorded rebound values of each rock outcrop were determined after which the rock compressive strength were obtained from a Table/Chart (Appendix I). The compressive strengths were assessed for correlation with the Uniaxial Compressive Strength (UCS) test results obtained in the laboratory. The scatter plots of the compressive strengths from the rebound values

were plotted against their corresponding UCS values which were found to correlate well as shown in linear regression equation obtained Equation (3.4).

$$\text{UCS strength} = 0.593 \text{ Schmidts reading} + 5.678 \quad (3.4)$$

The Rebound hammer technique was used for this study because the testing procedure was simple and accurate and non-destructive.



Figure 9: Photograph showing Measurement of Rebound Value at Abuesi

### 3.2.7 Measurement of Soil Resistance to Penetration

The resistance of coastal soils to shearing was measured for the study area using the Dynamic Cone Penetrometer Tests (DCPT). This test was performed with a 10 kg steel hammer falling 500 mm using a 60° cone. The number of blows required for every 10 cm penetration into the soil was recorded until refusal when 50 hammer blows were unable to cause a penetration of 10 cm into the soil, or resistance to further penetration was encountered. The penetration test was carried out

for all sampled locations until refusal was encountered at which point the depth of overburden was recorded.

The shear displacement of soil by a DCPT transforms the equilibrium status of the soil from elastic to plastic state. Assuming an ideal soil and smooth cone tip, the punch resistance ( $q$ ) of an ideal plastic medium is expressed as follows:

$$q = NS \quad (3.5)$$

Where  $q$  = the average punching or penetration stress;  $S$  = the shearing resistance of the medium, and  $N$  a coefficient which depends on the geometry of the cone and surface it penetrates (the internal friction of the soil).

The penetration was caused by the increment of work done  $\Delta W$  applied to the Penetrometer anvil to force the tip through a distance  $\Delta s$  is as follows:

$$\Delta W = \Delta s q A \quad (3.6)$$

where  $A$  = the penetrometer cone area.

Now the work done by a hammer of mass  $m$  falling  $n$  number of times from a height  $h$  to cause a penetration of soil by depth  $\Delta s$  is given as follows:

$$\Delta W = nmgh \quad (3.7)$$

where  $g$  is acceleration due to gravity.

From Equations (3.5), (3.6) and (3.7)

The soil strength  $S$  is expressed as follows:

$$S = \frac{nmgh}{\Delta sA} * \frac{1}{N} \quad (3.8)$$

DCPT technique was adopted because the equipment was simple to use and it is widely used for geotechnical site investigation in support of analysis and allows the shear strength of soils to be determined on site.

### 3.2.8 Alongshore Sediment Transported due to Breaking Waves

From directional wave data measured from a buoy offshore the study site (about 80 nautical miles or 129 km off the shores), short term analysis of the data using statistical methods enabled the significant wave height  $H_s$  to be computed as follows:

$$H_s = \frac{1}{N_s} * \sum_{i=1}^{N/3} H_i \quad (3.9)$$

where  $N$  = number of individual wave heights  $H_i$  in accordance with records ranked from the highest to the lowest.

Net wave direction  $\theta_w$  was also determined using a wave rose generated from the recorded and classified wave directions at specified intervals. Knowing the mean shore angles  $\theta_s$  of the different sections of the shoreline measured from topographic map, the angle between the wave angle from the north and the shore angle from the north gives the direction of the wave entering from deep sea to the surf zone (Figure 10).

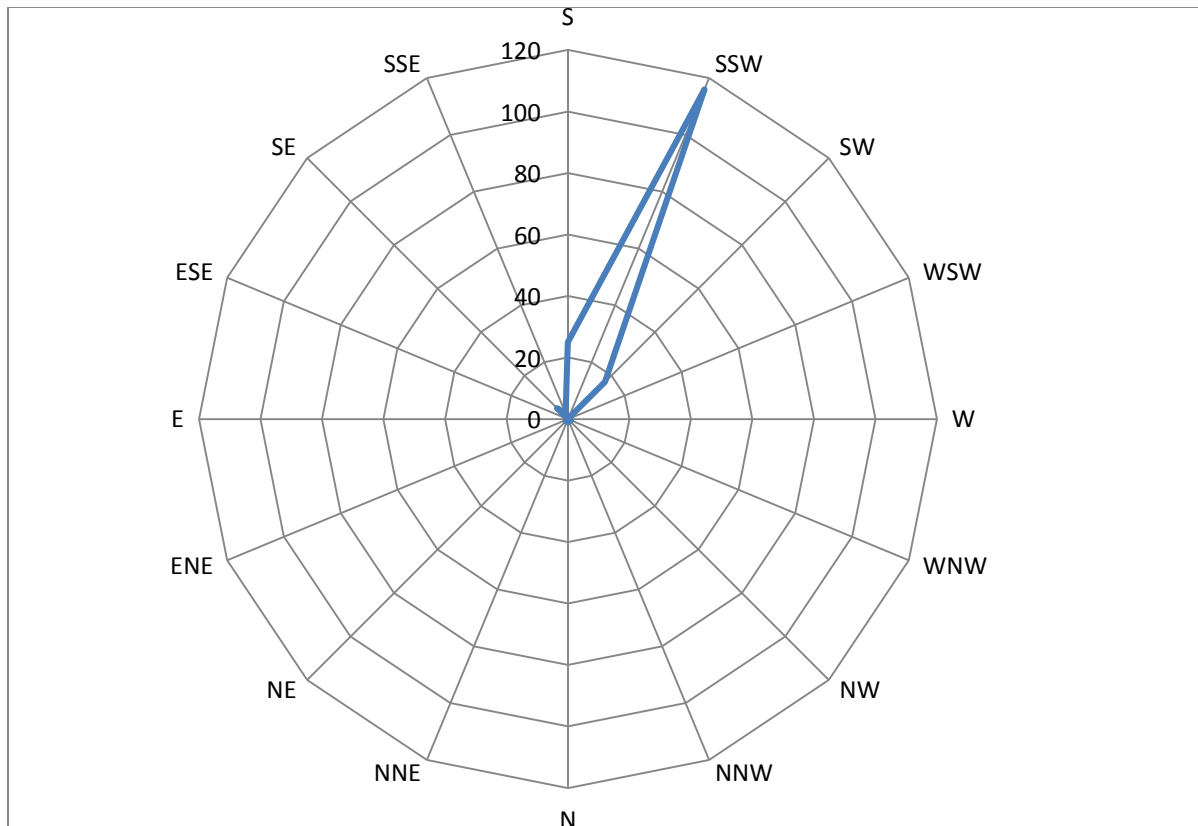


Figure 10: Waverose Generated from Data Showing Net Wave Direction

The angle of the breaking wave crest with the shoreline  $\alpha$  is given as follows:

$$\alpha = \theta_w - \theta_s \quad (3.10)$$

where  $\theta_w$  is the mean wave direction in water and  $\theta_s$  the mean direction of shoreline.

Assuming no wave energy is lost as wave travels from deep water to wave breaking point; Snells' wave refraction calculation is used to determine the parameters of the wave in shallow water. Equations generated from consideration of the respective wave energy transport per second are equated from which the wave height at breaking can be determined, knowing the wave velocity (celerity) in deep water  $C_o$  and at breaker line  $C_{br}$ .

Wave energy transported per second in deep water (off shore) is given as follows:

$$E_o = \frac{1}{8} * \rho g H_o^2 B_o C_o \quad (3.11)$$

Similarly, wave energy transported per second at the breaker line is given by:

$$E_b = \frac{1}{8} * \rho g H_b^2 B_b C_{br} \quad (3.12)$$

where  $H_o$ ,  $H_b$  = significant wave height at deep water and breaker line respectively. Equations (4.11) and (4.12) are equated to determine the wave height at breaking  $H_b$ .

The wave incidence angle at breaker line br can be determined from the Snell's equation as follows:

$$\sin \theta_{br} = \frac{C_{br}}{C_o} * \sin \theta_o \quad (3.13)$$

where  $\theta_o$ ,  $\theta_{br}$  = wave incidence at deep water and breaker line from which  $\theta_{br}$  can be determined and therefore  $\alpha$  can be calculated. Substitution of the determined values  $H_b$ ,  $\alpha$ ,  $C_{br}$  and specific weight of water  $\gamma$  the wave energy flux factor Pls (3.14) and subsequently the longshore sediment transport rate can be computed for the various sections of the shoreline based on the orientation of the coast.

Using the CERC equation or the energy-flux method (USACE, 2002) the longshore sediment is computed as follows:

$$Q = KPls \quad (3.14)$$

where Pls = wave energy flux factor

+K = Empirical Coefficient (K = 7 500 when Q is expressed in yd<sup>3</sup>/year and Pls in Ib/s). The CERC equation was used in the computation of the longshore sediment rate because of its popularity and accuracy.

Now the sediment transport relates the CERC equation as follow:

$$Pls = \frac{\gamma}{16} * H_b^2 C_{gb} \text{Sing} (2\alpha) \quad (3.15)$$

where Q = longshore sediment transport, and

$H_b$  = wave height at breaking

$C_{gb}$  = wave celerity at breaking

$\alpha$  = angle of the breaking wave crest with the shoreline

$\gamma$  = specific weight of water

### 3.2.9 Estimation of Rate of Sediment Discharged into the Sea by the Rivers

The quantity of sediment load discharged into the sea per year by the four different coastal basin systems were estimated. This enabled sediment deposited at each shore chainage within the study area to be determined. These values were analysed for any correlation between them and their corresponding shoreline change rates obtained. The total area coverage of each coastal river basin was computed from a topographic map of scale 1:50 000. The Rational method was employed in the estimation of the total flood discharged by the rivers in their respective catchment areas, having computed beforehand the rainfall intensity of the region and the time of concentration. The total flood discharge  $Q_{\max}$  is given as follows:

$$Q_{max} = 0.277CAI \quad (3.16)$$

where  $Q_{max}$  = total flood discharge ( $m^3/s$ )

C = runoff coefficient

A = catchment area ( $km^2$ )

I = mean intensity of rainfall in mm/h during the time of concentration

The rainfall intensity I is computed from the depth duration equation as follow:

$$I = \frac{a}{(b+T_c)^n} \quad (3.17)$$

where a, b and n are estimated from the table of intensity duration equation constants, and the Time of Concentration  $T_c$  is the time required for the most distant part of the catchment to contribute to the outflow of the rivers. The time of concentration  $T_c$  is expressed as follows:

$$T_c = 2.8 * \frac{L}{\sqrt{S}} \quad (3.18)$$

Where L is the length of the main stream (km) and S is the main stream slope.

Using a relationship developed between measured values of corrected suspended sediment concentration Q and the total flood discharge  $Q_{max}$ , the suspended sediment concentration for each the small rivers in the basin were computed from the relation in Equation (3.16).

For three major rivers namely, Pra, Ankobra and Butre, their mean flow rates (V) were computed from available historic flow data and multiplied by their measured cross sectional areas (A) obtained by means of a digital planimeter. Equation 3.19 shows the flow discharge  $Q_l$ .

$$Flow Discharge Q_l = VA \quad (3.19)$$

$$Q = kQ_{max}^n \quad (3.20)$$

where  $Q$  = the sediment discharge ( $t \text{ day}^{-1}$ ),  $Q_{max}$  = total water discharge ( $m^3/s$ ),

$n$  = exponential and  $k$  = constant.

Knowing the total length of each segment of the coastline recharged by each of the three river basins, and the total sediment discharged into the coastline for each of the catchment areas, the sediment supplied to the coastline per unit length was computed.

Using the suspended sediment discharge rating function (Equation 2.10) enabled the suspended sediment concentration and the sediment discharged into the sea per the total length of each segment of the coastline recharged by each of the three river basins to be computed. The discharges for the large (basin) rivers were determined from available stream flow data using the Manning Formula Equation (3.19) (Watkins & Fiddes, 1984).

### 3.3.9 Human Impact on Shoreline Change

Anthropogenic impact on shoreline change is difficult to quantify since it depends on several influencing factors. To surmount this challenge a Multi-Criteria Decision Analysis (MCDA) technique was adopted that requires selection of the criteria, ranking of the designated criteria and sensitivity analysis of the results. Three variables viz. population density, distance off coastal structures and amount of coastal material mined were considered to be the causative variables influencing shoreline position change. The Analytic Hierarchy Process (AHP), a technique that supports complex decision making was adopted. AHP combines expert knowledge and well-defined mathematical structure of consistent matrices to generate true or approximate weights. By

means of personal judgement, values were assigned to the various alternatives of each variable and pairwise comparisons were generated based on their Scale of Relative Importance (Saaty, 1980). These assigned values congruent with the variables' individual influence on shoreline change provided fundamental data from which matrices were generated and normalised. The ensuing results (i.e. Eigen values and Eigen vectors of the squared matrix) served as the criteria weight vectors obtained from the three pairwise comparisons together with their respective ranks of the options. The criteria weight vectors enabled a mathematic relationship to be developed for quantifying human impact in terms of the input variables and for the various alternative options. The pairwise evaluation criteria and their respective alternatives were obtained from expert knowledge and are showed in the Tables (5 - 8).

**Table 5: Evaluations of Pairwise Criteria**

|                                  | Coastal Mining | Population density | Distance from Coastal Structures |
|----------------------------------|----------------|--------------------|----------------------------------|
| Coastal Mining                   | 1              | 3                  | 5                                |
| Population density               | 1/3            | 1                  | 3                                |
| Distance from Coastal structures | 1/5            | 1/3                | 1                                |

**Table 6: Pairwise Comparison of Criteria Alternatives (Coastal Mining and Population Density)**

|           | Very low | Low | Moderate | high | Very high |
|-----------|----------|-----|----------|------|-----------|
| very low  | 1        | 2   | 3        | 5    | 7         |
| low       | 1/2      | 1   | 4        | 6    | 8         |
| Moderate  | 1/3      | 1/4 | 1        | 7    | 9         |
| high      | 1/5      | 1/6 | 1/7      | 1    | 9         |
| Very high | 1/7      | 1/8 | 1/9      | 1/9  | 1         |

**Table 7: Pairwise Comparison of Criteria Alternatives (Coastal Mining and Distance from Coastal Structures)**

|           | Very low | Low | Moderate | high | Very high |
|-----------|----------|-----|----------|------|-----------|
| very low  | 1        | 3   | 5        | 7    | 9         |
| low       | 1/3      | 1   | 3        | 5    | 7         |
| Moderate  | 1/5      | 1/3 | 1        | 3    | 5         |
| high      | 1/7      | 1/5 | 1/3      | 1    | 3         |
| Very high | 1/9      | 1/7 | 1/5      | 1/3  | 1         |

**Table 8: Pairwise Comparison of Criteria Alternatives (Population Density and Distance from Coastal Structures)**

|           | Very low | Low | Moderate | high | Very high |
|-----------|----------|-----|----------|------|-----------|
| very low  | 1        | 1   | 2        | 3    | 4         |
| low       | 1        | 1   | 1        | 2    | 3         |
| Moderate  | 1/2      | 1   | 1        | 1    | 2         |
| high      | 1/3      | 1/2 | 1        | 1    | 1         |
| Very high | 1/4      | 1/3 | 1/2      | 1    | 1         |

### *3.2.10 Shoreline Change Modelling using Multiple Linear Regression Analysis (MRA) Techniques*

To achieve the goal of modelling the natural shoreline change pattern taking into cognisance the contribution of some identified environmental driving forces influencing coastal system and their properties, the following criteria were set to be realised in the prospective process based modelling approach to be used:

- The modelling approach must provide a means of selection of dynamic variables to use in the model from an infinite number of variables characterising the system.
- The approach must provide for attributing the reaction of the system to the changes in the environment external to the system. (The external environmental influences in this context include the effect of waves, tides and currents, the coastal material properties, the beach slope and width, coastline orientation and the sediment supply by rivers within the basin).
- The approach must be process-based modelling which allows simulation of physical processes that occur in reality as opposed to models that attempt to predict outcomes under certain boundary conditions.
- The modelling technique must allow for spatial and temporal modelling using multiple variables selected from the external environment of the coastal system.

*Model Specification*

Of all the physical processes within the coastal system of the study area and their properties, the following dynamic variables influencing shoreline position evolution were identified as independent and dependent Variables based on review of literature:

1. Mean exposed Beach width (Bw) – this factor is expected to control the extent to which erosive wave energy is dissipated by the beach
2. Beach Slope (Bs) – this controls the sea-level- rise induced shoreline excursion.
3. Coastal soil shear strength (Cs) - this factor relates to the resistivity of the coastal soil to erosion.
4. Coastal rock strength (Cr) –this factor relates to the strength of consolidated coastal material to resist shoreline evolution
5. Depth of Overburden (Do) – distance between soils and the parent rocks
6. Rate of sediment transport into the sea by Rivers within the basin (Rr) – this factor controls the major sediment sources to the shores.
7. Rate of sediment transport from the shore by breaking wave generated currents (Rc)
8. Quantified human impact (Hi) on shoreline change

The dependent or response (predictor) variable is identified as the shoreline change rate (SC) – this is the change rates computed from multi-temporal spatial shoreline datasets.

By the study hypothesis:

$$sc = f(Bw, Bs, Cs, Cr, Do, Rc, Rr, Hi) \quad (3.21)$$

Let  $Y$  represent the dependent shoreline change rate (SC) variable and  $X_1, X_2, X_3, X_4, X_5, X_6, X_7$  and  $X_8$  represent the independent variables of exposed Beach width, exposed Beach slope (Bs), coastal soil shear strength (Cs), Coastal rock outcrop compressive strength (Cr), Depth of the overburden (Do), Rate of sediment deposition by rivers into the sea (Rr), Rate of sediment transport from the shores (Rc), and Human impacts (Hi) respectively.

Employing the general linear regression formula to Equation (3.21) the following was obtained:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_8 X_8 + \varepsilon_i \quad (3.22)$$

where

$$\begin{aligned} X_1 &= X_{11}, X_{12}, X_{13}, \dots, X_{1k} \\ X_2 &= X_{21}, X_{22}, X_{23}, \dots, X_{2k} \\ X_3 &= X_{31}, X_{32}, X_{33}, \dots, X_{3k} \\ X_4 &= X_{41}, X_{42}, X_{43}, \dots, X_{4k} \\ X_5 &= X_{51}, X_{52}, X_{53}, \dots, X_{5k} \\ X_6 &= X_{61}, X_{62}, X_{63}, \dots, X_{6k} \\ X_7 &= X_{71}, X_{72}, X_{73}, \dots, X_{7k} \\ X_8 &= X_{81}, X_{82}, X_{83}, \dots, X_{8k} \end{aligned}$$

and ,  $X_{11}, X_{12}, X_{13}, \dots, X_{1k}; X_{21}, X_{22}, X_{23}, \dots, X_{2k}; X_{31}, X_{32}, X_{33}, \dots, X_{3k}; X_{41}, X_{42}, X_{43}, \dots, X_{4k}; X_{51}, X_{52}, X_{53}, \dots, X_{5k}; X_{61}, X_{62}, X_{63}, \dots, X_{6k}; X_{71}, X_{72}, X_{73}, \dots, X_{7k}$  and  $X_{81}, X_{82}, X_{83}, \dots, X_{8k}$  are the measured explanatory variables influencing the predicted variable.

For the  $k$  number of shoreline sample locations investigated, Equation (3.22) can be written in matrix form as follows:

$$Y = \beta X + \varepsilon \quad (3.23)$$

where

$$Y = \begin{bmatrix} Y1 \\ Y2 \\ Y3 \\ Y4 \\ Y5 \\ Y6 \\ Y7 \\ Y8 \end{bmatrix} \mathbf{X} = \begin{bmatrix} 1 & x11 & x12 & x13 & \dots & \dots & \dots & x1k \\ 1 & x21 & x22 & x23 & \dots & \dots & \dots & x2k \\ 1 & x31 & x32 & x33 & \dots & \dots & \dots & x3k \\ 1 & x41 & x42 & x43 & \dots & \dots & \dots & x4k \\ 1 & x51 & x52 & x53 & \dots & \dots & \dots & x5k \\ 1 & x61 & x62 & x63 & \dots & \dots & \dots & x6k \\ 1 & x71 & x72 & x73 & \dots & \dots & \dots & x7k \\ 1 & x81 & x82 & x83 & \dots & \dots & \dots & x8k \end{bmatrix}$$

The matrix  $\mathbf{Y}$  is the observed predicted matrix,  $\mathbf{X}$  the design matrix and  $\boldsymbol{\beta}$  the unknown coefficient of regression model.  $\boldsymbol{\beta}$  was determined as follow:

$$Y = \beta X \quad (3.24)$$

(as the expectation of  $\varepsilon_i$  approach zero  $\varepsilon_i$  is assumed to be normally distributed with mean equals zero ), since  $X$  is not usually a squared matrix it is multiplied by the transpose of  $\mathbf{X}$ , and then by the inverse  $(\mathbf{X}^T\mathbf{X})$  to obtain the values for  $\boldsymbol{\beta}$  the optimum solution as follows:

$$\mathbf{YX}^T = \boldsymbol{\beta}(\mathbf{XX}^T) \quad (3.25)$$

$$\mathbf{YX}^T(\mathbf{X}^T\mathbf{X})' = \boldsymbol{\beta}(\mathbf{X}^T\mathbf{X})(\mathbf{X}^T\mathbf{X})' = \boldsymbol{\beta}\mathbf{I} = \boldsymbol{\beta} \quad (3.26)$$

where  $\mathbf{I}$  is unit matrix.

Using MATLAB the values for the coefficient of regression  $\boldsymbol{\beta}$  was calculated and the prediction equation denoted by:

$$y = a + b1x1 + b2x2 + \dots + \quad (3.27)$$

The predicted values of  $\hat{y}$  for a subject can be obtained by substituting the x-values for that subject into the prediction equation.

Two regression modelling approaches were adopted: (1) Entering all the independent variables in the model to assess the contribution of each predictor variable in the regression equation. (2) Information obtained from the first model results (1) inform selective removal of some independent variables in a stepwise regression process to obtain variables that significantly influence the model and subsequently the regression equations for estimating shoreline positions.

### *3.2.11 Standard Procedure for testing Generated Model*

#### *3.2.11.1 Estimation of Prediction Error of the Multiple Regression Model*

The residuals of the model are indicative of the measure of the prediction error. For a given number of observed values of y, the residual  $(y - \hat{y})$  are evaluated since it gives the measure of the prediction errors.

#### *3.2.11.2 Determination of the closeness of the prediction equation to the response data*

The sum of the squared errors (SSE) given by  $\sum(y - \hat{y})^2$  are computed to ensure it satisfies the least squares criterion that is the predictor equation should have the smallest SSE value of all the possible Equations of the form (3.28).

$$SSE = \sum(y - \hat{y})^2 \quad (3.28)$$

*Determine the proportional reduction in prediction equation instead of the mean*

The mean value for the predictor variable  $\bar{y}$  was determined for the sample population and that of the prediction equation  $\hat{y}$  determined as well, from which the coefficient of multiple Determination or R-squared is computed.

$$R^2 = [(\Sigma(y-\bar{y})^2 - \Sigma(y-\hat{y})^2) / \Sigma(y-\bar{y})^2] \quad (3.29)$$

The determined value of  $R^2$  shows the proportion of the total variation of  $y$  that is explained by the predictive power of the entire explanatory variable, through the regression model.

### *Testing Regression Model*

Regression models are tested by computing various statistics that measure the difference between the predicted value and the expected values.

The goal in regression analysis is to determine values of parameters that cause the function to best fit a set of data observation that is provided.

The Root Mean Squared Errors (RMSE), are statistics for evaluating the overall quality of the regression model.

$$RMSE = \sqrt{\frac{1}{n} \sum_{j=1}^n (y_i - \hat{y})^2} \quad (3.30)$$

The Mean Absolute Error (MAE) is the mean of the absolute value of the residuals. The MAE is very similar to the RMSE but it is less sensitive to large errors.

$$\text{MAE} = \frac{1}{n} \sum_{j=1}^n |y_j - \hat{y}_j| \quad (3.31)$$

## **CHAPTER 4**

### **RESULTS**

#### **4.1 Introduction**

The outcomes of laboratory analysis carried out, results of computations performed to determine values for the shoreline change rates and the corresponding responsive variables for the sampled data are presented in this chapter in line with the research objectives. The outcomes of experimental results include the particle size distribution analysis and the compressive strength of intact rock crops samples by the Unconfined Compressive Strengths (UCS) testing procedure. Results of Geo-referencing of digital images (1895 and 1955), extraction of shorelines from multi-temporal datasets and the results of shoreline change rates are provided in Section 4.2. Thirdly, the results of positional accuracy assessments are presented for both long and short terms shoreline change rates categories computed. Finally, results obtained from the regression analyses are presented in Section 4.5.

#### **4.2 Shoreline Change in the Western Region of Ghana**

This section deals with results of geo-referencing of digital images, shoreline extraction, rate of change computations, and positional accuracy assessments that enabled evaluation of uncertainties in the information obtained. Results of shoreline change rates at the sampled sites analysed in short and long terms are presented in this section. A snap of the transect cast on the overlaid shoreline datasets (2005 orthophotos, the 1994, 1974, 1955 and 1895 maps) for the shoreline change rates calculations is also shown together with the rates computed (Figure 11).

#### *4.2.1 Geo-referencing of Images and Accuracy Assessment*

Results of geo-referencing of the available 1955 and 1895 maps obtained in image format using selected clearly identifiable grid intersection points as controls are shown in Tables 11 and 12. The total Root Mean Square error of 0.0245 m and 1.6043 m were obtained as adjusted digitising errors for the 1895 and 1955 images respectively. Higher positional accuracy was obtained in the 1895 map relative to the 1955 image dataset (see Tables 9 and 10).

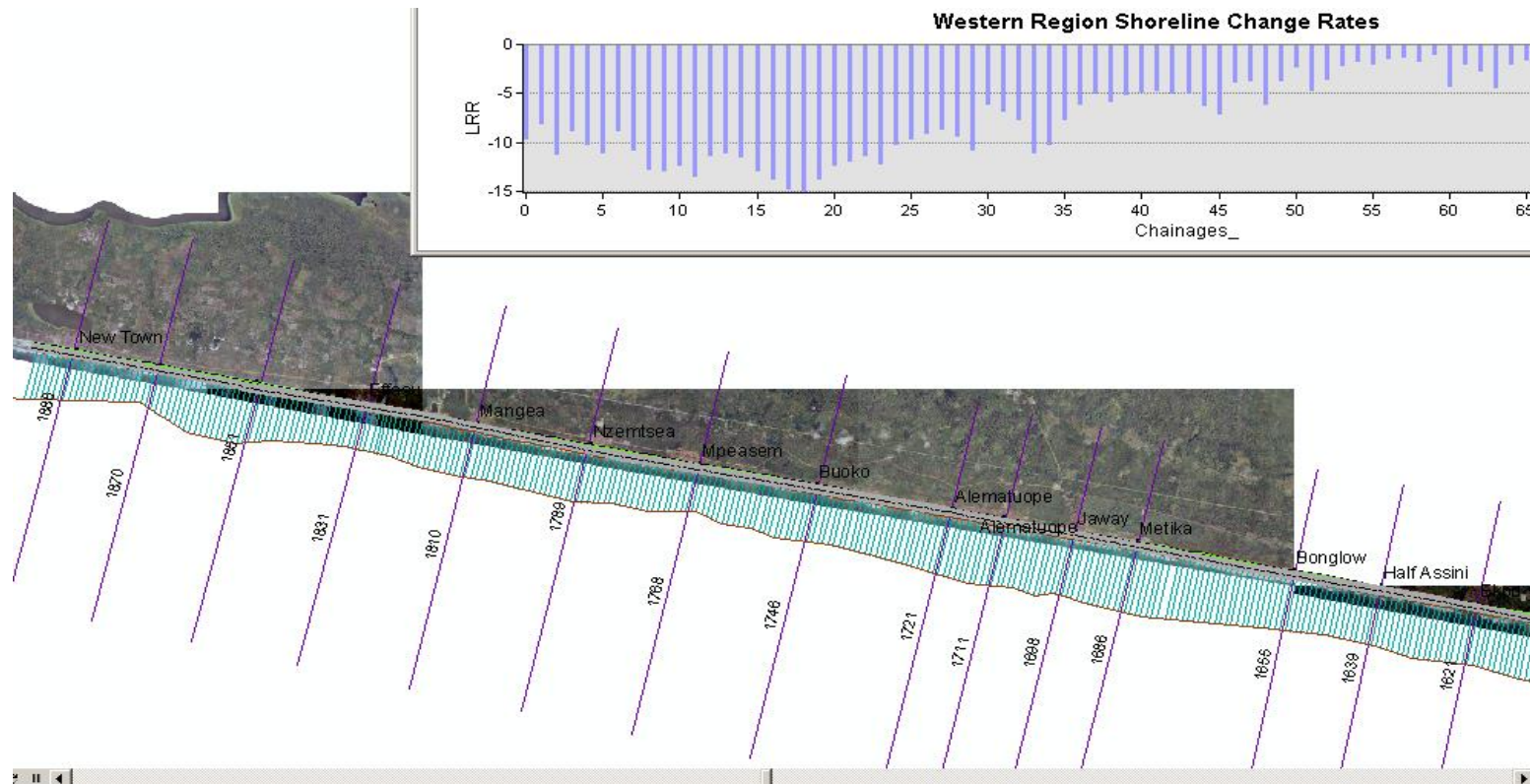


Figure 11: Snapshot of Transects Cast on Shoreline Datasets for Rate Change Computation

**Table 9 Accuracy Assessment of Geo-referenced Digital Image (1895)**

| Point ID | Grid Lat. | Grid Long. | Easting (X) | Northing (Y) | X Source   | Y Source   | X Map  | Y Map  | Residual | Remarks |
|----------|-----------|------------|-------------|--------------|------------|------------|--------|--------|----------|---------|
| 1        | 5.00      | -3.00      | 52498.018   | 36903.305    | 52498.006  | 36903.288  | 2.995  | 4.475  | 0.0364   | BL      |
| 2        | 5.00      | -2.00      | 163408.393  | 36651.567    | 163408.187 | 36651.565  | 11.585 | 4.495  | 0.0269   | BM      |
| 3        | 5.00      | -1.00      | 274285.335  | 36568.567    | 274285.788 | 36567.985  | 20.255 | 4.515  | 0.0115   | BR      |
| 4        | 6.00      | -3.00      | 52866.812   | 147527.073   | 274283.996 | 147125.821 | 20.215 | 13.095 | 0.0057   | ML      |
| 5        | 6.00      | -2.00      | 163591.981  | 147225.448   | 163591.982 | 147225.443 | 11.545 | 13.065 | 0.0307   | MM      |
| 6        | 6.00      | -1.00      | 274283.999  | 147125.871   | 52866.731  | 147527.198 | 2.955  | 13.036 | 0.0185   | MR      |
| 7        | 7.00      | -3.00      | 53302.607   | 258154.444   | 274282.324 | 257687.231 | 20.195 | 21.675 | 0.0371   | TR      |
| 8        | 7.00      | -2.00      | 163809.012  | 257803.298   | 163809.956 | 257802.767 | 11.525 | 21.635 | 0.0165   | TM      |
| 9        | 7.00      | -1.00      | 274282.596  | 257687.266   | 533002.689 | 258153.506 | 2.9065 | 21.616 | 0.0163   | TR      |

First Order Polynomial (Affine)  
Transformation

Total 0.0245 m

**Table 10 Accuracy Assessment of Geo-referenced Digital Map (1955)**

| Point ID | Grid Lat. | Grid Long. | Easting (X) | Northing (Y) | X Source   | Y Source    | X Map    | Y Map         | Residual        | Remarks |
|----------|-----------|------------|-------------|--------------|------------|-------------|----------|---------------|-----------------|---------|
| 1        | 5.00      | -3.00      | 52498.018   | 36903.305    | 52499.691  | 36884.35272 | 384.063  | -1207.060     | 2.2720          | BL      |
| 2        | 5.00      | -2.50      | 107959.479  | 36756.325    | 107961.068 | 36752.40811 | 822.7632 | -1206.010     | 1.1270          | BL1     |
| 3        | 5.00      | -2.00      | 163408.393  | 36651.567    | 163520.659 | 36454.7887  | 1258.535 | -1205.140     | 2.1361          | BR1     |
| 4        | 5.00      | -1.50      | 218848.949  | 36588.988    | 218847.115 | 36594.66983 | 1693.053 | -1204.940     | 0.9338          | BR      |
| 5        | 5.50      | -3.00      | 52674.032   | 92214.775    | 219123.901 | 91565.96641 | 1692.048 | -776.020      | 3.2523          | ML      |
| 6        | 5.50      | -2.50      | 108091.267  | 92053.215    | 218941.285 | 147148.3367 | 1693.732 | -340.531      | 0.8034          | ML1     |
| 7        | 5.50      | -2.00      | 163496.003  | 91938.05     | 163585.143 | 147233.6924 | 1260.942 | -341.360      | 0.9883          | MR1     |
| 8        | 5.50      | -1.50      | 218892.416  | 91869.238    | 52871.716  | 147512.4626 | 390.331  | -341.151      | 0.7163          | MR      |
| 9        | 6.00      | -3.00      | 52866.812   | 147527.073   | 108234.420 | 147338.7031 | 826.324  | -340.716      | 1.3191          | TL      |
| 10       | 6.00      | -2.50      | 108235.618  | 147350.983   | 108096.981 | 92051.08605 | 824.993  | -774.535      | 1.5948          | TL1     |
| 11       | 6.00      | -2.00      | 163591.981  | 147225.448   | 52678.759  | 92246.02676 | 387.944  | -774.447      | 0.9309          | TR1     |
| 12       | 6.00      | -1.50      | 218940.058  | 147150.426   | 163495.960 | 91937.98669 | 1259.494 | -773.656      | 1.07515         | TR      |
|          |           |            |             |              |            |             |          | Total<br>RMSE | <b>1.6043 m</b> |         |

First Order Polynomial (Affine) Transformation

Total RMSE =1.6043 m

#### *4.2.2 Shoreline Change Rates at 100 m Transects along the Study Area*

Shoreline change rates computed at 100 m transect intervals across the 192 km stretch of the shoreline in the study area is presented. Out of the 1705 transects (Appendix C) used for the change rates computations, a mean change rate of -6.25 m/year was obtained with values ranging between -14.74 m/year and +0.67 m/year. Most portions of the study area are eroding with little accretion in the long term. Figure 12 shows the shoreline change envelope and the corresponding scatter plot of change rates against transects for the study area.

#### *4.2.3 Short Term Shoreline Change Rates at Sampled Sites*

The short term shoreline rates computed for the samples sites also showed a general trend of recession over most portions except that the recession values were less than the long term rates. A mean shoreline change value of - 4.18 m/year was recorded for the entire study area. The Western Section recorded a mean of -5.4 m/year and the Eastern Section recorded a mean of -2.36 m/year. The rocky portions of the Eastern Section of the study area recorded minimal recession rates with the least value of 0.07 m/year recorded at Pumpuni. This is followed by Atwiwa, Miamea and Dixcove with recession rates figures between 0.2 and less than 0.5 m/year. Recession rates less than 1 m/year were recorded at Aboadze, Adwowa, Akyinim and Axim Nkekan. Recession rates exceeding 6 m/year were recorded at locations around Elve, Benyin, Eikwe, Sanzule Ampaim, Bankata and Azulewanu all within the western section of the study area which is predominantly sandy coastline, with the maximum recession of value 9.67 m/year recorded at Anochi. A scatter plot of the shoreline change rates against their corresponding chainages is shown in Figure 13.

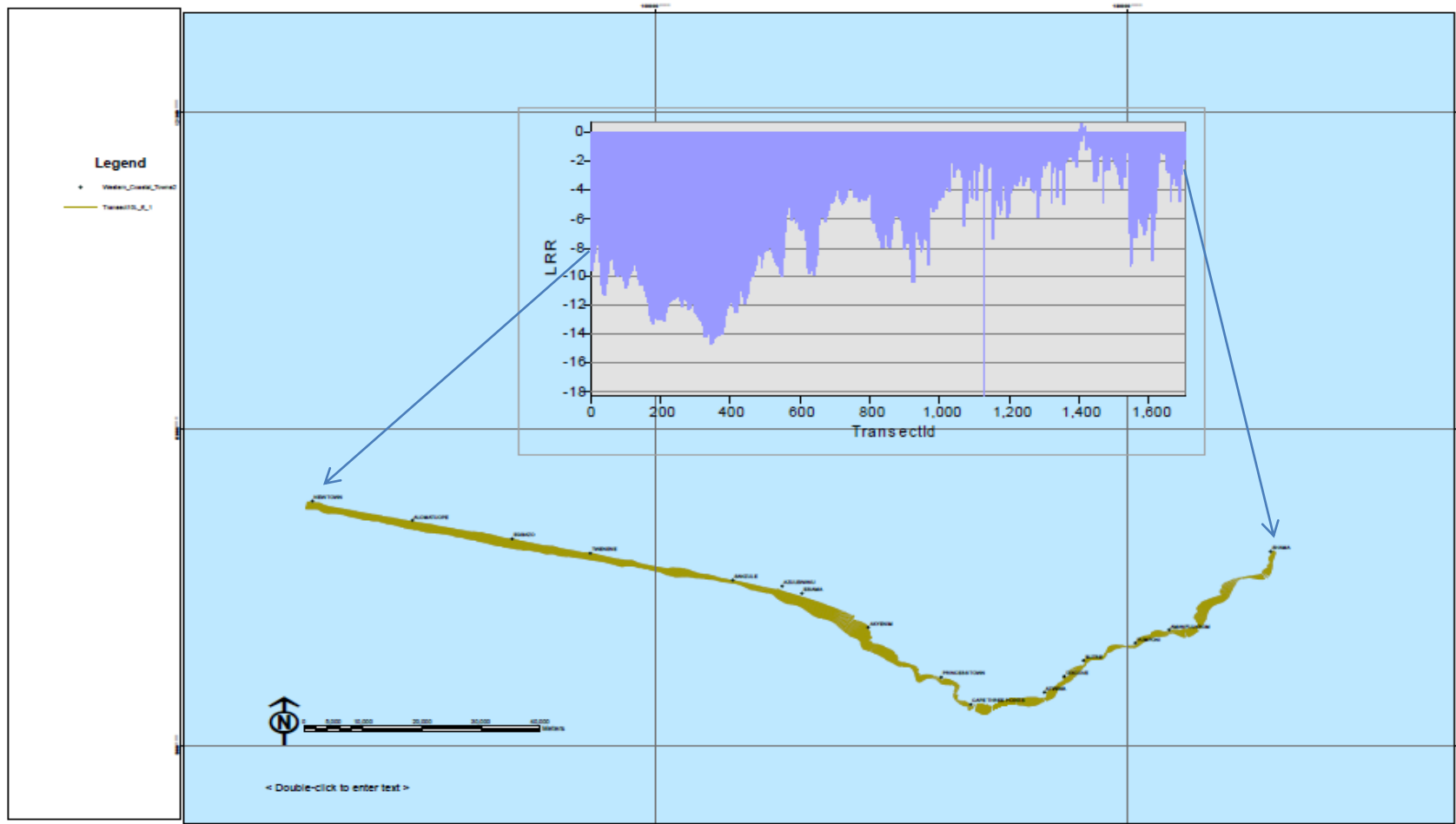


Figure 12: Shoreline Change Envelope and Rates at 100 m Transects along the Entire Study Area

#### *4.2.4 Long Term Shoreline Change Rates*

The rate of change statistics of the shoreline using the Average of Rate and Linear Regression by Least Squares methods for the entire study area are presented in Figure 13. The study revealed a general long term shoreline change over the entire study area with a mean value of -7.18 m/year and standard deviation of 4.38 at 95% confidence interval. Average shoreline change rates of -11.64 m/year were recorded for the Western Section of the study area (i.e. from Ankobra River Estuary to New Town) whereas a mean value of -2.81 m/year was obtained for the eastern portion of the study area (i.e. from Ankobra River Estuary to the Pra Estuary at Shama) with values ranging from less than 0.1 to 6.2 m/year.

#### *4.2.5 Comparison of Short and Long Term Shoreline Change Rates*

The analysis of the short and long terms shoreline change trends revealed a condition of long period of erosion of the shoreline with little accretion at most portions of the study area (See Figures 13 & 14). The general shoreline change rates recorded may be categorised into three: minimal, high or extreme levels. Minimal levels of shoreline change rates (<-1.0 m/year) were registered along about 10% of the study area, while the remaining portions are experiencing high to extreme levels of change rates in the short term. Similarly, the long term category showed high to extreme levels of change rates along most portions of the study area except for 2% of the stretch, which are undergoing minimal changes (-1.0 m/year) in the shoreline feature.

The short term change rates generally recorded lower values relative to the long term change rates, except for some isolated sites such as Abuesi, Atuobo and Trinity yard (an embayment near Cape Three Points), where the short term rates exceeded the long term changes rates.

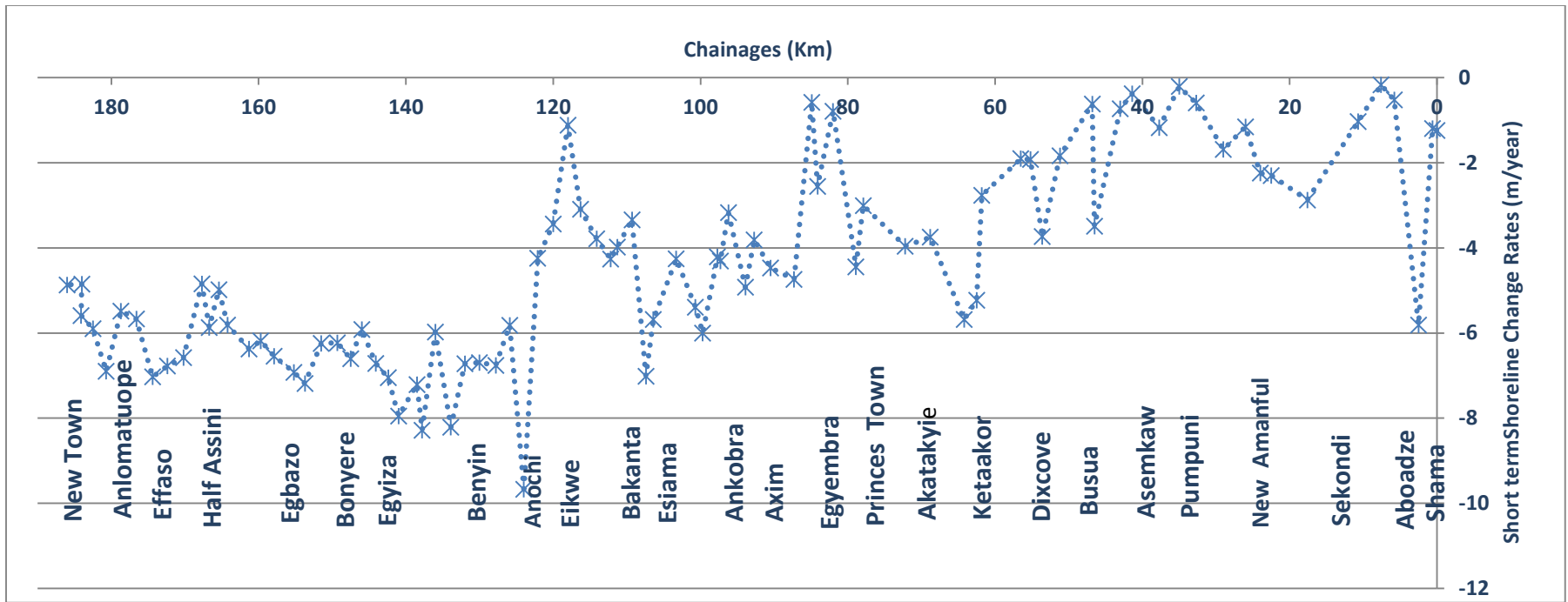


Figure 13: Short Term Shoreline Change Rates for Sampled Sites per Chainage

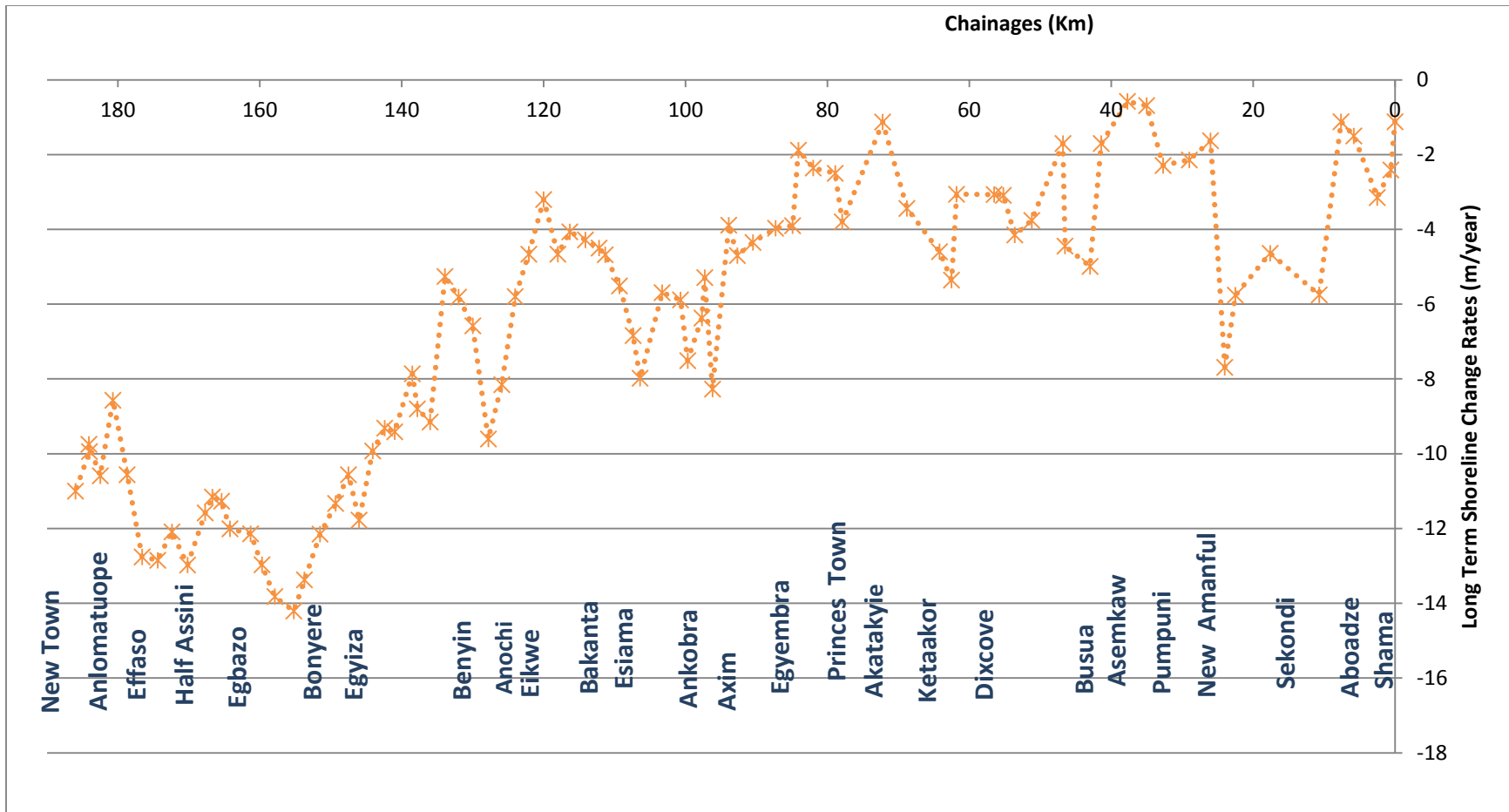


Figure 14: Long Term Shoreline Change Rates at Sampled Sites per Chainage

For instance, Abuesi, which recorded one of the highest short term rate changes (-5.82 m/year), is known to have sandy shores which are generally more prone to erosion. Besides, the slightly curved coastline and flat to slightly hilly landscape could render the shoreline vulnerable to currents generated from breaking waves and tides.

Again, a sharp contrast was observed between the short and long terms change rates from Ngyiresia through Sekondi, Nkontompo to New Takoradi (see Figure 15). The short term analysis recorded a mean change rate of -1.5 m/year along that stretch of the coastline, whereas the long term registered an average of about -6.0 m/year.

#### *4.2.6 Accuracy Assessment Shoreline Change Statistics*

An overall accuracy assessment of the shoreline change statistics determined as sum of errors accumulated from geo-referencing, digitising, topographic map sources and from the linear model used in the computation of the change rates is presented in Table 11. Total uncertainties of 1.350 m and 2.278 m respectively were obtained for the short and long term shoreline change rates. Uncertainties associated with the 1955 image map alone contributed more than 50% of the total errors obtained for the long term rate change.

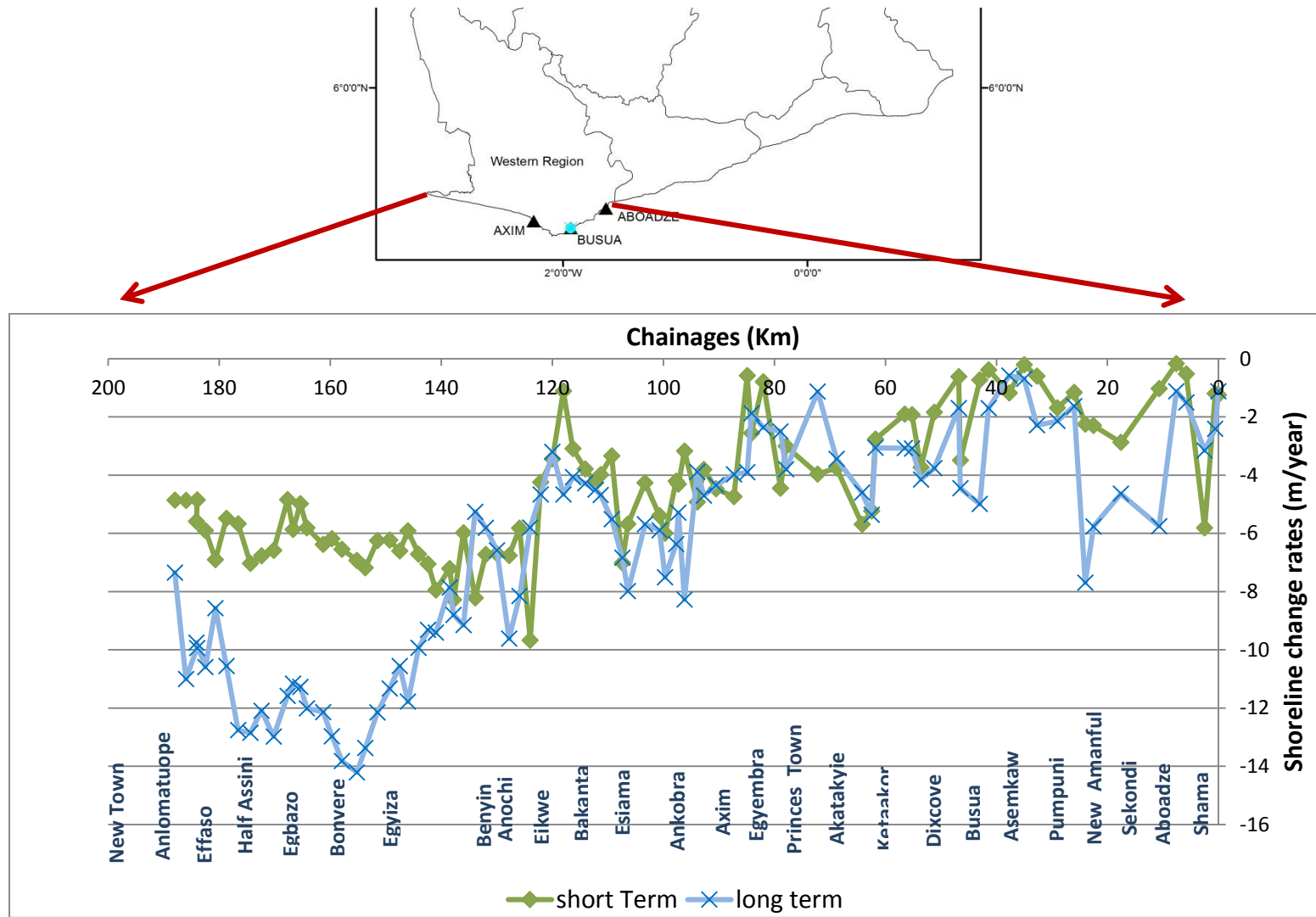


Figure 15: Composite Plot of Short term and Long Term shoreline Change Rates

**Table 11: Overall Accuracy Assessment of Shoreline Change Rates**

| Measurement Errors            | Short Term Change Rate | Long Term Change Rates |
|-------------------------------|------------------------|------------------------|
| Geo-referencing (1895)        | -                      | 0.024 m                |
| Geo-referencing (1955)        | -                      | 1.604 m                |
| Digitising Errors             | 0.500 m                | 0.500 m                |
| Topographic Map Errors        | 0.200 m                | 0.200 m                |
| Linear Model Errors           | 0.650 m                | 0.650 m                |
| Total Shoreline Uncertainties | 1.350 m                | 2.778 m                |

### 4.3 Coastal Material Resistivity to Shoreline Change

This section presents results of the resistivity of coastal material to shoreline change investigated. These are the exposed width and slope of the beach, the texture of the sampled soft soil, the hard shore compressive strength and the shear strength of the soft shore soil. The details of the results comprise experimental analysis of particle size distribution of dune soil and sampled hard shore outcrops, results of *in situ* shear strength of dune soil and hard shore rebound. The correlations between the coastal material parameters and the shoreline change are presented.

#### 4.3.1 Physical Characteristics of Soft Shore

The site specific physical characteristics considered to influence shoreline were the exposed beach width, the exposed beach slope and the thickness of the overburden of the soft shore.

#### 4.3.1.1 Exposed Beach Width

A measured mean value of 14.1 m was obtained for Exposed Beach Width with a standard deviation of 5.3 m over the total study area. A minimum value of 4.3 m was recorded at the outskirts of Mpatano whereas a maximum of 29.3 m was obtained for New Amanful. High values ( $> 25$  m) were also recorded at locations such as Aboadze and Kameakrom. A scatter plot of exposed beach width against their respective chainages is presented in Figure 16.

#### 4.3.1.2 Exposed Beach Slope

The variability of the exposed beach slope as against their respective chainages is presented in Figure 17. The exposed beach slope varied marginally along the study area, with a mean of 12.9% over the entire area. A mean of 11.45% was obtained for the Eastern Section where a slightly higher figure of 14.6% was recorded for the Western Section.

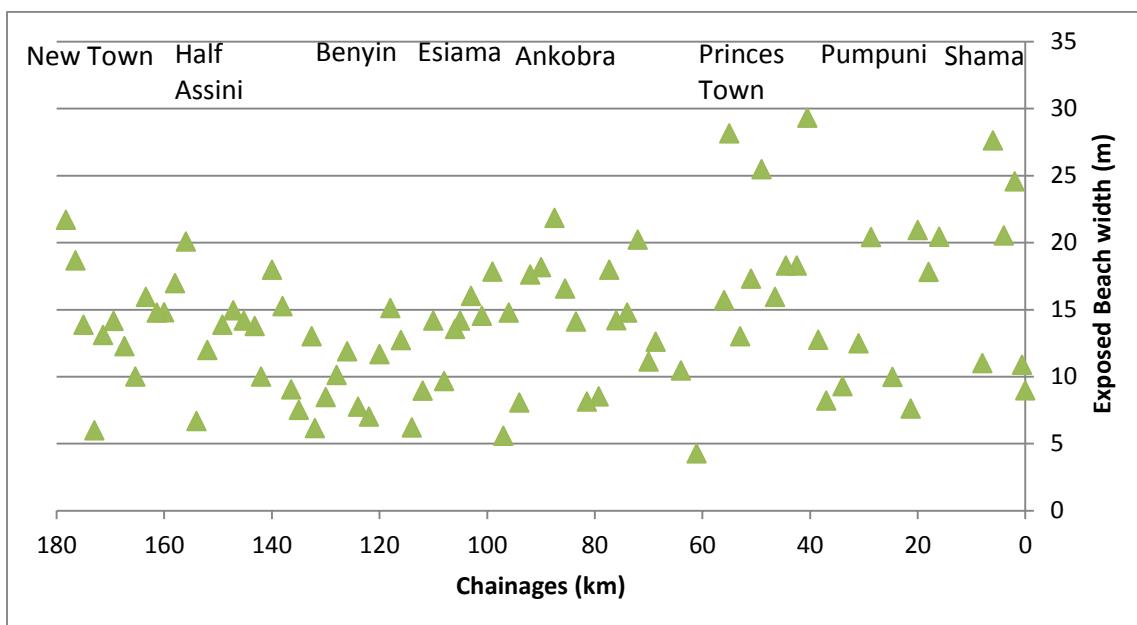


Figure 16: Scatter Plot of Exposed Beach Width against Chainage

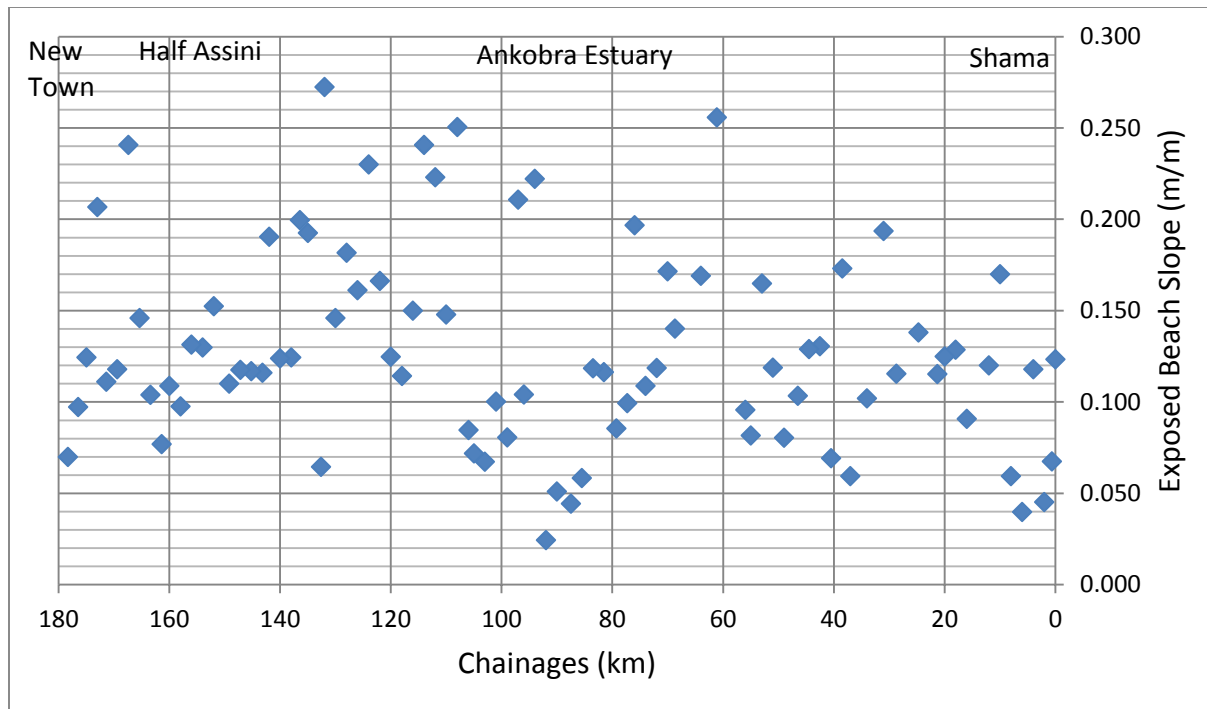


Figure 17: Exposed Beach Slope against Chainages

#### 4.3.1.3 Thickness of Overburden

The thickness of soil overburdening the parent rocks were found to correlate fairly with the shoreline change rates. A mean value of 2.31 m was obtained for the entire study area with values ranging between 0.4 m to 4.5 m. Lower thickness of soil were obtained for the eastern section with a mean of 1.87 m while an average of 2.59 m was measured for the western section scatter plot of thickness of overburden against their respective chainages is presented in Figure 18.

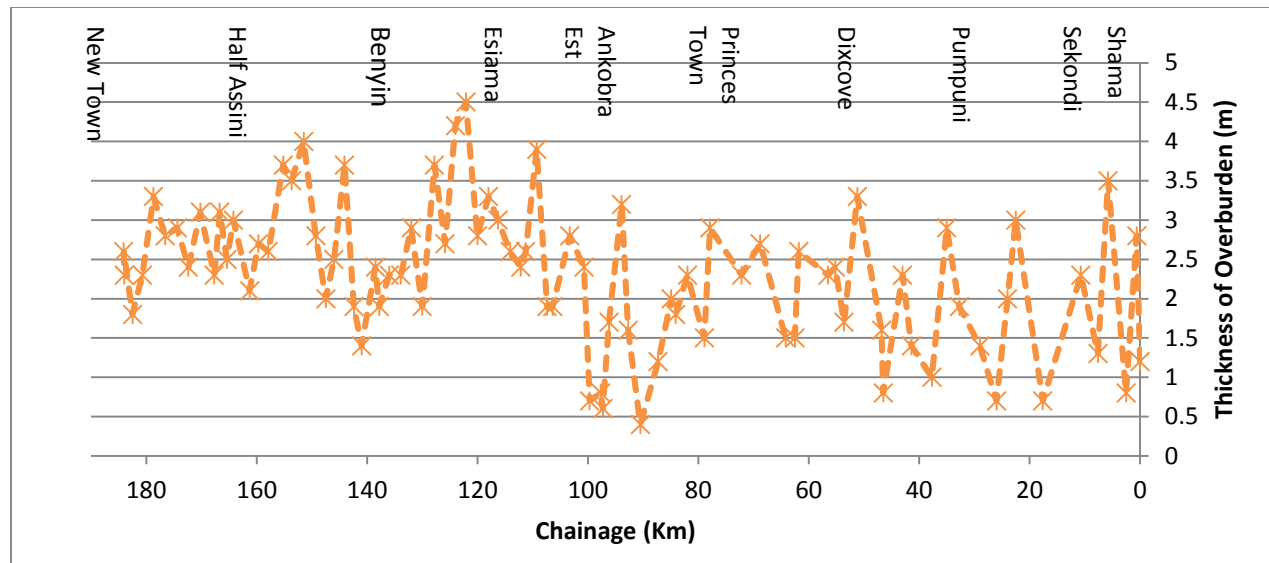


Figure 18: Thickness of Overburden against Chainages

#### 4.3.2 Coastal Soft Shore

The results of the shear strength of the coastal soft shore determined using the dynamic cone penetrometer at the sampled locations are presented together with laboratory analysis of soil samples collected from the study area.

##### 4.3.2.1 Shear Strength of Coastal Soft Shore

The results revealed a general increase in the soil shear strength as one moves from the shore landwards. An average shear strength value of about 228  $\text{Nm}^2$  was obtained near the back shore (0 m), with values ranging between 0  $\text{Nm}^2$  and 960.6  $\text{Nm}^2$ . The highest value was obtained at New Takoradi followed by Asankaw with about 720  $\text{Nm}^2$ . Values above 500  $\text{Nm}^2$  were recorded at places such as Sanzule, Esiam, Asanko, outskirts of Ankobra beach and New Amanful. Lowest value of zero (0  $\text{Nm}^2$ ) was recorded at Egbazo and values less than 100  $\text{Nm}^2$  were reckoned for

locations such as Bakanta, Anochi, Nzemtsea and Effasu close to New Town a hand length off the Ghana Cote D'voire border. Mean shear strength values of about 310 Nm<sup>2</sup> and 335 Nm<sup>2</sup> respectively were recorded at the 50 m and 100 m off the shores toward the hinterlands. Lowest values of about 60 Nm<sup>2</sup> were obtained for some locations with maximum values of 900 Nm<sup>2</sup> and 1180 mN<sup>2</sup> recorded respectively for the 50 m and 100 m off the backshore. The results exhibited a general increase in shear strength of the coastal soil as one moves landwards from the backshore. A scatter plot of the mean shear strength of the dune soil measured at 0.5 m and 1.0 m depth respectively against their individual chainages is shown in Figure 19.

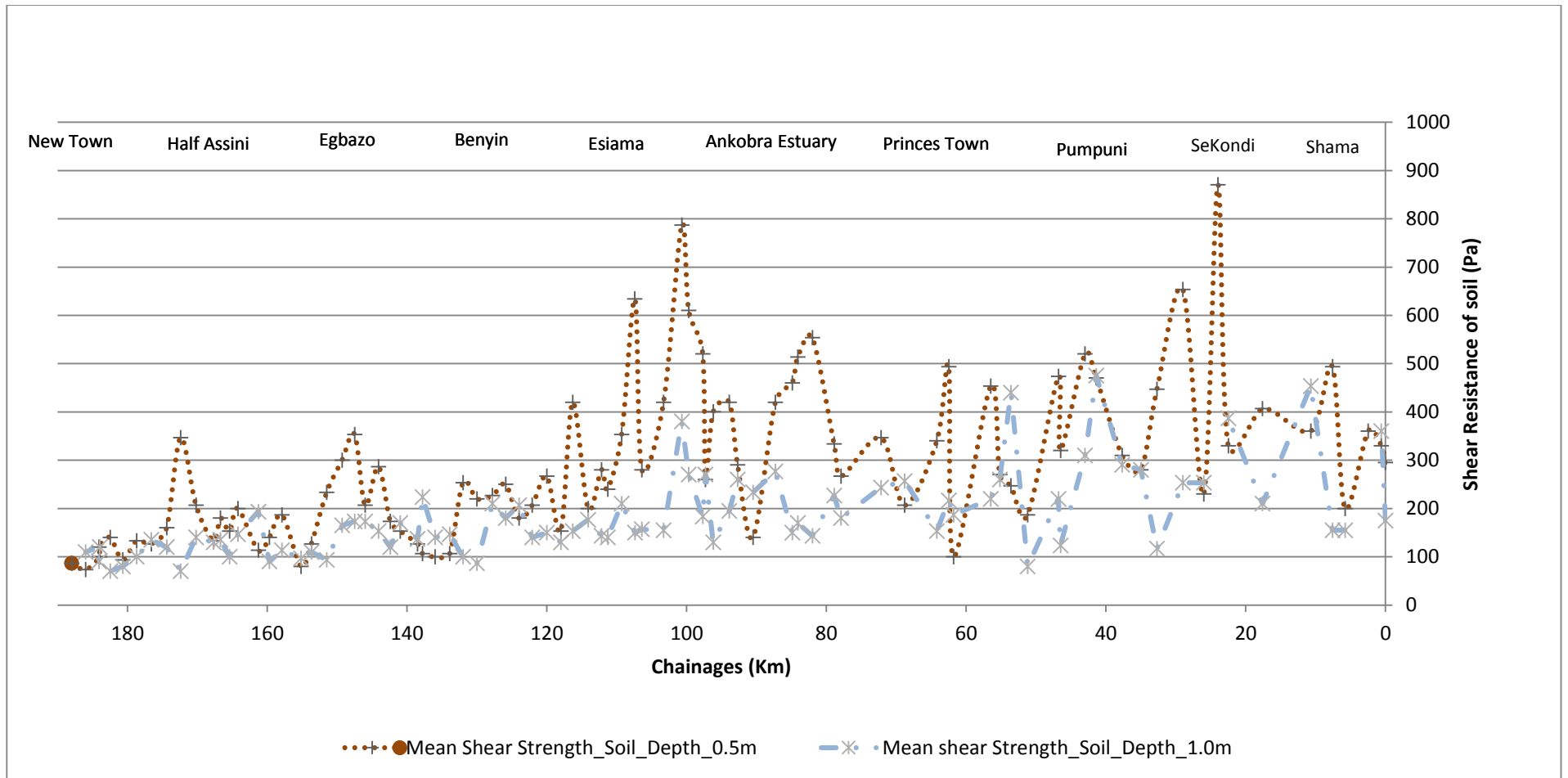


Figure 19: Mean Shear Strength of Coastal Soil at their Respective Chainages

#### 4.3.2.2 Analysis of Particle Sizes Distribution of Coastal Soils

Particle size distributions of coastal soil sampled along the study area are presented. Samples of the recordings made during the analysis and the scatter plots produced are shown in Tables 12 and 13 and Figures 20 –22.

**Table 12: Sample Particle Size Distribution Record at Atwiwa (Eastern Section)**

| Particle Size Analysis Data Sheet (Atwiwa_Ch_42.5 km) |                   |                  |                  |
|---|-------------------|------------------|------------------|
|   | 282.9             | Sample ID: P20A1 | Depth =0 - 0.6 m |
| Sieve Size (mm)                                       | Mass retained (g) | % Retained       | % Passing        |
| 2.800   |                   |                  | 100              |
| 2.000   | 0.0               | 0.0              | 100              |
| 1.180   | 0.0               | 0.0              | 100              |
| 0.600   | 3.9               | 1.4              | 98.6             |
| 0.425   | 2.4               | 0.8              | 97.8             |
| 0.300   | 24.0              | 8.5              | 89.3             |
| 0.212   | 157.9             | 55.8             | 33.5             |
| 0.150   | 75.8              | 26.8             | 6.7              |
| 0.075   | 14.9              | 5.3              | 1.4              |
| 0.063   | 2.0               | 0.7              | 0.7              |
| under Size  | 0.0               | 0.0              | 0.7              |

From Table 12, the scatter plot in Figure 20a was obtained for the soil samples collected from the Eastern Section (Shama – Ankobra estuary). The soil sample which weighed 282.9 grams, was collected between the ground level up to 0.6 m depth of the subsurface soil. The scatter plots of the particles sizes against the percentage of samples passing through their respective sieves enabled the mean diameter of soil ( $D_{50}$ ) to be interpolated as 0.23 mm; this range of particle sizes distribution is categorised as fine sand. Similarly, Figure 20b shows that soil particles sizes range between 0.063 – 2 mm (sand) for samples collected for the Western Section (Ankobra estuary –

New Town). Per the generic names (Table 15) the sample is categorised into their respective percentage composition as 33.5% fine sand, 65.1% medium sand and 1.4% coarse sand.

**Table 13: Sample Particle Size Distribution Record at Nglekazu (Western Section)**

| Particle Size Analysis Data Sheet (Nglekazu) |               |                  |                   |
|--|---------------|------------------|-------------------|
| Mass of Sample (g)                           | 336           | Sample ID: P58B1 | Depth = 0 - 0.4 m |
| Sieve Size (mm)                              | Mass retained | % Retained       | % Passing         |
| 2.800  |               |                  | 100.0             |
| 2.000  | 0.0           | 0.0              | 100.0             |
| 1.180  | 6.6           | 2.0              | 98.0              |
| 0.600  | 167.3         | 50.0             | 48.2              |
| 0.425  | 97.7          | 29.1             | 19.2              |
| 0.300  | 36.4          | 10.8             | 8.3               |
| 0.212  | 14.1          | 4.2              | 4.1               |
| 0.150  | 5.0           | 1.5              | 2.6               |
| 0.075  | 5.1           | 1.5              | 1.1               |
| 0.063  | 1.0           | 0.3              | 0.8               |
| under Size                                   | 0.0           | 0.0              | 0.8               |

Table 13 shows a typical dune soil sample distribution record from the Western Section of the study area (Nglekazu). The soil sample which weighed 336 g and had an interpolated mean diameter ( $D_{50}$ ) equals 0.60 mm, lies within the coarse sand range. The percentage compositions of the different particle size range of the soil sample are as follows: 6% of fine sand, 42% of medium sand and 52% of coarse sand. A scatter plot of the particle size distribution for the different categories along the chainages of the study area are shown in Figures 20 (a & b) (Eastern and Western Sections respectively).

Figure 21 presents a plot of constituent composition of the soil samples analysed from the study area, while a plot of the  $D_{50}$  and their corresponding measured slope are presented in Figure 22.

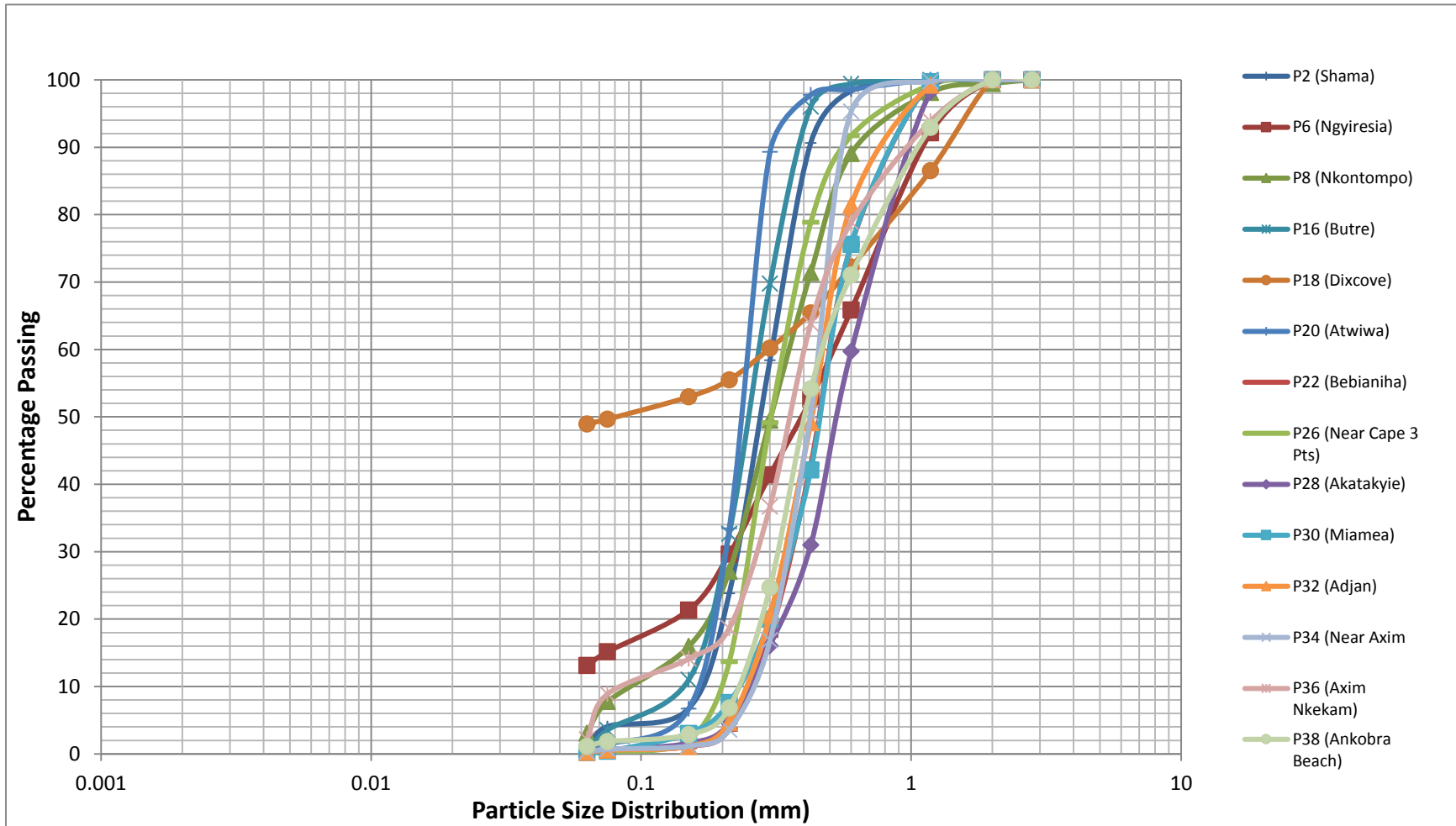


Figure 20a: Particle Size Distribution of Soil Samples (Eastern Section of Study Area)

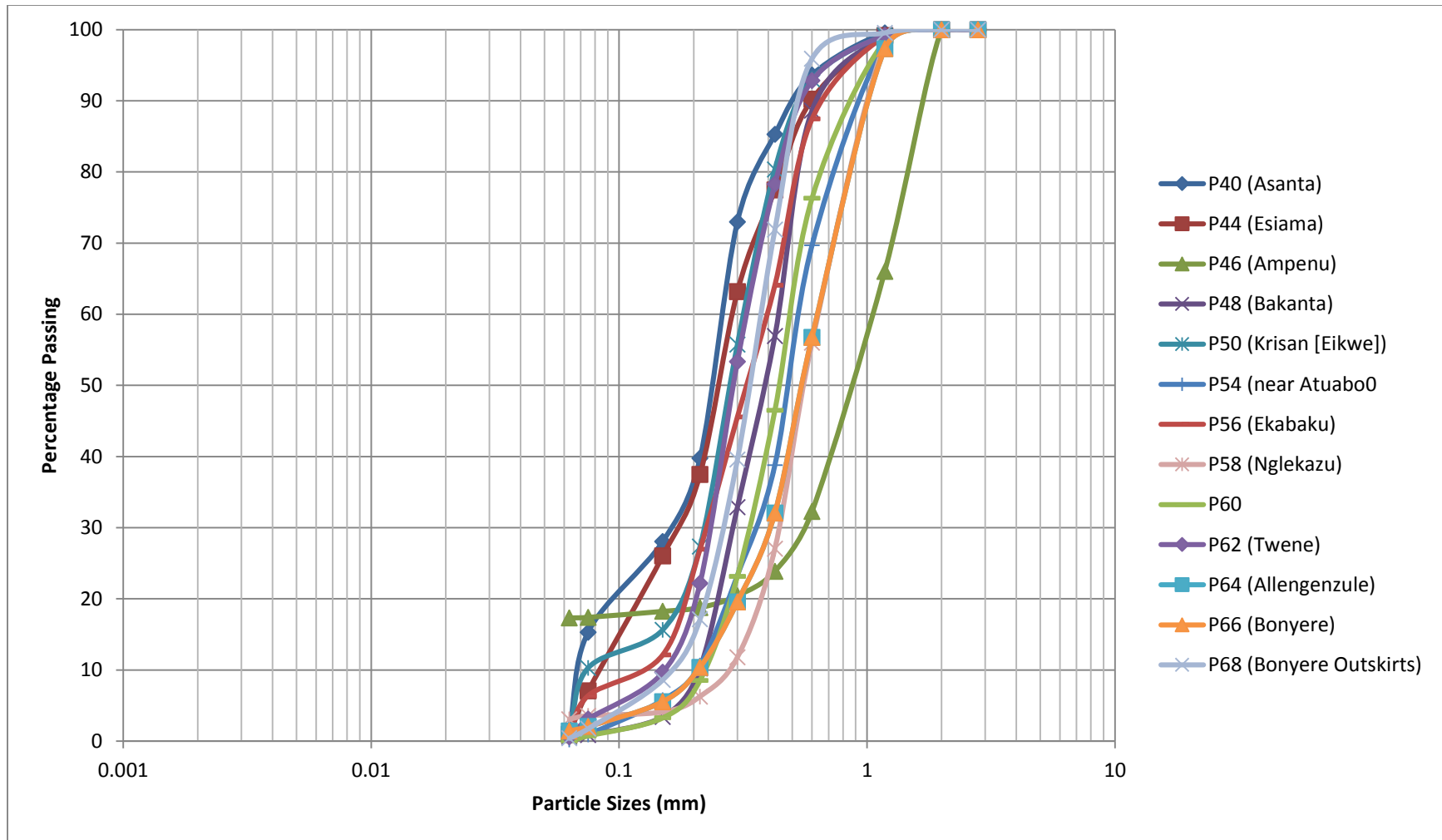


Figure 20b: Particle Size Distribution of Soil (Western Section of Study Area)

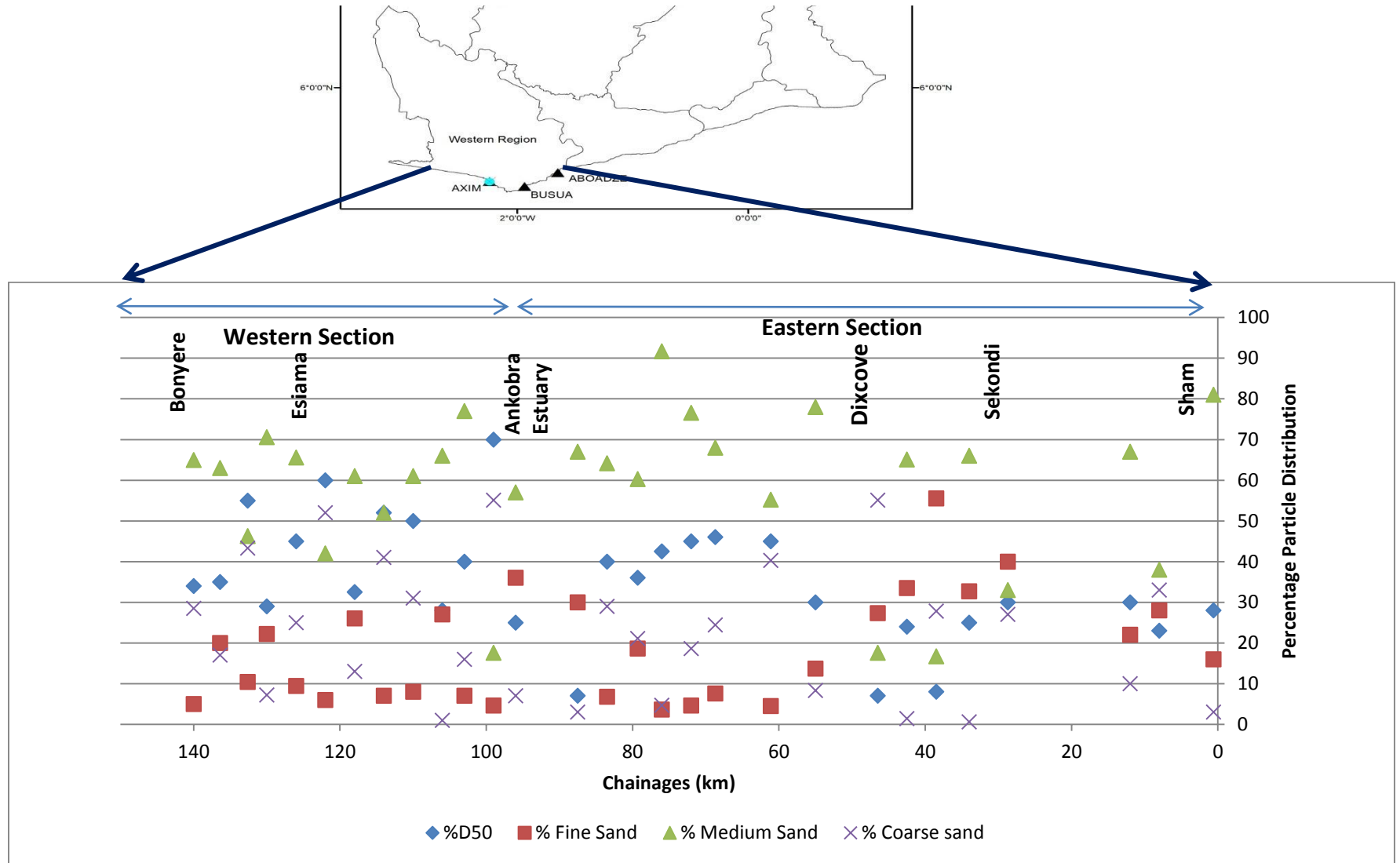


Figure 21: Coastal Sample Soil Composition against Chainages

A scatter plot of mean particles sizes and the exposed beach slope is presented in Figure 22.

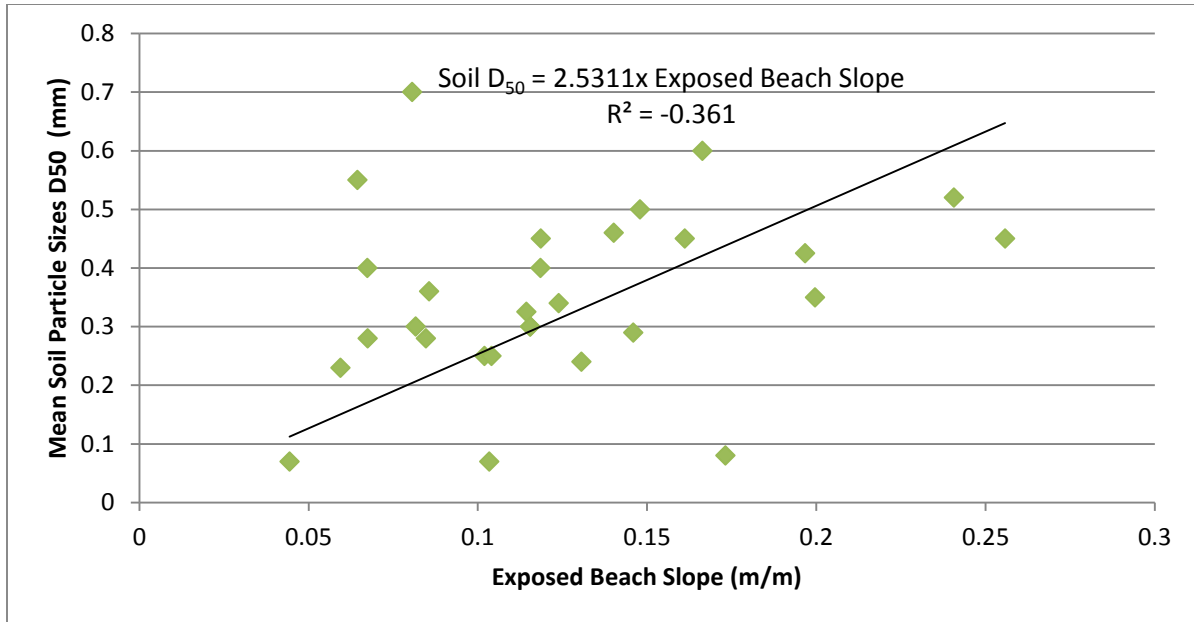


Figure 22: Mean Soil Particle Sizes against Exposed Beach slope

The mean diameter of the particle sizes of the dune soil showed positive correlation with their respective exposed beach slope measure on the field. Applying a linear regression analysis to the data showed the following relation.

$$Soil D_{50} = 2.5311x \text{ Exposed Beach Slope} \quad (4.1)$$

#### 4.3.3 Compressive Strength of 'Hard' Shore

The outcome of analysis of the 'hard' shore through laboratory analysis and *in-situ* measurements yielded the compressive strength of the 'hard' shore. This engineering property of the coastal material served as proxy for the competence of the hard shore to resist erosive stresses. A

comparative analysis of the field measurement and the laboratory analysis served two purposes: validation and for confirmation of the field measurements. A petrographic analysis carried out in support of this research enabled the naming of the main rocks found along the study area where possible (See Figure 23).

#### *4.3.3.1 Compressive Strength of Coastal Hard Shore from Laboratory Analysis*

The results of intact rock sample locations and the magnitudes of the mean unconfined compressive strength (UCS) values obtained are shown in Figure 24. A mean UCS value of 92.25 MPa was recorded for the 29 samples tested with the highest value of 272.6 MPa registered for Trinity Yard (close to Cape Three Points) and a lowest of 7.2 MPa obtained for Ekuasi (Sekondi).

Mineralogy and petrological studies carried out in support of the analysis led to the naming of the rocks.

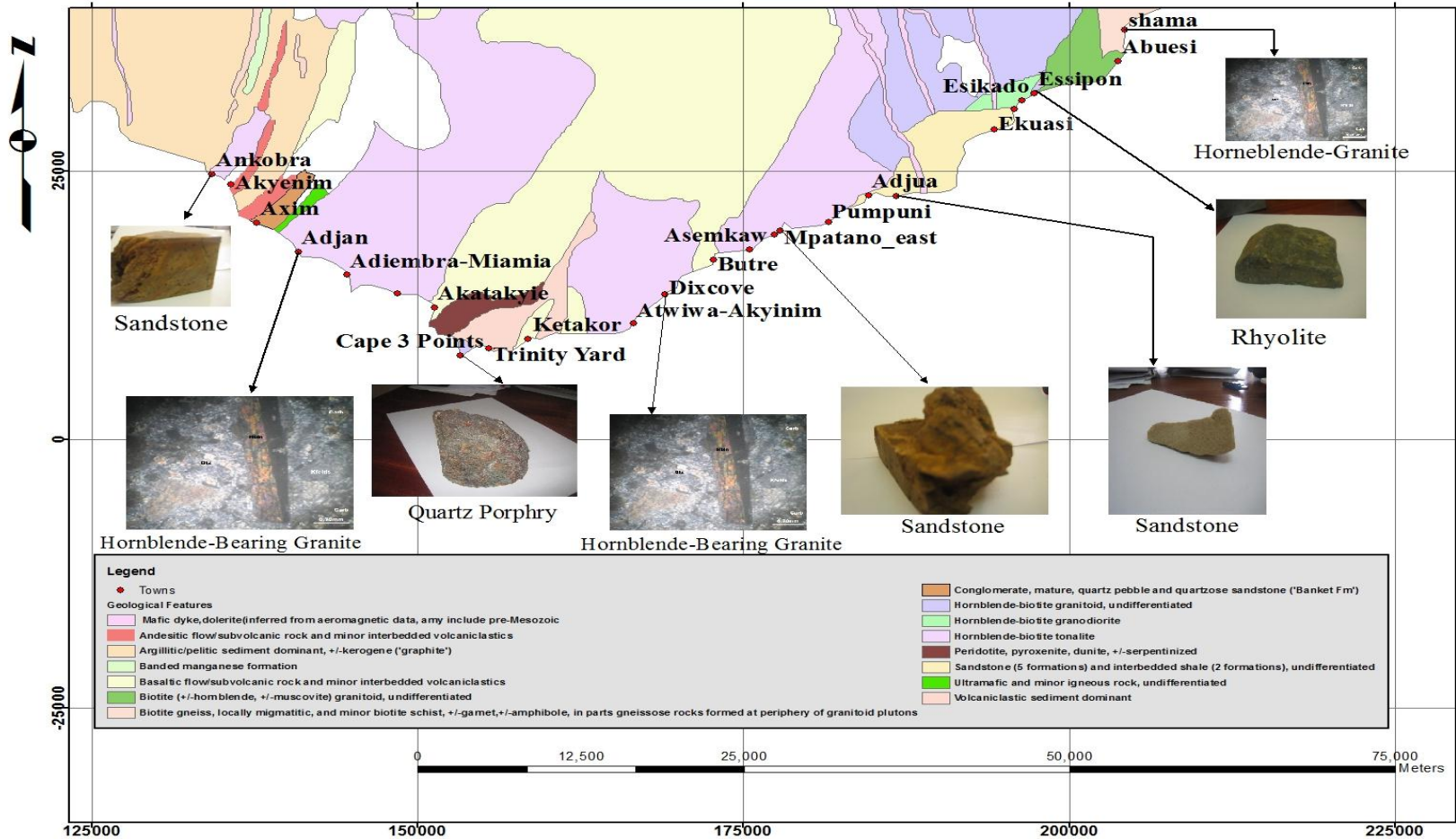


Figure 23: Sampled Rock Types along the Study Area Shown on a Geological Map

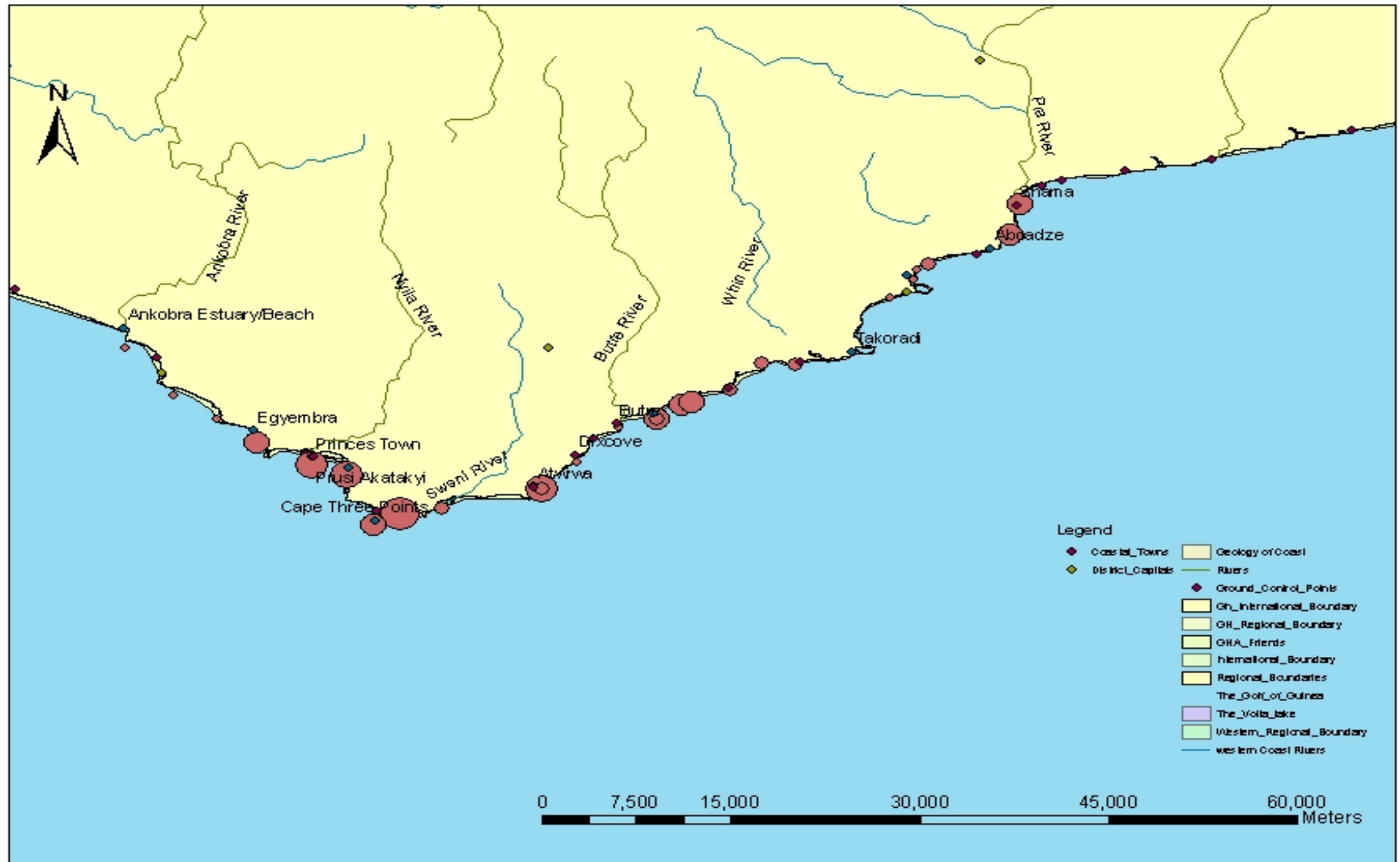


Figure 24: Magnitude of Compressive Strengths (UCS) of Hard Shore along the Study Area

#### *4.3.3.2 Compressive Strength of Coastal Hard Shore from Field Measurement*

The results obtained for the compressive strength of coastal hard shore outcrops using the Schmidt hammer gave a mean value of 12.15 Nm<sup>2</sup> with a standard deviation of 20.88. Sample Table of mean compressive strength and standard deviation derived from rebound values measured at Akatakyie is shown in Appendix A. All hard shore outcrops measured were found within the Eastern Section of the study area. Highest value of 58.6 Nm<sup>2</sup> was recorded at Ketaakor near Cape Three Points with the lowest value of 13.4 Nm<sup>2</sup> recorded for Bongo Beach near Sekondi. Locations with no rock outcrops were assigned the value zero. A scatter plot of the rebound strength of the rock outcrops against their respective chainages is shown in Figure 25. Also scatter plot of the rebound strength against their respective unconfined compressive strength of the intact rock samples are presented in Figure 26 for validation purposes as well as to establish relationship between the two methods applied.

The UCS strength of the intact rocks correlated positively with the field rebound strength measured for the coastal hard shore rock masses (Figure 26). An indication that the field procedure adopted is consistent with the laboratory analysis carried out.

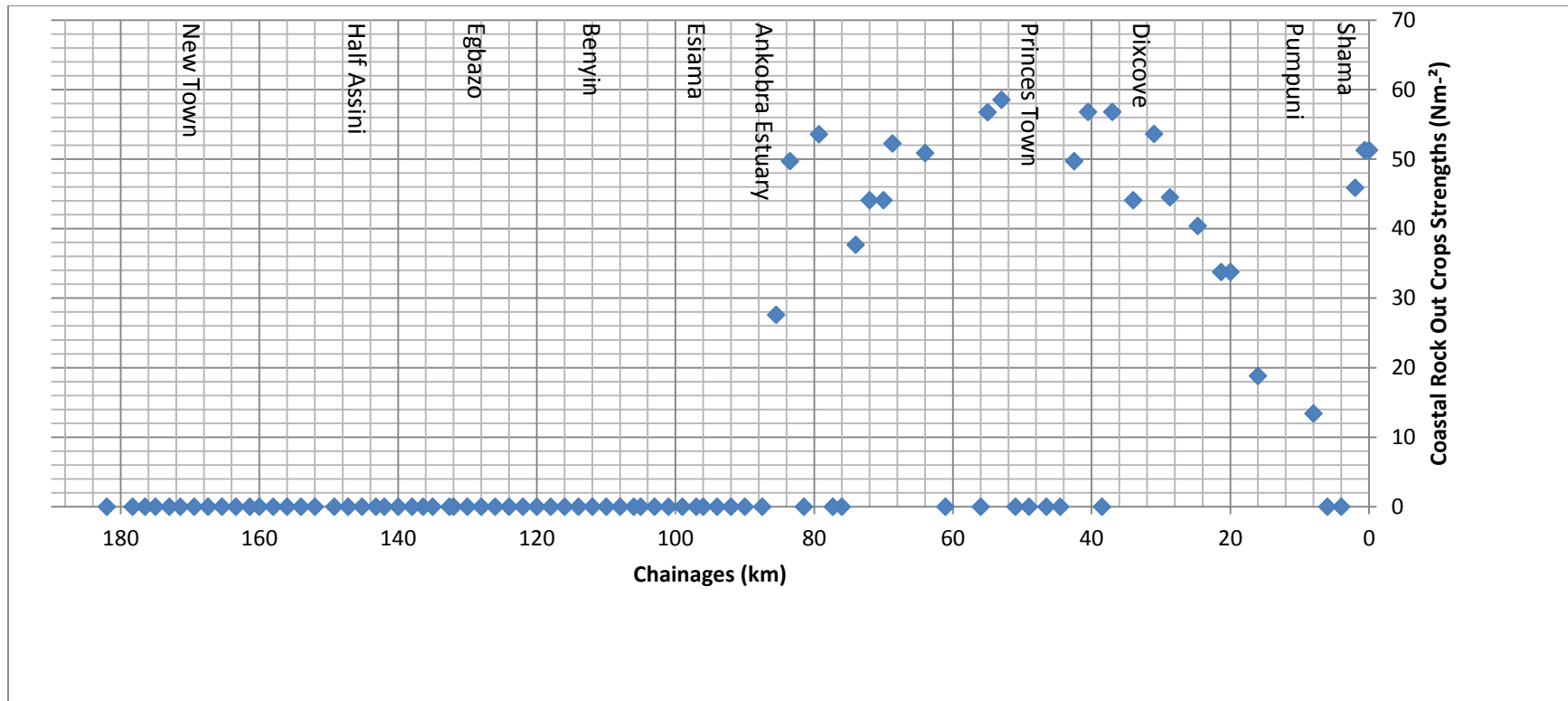


Figure 25: Compressive Strength of Coastal Hard Shore Outcrops against Chainages

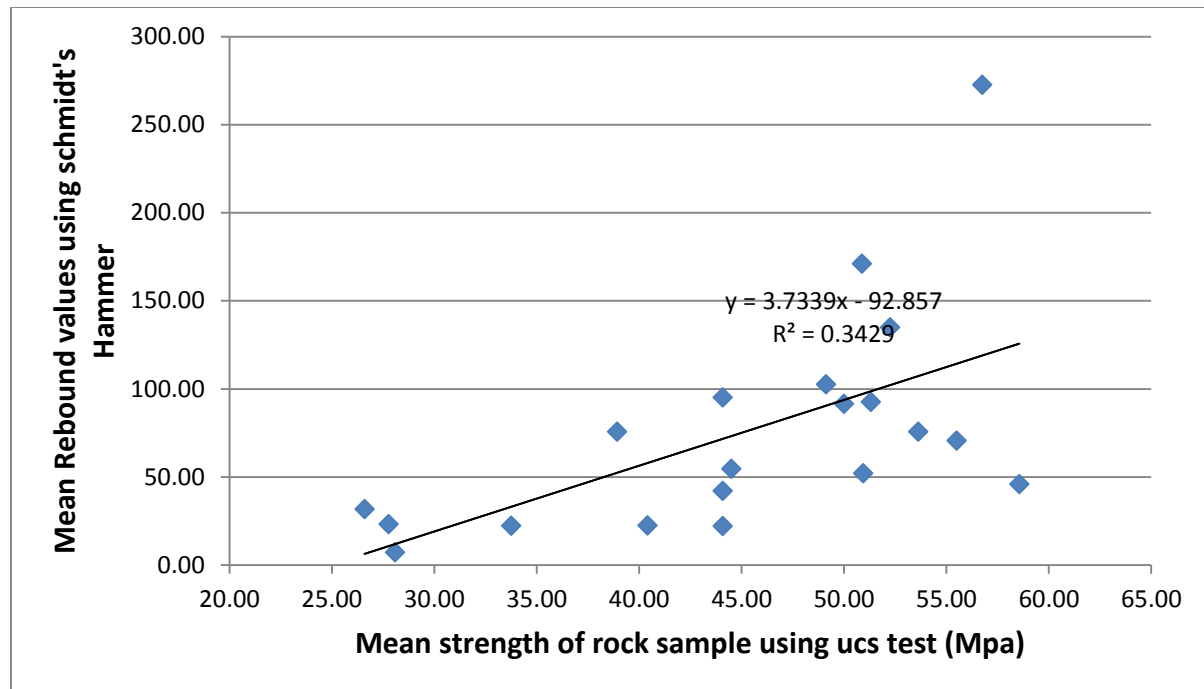


Figure 26: Correlation between Laboratory (UCS) and Field Measured (Mean Rebound) Hard Shore Strengths

#### 4.3.4 Net Coastal Material Resistivity to Shoreline Change

From Figures 19 and 25 the Eastern Section of the study Area has relatively higher shear strength values for the soil as well as showed evidence of consolidated coastal material, whereas the Western Section exhibited relatively lower figures of shear strength values for the soil and showed no evidence of consolidated material along the coast.

#### 4.4 Sediment Supply and Transport along the Shore

The estimated volume of sediment supplied by rivers from the hinterlands to the sampled locations and the estimated volume of sediment transported from the sampled locations along the shore are presented. The values obtained correlated with the shoreline change rates at the sampled sites (see Tables 15 & 16).

#### 4.4.1 Sediment Supplied by Rivers

Mean value of potential sediment transport rate computed for each chainage is about  $3.3 \times 10^6$   $\text{m}^3/\text{sec}$  of sediment was estimated to be supplied by the coastal rivers into the sea with a standard deviation of  $8 \times 10^6$ . A total of forty nine (49) rivers were identified at the study area each of which nourishes a give drainage area of the coastline. Astronomically high values were recorded close to the two major rivers namely: Pra and Ankobra were recorded over the entire stretch of the coastline. Minimum sediment supplied value of about  $47 \text{ m}^3/\text{sec}$  was computed for Benglow whereas highest value of  $1.08 \times 10^{10} \text{ m}^3/\text{sec}$  was computed for Shama. A plot of the sediment supplied by rivers into the sea at each chainage against their respective chainages is shown in Figure 27.

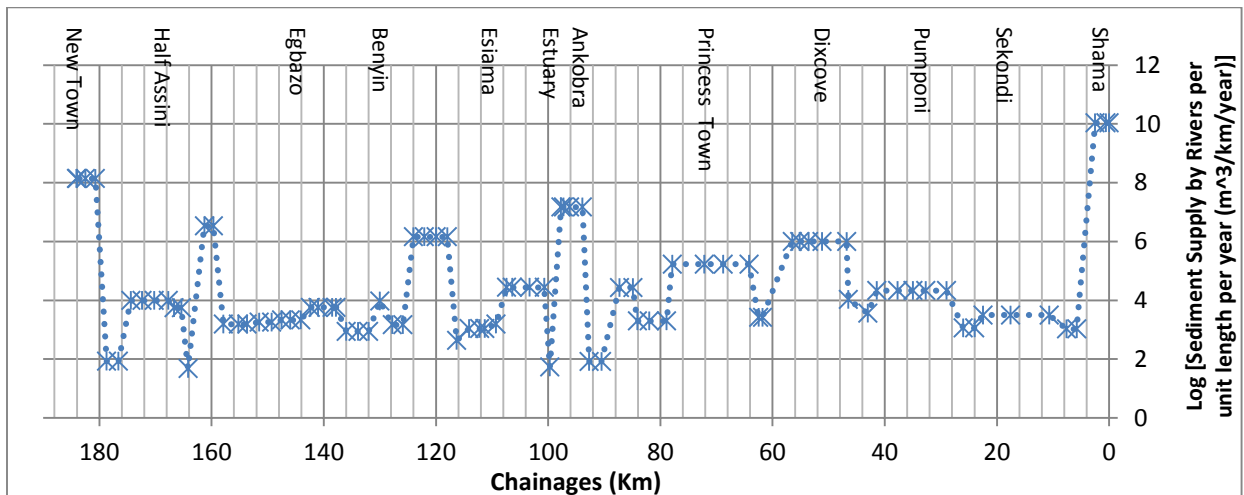


Figure 27: Sediment Supplied by Rivers to the Sea against Chainages

#### 4.4.2 Potential Sediment Transport Alongshore

The potential sediment transported alongshore from outside the study area was computed using the CERC equation which is based on the wave energy flux reaching the sampled locations. Highest values of  $894\,417\,853\text{ m}^3/\text{s}$  was computed for Shama shore which is oriented at  $345^\circ 06'$  relative to the direction of breaking wave crest. A low value of  $-890\,513\,255\text{ m}^3/\text{s}$  was obtained for Azulenumu shore which is also sloping at an angle of  $189^\circ 48'$  relative to the direction of breaking wave crest. Mean value of about  $7081511\text{ m}^3/\text{s}$  was recorded over the study area with a standard deviation of  $6.69 \times 10^8$ . A scatterplot of potential sediment transport against chainages is presented in Figure 28.

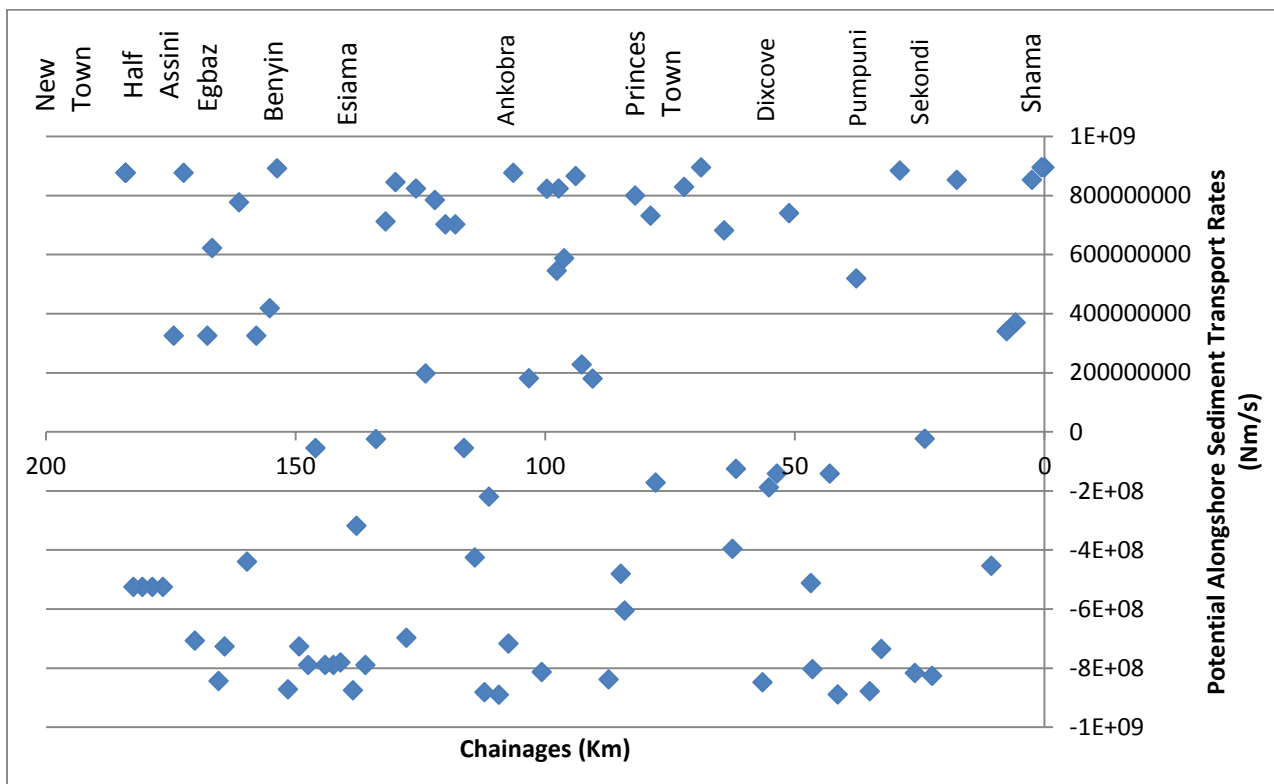


Figure 28: Potential Sediment Transport Rates against Chainages

#### **4.5 Modelling Shoreline Change with Multiple Regression**

Modelling shoreline change in terms of the selected driving factors perceived to influence the position of the shoreline in the study area was based on a joint relationship between the shoreline variable and the response driving variables. The response variable investigated are the coastal material resistance to shoreline change, sediment supplied by rivers into the sea, potential sediment transport along the shore, effects of sea level rise on shoreline and the effect of human activities on shoreline. The effect of sea level rise and human impact on shoreline change along the study area were evaluated; the former showed little correlation whereas the latter showed some correlation, thus the human impact variable was included in the multiple regression model. The outcome of the individual effects of sea level rise and human impact on the shoreline are presented in this section.

Of all the variables investigated, eight were selected and included in the regression model based on their respective correlation with the shoreline change variable(s). These variables are: the exposed beach width, exposed beach slope, thickness of the overburden, shear strength of the soft coastal material, compressive strength of the hard coastal material, sediment supplied by rivers, sediment transported along shore and human impact on shoreline change. The model identified the compressive strength of the coastal hard shore, the shear strength of the coastal soft shore and the human impact as significantly influencing the shoreline change variable at 5% p-values.

##### *4.5.1 Effects of Sea Level Rise on Shoreline Change*

The results of the sea level rise effect on shoreline change rates computed for the study area and analysed using Linear Regression analysis are presented. The shoreline excursion due to sea level

rise and actual shoreline change rates plotted against their respective chainages are presented for the short and long terms change analysis in Figures 29 and 30 respectively. The plots of the shoreline excursion due to sea level rise in both short term and long terms remain fairly constant throughout the study area, while the actual shoreline change rates vary significantly. There was vast deviance between the shoreline positions especially from 125 km (Esiama) toward the western end (New Town) of the study area. No correlation was observed between the shoreline change due to sea level rise and the actual shoreline change measured; hence the variable was excluded in the model.

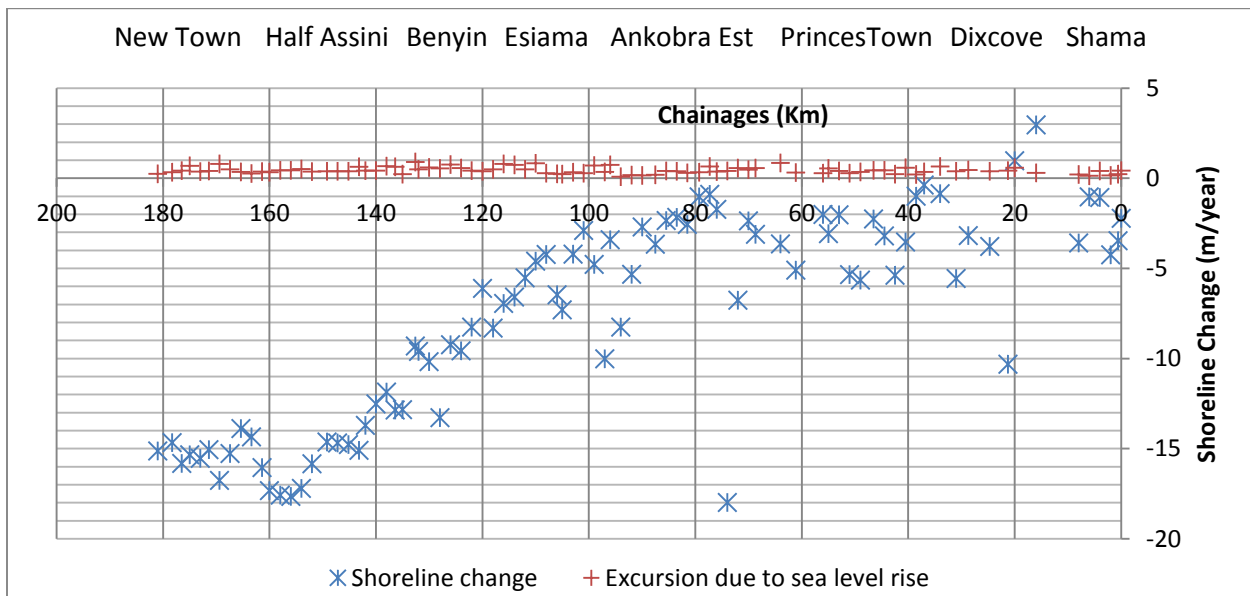


Figure 29: Short Term Shoreline Change / Excursion Due to Sea Level Rise against Chainages

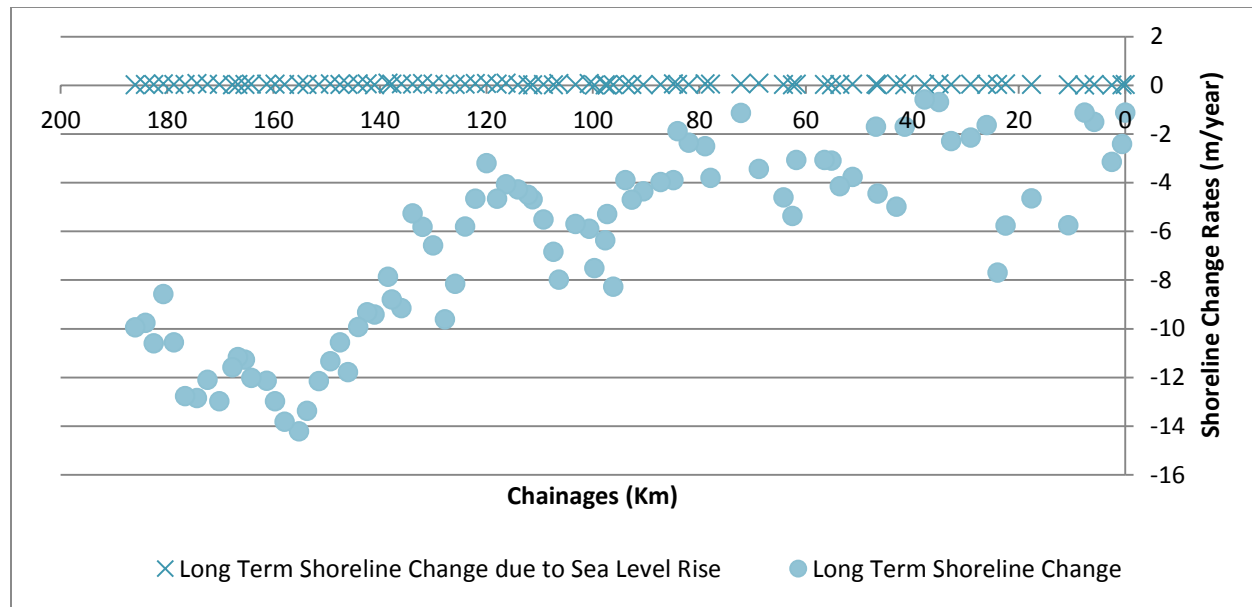


Figure 30: Long Term Shoreline Change / Excursion Due to Sea Level Rise against Chainages

#### 4.5.2 Human Impact

Human impact on shoreline change was derived from the relation in Equation (4.1):

$$\text{Human Impact} = 63.7\% * \text{Coastal Mining} + 25.8\% * \text{Population density} + 10.5\% * \text{Distance of Coastal Structures} \quad (4.1)$$

An average value of about 236 was obtained for the entire study area with values ranging between about 39 and 639. A scatter plot of human Impact on shoreline change against their respective chainages is presented in Figure 31.

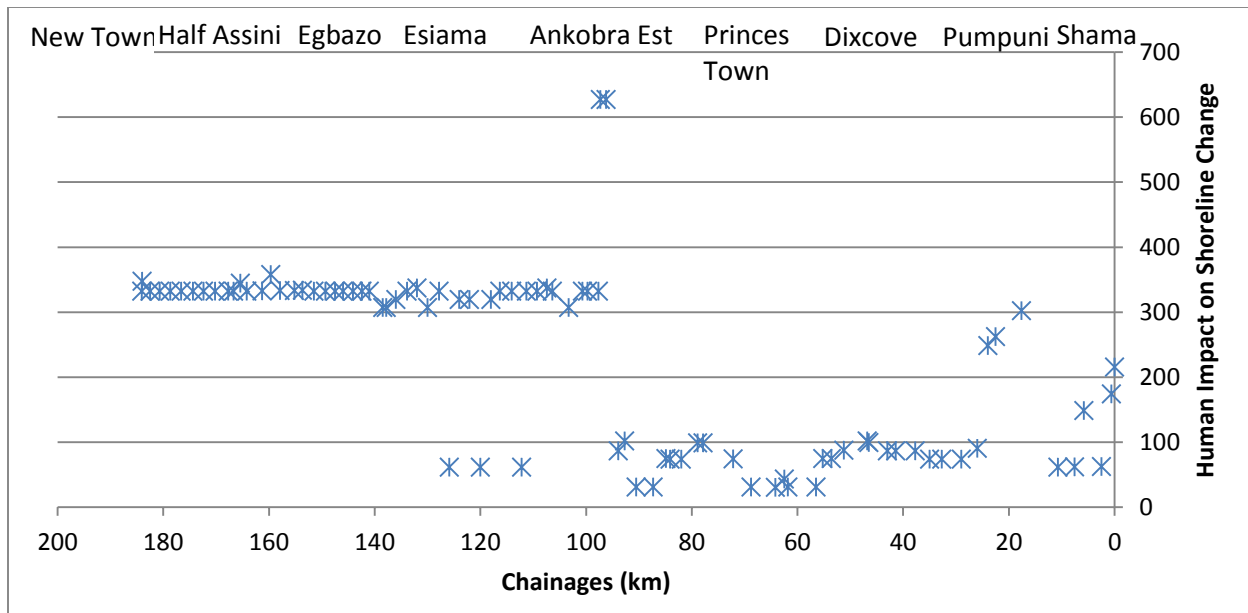


Figure 31: Human Impact on Shoreline Change against Chainage

#### 4.5.3 Model Results using Stepwise Regression Approach

Results of the Multiple Regression analysis of variables fed into the modelling process are presented. Initial bivariate relationships between the shoreline change variables and those of the selected independent variables are assessed; this provides a validation of the research hypothesis that suggests functional relations between the driving variables and the response shoreline change variable (s). The coefficients of correlation determined for each driving variable with respect to the shoreline change variable showed considerable variations in their values (Table 15). This reveals the magnitude of variation accounted for by each independent variable in a unit change of the shoreline variable. The correlation between the long term shoreline change and the independent variables for instance (Table 15) shows maximum correlation of 0.577 with the compressive strength of the hard shore. The thickness of the dune soil and the shear strength of the dune soil

also account for 0.460 and 0.389 respectively per unit change in the shoreline change variable. Similarly, from Table 14 a relatively high but negative correlation (-0.615) was obtained between the exposed beach width and the exposed beach slope variables. A correlation Table for the short term shoreline change analysis is presented in the Table 15.

The short term correlation analysis showed similar coefficients for the independent variables as in the case of the long term; however, relatively lower values of 0.489 and 0.426 were recorded for the compressive strength of the hard shore and the shear strength of the dune soil respectively. A negative coefficient of 0.450 was registered for the human impact and the shoreline change variable. The other variable namely, exposed beach width, exposed beach slope, thickness of overburden, sediment supplied by rivers and the potential sediment transported alongshore all showed small effect ( $<0.30$ ) as indicated by Cohen (1988).

The results of the next stage of the modelling process, which took into consideration the magnitude of the partial correlation coefficients of the shoreline driving variables together with their respective levels of significance (set as 0.05) of the selected independent variables to be included or otherwise in the stepwise modelling approach, is presented.

**Table 14: Correlation Table of Variables after Transformation for Long Term Shoreline Change**

|                    | AoR_Long Term | Exp Beach Width | Exp Beach Slope | Soil Thickness | Soil Strength_0.5m | Rock Strength | Log Sed Rivers | Log longshore Sed | Human Impacts |
|--------------------|---------------|-----------------|-----------------|----------------|--------------------|---------------|----------------|-------------------|---------------|
| AoR_Long Term      | 1.000         | .079            | -.047           | -.335          | .423               | .538          | .182           | -.018             | -.584         |
| Exp Beach Width    |               | 1.000           | -.615           | -.206          | .267               | .012          | .052           | -.068             | -.152         |
| Exp Beach Slope    |               |                 | 1.000           | .408           | -.153              | .019          | -.091          | -.048             | -.022         |
| Soil Thickness     |               |                 |                 | 1.000          | -.334              | -.259         | -.101          | -.040             | .178          |
| Soil Strength_0.5m |               |                 |                 |                | 1.000              | .275          | -.045          | -.043             | -.213         |
| Rock Strength      |               |                 |                 |                |                    | 1.000         | .159           | .029              | -.566         |
| Log Sed Rivers     |               |                 |                 |                |                    |               | 1.000          | .225              | .013          |
| Log longshore Sed  |               |                 |                 |                |                    |               |                | 1.000             | .049          |
| Human Impacts      |               |                 |                 |                |                    |               |                |                   | 1.000         |

**Table 15: Correlation Table of Variables after Transformation for Short Term Shoreline Change**

|               | AoR_ShortT | ExpBeachWidth | ExpBeachSlope | SoilThickness | SoilKPa_0.5m | RockKPa | LogSedRivers | logAlongshore | HumanImpact |
|---------------|------------|---------------|---------------|---------------|--------------|---------|--------------|---------------|-------------|
| AoR_ShortT    | 1.000      | 0.225         | -0.162        | -0.21         | 0.426        | 0.489   | 0.103        | 0.034         | -0.450      |
| ExpBeachWidth |            | 1.000         | -0.615        | -0.206        | 0.267        | 0.012   | 0.052        | -0.037        | -0.152      |
| ExpBeachSlope |            |               | 1.000         | 0.408         | -0.153       | 0.019   | -0.091       | -0.049        | -0.022      |
| SoilThickness |            |               |               | 1.000         | -0.334       | -0.259  | -0.101       | -0.077        | 0.178       |
| SoilKPa_0.5m  |            |               |               |               | 1.000        | 0.275   | -0.045       | -0.026        | -0.213      |
| RockKPa       |            |               |               |               |              | 1.000   | 0.159        | 0.08          | -0.566      |
| LogSedRivers  |            |               |               |               |              |         | 1.000        | 0.354         | 0.013       |
| logAlongshore |            |               |               |               |              |         |              | 1.000         | -0.048      |
| HumanImpacts  |            |               |               |               |              |         |              |               | 1.000       |

The variables which pass the significance test in the modelling process for the long term analysis for the entire study area are the human impact, shear strength of soft shore, sediment supplied by rivers and the compressive strength of hard shore outcrop with standard errors of 0.003, 0.000, 0.161 and 0.000 respectively.

$$Y_L = -7.917 + 0.001 * X_1 + 3.58 * 10^{-8} * X_2 - 0.337 * X_3 - 0.011 * X_4 \quad (R^2=0.5) \quad (4.2)$$

where  $Y_L$  is the Long Term Shoreline change variable estimator;  $X_1$  the shear strength of the soft shore variable;  $X_2$  the compressive strength of the hard shore outcrops variable,  $X_3$  the sediment supplied by rivers, and  $X_4$  the human impact variables.

The short term analysis for the entire study area identified the compressive strength of hard shore, the shear strength of soft shore and the human impact as passing the significance test in the modelling process with standard errors of 0.000, 0.000 and 0.002 respectively.

$$Y_S = -5.161 + 0.0001 * X_1 + 3.083 * X_2 - 0.040 * X_4 \quad (R^2=0.37) \quad (4.3)$$

where  $Y_S$  is the short term shoreline change variables estimator and  $X_1$ ,  $X_2$  and  $X_4$  are independent variables defined as in Equation 4.2.

Stepwise multiple regression analyses carried out for the long term shoreline change variables for the Eastern and the Western Sections of the study area are also presented. The Eastern Section identified the alongshore sediment transport rate as the variable that pass the significance test with a standard error of 0.691 (see Equation 4.4). Whereas analysis conducted for the Western Section had the shear strength of the soft shore as the only variable that passed the significance test with a standard error of 1.461.

$$Y_{LE} = -19.042 + 1.960 X_5 \quad (R^2=0.235) \quad (4.4)$$

where  $Y_{LE}$  is the shoreline change estimator for the Eastern Section of the study area in the long term analysis, and  $X_5$  is the alongshore sediment transport variable estimator.

$$Y_{LW} = 0.235 + 0.010 * X_1 \quad (R^2=0.148) \quad (4.5)$$

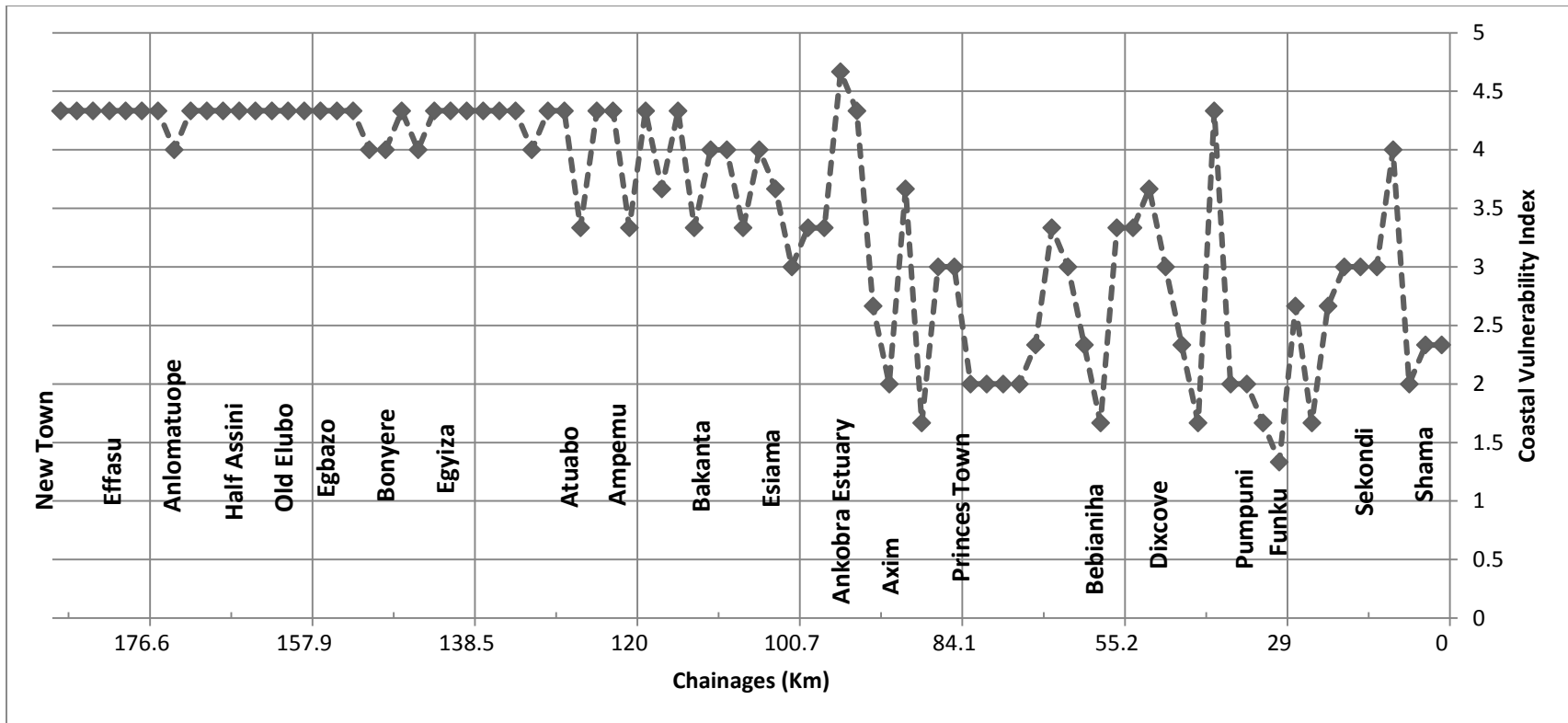
where  $Y_{LW}$  is the shoreline change estimator for the Western Section of the study area in the long term analysis.

On the contrary, none of the selected independent variables was identified to be responsible for influencing the short term change in the shoreline for the Eastern and Western Sections respectively.

#### 4.5.4 Assessment of Coastal Vulnerability to Shoreline Change Rates

Based on the model results, Figures 32 & 33 show an assessment of the vulnerability of the study area to shoreline change using a 1-5 scale ranking adopted from Pendelton *et al.*, (2005). A scatter plot of the short and long terms shoreline change rates plotted against their respective vulnerability indices show negative strong correlation with degree of the relationship being 0.61 and 0.67 respectively; this shows large effect of the relationship ( $r > 0.5$ ) according to Cohen (1988). Generally the Eastern Section from Figures 34 & 35 was ranked with lower values of vulnerability relative to the Western Section. The Eastern Section exhibits erratic changes in the vulnerability status possibly due to the variability in the human impact and the compressive strength of the rock along the coast. The shoreline in the Western Section is ranked relatively more vulnerable to

erosive forces throughout that Section. This reflects the site conditions of the coastline characteristics in terms of coastal material composition, human impact as a result of the availability of sand for mining activities. The strong degree of correlation between the shoreline change trends and the vulnerability ranking attest to the reliability of the model developed.



**Figure 32: Coastal Vulnerability to Short Term Shoreline Change against Chainages**

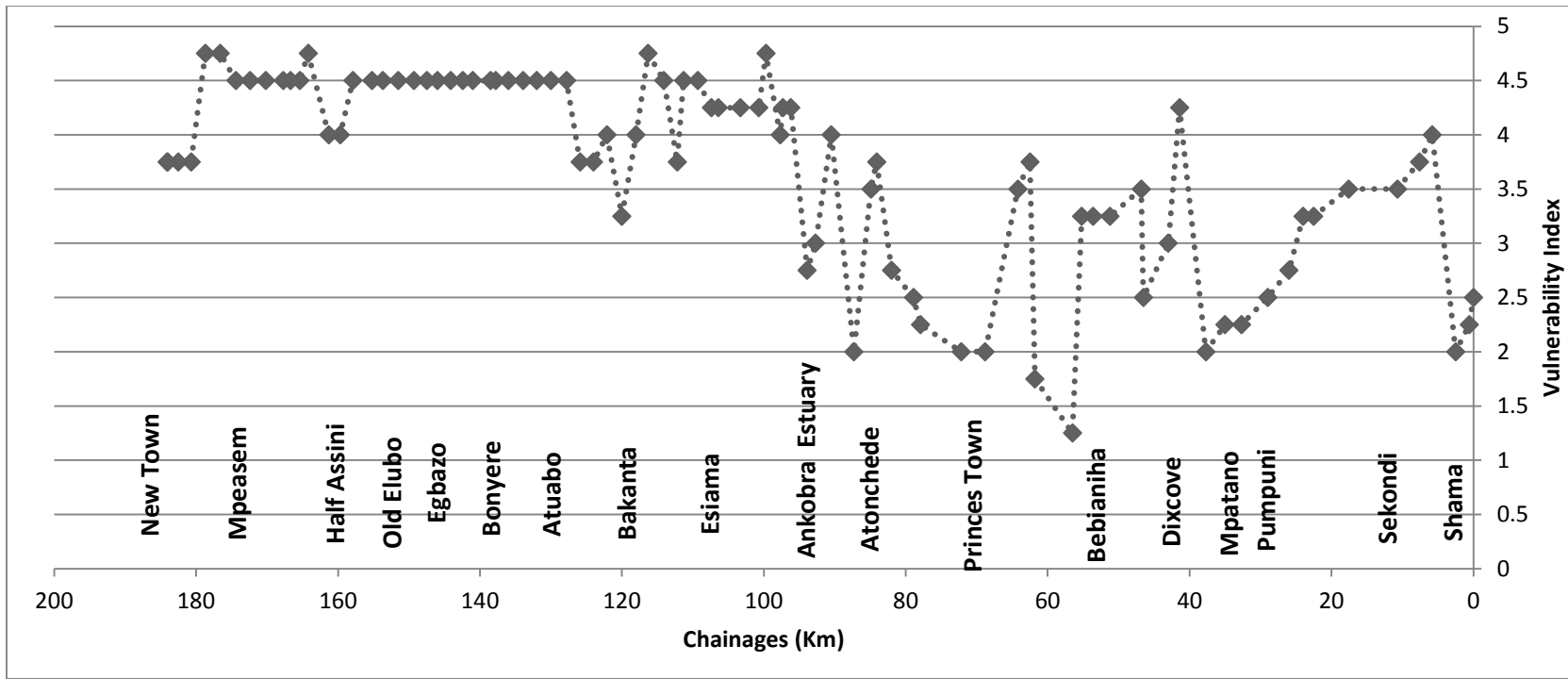
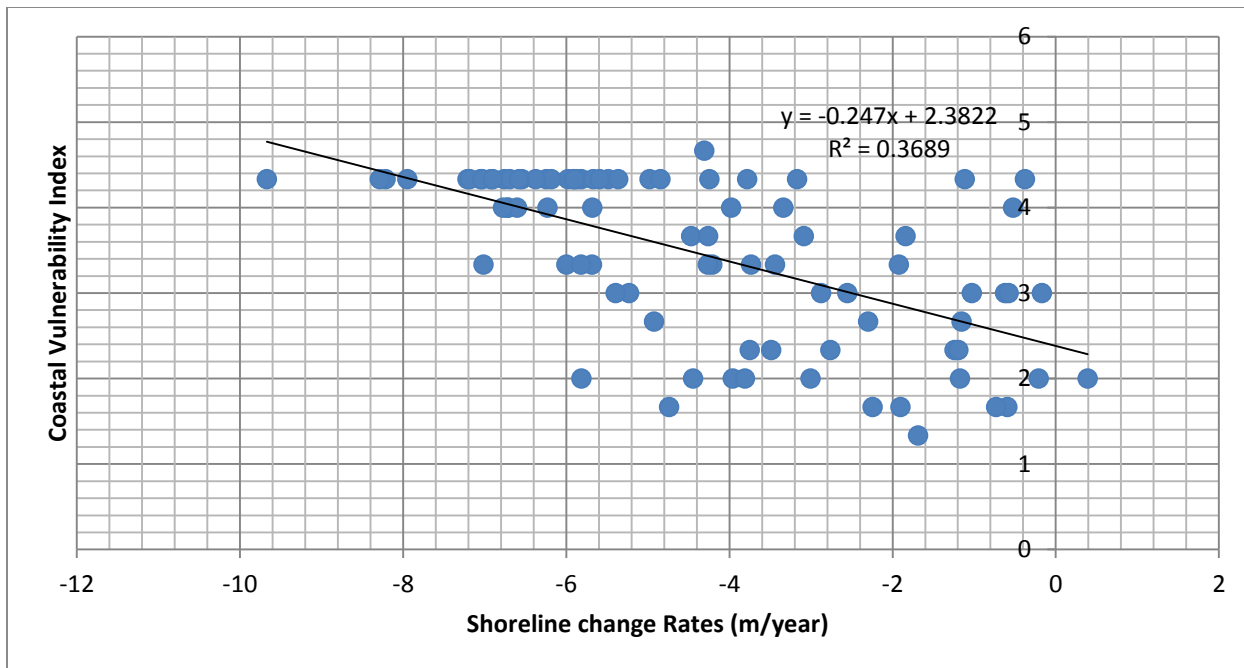
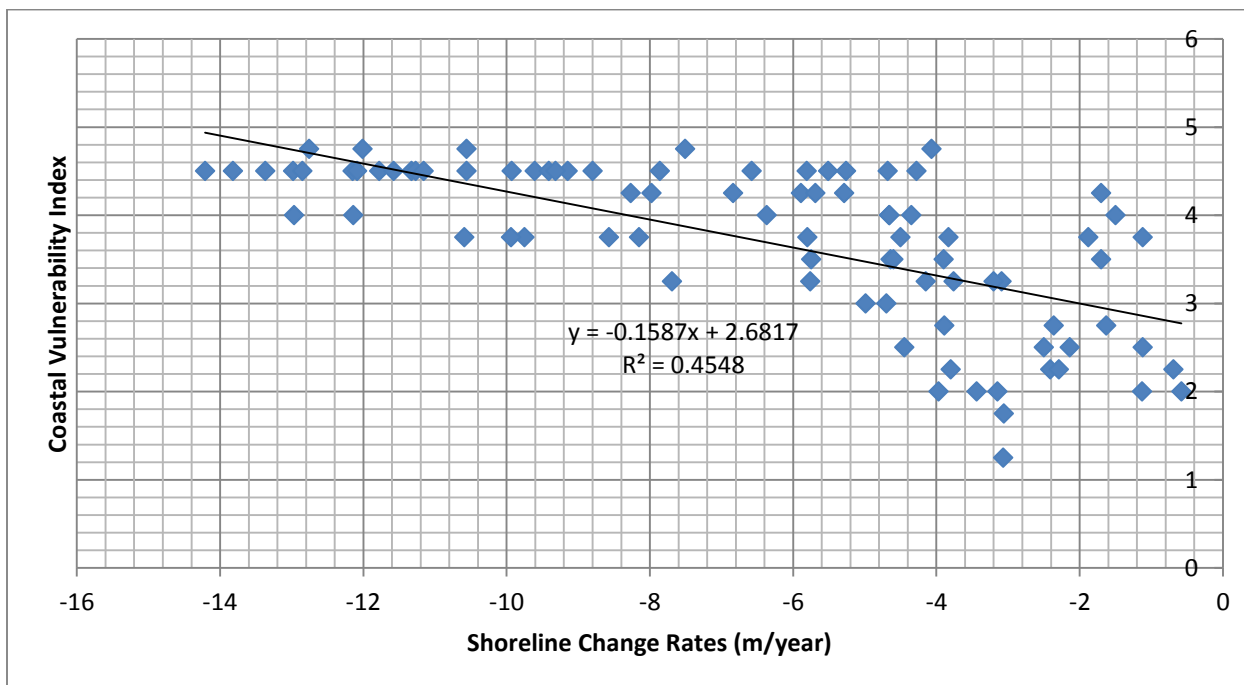


Figure 33: Coastal Vulnerability to Long Term Shoreline Change against Chainages



**Figure 34: Scatter Plot of Short Term Shoreline Change Rates against Vulnerability Index**



**Figure 35: Scatter Plot of Long Term Shoreline Change Rates against Vulnerability Index**

## CHAPTER 5

### DISCUSSION

#### 5.1 Introduction

The reliability of shoreline change information plays a vital role in understanding future shoreline evolution trends and in formulating coastal management policies. The usefulness of such information is dependent on the inherent uncertainties in the change trends so determined. Uncertainties associated with shoreline change trends in any region emanate from three main sources: the data source, the computational procedures employed and the natural shoreline variability (excluding the uncertainty associated with shoreline proxy used). Efforts are often made by researchers to reduce errors associated with data and computational procedures in order not to obscure the natural variability of the shoreline change trends under investigation. This chapter discusses the shoreline change trends observed in the Western Region of Ghana. Change rates in the short and long terms categories and the effects of the five main driving factors considered in the research, namely sea-level rise, wave impact, sediment transport, coastal material resistance and anthropogenic effects are also discussed.

#### 5.2 Shoreline Change in the Western Region of Ghana

In this research, the rate of change in shoreline with time was assigned negative values where the shoreline migrates landwards (erosion) while positive change rate connoted shoreline migration seawards (accretion). In Figure 12, the bar graph shows the magnitude of shoreline change rate at 100 m transects intervals. It portrays downward movement of the shoreline change rates from the starting transect point at Shama through to transect IDs 360 - 367 and 373 -378 (*i.e.* around

Pumpuni and Mpatano) where the bars move upwards a little (accretion) and revert back to the downward trend at the end of the study site at New Town (see Appendix II). This portrays the magnitude and direction of the shoreline migration throughout the study area.

The Shoreline Change Envelope (SCE) shows the total change in distance recorded over the 110 year period of the study. Although the rates vary along the entire study area, relatively lower changes are recorded for the section east of Ankobra River towards shama compared to the western section i.e. towards New Town (Figure 7). The SCE also shows high distance of traverse from the base year (1895) to the last year of the investigation (2005). Larger values are recorded for the Western Section compared with the Eastern Section (see Appendix II). Along the Western Section, highest SCE figures were recorded between Axim Nkekam and Ankobra Town while isolated moderate values were recorded from Ampemu to Anochi. Within the Eastern Section, however, considerable values of SCE were registered from Ngyiresia, through Sekondi/Takoradi (harbour) to New Amanful similar to that recorded along the Eastern Section. The portion of the Eastern Section from New Amanful through Cape Three Points towards Princes Town observed minimal SCE values. For better understanding of the shoreline change trends along the study area short and long term shoreline change rates are discussed further.

### *5.2.1 Short Term Shoreline Change Trends*

From Figure 13, the scatter plot of the shoreline change shows that in most parts of the study area during the period under investigation (1974-2005) the shoreline eroded landwards, with an average short term change rate of about  $-4.4 \pm 1.38$  m/year for the entire study area. A relatively slower average change rate of about  $-2.5 \pm 1.38$  m/year was recorded for the Eastern Section while an average figure of about  $-5.9 \pm 1.38$  m/year was computed for the Western Section.

Generally, the Western Section tends to erode at much faster rate compared to the Eastern Section of the study area. Some portions of the Eastern Section, for instance, Essipong and Pumpuni recorded minimal values of about -0.17 m/year and -0.21 m/year respectively. Rates less than -1.0 m/year were registered for Asemkaw, Aboadze, Adwowa, Butre, Dixcove, Miamea and Adjan. Such sites have either hard shores or are close to river mouths where there is abundant supply of sand from the hinterland.

The variability in the shoreline change rates along the study area gives an indication that the causative factors and the corresponding response factors (i.e. mostly the coastal material) vary in magnitude along the study area. If equal variability were recorded for the shoreline change, then it could be assumed that both erosive and resistive forces are in a state of dynamic equilibrium. In that case, the shoreline change driving and response factors could be considered at a regional scale. However, the short term changes in the shoreline range varied considerably, i.e. between -9.67 m/year (Anochi in the Western Section) and -0.07 m/year (Pumpuni in the Eastern Section). This observation suggests that the site specific characteristics play a crucial role in modelling shoreline change in the study area. This could be explained in terms of the magnitude of the erosive force and the corresponding resistances offered at the various sites. This observation is in line with Hapke *et al.*, (2006) which attributed short term variation in shoreline to localised seasonal changes in wave conditions along the coast.

### 5.2.2 Long Term Shoreline Change Trend

From figure 14 the long term shoreline change trend in the study area reflects changes in the shoreline position spanning over 100 year (i.e. 1895-2005). Similar to the short term trend, most parts of the shoreline in the study area are eroding with an average rate of -6.55 m/year recorded

for the entire study area in the long term analysis. Change rates range between -0.58 m/year and -14.21 m/year. The least shoreline change rate was recorded at Pumpuni followed by Mpatano, whereas the highest rate was recorded for Egbazo. The Eastern Section generally tends to be eroding at a slower rate compared to the Western Section. The consolidated portions within the Eastern Section tend to generally offer higher resistance to the erosive forces within that stretch of the shore. The sandy embayment interspersing the headlands, however, experiences high levels of erosion but not to the tune as pertains in the Western Section.

### *5.2.3 Comparison of the Short and Long Term Shoreline Change Trends*

From the composite graph (figure 15) of short and long term shoreline change trends, the rate of change for the same spatial location are observed to vary for the short and long term categories. This give an indication that factors driving short term change vary in magnitude compared to the long term rates.

The short term change trends generally recorded lower values relative to the long term change rates, except for some isolated sites such as Abuesi, Atuobo and Trinity yard (an embayment close to Cape Three Points), in which case the short term rates exceeded the long term changes rates. For instance, Abuesi, which recorded one of the highest short term rate changes (-5.82 m/year), is known to have sandy shores which are generally more prone to erosion. Besides, the slightly curved shore and flat to slightly hilly land scape could render the shoreline vulnerable to currents generated from breaking waves and tides. Furthermore there is a high tendency of littoral sediment trapping by the artificial coastal structure of the Sekondi and Takoradi harbours located west of Abuesi.

Again, a sharp contrast was observed between the short and long terms change rates from Ngyiresia through Sekondi, Nkontompo to New Takoradi. The short term analysis recorded a mean change rate of -1.5 m/year along that stretch of the coastline, whereas the long term registered about -6.0 m/year. The lower values logged for the short term could be attributed to the construction of the Nkontompo Emergency coastal protection works (Armour rock revetment), a project completed in 2005 stretching about 1200 m length of the coastline to mitigate the effect of erosion (See Figure 15). Moreover, increased education on the effects of sand mining from the beaches coupled with evidences of destroyed human habitation along the coast could be accountable for bringing about behavioural change resulting in the abrupt reduction in the short term rates of the shoreline recession.

Conversely, the long term rates which were computed from datasets captured dating back to 1895 and 1955 before the Takoradi harbour which was constructed in the 1920, and later the Sekondi Naval base Wharf also constructed (1963-1964) may be responsible for the high figures recorded by the long term analysis. The combination of datasets pre and post Takoradi harbour construction could account for the sharp discrepancy between the short and long terms rates. This is because the construction of such structures along the coastline often interferes with coastal physical processes by blocking the natural flow of sediment along the shore. This may result in sediment deficiency at the downstream thereby resulting in severe erosion. The sharp deviation between the short and long term rates may also have originated from cyclical changes along the coast due to seasonal variations in storm.

Such seasonal variations in storm may be directly or indirectly aggravated by anthropogenic effects by way of removal of coastal material such as sand and shingles, which serves as the first line of

defence against erosive forces. These factors may be responsible for the large differences between the short and long term rates as recorded for Ezilinbo (near Bonyere) through Half Assini to the New Town at the Ghana -Cote d'Ivoire border.

Examination of the short and long terms shoreline change trends revealed a condition of long period of recession of the shoreline with little accretion at most portions of the study area. This observation is in conflict with the expected cyclical variations present in all shoreline data compilation (Hapke *et al.*, 2006). This suggests that the shoreline in the Region will continue to erode unless some mitigation efforts are put in place to reverse the trend.

The uncertainties associated with the shoreline change in the Western Region of Ghana is analysed in both short and long terms. In this research, the uncertainty associated with determination of long term rates of change was higher than that of short term rates. This observation is attributed largely to source data errors and due to the scarcity of available temporal datasets covering the long term period. The data used for the long term rates had an overall inherent positional error of 2.78 m, and this is further aggravated by the sparse sampling interval period between the 1955 and 1895 topographic image used. The sixty (60) year period interval (1895-1955) is conceived to be too long to track relevant changes in the shoreline evolution, thus vital information was probably missed out. Besides possible distortions resulting from shrinkage of the original 1895 and 1955 hard paper maps, digitizing errors and lack of distinct ground controls on the maps to aid geo-referencing could lead to increase in the level of uncertainties in the source datasets.

On the other hand, inherent errors in the shoreline change rates due to limitation of the numerical model employed in the computation were observed to be comparable for both short and long term

shoreline change categories for the study area. This is evidenced by the change rate discrepancies noted for the two methods (Average of Rate and Linear Regression by Least squares numerical methods) employed in the long term shoreline change rates determination.

Although the reliability of the multi-temporal datasets used were ascertained using standard techniques, more confidence is placed in the short terms shoreline change trends compared to the long term shoreline trends obtained because of the following reasons:

- The non-uniformity in the multi-temporal spatial shoreline data acquisition periods (1895; 1955; 1974; 1994 and 2005). For instance the sampling period interval of 60 years (i.e. 1895 - 1955) is too long to detect changes in the shoreline evolution during the intermediary period;
- Besides, the uncertainties associated with the 1955 topographic maps was found to be rather high; and
- Field evidence and interview with some coastal dwellers (Olympio & Amos-Abanyie, 2013) and findings of (Boateng, 2009) confirm the validity of the results obtained for the short term shoreline change trends.

### **5.3 Sea Level Rise**

From figures 29 and 30, the values of shoreline change due to sea level rise remains fairly constant throughout the study area, while the actual shoreline change values vary considerably. The deviance of the actual values from the change due to sea level rise is minimal along the Eastern Section whereas no correlation is noted for the Western Section of the study area. The little correlation between the actual shoreline changes and those resulting from sea-level rise in the

Eastern Section could be due to the micro tides along the coast and topography elevation of the Eastern Section. The actual shoreline change trends in the Western Section of the study area showed little relation with changes in the shoreline due to sea-level rise. This implies that changes noted in the shoreline are not much influenced by rise in sea-level, or other factors such as waves may be more responsible for the changes noted.

### *5.3.1 Relative Land and Sea-Levels*

Local changes in sea levels at any coast according to Nicholls *et al.* (2003) is dependent on the sum of the global mean sea level rise (GMSLTS, 2014), the regional meteorological-oceanographic factors (ARIWA, 2008), and the vertical land movement (Nicholls, 1995). Of these, the global factors resulting from thermal expansion and melting of glaciers from non-polar regions are the dominant issues in this research. This is because there is no significant spatial variation in regional weather conditions recorded and therefore could to be assumed as constant. With the exception of the Axim district which had a previous history of earthquake, little tectonic activities have been recorded in the study area (Kutu, 2013). Tectonic activities are linked to earthquakes which in turn cause vertical land movement along the shore, none the less little of such occurrence is recorded for the study area. Therefore global factors become the prime factors to be considered. Since the area lies within the tropics, thermal expansion of the upper ocean could be responsible for the gradual increases in the volume of the ocean causing sea level rise. However, the additional water injected from glaciers would be minimal due to the long distance of the area from the temperate regions. This could account for the relatively lower sea level rise rates recorded (3.0 mm/year) in the study area as compared to the global values ( $3.2 \pm 0.4$  mm/year) since the 1993 (Nerem *et al.*, 2010).

## 5.4 Wave impact

From figure 28 the potential sediment transport rate resulting from breaking waves and the ensuing currents, which serve as the proxy for the wave impact on shoreline change in this research, was present over the entire study area. The isolated sites include New Takoradi in the Eastern Section and Sanzule, Nglekazu and Ezilinbo all in the Western Section. The value registered at New Takoradi, for example, may be due to the effect of the breakwaters at the Takoradi harbour. The presence of potential sediment transport rates observation could be due to three possible reasons; the location and characteristic features of the study area relative to erosive forces, the configuration of the shore, and the shoreline orientation relative to direction of approaching wave crest.

### *5.4.1 Location and characteristic features of Study Area Relative to Erosive forces*

The location of the study area along the open coast of the Gulf of Guinea exposes it to high wave energy from the Atlantic ocean. Strong prevailing winds from the south west over the Atlantic Ocean generate large waves due to the available long fetch and no interference with any land masses (Hopsch *et al.*, 2007; Robinson & Brink, 2005). These waves approach the coast of Ghana as swell. As waves from the offshore approaches the near shore, the waves break due to bottom friction and part of the energy is dissipated by virtue of the bathymetry. However, a considerable portion of the energy is expended on littoral transport along the shores. Sections of the shoreline forming an oblique angle with the direction of approaching wave crest experiences higher sediment transport along the shore. This scenario results in beach /shoreline erosion where sediment supplied by rivers is less than that carried alongshore. It was observed from the research that the sign of the potential sediment transport computed along the study area were in two opposite

directions (i.e. positive negative values). The littoral transport along the shores were in the west-east as well as east-west directions.

#### *5.4.2 Configuration of the shore*

The physiography of the study area renders the Western Section of the shore more linear, whereas the Eastern Section for series of curvilinear shapes as a result of the hard resistant head lands. As approaching waves encounter headland the process of reflection and refraction occurs. The relatively higher shoreline change rates recorded along the embayment of the Eastern Section could be due to high energy generated along the shore as breaking wave or the ensuing currents collide with high resistant headlands. This is particularly true where wave energy is reflected by high resistant (eg. granitic) headlands instead of the energy being dissipated as in the case of soft coastal material such as sandy.

Mpatano headlands, for instance, produces energetic reflected waves along the study area. The condition of reinforcement of wave energy by headlands, cliffs and sloping shore platforms are processes likely to contribute to erosion of adjacent shores, typically the embayment. Again, the presence of headlands along the shore causes refraction of waves as they approach the shore thus redirecting waves towards portions along the shore with lower elevation. This phenomenon also leads to increased erosion at downstream of headlands such as bays. Furthermore, headlands like other coastal structures such as jetties trap sediment transport along the shore, thus creating sediment deficiency at the down drift side. This phenomenon results in the formation of curvilinear shores adjacent to headlands as pertains in the study area. Also the effects of waves encounter with high resistant headlands or shallower sites along the shore could be responsible for the numerous pocket beaches and sea stacks found within portions of the Eastern Section of the study

area. Pocket beaches have the tendency to create congenial restrictive areas, a condition suitable for tidal waves occurrence as water levels rise. Such sites tend to erode much faster than the surrounding shores, predominantly where the shore is soft such as sandy beaches. A typical pocket beach is found at Miamea located between Princes Town and Axim, whereas sea stacks are found dotted round the rocky portions at places such as Aboadze, Sekondi, Axim and Adjan.

#### *5.4.3 Shoreline Orientation Relative to Direction of Approaching Waves*

The relatively higher values of shoreline change recorded in the Western Section could be due to its orientation in relation to the direction of approaching wave crest. The north-eastern general orientation of the shoreline makes an oblique angle with the direction of approaching wave crest (south-south west) resulting in sediment transportation along the shore. Besides, the coastal material is soft (sandy), which offers relatively less resistance to erosive forces compared to consolidated shore as pertains along some portions of the Eastern Section. These findings are in agreement with earlier researches that claim that most parts of the coastline of Ghana are prone to erosion (Armah & Amlalo, 1998; Dei, 1972; Nai *et al.*, 1993).

The varying quantum of potential sediment transport rates observed and algebraic sign of the values implies that sediment movement along the shore is not constant throughout the study area and also not limited to the west-east direction alone but occurs in the east-west direction as well. This condition suggests the existence of sediment self-containment independent of other sediment cells. This finding confirms Boateng's observation of sediment cell units and sub-units along certain portions of the Ghanaian coast (Wiafe *et al.*, 2013). The observation, however, contradicted the general perception of west-east littoral drift along the coast of Ghana (Armah, 1991).

Again, the distribution of coarser textured mean dune soil particles observed in the study area gives an indication of long term high energy winds blow beach materials and deposits them on the dune. Since high winds are usually associated with a corresponding high waves, it is conceived that the shore of the study area subjected to high wave impact from the Atlantic Ocean. This observation contrasts earlier description of the coastline in that portion of the study area, particularly the Western Zone of the Ghanaian coastline as stable.

### **5.5 Sediment Supplied by Rivers**

It was identified that 49 different rivers serve as sources of sediment to the study area. It was also observed that these rivers supplied variable amounts of sediment to different sections of the shore along the study area; bringing in sediment mostly carried in suspension from the hinterland and depositing those at the shores where the fines (silt and clay) are carried offshore leaving the denser sediment mostly sand at the beach. These rivers are also capable of transporting larger size grains of fragmented rocks by bed load transport during high periods of precipitation. These rock fragments are worked on by currents over time to form the rounded shingles often found at some portions along the beaches. Accumulation of sediment supplied by rivers along the beach provides stability to the beach and shoreline. Highest values of sediment supplied by rivers were recorded for stretches of the shores nourished by large basin rivers such as the Pra, Ankobra and Tano Rivers. Sections of the shore with adequate sediment nourishment by rivers tend to have wider beaches.

For instance, Butre a village located close to the shore, which is named after a River that discharges its sediment load into the sea, is at an estuary. The shore of Butre is calm and the estuary is devoid of the usual turbulence due to salinity differences between the fresh water and that of the sea, and

other currents generated from breaking waves along the surf zone. Sediment supplied by the River to the beach seems to serve the purpose of nourishing the beach. Although sand mining activities were evident at the shore, the challenge of vehicular inaccessibility to the shore coupled with the surveillance of the community minimises large scale sand mining tendencies at the shore. Shoreline change rate of the magnitude recorded in this section is considered as moderate (*meso*) according to European standards (BeachMED, 2008). By their standard recession rates  $>1\text{m/year}$  is considered as ranging from high to extreme levels.

The research revealed that considerable quantities of sediment are supplied by the rivers to the sea and no major blockage of rivers sediment by damming was noticed, except for sand winning activities by dredging of the Hwin River near Takoradi. The Pra River supplies the largest sediment amount followed by the Tano and the Ankobra rivers and this confirms Akrasi (2011). Portions of the Western Section of the study area drained by the Amunzuri River were found to receive minimal proportions of the potential sediment supplied. This is because the swampy nature of the topography does not permit direct flow of the River into the sea except during periods of high precipitation; otherwise the River sediment is discharged into lagoons.

A vulnerability assessment of the short term shoreline change trends of the study area categorised into minimal, high or extreme levels enabled useful inference to be made. Minimal levels of shoreline change rates ( $<-1.0\text{ m/year}$ ) were registered for about 10% of the study area, while the remaining portions (90%) are experiencing high to extreme levels of change trends.

It could be inferred from the continuous recession in most portions of the study area with limited accretion that sediment are being lost constantly from the coastal system (beach, shore or coastal dune) either to the hinterland through sand mining, trapped in sinks or lost offshore. This assertion is based on the following reasons:

- Evidence of sand mining activities as observed on the field. This situation results in the removal of sand from the coastal system which is otherwise required for energy dissipative processes along the surf zone;
- Documented reports confirmed that human impact by way of sand mining activities is responsible for the high to extreme rates of shoreline change recorded in the country (Ibe & Queleennac, 1989 ; UNEP, 1999) and specifically along the study area (Mensah, 1997), and
- Reported potential hazards along the coast of West Africa that modify littoral transport (Allersma & Tilmans, 1993). These could emanate from the construction of coastal structures perpendicular to the shores such as ports and harbours that obstructs the natural littoral zone, or increasing human population (UNEP, 1999; Wellen-Mensah, 1994).

Discrepancies between the short and long term shoreline trends may also be probably due to variations in site conditions that is coastal material responses to erosive forces. Although the Western Section has soft shores, the material strength vary considerably, based on the geological properties. For instance, Egbazo registered the least shear strength offering practically little resistance to deformation of the material at depth 1.0 m depth below the surface as compared to Bonyere which recorded four times the value registered at Egbazo.

## 5.6 Coastal Material Resistance to Shoreline Change

The resistance offered by coastal material to counteract erosive forces causing shoreline migration was observed to emanate from the strength of the hard shore outcrops, the strength of the soft shore as well as the beach material characteristics. The research has shown that the Eastern Section has relatively higher shear strength values for the soil as well as showed evidence of consolidated coastal material. The Western Section on the other hand, exhibited relatively lower figures of shear strength values for the soil and showed no evidence of consolidated material along the coast. The presence of 'hard' shore material along the coast usually offers higher resistance to erosive forces compared to those offered by the 'soft' shores material. The material composition of the beach, the exposed width and slope also contribute to the overall resistance rendered by the coastal material against erosive forces.

### *5.6.1 Strength of Hard and Soft Coastal Material*

Apart from coastal material elevation playing a role in providing security to the shoreline from rising sea levels, it does offer resistance to the other physical processes such as waves, tides and currents generated from breaking waves. The responses of the coastal material to such erosive forces vary depending on the material inherent strengths. For instance the potency of hard shore cliff determines the rebound of erosive force incident on it. Coastal material with high relative compressive strength generally tends to be more resilient compared to those with lower strength. Similarly, the presence of highly resistant rocks serves as a protective shield within its immediate neighbourhood to the detriment of the adjoining weaker zones of the coastline.

Shoreline response to erosive forces is dependent on coastal material inherent properties which are linked to coast formation origin, the lithology and the extent of weathering of the rock. The coastal material characteristics in the study area are grouped broadly into two: the Western Section formed from sedimentary origin and mainly sandy shores, and the Eastern Section portions of which are formed from volcanic origin and the remaining parts formed by sedimentary processes. The Western Section which is underlain by sedimentary rocks (sandstone shales and limestone) with relatively lower topographic elevation is eroding much faster and confirms the assertion that sedimentary coasts erode with time (Masselink & Hughes, 2003). Conversely, the Eastern Section which is underlain by more competent rocks such as igneous (e.g. granites and granitoids) and some sedimentary (e.g. sandstones and shales) rocks with relatively higher topographic heights (reaching 30 m at some locations example Cape Three Points) recorded relatively lower recession values.

The Western Section lies on sedimentary marine deposits of sands and limestone. The limestone is liable to chemical weathering processes as it comes into contact with carbonic acid (rain water) resulting in decomposition of the rocks into fragments while the minerals in them are transformed into other minerals (example limestone (calcite) to clay minerals). The process involve chemical break down of the carbonates in limestone which contains calcite ( $\text{CaCO}_3$ ) into soluble Calcium Bicarbonate ( $\text{Ca}(\text{HCO}_3)_2$ ) in the presence of rain water. The chemical process of weathering in limestone is evidenced by the production of thick layers of soil above the parent rock (Granja, 2004). It was observed that the Western Section, which recorded higher shoreline change values, logged equally high thickness of the soil overburdening the parent rocks. With the exception of

isolated cases most portions of the samples sites within this Section recorded values between 2.5 m and 4.5 m as thickness of overburden possibly as a result of weathering leading to soil formation.

Apart from soil formation over the parent rocks, the combined compressive strength of the hard shore outcrops and the shear strength of the soil offer some resistance to the erosive forces at play for each site of the study area. Thus the coastal material in the Eastern Section provided stronger resistance to the erosive forces compared with the Western Section where rocks outcrops were absent. Portions of the Eastern Section (especially along the embayment interspersing headlands and the some sandy parts) also mimic the shoreline change pattern of the Western Section to a lesser degree. It was also observed generally that sites with consolidated coastal material tend to be more resilient compared to sites with unconsolidated coastal material. It became clear that, under the condition of continuous erosion of the shoreline with little or no accretion, the more consolidated portions tend to erode at a slower rate compared with the 'soft' shores.

It was further noted that within the portion with unconsolidated material, the recession of the shoreline was directly linked to the shear strength (internal resistance per unit area) of the dune soil. The research recorded relatively higher shear strength values of the coastal dune soil at the selected depths of 0.5 m and 1.0 m respectively for the Eastern Section, where the parent rocks were generally closer to the terrain surface, compared with the Western Section. The proximity of the bed rock to the surface seem to increase the material strength generally to erosive forces thus high shoreline changes rates were recorded for the Western Section. Conversely, thicker soil overlaying bed rocks is an indication of extensive soil production as a result of weather processes (Granja, 2004), except for low lying portions such as valleys and locations of natural depressions. Since the shear strength of coastal soil influences the shoreline change along the coast, it confirms

Prasetya (2006) claim that the soil serves as a second line of defence from wave attack next after the beach material.

### *5.6.2 Beach Material Characteristics*

The characteristic of a beach, which refers to the accumulation of unconsolidated sand extending from the low tide level to the uppermost extent of wave impact, also play a key role in maintaining the shoreline stability. The beach face is described as the zone of most activity by Dolan (1972). The extent of wave activity along the beach face is dependent on the inclination ( $>30^\circ$ ) which is also reliant on the wave energy and the grain sizes of the sediment. Verification of the foreshore beach slope – mean grain size relation for the study area using the exposed beach profiles and the dune soil as respective proxies confirmed a strong relation between slope and mean grain sizes. The mean grain size of the dune soil at any part of the study area is estimated as 2.5 scaler multiple of the exposed beach slope at that part of the shore. It can be inferred that the exposed back beach slope could be used in place of the foreshore slope, acquisition of which involves underwater profiling that is associated with logistical challenges in some developing country such as Ghana. The relation developed could allow the stability of any portion of the coast to be assessed based on beach profiles of the exposed beach from which classification of the beaches could evolve as either dissipative or reflective (Bryant, 1982; Wright & Short, 1984). Though the mean grain sizes and beach slope can help in assessing the stability of a coast to some extent, the intensity of wave impact along the shore equally influence the shoreline at different time scales.

### *5.6.3 Physiography Coast Material*

The geographic location of the study area (open coast) along the Atlantic Ocean exposes it to high tendency physical processes moderated slightly by the wide continental shelf that dissipate considerable amount of the wave energy as they approach the shore. The bathymetry influences the intensity of waves approaching the shores of the study area. This is because as the water depth decreases towards the coast, the waves feel bottom and break. The presence of several high resistant headlands, cliffs and sloping rocky shores (example Princess Town, Egyembra, Dixcove, Mpatano and Cape Three Points) form reflective surfaces that reflect approaching waves resulting in reinforcement of their energies. Energies so generated are expended on geomorphic work along the less resistive portions of the coastline. This is particularly true especially where unbroken waves collide with a near vertical cliff creating a condition of standing waveform. This condition forces air bubbles into the crevices of vertical cliffs thereby widening discontinuities within the rock mass thus weakening and finally dislodging rock particles from it repeatedly (Granja, 2004). A typical example of such standing waves occurs along the cliffs of Mpatano causing to shoreline change at the adjacent shores.

The notion of waves causing shoreline change within the study area is furthermore buttressed by Shepard (1973) classification of coastlines based on energy processes prevailing along them.

The general orientation of the coastline, particularly the Western Section of the study area which is aligned in the North Eastern direction is intersected normally by the mean direction of approaching waves from the South Southwest direction. Per the orientation of the coastline relative to the direction of approaching waves and by the classification of the coast as micro-tidal, the energy driving the coast is dominated by waves. This is because the longshore currents, which are

the main driving forces of coastal circulation along the Ghanaian coast, are said to be generated by breaking waves (Boateng, 2009; Wiafe *et al.*, 2013). Since the effect of tides is minimal, it therefore implies that the coast of the Western Region and Ghana as a whole is wave dominated.

It can be inferred that the shoreline change trends observed in the study area are driven by wave energies as opposed to Ly (1980) description of that section of the Ghanaian coastline as low energy coastline. These high energy waves are doubtlessly generated from the Atlantic ocean due to the available long distance of open water the waves have to travel under the influence of winds without any interference by land masses. These high energy waves arrive at the coast of Ghana with their energies reduced considerably as a result of the wide continental shelf which dissipate part of the energy due to bottom friction. Nevertheless, the modified offshore waves often break releasing sufficient energy within the surf zone for sediment transport.

The wave impact along the coast and the corresponding resistance of the coastal material counteracting the erosive forces within the Western Region Coast influences the position of the shoreline at any point in time. The resistance offered by the coastal material are derived from the rock out cropping the coast, the beach material characteristics and the internal resistance to shearing of the dune soil. Locations with little or no rock outcrops tend to have lower net resistance thus higher shoreline recession rates (Granja, 2004).

### **5.7 Human Impacts on the Shoreline Change**

The impact of human activities such as removal of coastal material (mostly beach sand), construction of artificial structures along the shores and stress exerted by human population density along the coast, ultimately interfere with the natural sediment transport pattern along the coast.

The research considered human impact as a multi criteria decision expressed in terms of three dominant variables: coastal material mining, distances off coastal structures along the shore human population density. The results revealed that about 64% of human impact is attributed to coastal (sand) mining, while about 26% is contributed by population density and the remaining close to 10% is due to distances off coastal structures along the shore that obstructs sediment movement along the coast.

Scatter plot of the human impact on shoreline change at the various chainages along the study area (Figure 31) revealed variability in the magnitude of the values. The values obtained for the sampled site within the study area was significantly influenced by the presence of sand mining activities, followed by population density and then distance off coastal structures. Sites with high availability of coastal material, particularly sand, showed evidence of mining activities along those shores. Also sites having moderate to high population densities recorder considerable values of human impact index.

The Eastern Section of the study area, where there is limited availability of sand for mining activities, recorded a mean value of about 112, whereas the Western Section logged a mean of about 326. A least value of 39 was obtained for the outskirts of Axim where availability of coastal material is minimal with little or no human habitation. Highest figure of 639 was obtained within the neighbourhood of the Ankobra River estuary, where substantial sand mining activities were observed and there was availability of sand deposited at the shore by the Ankobra River.

The research has successfully quantified human impact on shoreline change in terms of the three factors which jointly contribute to its occurrence in the study area. It has further shown that human

impact resulting from coastal material mining is the major cause of shoreline change in the study area and contributes about 64% of the total loss of sand from the shores. This is because coastal material mining deprives the shore of sand which serves as the front line of defence against wave attack thus rendering the shore and immediate coastal dune vulnerable to erosion.

The coastal population density which accounted for about 26% of the human impact on shoreline change was observed to be relatively high along the coastal communities and minimal for uninhabited portions of the coastline. The coastal communities such as the Shama district have higher population growth rate (3.5%) (Diallo *et al.*, 2010) compared with the national average possibly due to food security along the coast and congenial weather/climate conditions. Population increases usually go with a commensurate demand for accommodation which results in the clearing of the vegetation thus exposing the land to gully erosion. This process increases the erodibility of the coastal material rendering the shore vulnerable to erosive forces.

It was identified that distances off coastal structures that obstruct natural sediment transport paths along the coast constituted about 10% to the human impact causing shoreline change. It was also observed that portions of the shore having high engineering structures example break waters from harbour, jetties and coastal defence structures such as groynes registered relatively higher values. Such structures trap sand on the upstream leaving the downstream with insufficiency sand required for natural geomorphic processes. Thus sediment budgetary along the shore is interrupted. In cases where adequate fluvial sediment is non-existent the beach is eroded to provide the deficit. From this research, sediment blockage by structures contributed marginally to the overall human impact due to their relatively low weights.

The net effect of human interference on coastal sediment transport pattern was found to correlate moderately but negatively with the shoreline change rate within the study area. The negative coefficient of correlation shows a reversal effect on the shoreline change rates. The strength of the relation between the shoreline change rates and the computed human impact was observed to increase from 45% for the short term category to about 58% in the long term analysis (see Tables 15 and 16). It could be inferred from the research that the effect of human impact on shoreline change increases as the duration of the shoreline change analysis increases (example from the 31years (1974 – 2005) period to 110 years (1895 – 2003)). The finding of this research partly contrast, the notion that long term change analyses are less influenced by local factors within the study area (Hapke *et al.*, 2010).

## **5.8 Numerical Modelling and Predicting Shoreline Change**

Modelling shoreline change as a function of the driving causative and resistive variables enable the research hypothesis to be tested through the use of multiple regression modelling techniques. The techniques allow relationship between set of variables and their dependent variables to be assessed, as well as the overall effects of the driving independent variables on the dependent variable quantified. From the correlation tables (Tables 14 and 15), the first rows of values in the tables, which show the strength and direction of the relationship between the shoreline change rates for the short and long terms and the independent driving variables, indicate that all the selected variables correlated with the shoreline change rates in both the short term and the long term categories.

The extent of relationship between the dependent and independent variables vary between -0.162 and 0.489 for the short term analysis of the shoreline change. The correlation coefficient between

shoreline change and the compressive strength of the coastal rock outcrops, for instance, exceeds 0.42 and that indicates a weakly positive bivariate relationship between the variables (Cohen, 1988). Similar relationship exists between the short term changes in the shoreline and the shear strength of the coastal soil. Likewise, the long term change rates correlated much better with the independent variables, with values ranging between -0.584 and 0.538. The highest negative correlation coefficient of 0.584 was registered for the human impact independent variable, whereas correlation coefficient of 0.538 was logged for the compressive strength of rock outcrops. From the correlation tables (Tables 14 and 15), it clear that all selected independent variables showed some degree of linear relation with the short and long terms shoreline change rates.

It was also noted that some degree of correlation exist between the various pairs of independent variables, notably is the inverse correlation between the exposed beach widths and the exposed beach slope (61.5%). The correlation between the exposed beach width and the exposed beach slope could probably be due to the fact that the exposed beach slope is a derived quantity of the former since slope is a ratio of change in vertical distance to horizontal distance. Apart from the correlation between the shoreline change variable(s) and the selected driving variables, statistical significance test results enabled the selection of variables that significantly influence the shoreline change variables or otherwise to be identified.

Again it emerged from the study that the long term shoreline change rates indicate that a unit measure of standard deviation change in the shoreline is caused by 0.39 units of shear strength of dune soil; negative 0.282 units of human impact; 0.241 units of the compressive strength of the coastal rock outcrops and 0.177 units of thickness of thickness of dune soil. The coefficient of determination ( $R^2$ ) of 0.58 and an adjust value of 0.57 shows that about 58% of the variations

observed in the long term shoreline change is explained by changes in the selected independent variables. It therefore implies that 42% of changes recorded in the shoreline change rates cannot be explained by the model generated. Thus the accuracy of the model used is assessed.

#### *5.8.1 Factors Driving Short Term Shoreline Change Rates*

From the Stepwise Multiple Regression Modelling carried out at the 86 sample sites along the entire stretch of the study area, three models were generated using the Software MATLAB for the independent eight variables entered into the model. The first modelling process identified the compressive strength of the coastal rock outcrops as contributing considerably to the variations observed in the short term changes in the shoreline. The chosen variable (compressive strength of the coastal rock outcrops) accounts for 0.49 units of variations recorded per unit shoreline change rates. The second modelling process selected a combination of the compressive strength of the rock outcrops and the shear strength of the soil each of which contributed 0.40 and 0.315 units respectively and jointly account for about 58% a unit variation in the shoreline change rate. Finally a third modelling process generated combined the strength of the coastal rock outcrops, the shear strength of the coastal soil and the human impact variable each contributing 0.28, 0.30 and -0.23 units respectively to a unit change in the shoreline position. They altogether accounted for 60% of changes registered in the shoreline change.

The third modelling was chosen for the purpose of this research because it explained a substantial amount of the variations in the shoreline change. It has also brought to the fore that apart from the coastal material which offers resistance (from the coastal rock outcrops and the soil) to combat the erosive factors, the effect of human impact rather aggravates the situation. The effect of human

impact on coastal processes (which is often due to sand mining, coastal population density and the construction of coastal structures) negatively influences the shoreline position.

The research modelling technique has shown that short term changes in the shoreline are resisted by the coastal material, and that portions of the shore which possess both coastal rock outcrops and competent soil tend to be more resilient to erosive forces. This explains why portions of the Eastern Section of the Study area which have consolidated rock outcrops and corresponding competent soil are eroding at slower rates. Again, the effect of human impact on the shoreline tends to aggravate the erodibility of the shoreline.

It was observed from the stepwise modelling carried out separately for the Eastern and Western Sections (using 36 and 50 sample sites respectively), that none of the variables passed the statistical significance test for the short term analysis. This implies that none of the independent variables considerably accounted for variations observed in the shoreline change per the linear model used. This implies that the form of relationship between shoreline change and the identified driving variables for the selected section may be non-linear in nature and not linear.

#### *5.8.2 Factors Driving Long Term Shoreline Change Rates*

From the multiples regression analysis carried out for the long term shoreline change category, four different models were generated from which four variables were selected. The variables chosen in the order of statistical significance are the human impact, the shear strength of the coastal dune soil, sediment supplied by the coastal rivers and the compressive strength of the coastal rock outcrops. The first model selected human impact as responsible for causing change of about -0.58 units to the shoreline change rates per unit change in the human impact. The second model selected the compressive strength of the coastal dune soil (0.31) in addition to the initially selected human

impact which contributed -0.52 units to the changes in the shoreline change. Individual contributions of -0.58, 0.32 and 0.20 units were recorded for the human impact, shear strength of the dune soil, and the sediment supplied by coastal rivers respectively for the third modelling process. The three variables jointly explain 47.5% of the changes observed in the shoreline change rates. A fourth model selected the compressive strength of the rock outcrops in addition to the variable selected by the third model to jointly explain 50% of the variation recorded in the shoreline change rates. The fourth model was chosen since it explains a substantial amount of the variation recorded in the shoreline.

In general the long term effect of human impact on shoreline change contributed significantly to the overall shoreline changes registered. The contribution of the coastal material selected (dune soil and rock outcrop strengths) was relatively minimal compared with the human impact. Similarly, value less than 20% was contributed by the sediment supplied by the coastal rivers.

The outcome of the model run for only the Eastern Section of the study area (36 sample sites) show that the longshore sediment transfer significantly influence the shoreline change rates; while the model run exclusively for the Western Section (50 sample sites) selected the shear strength of the soil as the only valid candidate responsible for causing 0.38 units of change in the shoreline change rates per unit change in the natural log of the longshore sediment transported along the shore.

### *5.8.3 Comparison of Short and Long Terms Factors Driving the Shoreline Change Trends*

It was observed from this research that a combination of different variables influenced the shoreline change at different time scales. The short term analysis detected that the compressive strength of the coastal rock outcrops, the shear strength of the dune soil and the human impact

significantly controlled the shoreline change rates in descending order. Conversely, the long term analysis revealed that the human impact, the shear strength of the coastal dune soil, the sediment supplied by rivers and lastly the compressive strength of the coastal rock outcrops impact on the shoreline change. Although human impact and the compressive strength of the coastal rock outcrops variables jointly affected the rate of shoreline change, the strength of the rocks served as a resistive factor while the human impact acted as a causative factor.

Again, it was observed generally that the compressive strength of the coastal rock outcrops largely controlled the short term analysis, while the human impact showed marginal effect on the rate change computed. In contrast, the long term shoreline analysis showed that the shoreline change was largely attributed to human impact, often caused by sand mining activities and also due to interference with natural coastal sediment transport pattern along the shores. This is because as human activities such as sand mining activities impacts negatively on the coastal material over a considerable length of period, the internal resistances of the coastal material are weakened thus reducing their inherent resistivity to erosive forces. This is evidenced by the several sea stacks dotted around portions of the Eastern Section, coupled with the subsequent high shoreline change rates observed along the sandy portions of the study area. This opinion is generally valid for sites with low coastal rock outcrops strength, however, for some rocky portions with high resistant rock outcrops bounding the coastline such as Cape Three Points, the promontories formed, tend to dictate the characteristic shape of the coastline involved.

Furthermore, the research has demonstrated that the shear strength of the coastal soil offered the second highest impact on the shoreline change variables in both short and long term categories. The coastal soil strength variable contributed nearly equal proportions of 0.3 unit per unit change

on shoreline change. Since approximately 30% of the shoreline change variable is controlled by the strength of the coastal soil that explains why portions of the coast which have no cliffs or consolidated platforms are eroding faster. It may also provide a justification for the *ad hoc* methods adopted here in Ghana for mitigating shoreline change along portions of the Ghanaian coastline using 'hard' engineering structures.

The research has further indicated that the long term shoreline change is partly controlled by the sediment supplied by the coastal rivers. The variables accounted for about 17% per unit change recorded in the long term shoreline change rates. Although it did not show its effect in the short term analysis, it is important to guard against blocking of sediment due to damming of rivers that nourish the beaches. The findings of the research ties in well with the findings of Ly (1980), in which he attributed the several shoreline recession rates along portions of the Eastern and Central Zones of the Ghanaian coastline to damming of the Volta River at Akosombo for hydroelectric power generation.

The results of separate stepwise multiple regression modelling carried out for the Eastern and Western Sections of the study area, expressed that none of the variables control the short term shoreline change. Conversely, the long term shoreline change indicated that the Eastern Section is controlled by the alongshore sediment transport rates, whereas the Western Section showed that the shear strength of the dune soil controls to a large extent the shoreline change in their respective Sections.

The Eastern Section which is characterised by several headlands interspersed by embayment showed specific sediment movement pattern due to the sediment compartment or cells so formed by the headland-bay-headlands configurations. These sediment cells within the Eastern Section of

the study area tend to control sediment transport paths along the shores. This claim was confirmed by the change in the algebraic sign (indicating direction) of alongshore sediment transport rates computed; indicating possible reversal in the direction of littoral transport along certain portions of the coastline. Usually segments of the shore exposed to high littoral transport tend to lose sediment rapidly from the surf zone, which often translates to beach recession. This condition brings about deficit in the sediment budget leading to shoreline recession as observed by Leont'yev (2011) and Davis & Duncan (2009). This situation is particularly true where limited sediment from other sources, for example fluvial sediment, come in to replenish sediment losses along the shores. The long term model results along the Western Section buttresses the observations made in the short and long term analyses for the entire study area. The findings of the entire study area revealed that the shear strength of the dune soil places second in determining the extent of shoreline change rates pertaining, next after the effects of rocks and human impact. It was noted that the Western Section only indicated the shear strength of the dune soil as largely impacting on the shoreline change variable. The Section recorded relatively lower values of the shear strength of the dune soil variables that controls the shoreline change trends compared with the Eastern Section, thus the Western Section tends to erode at a faster rate with most portions of the shoreline eroding at high rates relative to the Eastern Section.

#### *5.8.4 Vulnerability Assessment of Shoreline Change Analysis*

A Coastal Vulnerability Index (CVI) derived from the modelling equations gave a 1-5 rank of the coastal status. The most stable sites had lowest ranking of 1 while highest values of 5 was assigned to most unstable sites.

From the short term analysis (Figure 32 &34), the Eastern Section of the study area particularly the rocky portions of the coastline tends to be more resilient to the erosive forces, though some degree of erosion of portions of the shore platform are taking place, it is generally slow (Granja, 2004). Conversely, the Western Section which is composed basically of soft coastal material (sand) was found to be more vulnerable to erosive forces. Since the shear strength of coastal soil is far less than the compressive strength of consolidated rocks outcrops, their comparative resistances to erosive forces differ significantly, thus the observed shoreline change trends in the Western and Eastern Sections respectively.

From the long term analysis (Figure 33 &35), the vulnerability of the coast for the Eastern and western Sections show similar behaviour as that of the short term analysis. This trend could explain the physiography of the study area and the Ghanaian coastline in general.

## CHAPTER 6

### CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 Introduction

Investigation into the causes and trends in shoreline change of the Western Region of Ghana has brought to the fore important findings applicable beyond the confines of the study area; this is because the segment of the country's shoreline used for the research bears all the distinctive characteristic features of the entire Ghanaian coastline. The study of the causative factors, driving the shoreline change, in the Region was crucial for understanding the observed trends. From these trends strategies and policies could be formulated for effective management of the coastal zone in the Region and the country at large. Thorough understanding of the causes of shoreline change in the study area will help in the implementation of measures to avert the observed shoreline change trends prevailing in most parts of the study area.

The causes of shoreline change trends in the study area could not be determined initially, but rather had to be teased out from accurately measured multi-temporal shoreline datasets. This enabled field data to be integrated with theory to yield reliable relationship between the shoreline change variables and their corresponding independent variables. A relation between the observed shoreline change trends and the speculated driving factors, namely the sea level effect, wave impact, sediment supplied by rivers, resistance of coastal material and human impact on shoreline change enabled specific equations to be formulated for the Western and the Eastern Sections. Accurate shoreline change information covering the entire 192 km stretch of coastline of the

Region is essential for two purposes; first, to provide information to enlighten coastal developers so as to minimise potential losses due to coastal erosion; then, to derive mathematical relations between the change trends and the actual causative variables through modelling.

The modelling process using stepwise multiple regression techniques enabled numerical equations to be formulated for the short and long term shoreline change trends. These equations could be used to estimate and predict future shoreline trends for the rest of the coastline of Ghana and also for the West Africa Subregion. The resistance offered by different types of coastal material to erosive forces has for the first time been quantified by this research. The study has also confirmed the fact that coastal soil serves as the second line of defence next after the beach. This proceeding sections of the thesis deals with the conclusions drawn from the research and recommendations made for further research work.

## **6.2 Conclusions**

The research hypothesized that the shoreline change trend is a function of all the driving (causative and resistive) factors was proved right. The shoreline change variable in both short and long terms correlated with all eight variables used as proxies, namely: exposed beach width, exposed beach slope, thickness of coastal soil, shear strength of coastal soil, compressive strength of coastal rock outcrops, fluvial sediment by rivers, alongshore sediment transport rates and human impact index. It was found that all the selected independent variables showed some degree of linear relation with the short and long terms shoreline change rates, and that no single independent variable strongly (i.e.  $r > 0.95$ ) correlated with the shoreline change rates for the study area. It therefore implied that two or more independent variables operate jointly to cause changes in the shoreline within the

study area. This observation confirms the research hypothesis of the shoreline change trends in the study area. The shoreline change trends in the study area are therefore a function of some of the selected independent variables measured along the area. This finding satisfies the general aim of the research.

The research has also determined the shoreline change rates along the entire study area considered in the short and long terms. The shoreline in the study area is generally receding at most parts with little accretion in both the short and long terms analysis. Average shoreline change rate of about -4.2 m/year was recorded for the short term (31 years) period for the entire the study area whereas an average change rate of -6.55 m/year was recorded for the long term (110 years) period. The short term rates were perceived to be more reliable compared with the long term change rates. It was also observed that the Western Section of the study area was eroding much faster than the Eastern Section. The general findings from the long and short terms analyses have shown that the specific site conditions influence the shoreline change rates. This finding is in line with the first objective of the research.

The research has shown that the exposed beach width, exposed beach slope, thickness of the soil shear strength of the coastal soil and the compressive strength of the coastal rock outcrops together offer resistance to shoreline change in the study area. The shear strength of the coastal soil was found to generally increase with increasing depth. The mean particle sizes of the coastal soil at any part of the study area was estimated as 2.5 scaler multiple of the exposed beach slope at that part of the shore. Also the study revealed that the proximity of the parent rocks to the surface of the topsoil is a measure of the coastal material resistance to erosive forces. Also portions of the shore with consolidate material outcrops showed much more resilience to shoreline change

compared with portions of the shore with only unconsolidated material. The Eastern Section of the study area where rock outcrops were present showed less shoreline recession compared to the Western Section where rock outcrops were non-existent. Higher recession rates were noted along the Western Section partly because the underlying sedimentary rocks (limestone) was weak and conceived to be undergoing chemical weathering to form thick layers of soils. The variability of the coastal material along the study area could explain the evolution trend of the shoreline as well as the physiography of the study area. This finding is in line with the second objective of the research.

The research has also confirmed the fact that the location of the study area along the Gulf of Guinea exposes it to high energy waves from the South Atlantic Ocean. These waves break obliquely along the shores thereby causing littoral transport along the shores. This could explain the continuous shoreline recession recorded along most parts of the study area with limited accretion. The continuous shoreline recession gives an indication that sediment is being lost constantly from the coastal system (beach, shore or coastal dune) either to the hinterland or offshore. Sediments lost to the hinterland could be through sand mining or other human activities. The research has also demonstrated the presence of alongshore sediment transport along the study. The research observed two directions of sediment drift along the shores (*i.e.* west-east and east-west) contrary to the west-east drift known. This suggests the presence of sediment cells and sub-cells in the study area, and these control the direction of erosion and deposition of sediment within each cell. Particle size analysis carried out along the study site revealed the presence of coarse grain sediment which could only be deposited by high energy wave, thus confirming the presence of high energy waves along some portions of the study area. The research also found out that fluvial sediment from rivers

provide adequate sand to nourish the beaches. This implies that fluvial sediment play a vital role in the sediment budget of the study area. When fluvial sediment supply is blocked by damming the rate of shoreline recession may increase along the study area. This finding addresses the third objective of the research.

The research has shown that multiple linear regression modelling using the stepwise approach is capable of predicting future shoreline change for the study area. It however requires strict adherence to the model assumptions of linearity, data independence, homoscedasticity and normality. Failure to which results in erroneous predictions. Of the five factors considered namely, effect of sea level rise, waves impact, sediment transport rates, coastal material resistance and human impact on shoreline change, the effect of sea-level rise was eliminated for lack of correlation with the shoreline change variable. Eight (8) proxy parameters were generated from the remaining four factors to serve as independent variables.

The model has shown that the factors resisting shoreline change in the short term period are the rock outcrops, the coastal soil shear strength and the human impact on coastal processes. These three factors together contributed about 61% of the variation in the short term shoreline position. The long term variations in the shoreline was observed to be caused by human impact on the coast, the shear strength of the dune soil, the sediment supplied by rivers and the compressive strength of the 'hard' shore outcrops. These four variables jointly accounted for about 71% of changes registered in the shoreline position.

Analysis of the long term change in the shoreline revealed that the Eastern Section is influenced by the potential sediment transport rates; while the Western Section is mainly influenced by the

shear strength of soil. Vulnerability assess generated from the model results shown that a total of about 10% of the shoreline of the Region were found to be experiencing low levels of change rates while the remaining 90% are eroding at high levels (i.e.  $>1$  m/year) in the short term.

The quest to quantify human impact on shoreline change has been demonstrated by using a multi-criteria approach offered by the Analytical Hierarchy Process. It was found out that, of the three criteria variables used, coastal mining (sand) contributed to about 63% of the human impact, followed by coastal population density (27%) and lastly the distance off coastal structures which accounted for the remaining 10%. Coastal management policies could be formulated to regulate sand mining activities and population distribution along coastal areas.

This findings of the research satisfies the last/forth objective of the research. This research has been a baseline research, however, the researcher was unable to compare all the resulting findings with other works within the sub region to ascertain consistency or otherwise with other research efforts.

### **6.3 Recommendations**

It is recommended that various numerical modelling techniques be employed to understand the dynamics of natural patterns such as shoreline change so as to formulate accurate predictive models. This could be achieved through availability of accurate data. It is therefore recommended that data of the environment from monitoring of the coastal zones be made available be made by Government, stakeholders and donor agencies for research purposes and also readily available. This is because since the effects of erosive forces on the shoreline are irreversible and scenarios of climate change predict worsen trends, data and technology for predicting future shoreline

migration trends to minimise loss of valuable lands and properties from erosion. Funds should be made available for the acquisition of current spatial data by the Survey and Mapping Agency of Lands Commission to facilitate active research for national Development. Currently the available aerial photographs covering the coasts date back more than ten years. Again, tidal monitoring data stations are sparse (only two tide gauges along the coast of Ghana) and tidal records often have gaps making prediction difficult. Efforts should be made to maintain continuous tide gauge recording in the Country. Data of measurements of offshore wave, off the shore of the Western Region, was for a short period due to disturbances from fisher folks. It is recommended that concerted efforts from Government, Security Agencies, stake holders and local communities to support the operation of the wave rider offshore for monitoring.

The findings of shoreline change trend in the study area calls for pragmatic measures to minimise or possibly reversed the high to extreme levels of shoreline change trend along the study area as well as the entire shoreline of Ghana in general. Coastal protection agencies, policy makers and law enforcing agencies should ensure that awareness is created on the effect of shoreline recession on coastal lands.

It is also recommended that efforts be made to ensure fair sediment budget is maintained along the coast through constant supply of fluvial sediment to the coast. This is because sediment transport alongshore is control by physical process of wave breaking which cannot be easily controlled, it is important that possible damming or winning of sand from coastal rivers as pertains on a small

scale along the Hwin river be controlled, otherwise it could lead to severe shoreline recession along of the study area

The research has successfully demonstrated the role coastal material play in resisting shoreline change. It is therefore recommended that coastal communities be educated on the effects of sand mining activities along the study sites. Effective integrated coastal zone management plan be put in place for the Western region and the nation as a whole. Also, efforts be made to establish the existing Integrated Coastal and Fisheries Governance for the Western Region of Ghana should be strengthened so as to prioritize both development in fishers and protection of the coast. Involvement of experts in the field and the public will facilitate the development and implementation of new strategies by creating awareness on human impact on shoreline change. These may include exploring other alternatives to coastal sand mining for construction purposes. Other strategies may include setting safety margins for coastal development to minimise losses from coastal erosion, and to adopt best practices of community involvement in managing coastal heritage.

It can be inferred from the research that the exposed back beach slope could be used in place of the foreshore slope, since field observations under water is often faced with logistical challenges.

It is recommended for future work that application of a non-linear model should be employed so as to capture both the linear and non-linear variables influencing the shoreline change trends in the study area. Furthermore, other modelling techniques such as Artificial Neural Network, which is

not dependent on correlation between shoreline and the driving shoreline change variables, be applied to the data for confirmation of the findings.

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**APPENDICES****Appendix I: Table of Rebound Values**

| Rebound Value R | IMPACT ANGLE (a) |      |      |      |      |
|-----------------|------------------|------|------|------|------|
|                 | -90              | -45  | 0    | 45   | 90   |
| 20              | 14.9             | 13.7 | 10.3 |      |      |
| 21              | 16.2             | 14.9 | 11.4 |      |      |
| 22              | 17.4             | 16.0 | 12.5 |      |      |
| 23              | 18.8             | 17.4 | 13.7 | 10.3 |      |
| 24              | 20.0             | 18.6 | 14.9 | 10.5 |      |
| 25              | 21.5             | 20.0 | 16.2 | 11.6 | 10.3 |
| 26              | 22.8             | 21.4 | 17.5 | 12.8 | 11.0 |
| 27              | 24.5             | 22.8 | 18.9 | 14.0 | 11.9 |
| 28              | 25.9             | 24.3 | 20.3 | 15.4 | 13.4 |
| 29              | 27.6             | 25.9 | 21.8 | 16.7 | 14.8 |
| 30              | 29.1             | 27.4 | 23.3 | 18.2 | 16.2 |
| 31              | 30.9             | 29.9 | 24.9 | 19.6 | 17.6 |
| 32              | 32.5             | 30.7 | 26.5 | 21.2 | 19.1 |
| 33              | 34.4             | 32.5 | 28.2 | 22.7 | 20.8 |
| 34              | 36.1             | 34.2 | 30.0 | 24.5 | 22.4 |
| 35              | 38.2             | 36.1 | 31.8 | 26.0 | 24.1 |
| 36              | 39.9             | 37.9 | 33.6 | 27.9 | 25.9 |
| 37              | 42.0             | 39.9 | 35.5 | 29.6 | 27.8 |
| 38              | 43.9             | 41.8 | 37.5 | 31.6 | 29.6 |
| 39              | 46.1             | 43.9 | 39.5 | 33.5 | 31.6 |
| 40              | 48.1             | 45.9 | 41.6 | 35.5 | 33.6 |
| 41              | 50.4             | 48.1 | 43.7 | 37.5 | 35.5 |

| Rebound Value R | IMPACT ANGLE (a) |           |      |      |      |
|-----------------|------------------|-----------|------|------|------|
|                 | -90              | -45       | 0    | 45   | 90   |
| 42              | 52.4             | 50.2      | 45.9 | 39.7 | 37.7 |
| 43              | 54.8             | 52.5      | 48.1 | 41.8 | 39.7 |
| 44              | 57.0             | 54.6      | 50.4 | 45.1 | 42.0 |
| 45              | 59.5             | 57.0      | 42.0 | 46.3 | 44.1 |
| 46              | over 60.0        | 59.2      | 55.0 | 48.1 | 46.5 |
| 47              | over 60.0        | over 60.0 | 57.5 | 51.0 | 48.7 |
| 48              | over 60.0        | over 60.0 | 60.0 | 53.0 | 51.3 |
| 49              |                  |           |      | 56.0 | 53.6 |
| 50              |                  |           |      | 58.8 | 56.8 |

**Appendix II: Computed Shoreline Change Rates at 100 m Transects with Sampled Sites**

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks                |
|-----------|-------------|---------|-------|------|--------|-------|------------------------|
| 1         | 1           | 490.88  | -1.12 | 0.04 | 272.19 | 15.85 | Shama Pra estuary (P1) |
| 2         | 2           | 472.54  | -1.75 | 0.15 | 205.95 | 7.58  |                        |
| 3         | 3           | 441.86  | -1.58 | 0.14 | 198.98 | 7.32  |                        |
| 4         | 4           | 475.52  | -1.65 | 0.13 | 208.59 | 7.67  |                        |
| 5         | 5           | 489.24  | -1.72 | 0.13 | 223.08 | 8.21  |                        |
| 6         | 6           | 532.08  | -1.93 | 0.14 | 241.95 | 8.9   |                        |
| 7         | 7           | 579.93  | -2.13 | 0.14 | 261.1  | 9.61  |                        |
| 8         | 8           | 604.54  | -2.01 | 0.12 | 268.83 | 9.89  |                        |
| 9         | 9           | 592.29  | -1.81 | 0.1  | 269.42 | 9.91  |                        |
| 10        | 10          | 608.76  | -1.94 | 0.11 | 279.78 | 10.29 |                        |
| 11        | 11          | 647.48  | -2.26 | 0.13 | 294.73 | 10.84 |                        |
| 12        | 12          | 680.8   | -2.41 | 0.14 | 302.96 | 11.15 | Shama (P2)             |
| 13        | 13          | 711.31  | -2.47 | 0.13 | 316.83 | 11.66 |                        |
| 14        | 14          | 741.58  | -2.49 | 0.12 | 331.95 | 12.21 |                        |
| 15        | 15          | 747.92  | -2.3  | 0.1  | 340.62 | 12.53 |                        |
| 16        | 16          | 761.5   | -2.51 | 0.12 | 342.95 | 12.62 |                        |
| 17        | 17          | 769.88  | -2.92 | 0.16 | 332.79 | 12.24 |                        |
| 18        | 18          | 725.33  | -2.65 | 0.16 | 303.8  | 11.18 |                        |
| 19        | 19          | 634.38  | -4.79 | 0.54 | 221.84 | 8.16  |                        |
| 20        | 20          | 599.38  | -3.74 | 0.5  | 186.58 | 6.86  |                        |
| 21        | 21          | 298.99  | -1.98 | 0.49 | 101.24 | 3.72  |                        |
| 22        | 22          | 341.76  | -2.15 | 0.41 | 128.56 | 4.73  |                        |
| 23        | 23          | 443.66  | -2.64 | 0.38 | 169.04 | 6.22  |                        |
| 24        | 24          | 531.8   | -2.53 | 0.25 | 216.22 | 7.95  |                        |
| 25        | 25          | 582.99  | -2.31 | 0.18 | 244.7  | 9     |                        |
| 26        | 26          | 640.28  | -2.53 | 0.17 | 282.54 | 10.39 |                        |
| 27        | 27          | 741.13  | -3.23 | 0.2  | 323.74 | 11.91 |                        |
| 28        | 28          | 829.99  | -3.76 | 0.22 | 357.45 | 13.15 |                        |
| 29        | 29          | 849.89  | -3.39 | 0.19 | 346.58 | 12.75 |                        |
| 30        | 30          | 785.85  | -3.15 | 0.19 | 328.82 | 12.1  | Aboesi (P3)            |
| 31        | 31          | 792.19  | -2.8  | 0.17 | 313.28 | 11.52 |                        |
| 32        | 32          | 625.73  | -2.08 | 0.12 | 279.23 | 10.27 |                        |
| 33        | 33          | 672.22  | -1.78 | 0.08 | 303.57 | 11.17 |                        |
| 34        | 34          | 802.23  | -2.16 | 0.08 | 369.04 | 13.58 |                        |
| 35        | 35          | 926.92  | -2.49 | 0.08 | 429.85 | 15.81 |                        |
| 36        | 36          | 1023.73 | -2.55 | 0.07 | 476.96 | 17.55 |                        |

| OBJECTID | TransectId | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks      |
|----------|------------|---------|-------|------|--------|-------|--------------|
| 37       | 37         | 1090.24 | -2.88 | 0.07 | 505.97 | 18.61 |              |
| 38       | 38         | 1146.43 | -3.22 | 0.08 | 530.49 | 19.52 |              |
| 39       | 39         | 1189.02 | -3.38 | 0.09 | 549.1  | 20.2  |              |
| 40       | 40         | 1224.55 | -3.45 | 0.08 | 565.4  | 20.8  |              |
| 41       | 41         | 1256.77 | -3.52 | 0.08 | 581.77 | 21.4  |              |
| 42       | 42         | 1275.29 | -3.49 | 0.08 | 592.33 | 21.79 |              |
| 43       | 43         | 1291.22 | -3.46 | 0.08 | 602.06 | 22.15 |              |
| 44       | 65         | 1304.59 | -4.74 | 0.15 | 574.05 | 21.12 |              |
| 45       | 66         | 954.46  | -2.18 | 0.05 | 462.44 | 17.01 |              |
| 46       | 67         | 945.9   | -2.25 | 0.06 | 456.65 | 16.8  |              |
| 47       | 68         | 949.91  | -2.4  | 0.07 | 450.29 | 16.57 |              |
| 48       | 69         | 920.92  | -2.31 | 0.07 | 436.08 | 16.04 |              |
| 49       | 70         | 873.06  | -2.18 | 0.06 | 412.87 | 15.19 |              |
| 50       | 71         | 852.73  | -2.42 | 0.08 | 406.3  | 14.95 |              |
| 51       | 72         | 844.17  | -2.62 | 0.1  | 396.03 | 14.57 |              |
| 52       | 73         | 832.68  | -2.79 | 0.12 | 383.38 | 14.1  |              |
| 53       | 74         | 811.64  | -2.74 | 0.12 | 370.86 | 13.64 |              |
| 54       | 75         | 778.89  | -2.65 | 0.12 | 360.21 | 13.25 |              |
| 55       | 76         | 737.31  | -2.38 | 0.11 | 340.04 | 12.51 |              |
| 56       | 77         | 682.31  | -2.03 | 0.09 | 319.74 | 11.76 |              |
| 57       | 78         | 612.46  | -1.83 | 0.09 | 286.2  | 10.53 |              |
| 58       | 79         | 521.76  | -1.53 | 0.09 | 249.65 | 9.18  |              |
| 59       | 80         | 470.01  | -1.54 | 0.11 | 220.3  | 8.1   |              |
| 60       | 81         | 427.15  | -1.56 | 0.14 | 191.34 | 7.04  |              |
| 61       | 82         | 383.29  | -1.54 | 0.17 | 168.32 | 6.19  |              |
| 62       | 83         | 332.26  | -1.5  | 0.21 | 145.31 | 5.35  | Aboadze (P4) |
| 63       | 84         | 302.69  | -1.51 | 0.28 | 122.17 | 4.49  |              |
| 64       | 85         | 256.08  | -1.35 | 0.32 | 97.88  | 3.6   |              |
| 65       | 86         | 217.25  | -1.3  | 0.41 | 77.79  | 2.86  |              |
| 66       | 87         | 166.68  | -1.34 | 0.62 | 52.21  | 1.92  |              |
| 67       | 88         | 161.27  | -1.43 | 0.88 | 26.77  | 0.98  |              |
| 68       | 89         | 157.28  | -1.38 | 0.97 | 13.07  | 0.48  |              |
| 69       | 90         | 141.2   | -1.18 | 0.96 | 12.21  | 0.45  |              |
| 70       | 91         | 140.09  | -1.13 | 0.82 | 26.57  | 0.98  |              |
| 71       | 92         | 140.79  | -1.09 | 0.66 | 39.04  | 1.44  |              |
| 72       | 93         | 156.94  | -0.97 | 0.47 | 51.84  | 1.91  |              |
| 73       | 94         | 162.92  | -0.9  | 0.38 | 57.81  | 2.13  |              |
| 74       | 95         | 171.91  | -1.16 | 0.57 | 50.06  | 1.84  |              |

| OBJECTID | TransectId | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks              |
|----------|------------|---------|-------|------|--------|-------|----------------------|
| 75       | 96         | 166.09  | -1.19 | 0.63 | 45.88  | 1.69  |                      |
| 76       | 97         | 106.51  | -0.64 | 0.49 | 32.57  | 1.2   |                      |
| 77       | 98         | 121.95  | -1.08 | 0.95 | 11.9   | 0.44  |                      |
| 78       | 99         | 156.1   | -1.12 | 0.45 | 61.33  | 2.26  | Bongo Beach (P5)     |
| 79       | 100        | 351.11  | -1.64 | 0.24 | 145.94 | 5.37  |                      |
| 80       | 101        | 459.48  | -1.15 | 0.06 | 220.12 | 8.1   |                      |
| 81       | 102        | 708.25  | -2.05 | 0.09 | 335.39 | 12.34 |                      |
| 82       | 103        | 931.24  | -2.26 | 0.06 | 448.89 | 16.51 |                      |
| 83       | 104        | 1023.71 | -2.51 | 0.06 | 497.06 | 18.29 |                      |
| 84       | 105        | 1171.78 | -2.96 | 0.07 | 555.75 | 20.44 |                      |
| 85       | 106        | 1292.48 | -3.86 | 0.09 | 609.44 | 22.42 |                      |
| 86       | 107        | 1449.95 | -5.22 | 0.13 | 670.5  | 24.67 |                      |
| 87       | 108        | 1595.38 | -5.54 | 0.12 | 747.1  | 27.48 |                      |
| 88       | 109        | 1703.71 | -5.25 | 0.1  | 804.07 | 29.58 |                      |
| 89       | 110        | 1800.26 | -4.82 | 0.07 | 871.68 | 32.07 |                      |
| 90       | 111        | 1886.1  | -5.75 | 0.09 | 892.35 | 32.83 | Ngyiresia (P6)       |
| 91       | 112        | 1904.84 | -6.26 | 0.11 | 894.38 | 32.9  |                      |
| 92       | 113        | 1902.56 | -6.71 | 0.13 | 883.04 | 32.48 |                      |
| 93       | 114        | 1741.99 | -5.54 | 0.1  | 823.03 | 30.28 |                      |
| 94       | 115        | 1604.13 | -4.79 | 0.09 | 759.79 | 27.95 |                      |
| 95       | 116        | 1750.33 | -7.03 | 0.16 | 799.52 | 29.41 |                      |
| 96       | 117        | 1789.26 | -8.03 | 0.2  | 800.77 | 29.46 |                      |
| 97       | 118        | 1809.84 | -8.53 | 0.22 | 795.41 | 29.26 |                      |
| 98       | 119        | 1775.15 | -8.65 | 0.24 | 769.92 | 28.32 |                      |
| 99       | 120        | 1673.3  | -8.86 | 0.27 | 724.47 | 26.65 |                      |
| 100      | 121        | 1321.83 | -5.59 | 0.18 | 596.23 | 21.93 |                      |
| 101      | 122        | 1225.13 | -4.68 | 0.15 | 560.8  | 20.63 |                      |
| 102      | 123        | 1130.08 | -3.73 | 0.11 | 523.56 | 19.26 |                      |
| 103      | 124        | 1022.12 | -2.74 | 0.07 | 490.68 | 18.05 |                      |
| 104      | 125        | 1026.54 | -2.68 | 0.07 | 483.59 | 17.79 |                      |
| 105      | 126        | 1205.48 | -4.35 | 0.14 | 539.32 | 19.84 |                      |
| 106      | 127        | 1249.03 | -4.89 | 0.16 | 557.21 | 20.5  |                      |
| 107      | 128        | 1292.57 | -4.64 | 0.14 | 581.93 | 21.41 | Ekuaasi/Sekondi (P7) |
| 108      | 129        | 1336.11 | -4.03 | 0.1  | 615.16 | 22.63 |                      |
| 109      | 130        | 1388.9  | -3.51 | 0.07 | 654.41 | 24.07 |                      |
| 110      | 131        | 1443.09 | -4.05 | 0.08 | 673.44 | 24.77 |                      |
| 111      | 132        | 1495.97 | -4.59 | 0.1  | 691.66 | 25.44 |                      |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks        |
|-----------|-------------|---------|-------|------|--------|-------|----------------|
| 112       | 133         | 1548.55 | -5.06 | 0.11 | 706.84 | 26    |                |
| 113       | 134         | 1542.65 | -5.44 | 0.13 | 698.02 | 25.68 |                |
| 114       | 135         | 1536.68 | -5.83 | 0.15 | 691.16 | 25.43 |                |
| 115       | 136         | 1562.8  | -6.29 | 0.17 | 684.05 | 25.16 |                |
| 116       | 137         | 1543.09 | -6.52 | 0.19 | 675.93 | 24.87 |                |
| 117       | 138         | 1543.79 | -6.78 | 0.2  | 671.97 | 24.72 |                |
| 118       | 139         | 1541.76 | -6.92 | 0.21 | 670.94 | 24.68 |                |
| 119       | 140         | 1536.5  | -7.01 | 0.22 | 665.99 | 24.5  |                |
| 120       | 141         | 1524.52 | -7.15 | 0.23 | 660.06 | 24.28 |                |
| 121       | 142         | 1517.04 | -6.88 | 0.21 | 660.55 | 24.3  |                |
| 122       | 143         | 1518.12 | -6.49 | 0.19 | 669.12 | 24.62 |                |
| 123       | 144         | 1497.12 | -5.76 | 0.15 | 673.94 | 24.79 | Nkontompo (P8) |
| 124       | 145         | 1468.69 | -4.83 | 0.11 | 677.89 | 24.94 |                |
| 125       | 146         | 1504.96 | -4.2  | 0.08 | 693.44 | 25.51 |                |
| 126       | 147         | 1561.31 | -4.33 | 0.08 | 714.14 | 26.27 |                |
| 127       | 148         | 1589.18 | -4.55 | 0.09 | 740.5  | 27.24 |                |
| 128       | 149         | 1615.8  | -4.7  | 0.09 | 750.65 | 27.61 |                |
| 129       | 150         | 1661.11 | -5.16 | 0.1  | 767.44 | 28.23 |                |
| 130       | 151         | 1706.79 | -5.66 | 0.11 | 786.32 | 28.93 |                |
| 131       | 152         | 1746.54 | -6.08 | 0.12 | 804.59 | 29.6  |                |
| 132       | 153         | 1771.86 | -6.27 | 0.13 | 812.94 | 29.91 |                |
| 133       | 154         | 1777.32 | -6.02 | 0.12 | 816.77 | 30.05 |                |
| 134       | 155         | 1769.41 | -5.72 | 0.11 | 826.77 | 30.41 |                |
| 135       | 156         | 1759.28 | -5.32 | 0.09 | 832.81 | 30.64 |                |
| 136       | 157         | 1764.53 | -4.93 | 0.08 | 843.29 | 31.02 |                |
| 137       | 158         | 1752.26 | -4.79 | 0.07 | 844.3  | 31.06 |                |
| 138       | 159         | 1752.48 | -4.64 | 0.07 | 834.55 | 30.7  |                |
| 139       | 160         | 1802.04 | -5.19 | 0.08 | 852.51 | 31.36 |                |
| 140       | 161         | 1863.97 | -5.63 | 0.09 | 875.25 | 32.2  |                |
| 141       | 162         | 1918.19 | -5.91 | 0.1  | 897.27 | 33.01 |                |
| 142       | 163         | 1954.74 | -5.92 | 0.09 | 914.07 | 33.63 |                |
| 143       | 164         | 1971.49 | -5.41 | 0.08 | 930.32 | 34.22 |                |
| 144       | 165         | 2008.06 | -6.41 | 0.11 | 934.74 | 34.39 |                |
| 145       | 166         | 2026.58 | -7.27 | 0.13 | 929.08 | 34.18 |                |
| 146       | 167         | 2007.33 | -7.22 | 0.13 | 922.93 | 33.95 |                |
| 147       | 168         | 1930.55 | -6.6  | 0.12 | 896.92 | 33    |                |
| 148       | 169         | 1727.31 | -4.7  | 0.07 | 828.46 | 30.48 |                |
| 149       | 170         | 1724.11 | -4.62 | 0.07 | 828.2  | 30.47 |                |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks           |
|-----------|-------------|---------|-------|------|--------|-------|-------------------|
| 150       | 171         | 1727.57 | -4.45 | 0.07 | 829.31 | 30.51 |                   |
| 151       | 172         | 1853.68 | -5.21 | 0.08 | 882.87 | 32.48 |                   |
| 152       | 173         | 1929.9  | -6.29 | 0.11 | 893.82 | 32.88 |                   |
| 153       | 174         | 1979.35 | -7.29 | 0.14 | 898.75 | 33.06 |                   |
| 154       | 175         | 1985.07 | -7.69 | 0.15 | 898.93 | 33.07 | New Takoradi (P9) |
| 155       | 176         | 1928.67 | -7.67 | 0.16 | 875.47 | 32.21 |                   |
| 156       | 177         | 1929.27 | -8.6  | 0.2  | 849.39 | 31.25 |                   |
| 157       | 178         | 1874.1  | -9.07 | 0.23 | 818.09 | 30.1  |                   |
| 158       | 179         | 1828.17 | -9.21 | 0.25 | 791.67 | 29.12 |                   |
| 159       | 180         | 1777.31 | -9.33 | 0.27 | 771.08 | 28.37 |                   |
| 160       | 181         | 1383    | -7.1  | 0.26 | 601.93 | 22.14 |                   |
| 161       | 182         | 1276.07 | -6.93 | 0.29 | 544.33 | 20.02 |                   |
| 162       | 183         | 1160.74 | -5.67 | 0.24 | 500.92 | 18.43 |                   |
| 163       | 184         | 1042.29 | -4.27 | 0.17 | 474.77 | 17.47 |                   |
| 164       | 185         | 764.28  | -1.26 | 0.03 | 383.42 | 14.1  |                   |
| 165       | 186         | 708.09  | -1.17 | 0.03 | 354.72 | 13.05 |                   |
| 166       | 187         | 655.58  | -1.08 | 0.03 | 327.81 | 12.06 |                   |
| 167       | 188         | 601.27  | -1.00 | 0.03 | 300.39 | 11.05 |                   |
| 168       | 189         | 545.85  | -0.92 | 0.03 | 272.43 | 10.02 |                   |
| 169       | 190         | 496.08  | -0.84 | 0.03 | 247.23 | 9.09  |                   |
| 170       | 191         | 446.99  | -0.77 | 0.03 | 222.37 | 8.18  |                   |
| 171       | 192         | 539.3   | -1.33 | 0.06 | 255.85 | 9.41  |                   |
| 172       | 228         | 878.81  | -2.62 | 0.09 | 414.13 | 15.23 |                   |
| 173       | 229         | 908.45  | -2.77 | 0.09 | 428.43 | 15.76 |                   |
| 174       | 230         | 937.91  | -2.89 | 0.1  | 441.07 | 16.23 |                   |
| 175       | 231         | 942.43  | -2.84 | 0.09 | 443.84 | 16.33 |                   |
| 176       | 232         | 960.16  | -2.88 | 0.09 | 449.69 | 16.54 |                   |
| 177       | 233         | 968.72  | -2.94 | 0.09 | 459.97 | 16.92 |                   |
| 178       | 234         | 1023.56 | -3.08 | 0.09 | 483.07 | 17.77 |                   |
| 179       | 235         | 1046.76 | -2.89 | 0.08 | 504.19 | 18.55 |                   |
| 180       | 236         | 1103.25 | -2.94 | 0.07 | 533.39 | 19.62 |                   |
| 181       | 237         | 1160.18 | -3.03 | 0.07 | 558.41 | 20.54 |                   |
| 182       | 238         | 1197.23 | -2.91 | 0.06 | 581.08 | 21.38 |                   |
| 183       | 239         | 1277.29 | -3.25 | 0.06 | 616.57 | 22.68 |                   |
| 184       | 240         | 1363.17 | -3.69 | 0.08 | 646.62 | 23.79 |                   |
| 185       | 241         | 1359.66 | -3.77 | 0.08 | 648.17 | 23.84 |                   |
| 186       | 242         | 1367.86 | -3.92 | 0.08 | 651    | 23.95 |                   |
| 187       | 243         | 1327.53 | -3.5  | 0.07 | 634.75 | 23.35 |                   |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks            |
|-----------|-------------|---------|-------|------|--------|-------|--------------------|
| 188       | 244         | 1303.66 | -3.07 | 0.05 | 636.09 | 23.4  |                    |
| 189       | 245         | 1348.35 | -2.72 | 0.04 | 665.66 | 24.49 |                    |
| 190       | 246         | 1371.67 | -2.4  | 0.03 | 688.29 | 25.32 |                    |
| 191       | 247         | 1408.67 | -2.26 | 0.02 | 710.89 | 26.15 |                    |
| 192       | 248         | 1511.49 | -2.89 | 0.04 | 741.74 | 27.29 |                    |
| 193       | 266         | 1485.96 | -2.9  | 0.04 | 729.72 | 26.84 |                    |
| 194       | 267         | 1472.71 | -2.83 | 0.04 | 724.42 | 26.65 |                    |
| 195       | 268         | 1452.68 | -2.86 | 0.04 | 710.32 | 26.13 |                    |
| 196       | 269         | 1375.49 | -2.69 | 0.04 | 671.12 | 24.69 |                    |
| 197       | 270         | 1249.7  | -2.35 | 0.03 | 620.23 | 22.82 |                    |
| 198       | 271         | 1195.28 | -2.12 | 0.03 | 595.54 | 21.91 |                    |
| 199       | 272         | 1183.51 | -2.3  | 0.04 | 581.22 | 21.38 |                    |
| 200       | 273         | 1090.3  | -2.06 | 0.04 | 535.24 | 19.69 |                    |
| 201       | 274         | 1046.78 | -2.14 | 0.04 | 508.52 | 18.71 |                    |
| 202       | 275         | 996.86  | -1.94 | 0.04 | 483.49 | 17.79 |                    |
| 203       | 276         | 956.03  | -1.91 | 0.04 | 461.29 | 16.97 |                    |
| 204       | 277         | 935.61  | -2    | 0.05 | 453.23 | 16.67 |                    |
| 205       | 278         | 909.4   | -1.9  | 0.04 | 444.61 | 16.36 |                    |
| 206       | 279         | 845     | -1.72 | 0.04 | 410.49 | 15.1  |                    |
| 207       | 280         | 768.88  | -1.91 | 0.06 | 366.16 | 13.47 |                    |
| 208       | 281         | 704.04  | -1.93 | 0.08 | 326.63 | 12.02 |                    |
| 209       | 282         | 640.27  | -1.78 | 0.08 | 294.95 | 10.85 |                    |
| 210       | 283         | 565.37  | -1.63 | 0.09 | 263.31 | 9.69  | New Amanful (P 10) |
| 211       | 284         | 544.92  | -1.34 | 0.06 | 257.97 | 9.49  |                    |
| 212       | 285         | 540.55  | -1.35 | 0.06 | 257.41 | 9.47  |                    |
| 213       | 286         | 544.98  | -1.39 | 0.07 | 258.46 | 9.51  |                    |
| 214       | 287         | 521.27  | -1.02 | 0.04 | 253.93 | 9.34  |                    |
| 215       | 288         | 639.6   | -1.17 | 0.03 | 313.25 | 11.52 |                    |
| 216       | 289         | 692.82  | -1.3  | 0.04 | 339.14 | 12.48 |                    |
| 217       | 290         | 755.49  | -1.68 | 0.05 | 359.58 | 13.23 |                    |
| 218       | 291         | 755.47  | -1.36 | 0.03 | 369.57 | 13.6  |                    |
| 219       | 292         | 818.63  | -1.81 | 0.05 | 395.28 | 14.54 |                    |
| 220       | 293         | 889.14  | -2.14 | 0.06 | 423.83 | 15.59 | Funke (P 11)       |
| 221       | 294         | 956.8   | -2.36 | 0.06 | 453.24 | 16.67 |                    |
| 222       | 295         | 1012.39 | -2.52 | 0.06 | 477.01 | 17.55 |                    |
| 223       | 296         | 1036.8  | -2.34 | 0.05 | 497.27 | 18.29 |                    |
| 224       | 297         | 1058.95 | -2.16 | 0.04 | 514.31 | 18.92 |                    |
| 225       | 298         | 1110.09 | -2.4  | 0.05 | 530.76 | 19.53 |                    |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks      |
|-----------|-------------|---------|-------|------|--------|-------|--------------|
| 226       | 299         | 1093.69 | -2.38 | 0.05 | 524.23 | 19.29 |              |
| 227       | 300         | 1079.6  | -2.31 | 0.05 | 517.82 | 19.05 |              |
| 228       | 301         | 1066.02 | -2.21 | 0.04 | 516.75 | 19.01 |              |
| 229       | 302         | 1056.22 | -2.06 | 0.04 | 514.37 | 18.92 |              |
| 230       | 303         | 1024.2  | -2.2  | 0.05 | 497.14 | 18.29 |              |
| 231       | 304         | 1012.17 | -2.41 | 0.06 | 483.2  | 17.78 |              |
| 232       | 305         | 1001.27 | -2.56 | 0.07 | 474.51 | 17.46 |              |
| 233       | 306         | 967.64  | -2.52 | 0.07 | 460.27 | 16.93 |              |
| 234       | 307         | 928.85  | -2.41 | 0.07 | 443.63 | 16.32 |              |
| 235       | 308         | 905.44  | -2.36 | 0.07 | 425.77 | 15.66 |              |
| 236       | 309         | 882.63  | -2.7  | 0.1  | 408.94 | 15.04 |              |
| 237       | 310         | 826.69  | -4.07 | 0.24 | 359.09 | 13.21 |              |
| 238       | 311         | 778.65  | -4.92 | 0.37 | 317.9  | 11.69 |              |
| 239       | 312         | 634.73  | -2.29 | 0.19 | 239.8  | 8.82  | Adwowa (P12) |
| 240       | 313         | 453.2   | -1.34 | 0.09 | 212.8  | 7.83  |              |
| 241       | 314         | 466.09  | -1.43 | 0.09 | 221    | 8.13  |              |
| 242       | 315         | 498.93  | -1.63 | 0.11 | 229.03 | 8.43  |              |
| 243       | 316         | 522.23  | -1.64 | 0.1  | 242.24 | 8.91  |              |
| 244       | 317         | 533.17  | -1.49 | 0.08 | 252.27 | 9.28  |              |
| 245       | 318         | 564.18  | -1.56 | 0.08 | 269.99 | 9.93  |              |
| 246       | 319         | 599.88  | -1.55 | 0.07 | 290.19 | 10.68 |              |
| 247       | 320         | 656.51  | -1.58 | 0.06 | 318.79 | 11.73 |              |
| 248       | 321         | 706.22  | -1.59 | 0.05 | 344.9  | 12.69 |              |
| 249       | 322         | 742.15  | -1.66 | 0.05 | 364.18 | 13.4  |              |
| 250       | 323         | 775.83  | -1.67 | 0.05 | 381.99 | 14.05 |              |
| 251       | 324         | 815.94  | -1.99 | 0.06 | 397    | 14.6  |              |
| 252       | 325         | 847.03  | -2.39 | 0.08 | 405.92 | 14.93 |              |
| 253       | 326         | 875.51  | -2.68 | 0.1  | 409.89 | 15.08 |              |
| 254       | 327         | 890.85  | -2.95 | 0.11 | 414.59 | 15.25 |              |
| 255       | 328         | 899.46  | -3.11 | 0.12 | 416.42 | 15.32 |              |
| 256       | 329         | 905.84  | -3.14 | 0.12 | 418.9  | 15.41 |              |
| 257       | 330         | 912.2   | -3.2  | 0.12 | 424.08 | 15.6  |              |
| 258       | 331         | 917.69  | -3.26 | 0.13 | 423.28 | 15.57 |              |
| 259       | 332         | 951.06  | -3.34 | 0.13 | 429.3  | 15.79 |              |
| 260       | 333         | 929.64  | -2.95 | 0.11 | 427.17 | 15.71 |              |
| 261       | 334         | 930.62  | -2.85 | 0.1  | 433.14 | 15.93 |              |
| 262       | 335         | 907.06  | -2.85 | 0.1  | 427.84 | 15.74 |              |
| 263       | 336         | 945.84  | -3.37 | 0.13 | 430.33 | 15.83 |              |

| Object ID | Transect ID | SCE    | LRR   | LR2  | LSE    | LCI95 | Remarks       |
|-----------|-------------|--------|-------|------|--------|-------|---------------|
| 264       | 337         | 903.11 | -2.36 | 0.09 | 386.71 | 14.23 |               |
| 265       | 338         | 768.13 | -1.79 | 0.05 | 373.96 | 13.76 |               |
| 266       | 339         | 771.28 | -1.95 | 0.07 | 369.33 | 13.59 |               |
| 267       | 340         | 228.76 | -0.51 | 0.05 | 110.2  | 4.05  |               |
| 268       | 341         | 260.03 | -0.69 | 0.07 | 124.5  | 4.58  | Pumpuni (P13) |
| 269       | 342         | 300.01 | -0.9  | 0.09 | 141.64 | 5.21  |               |
| 270       | 343         | 319.59 | -0.98 | 0.11 | 143.02 | 5.26  |               |
| 271       | 344         | 314.15 | -0.84 | 0.07 | 148.9  | 5.48  |               |
| 272       | 345         | 387.31 | -0.99 | 0.07 | 185.63 | 6.83  |               |
| 273       | 346         | 417.87 | -0.93 | 0.05 | 201.73 | 7.42  |               |
| 274       | 347         | 441.15 | -1.1  | 0.06 | 213.55 | 7.86  |               |
| 275       | 348         | 436.94 | -1.03 | 0.06 | 212.73 | 7.83  |               |
| 276       | 349         | 438.97 | -0.9  | 0.04 | 212.33 | 7.81  |               |
| 277       | 350         | 406    | -0.93 | 0.05 | 198.02 | 7.28  |               |
| 278       | 351         | 316.69 | -0.84 | 0.07 | 151.51 | 5.57  |               |
| 279       | 352         | 153.13 | -0.98 | 0.39 | 61.7   | 2.27  |               |
| 280       | 353         | 132.81 | -0.48 | 0.18 | 50.6   | 1.86  |               |
| 281       | 354         | 268.03 | -0.45 | 0.04 | 117.19 | 4.31  |               |
| 282       | 355         | 343.82 | -0.61 | 0.04 | 146.1  | 5.37  |               |
| 283       | 356         | 371.36 | -0.81 | 0.07 | 152.21 | 5.6   |               |
| 284       | 357         | 394.32 | -0.45 | 0.02 | 174.4  | 6.42  |               |
| 285       | 358         | 546.54 | -1.17 | 0.06 | 225.64 | 8.3   |               |
| 286       | 359         | 635.56 | -0.82 | 0.02 | 276.26 | 10.16 |               |
| 287       | 360         | 651.13 | 0.38  | 0    | 322.57 | 11.87 |               |
| 288       | 361         | 656.99 | 0.24  | 0    | 321.85 | 11.84 |               |
| 289       | 362         | 670.81 | 0.11  | 0    | 323.5  | 11.9  |               |
| 290       | 363         | 674.31 | 0.12  | 0    | 323.51 | 11.9  |               |
| 291       | 364         | 677.81 | 0.16  | 0    | 326.51 | 12.01 |               |
| 292       | 365         | 681.31 | 0.27  | 0    | 331.5  | 12.2  |               |
| 293       | 366         | 706.18 | 0.29  | 0    | 343.8  | 12.65 |               |
| 294       | 367         | 742.74 | 0.06  | 0    | 354.1  | 13.03 |               |
| 295       | 368         | 772.04 | -0.1  | 0    | 362.96 | 13.35 |               |
| 296       | 369         | 801.34 | -0.1  | 0    | 377.89 | 13.9  |               |
| 297       | 370         | 830.63 | -0.12 | 0    | 390.76 | 14.38 |               |
| 298       | 371         | 826.96 | -0.2  | 0    | 388.53 | 14.29 |               |
| 299       | 372         | 848.94 | -0.58 | 0.01 | 386.59 | 14.22 | Mpatano (P14) |
| 300       | 373         | 877.75 | 0.28  | 0    | 425    | 15.63 |               |
| 301       | 374         | 856.16 | 0.67  | 0.01 | 428.06 | 15.75 |               |

| Object ID | Transect ID | SCE    | LRR   | LR2  | LSE    | LCI95 | Remarks       |
|-----------|-------------|--------|-------|------|--------|-------|---------------|
| 302       | 375         | 804.15 | 0.4   | 0    | 396.61 | 14.59 |               |
| 303       | 376         | 752.15 | 0.21  | 0    | 364.18 | 13.4  |               |
| 304       | 377         | 654.58 | 0.31  | 0    | 320.12 | 11.78 |               |
| 305       | 378         | 521.78 | 0.2   | 0    | 255.44 | 9.4   |               |
| 306       | 379         | 427.66 | -0.05 | 0    | 203.6  | 7.49  |               |
| 307       | 380         | 342.89 | -0.14 | 0    | 160.73 | 5.91  |               |
| 308       | 381         | 229.32 | -0.31 | 0.02 | 99.81  | 3.67  |               |
| 309       | 382         | 73.36  | -0.59 | 0.71 | 18.6   | 0.68  |               |
| 310       | 383         | 85.43  | -0.84 | 0.81 | 20.28  | 0.75  |               |
| 311       | 384         | 190.14 | -1.12 | 0.38 | 70.83  | 2.61  |               |
| 312       | 385         | 305.14 | -1.43 | 0.24 | 128.29 | 4.72  |               |
| 313       | 386         | 385.12 | -2.31 | 0.35 | 157.84 | 5.81  |               |
| 314       | 387         | 244.21 | -0.54 | 0.05 | 115.69 | 4.26  |               |
| 315       | 388         | 242.45 | -0.52 | 0.05 | 118.54 | 4.36  |               |
| 316       | 389         | 226.71 | -0.7  | 0.1  | 104.75 | 3.85  |               |
| 317       | 390         | 241.09 | -0.86 | 0.15 | 102.05 | 3.75  |               |
| 318       | 391         | 334.97 | -0.94 | 0.09 | 149.48 | 5.5   |               |
| 319       | 392         | 422.46 | -1.14 | 0.08 | 195.57 | 7.19  |               |
| 320       | 393         | 436.51 | -1.5  | 0.12 | 198.9  | 7.32  |               |
| 321       | 394         | 396.51 | -1.7  | 0.19 | 176.87 | 6.51  | Asemkaw (P15) |
| 322       | 395         | 223.49 | -1.06 | 0.26 | 90.21  | 3.32  |               |
| 323       | 396         | 278.55 | -1.79 | 0.47 | 93.99  | 3.46  |               |
| 324       | 397         | 288.31 | -1.97 | 0.5  | 98.28  | 3.62  |               |
| 325       | 398         | 301.49 | -1.58 | 0.32 | 114.57 | 4.21  |               |
| 326       | 399         | 333.24 | -1.43 | 0.22 | 135.63 | 4.99  |               |
| 327       | 400         | 362.57 | -1.36 | 0.17 | 150.56 | 5.54  |               |
| 328       | 401         | 373.88 | -1.24 | 0.13 | 163.46 | 6.01  |               |
| 329       | 402         | 379.64 | -1.36 | 0.14 | 166.67 | 6.13  |               |
| 330       | 403         | 381.18 | -1.5  | 0.17 | 165.14 | 6.08  |               |
| 331       | 404         | 381.86 | -1.62 | 0.2  | 162.95 | 5.99  |               |
| 332       | 405         | 391.11 | -1.69 | 0.21 | 164.01 | 6.03  |               |
| 333       | 406         | 394.81 | -1.62 | 0.19 | 167.2  | 6.15  |               |
| 334       | 407         | 400.83 | -1.57 | 0.17 | 170.4  | 6.27  |               |
| 335       | 408         | 396.47 | -1.56 | 0.18 | 167.48 | 6.16  |               |
| 336       | 409         | 386.76 | -1.54 | 0.18 | 163.72 | 6.02  |               |
| 337       | 410         | 381.56 | -1.51 | 0.17 | 165.09 | 6.07  |               |
| 338       | 411         | 377.52 | -1.38 | 0.15 | 165.24 | 6.08  |               |
| 339       | 412         | 382.06 | -1.3  | 0.13 | 169.18 | 6.22  |               |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks     |
|-----------|-------------|---------|-------|------|--------|-------|-------------|
| 340       | 413         | 395.99  | -1.25 | 0.11 | 175.84 | 6.47  |             |
| 341       | 414         | 396.72  | -1.26 | 0.11 | 175.97 | 6.47  |             |
| 342       | 415         | 468.7   | -1.63 | 0.14 | 205.53 | 7.56  |             |
| 343       | 416         | 515.85  | -1.81 | 0.13 | 231.8  | 8.53  |             |
| 344       | 417         | 541.4   | -1.93 | 0.13 | 245.59 | 9.03  |             |
| 345       | 418         | 576.44  | -2.05 | 0.14 | 257.22 | 9.46  |             |
| 346       | 419         | 589.79  | -2.03 | 0.13 | 262.48 | 9.66  |             |
| 347       | 420         | 580.98  | -2.11 | 0.14 | 261.09 | 9.61  |             |
| 348       | 421         | 590.96  | -2.2  | 0.15 | 266.57 | 9.81  |             |
| 349       | 422         | 569.91  | -4.99 | 0.59 | 208.35 | 7.66  | Butre (P16) |
| 350       | 423         | 96.87   | -0.88 | 0.61 | 34.96  | 1.29  |             |
| 351       | 424         | 186.67  | -1.85 | 0.89 | 32.74  | 1.2   |             |
| 352       | 425         | 266.74  | -2.56 | 0.92 | 37.87  | 1.39  |             |
| 353       | 426         | 184.26  | -1.5  | 0.86 | 30.36  | 1.12  |             |
| 354       | 427         | 154.34  | -1.23 | 0.86 | 25.16  | 0.93  |             |
| 355       | 428         | 105.7   | -0.97 | 0.92 | 14.22  | 0.52  |             |
| 356       | 429         | 81.09   | -0.77 | 0.96 | 8.18   | 0.3   |             |
| 357       | 430         | 195.66  | -1.75 | 0.75 | 49.78  | 1.83  |             |
| 358       | 431         | 282.11  | -2.05 | 0.48 | 107.56 | 3.96  |             |
| 359       | 432         | 426.33  | -2.55 | 0.39 | 160.95 | 5.92  |             |
| 360       | 433         | 521.29  | -2.67 | 0.29 | 207.69 | 7.64  |             |
| 361       | 434         | 663.54  | -2.58 | 0.17 | 282.31 | 10.39 |             |
| 362       | 435         | 755.89  | -2.47 | 0.11 | 342.18 | 12.59 |             |
| 363       | 436         | 804.33  | -2.29 | 0.09 | 366.68 | 13.49 |             |
| 364       | 437         | 876     | -2.13 | 0.06 | 411.15 | 15.12 |             |
| 365       | 438         | 956.61  | -1.96 | 0.04 | 455.28 | 16.75 |             |
| 366       | 439         | 1042.52 | -2.08 | 0.04 | 496.91 | 18.28 |             |
| 367       | 440         | 1111.44 | -2.22 | 0.04 | 535.82 | 19.71 |             |
| 368       | 441         | 1203.25 | -2.23 | 0.04 | 582.04 | 21.41 |             |
| 369       | 442         | 1329.9  | -2.64 | 0.04 | 649.23 | 23.88 |             |
| 370       | 443         | 1426.88 | -2.66 | 0.04 | 693.74 | 25.52 |             |
| 371       | 444         | 1440.51 | -2.7  | 0.04 | 700.99 | 25.79 |             |
| 372       | 445         | 1437.2  | -3.19 | 0.05 | 685.93 | 25.23 |             |
| 373       | 446         | 1351.77 | -4.45 | 0.12 | 613.39 | 22.57 | Busua (P17) |
| 374       | 447         | 983.12  | -2.36 | 0.06 | 479.97 | 17.66 |             |
| 375       | 448         | 852.39  | -2.13 | 0.06 | 412.06 | 15.16 |             |
| 376       | 449         | 839.52  | -2.23 | 0.07 | 405.37 | 14.91 |             |
| 377       | 450         | 795.66  | -2.21 | 0.08 | 377.48 | 13.89 |             |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks       |
|-----------|-------------|---------|-------|------|--------|-------|---------------|
| 378       | 451         | 780.13  | -2.04 | 0.07 | 367.95 | 13.54 |               |
| 379       | 452         | 875.57  | -2.26 | 0.07 | 419.29 | 15.42 |               |
| 380       | 453         | 888.94  | -2.38 | 0.07 | 421.47 | 15.5  |               |
| 381       | 454         | 917.04  | -2.82 | 0.1  | 433.84 | 15.96 |               |
| 382       | 455         | 889.09  | -2.36 | 0.07 | 430.08 | 15.82 |               |
| 383       | 456         | 841.08  | -1.7  | 0.04 | 414.19 | 15.24 | Dixcove (P18) |
| 384       | 457         | 1132.66 | -4.58 | 0.17 | 508.51 | 18.71 |               |
| 385       | 458         | 1109.06 | -2.78 | 0.06 | 536.54 | 19.74 |               |
| 386       | 459         | 1033.6  | -4.93 | 0.23 | 456.45 | 16.79 |               |
| 387       | 460         | 618.9   | -1.86 | 0.09 | 290.23 | 10.68 |               |
| 388       | 461         | 528.05  | -1.4  | 0.07 | 250.79 | 9.23  |               |
| 389       | 462         | 503.77  | -1.1  | 0.05 | 241.34 | 8.88  |               |
| 390       | 463         | 514.52  | -1.17 | 0.05 | 246.24 | 9.06  |               |
| 391       | 464         | 590.98  | -1.87 | 0.1  | 275.64 | 10.14 |               |
| 392       | 465         | 580.41  | -1.65 | 0.09 | 266.56 | 9.81  |               |
| 393       | 466         | 590.67  | -2    | 0.12 | 272.17 | 10.01 |               |
| 394       | 467         | 550.77  | -1.67 | 0.09 | 259.32 | 9.54  |               |
| 395       | 468         | 560.52  | -1.46 | 0.07 | 258.34 | 9.5   |               |
| 396       | 469         | 530.74  | -1.02 | 0.04 | 255.45 | 9.4   |               |
| 397       | 470         | 662.34  | -1.75 | 0.08 | 293.82 | 10.81 |               |
| 398       | 471         | 654.33  | -1.92 | 0.09 | 311.73 | 11.47 |               |
| 399       | 472         | 660.89  | -2.17 | 0.12 | 297.24 | 10.93 |               |
| 400       | 473         | 644.04  | -2.16 | 0.12 | 292.85 | 10.77 |               |
| 401       | 474         | 635.89  | -2.3  | 0.13 | 293.62 | 10.8  |               |
| 402       | 475         | 658.41  | -2.46 | 0.14 | 304.19 | 11.19 |               |
| 403       | 476         | 610.88  | -1.82 | 0.09 | 288.02 | 10.6  |               |
| 404       | 477         | 564.61  | -1.29 | 0.05 | 276.64 | 10.18 |               |
| 405       | 478         | 581.58  | -1.24 | 0.05 | 282.16 | 10.38 |               |
| 406       | 479         | 623.36  | -1.5  | 0.06 | 297.89 | 10.96 |               |
| 407       | 480         | 639.38  | -1.42 | 0.05 | 312.06 | 11.48 |               |
| 408       | 481         | 692.15  | -1.51 | 0.05 | 339.35 | 12.48 |               |
| 409       | 482         | 760.77  | -1.66 | 0.05 | 369.06 | 13.58 |               |
| 410       | 483         | 817.65  | -2.23 | 0.08 | 384.92 | 14.16 |               |
| 411       | 484         | 800.26  | -1.93 | 0.06 | 371.54 | 13.67 |               |
| 412       | 485         | 834.76  | -2.12 | 0.07 | 390.33 | 14.36 |               |
| 413       | 486         | 946.79  | -2.57 | 0.08 | 447.49 | 16.46 |               |
| 414       | 487         | 996.97  | -2.67 | 0.07 | 480.26 | 17.67 |               |
| 415       | 488         | 1066.08 | -2.81 | 0.07 | 511.32 | 18.81 |               |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks         |
|-----------|-------------|---------|-------|------|--------|-------|-----------------|
| 416       | 489         | 1161.74 | -3.06 | 0.07 | 548.45 | 20.18 |                 |
| 417       | 490         | 1214.41 | -2.88 | 0.06 | 586.68 | 21.58 |                 |
| 418       | 491         | 1272.29 | -2.68 | 0.04 | 621.78 | 22.87 |                 |
| 419       | 492         | 1375.72 | -3    | 0.05 | 660.42 | 24.3  |                 |
| 420       | 493         | 1417.36 | -3.11 | 0.05 | 687.74 | 25.3  |                 |
| 421       | 494         | 1453.71 | -3.3  | 0.05 | 703.31 | 25.87 |                 |
| 422       | 495         | 1451.49 | -3.76 | 0.07 | 692.2  | 25.46 | Akyinim (P19)   |
| 423       | 496         | 1425.81 | -4.41 | 0.1  | 666.36 | 24.51 |                 |
| 424       | 497         | 1382.17 | -5.43 | 0.16 | 624.84 | 22.99 |                 |
| 425       | 498         | 1330.08 | -5.92 | 0.21 | 571.41 | 21.02 |                 |
| 426       | 499         | 1157    | -4.15 | 0.15 | 492.92 | 18.13 | Atwiwa (P20)    |
| 427       | 500         | 973.03  | -3.28 | 0.12 | 449.15 | 16.52 |                 |
| 428       | 501         | 964.11  | -3.98 | 0.17 | 437.09 | 16.08 |                 |
| 429       | 502         | 779.47  | -2.74 | 0.13 | 347.87 | 12.8  |                 |
| 430       | 503         | 683.73  | -2.44 | 0.13 | 310.84 | 11.44 |                 |
| 431       | 504         | 631.23  | -2.17 | 0.14 | 268.86 | 9.89  |                 |
| 432       | 505         | 526.04  | -1.85 | 0.13 | 238.48 | 8.77  |                 |
| 433       | 506         | 584.23  | -2.96 | 0.27 | 246.45 | 9.07  |                 |
| 434       | 507         | 588.81  | -2.83 | 0.24 | 254.1  | 9.35  |                 |
| 435       | 508         | 685.25  | -3.62 | 0.28 | 286.38 | 10.54 |                 |
| 436       | 541         | 709.15  | -4.15 | 0.33 | 295.07 | 10.85 |                 |
| 437       | 542         | 659.73  | -3.88 | 0.34 | 268.28 | 9.87  |                 |
| 438       | 543         | 530.84  | -2.53 | 0.28 | 204.69 | 7.53  |                 |
| 439       | 544         | 626.6   | -3.89 | 0.36 | 256.72 | 9.44  |                 |
| 440       | 545         | 709.39  | -4.09 | 0.33 | 291.25 | 10.71 |                 |
| 441       | 546         | 737.21  | -3.6  | 0.27 | 294.04 | 10.82 |                 |
| 442       | 547         | 761.36  | -3.87 | 0.25 | 331.88 | 12.21 |                 |
| 443       | 548         | 869.27  | -3.2  | 0.14 | 395.14 | 14.54 |                 |
| 444       | 549         | 1071.97 | -3.44 | 0.11 | 499.61 | 18.38 |                 |
| 445       | 550         | 1154.83 | -3.05 | 0.07 | 550.6  | 20.26 |                 |
| 446       | 551         | 1202.48 | -2.93 | 0.06 | 582.62 | 21.43 |                 |
| 447       | 552         | 1269.17 | -3.02 | 0.06 | 613.67 | 22.58 |                 |
| 448       | 553         | 1328.87 | -3.02 | 0.05 | 645.86 | 23.76 |                 |
| 449       | 554         | 1379.42 | -2.88 | 0.04 | 675.5  | 24.85 |                 |
| 450       | 555         | 1429.82 | -2.96 | 0.04 | 704.04 | 25.9  |                 |
| 451       | 556         | 1476.28 | -3    | 0.04 | 727.78 | 26.77 |                 |
| 452       | 557         | 1492.1  | -3.06 | 0.04 | 734.8  | 27.03 |                 |
| 453       | 558         | 1503.21 | -3.09 | 0.04 | 740.51 | 27.24 | Ahonakrom (P21) |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks          |
|-----------|-------------|---------|-------|------|--------|-------|------------------|
| 454       | 559         | 1513.44 | -3.11 | 0.04 | 746.42 | 27.46 |                  |
| 455       | 560         | 1523.84 | -3.1  | 0.04 | 750.26 | 27.6  |                  |
| 456       | 561         | 1526.2  | -3.05 | 0.04 | 753.63 | 27.72 |                  |
| 457       | 562         | 1533.36 | -3.01 | 0.04 | 756.86 | 27.84 |                  |
| 458       | 563         | 1547.91 | -2.99 | 0.04 | 767.34 | 28.23 |                  |
| 459       | 564         | 1563.53 | -2.89 | 0.03 | 773.07 | 28.44 |                  |
| 460       | 565         | 1583.45 | -2.94 | 0.03 | 779.85 | 28.69 |                  |
| 461       | 566         | 1600.99 | -3.2  | 0.04 | 786.12 | 28.92 |                  |
| 462       | 567         | 1595.7  | -3.38 | 0.04 | 780.1  | 28.7  |                  |
| 463       | 568         | 1589.06 | -3.51 | 0.05 | 770.91 | 28.36 |                  |
| 464       | 569         | 1579.25 | -3.62 | 0.05 | 761.86 | 28.03 |                  |
| 465       | 570         | 1557.29 | -3.76 | 0.06 | 749.9  | 27.59 |                  |
| 466       | 571         | 1512.75 | -3.77 | 0.06 | 722.54 | 26.58 |                  |
| 467       | 572         | 1464.63 | -3.75 | 0.07 | 696.8  | 25.63 |                  |
| 468       | 573         | 1417.94 | -3.75 | 0.07 | 674.19 | 24.8  |                  |
| 469       | 574         | 1368.95 | -3.56 | 0.07 | 649.86 | 23.91 |                  |
| 470       | 575         | 1302.97 | -3.24 | 0.06 | 620.57 | 22.83 |                  |
| 471       | 576         | 1239.61 | -2.93 | 0.06 | 591.6  | 21.76 |                  |
| 472       | 577         | 1201.33 | -2.7  | 0.05 | 575.73 | 21.18 |                  |
| 473       | 578         | 1189.75 | -2.62 | 0.05 | 570.34 | 20.98 |                  |
| 474       | 579         | 1197.66 | -2.81 | 0.06 | 576.18 | 21.2  |                  |
| 475       | 580         | 1202.4  | -2.94 | 0.06 | 574.54 | 21.14 |                  |
| 476       | 581         | 1195.96 | -3    | 0.06 | 568.55 | 20.92 |                  |
| 477       | 582         | 1179.59 | -3    | 0.07 | 561.29 | 20.65 |                  |
| 478       | 583         | 1168.94 | -3.07 | 0.07 | 553.96 | 20.38 | Bebianiha (P 22) |
| 479       | 584         | 1159    | -3.18 | 0.08 | 547    | 20.12 |                  |
| 480       | 585         | 1145.16 | -3.38 | 0.09 | 535.32 | 19.69 |                  |
| 481       | 586         | 1125.04 | -3.48 | 0.1  | 526.45 | 19.37 |                  |
| 482       | 596         | 1057.2  | -3.5  | 0.12 | 483.42 | 17.78 |                  |
| 483       | 597         | 1051.63 | -3.56 | 0.12 | 474.78 | 17.47 |                  |
| 484       | 598         | 1045.96 | -3.56 | 0.12 | 471.53 | 17.35 |                  |
| 485       | 599         | 1056.96 | -3.7  | 0.13 | 472.67 | 17.39 |                  |
| 486       | 600         | 1046.54 | -3.71 | 0.13 | 471.2  | 17.33 |                  |
| 487       | 601         | 1035.58 | -3.65 | 0.13 | 466.93 | 17.18 |                  |
| 488       | 602         | 1028.87 | -3.64 | 0.13 | 464.14 | 17.07 |                  |
| 489       | 603         | 1017.44 | -3.59 | 0.13 | 460.78 | 16.95 |                  |
| 490       | 604         | 991.62  | -3.38 | 0.12 | 450.68 | 16.58 |                  |
| 491       | 605         | 975.32  | -3.24 | 0.12 | 443.97 | 16.33 |                  |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks        |
|-----------|-------------|---------|-------|------|--------|-------|----------------|
| 492       | 606         | 955.19  | -3.1  | 0.11 | 437.16 | 16.08 |                |
| 493       | 607         | 932.87  | -2.88 | 0.1  | 426.9  | 15.7  |                |
| 494       | 608         | 913.43  | -2.91 | 0.11 | 415.68 | 15.29 |                |
| 495       | 609         | 887.53  | -3.06 | 0.13 | 396.98 | 14.6  | P 23           |
| 496       | 610         | 850.68  | -3.12 | 0.15 | 376.14 | 13.84 |                |
| 497       | 611         | 806.84  | -3.88 | 0.25 | 337.62 | 12.42 |                |
| 498       | 612         | 556     | -1.88 | 0.12 | 258.46 | 9.51  |                |
| 499       | 613         | 514.69  | -1.24 | 0.06 | 245.45 | 9.03  |                |
| 500       | 614         | 823.85  | -3.94 | 0.25 | 341.56 | 12.57 |                |
| 501       | 615         | 832.45  | -3.65 | 0.21 | 351.23 | 12.92 |                |
| 502       | 616         | 807.01  | -3.24 | 0.18 | 346.11 | 12.73 |                |
| 503       | 617         | 773.01  | -2.94 | 0.16 | 331.41 | 12.19 |                |
| 504       | 618         | 782.16  | -2.93 | 0.16 | 334.53 | 12.31 |                |
| 505       | 619         | 847.54  | -3.62 | 0.2  | 360.71 | 13.27 |                |
| 506       | 620         | 885.98  | -4.17 | 0.25 | 359.62 | 13.23 |                |
| 507       | 621         | 917.52  | -4.93 | 0.32 | 360.56 | 13.26 |                |
| 508       | 622         | 920.5   | -5.36 | 0.37 | 351.68 | 12.94 | Ketaakor (P24) |
| 509       | 623         | 935.16  | -5.57 | 0.38 | 353.56 | 13.01 |                |
| 510       | 624         | 979.9   | -5.89 | 0.4  | 360.41 | 13.26 |                |
| 511       | 625         | 808.88  | -4.14 | 0.34 | 290.4  | 10.68 |                |
| 512       | 626         | 565.97  | -2.5  | 0.25 | 218.38 | 8.03  |                |
| 513       | 627         | 498.45  | -2.44 | 0.28 | 194.82 | 7.17  |                |
| 514       | 628         | 478.44  | -2.16 | 0.24 | 191.21 | 7.03  |                |
| 515       | 629         | 555.51  | -4.36 | 0.56 | 192.84 | 7.09  |                |
| 516       | 630         | 637.18  | -4.48 | 0.51 | 218.37 | 8.03  |                |
| 517       | 631         | 535.09  | -3.08 | 0.37 | 198.74 | 7.31  |                |
| 518       | 632         | 583.62  | -3.14 | 0.34 | 218.01 | 8.02  |                |
| 519       | 633         | 602.98  | -4.68 | 0.58 | 198.32 | 7.3   |                |
| 520       | 634         | 144.97  | -1.17 | 0.64 | 43.4   | 1.6   |                |
| 521       | 635         | 233.37  | -1.44 | 0.45 | 79.75  | 2.93  |                |
| 522       | 645         | 923.7   | -3.55 | 0.17 | 393.42 | 14.47 |                |
| 523       | 646         | 978.07  | -2.64 | 0.08 | 456.83 | 16.81 |                |
| 524       | 647         | 1186.75 | -3.54 | 0.1  | 541.95 | 19.94 |                |
| 525       | 648         | 1278.34 | -3.19 | 0.07 | 587.41 | 21.61 |                |
| 526       | 649         | 1399.73 | -3.46 | 0.06 | 660.85 | 24.31 |                |
| 527       | 650         | 1540.7  | -3.62 | 0.06 | 720.77 | 26.52 |                |
| 528       | 651         | 1634.35 | -3.52 | 0.05 | 778.74 | 28.65 |                |
| 529       | 652         | 1736.8  | -4.21 | 0.06 | 812.19 | 29.88 |                |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks            |
|-----------|-------------|---------|-------|------|--------|-------|--------------------|
| 530       | 653         | 1841.47 | -5.15 | 0.08 | 847.41 | 31.17 |                    |
| 531       | 654         | 1816.45 | -5.39 | 0.09 | 831.54 | 30.59 |                    |
| 532       | 655         | 1750.96 | -5.61 | 0.12 | 766.49 | 28.2  |                    |
| 533       | 656         | 1451.41 | -3.43 | 0.06 | 683.2  | 25.13 |                    |
| 534       | 657         | 1716.61 | -5.67 | 0.12 | 772.62 | 28.42 |                    |
| 535       | 658         | 1778.23 | -5.08 | 0.09 | 813.85 | 29.94 |                    |
| 536       | 659         | 1779.14 | -4.5  | 0.07 | 820.6  | 30.19 |                    |
| 537       | 660         | 1766.2  | -4.6  | 0.07 | 814.32 | 29.96 | Trinity Yard (P25) |
| 538       | 661         | 1819.54 | -4.87 | 0.08 | 841.6  | 30.96 |                    |
| 539       | 662         | 1754.13 | -3.96 | 0.05 | 836.23 | 30.76 |                    |
| 540       | 663         | 1717.16 | -3.85 | 0.05 | 812.85 | 29.9  |                    |
| 541       | 664         | 1652.69 | -3.74 | 0.05 | 785.97 | 28.91 |                    |
| 542       | 665         | 1585.11 | -3.97 | 0.07 | 744.9  | 27.4  |                    |
| 543       | 666         | 1531.57 | -4.65 | 0.1  | 701.71 | 25.81 |                    |
| 544       | 667         | 1432.48 | -3.75 | 0.07 | 668.36 | 24.59 |                    |
| 545       | 668         | 1461.57 | -3.44 | 0.06 | 691.55 | 25.44 | P 26               |
| 546       | 669         | 1397.07 | -3.63 | 0.07 | 653.61 | 24.04 |                    |
| 547       | 670         | 1290.02 | -3.35 | 0.07 | 604.53 | 22.24 |                    |
| 548       | 688         | 828.09  | -2.64 | 0.43 | 303.71 | 11.17 |                    |
| 549       | 689         | 286.84  | -1.93 | 0.49 | 98.71  | 3.63  |                    |
| 550       | 690         | 672.52  | -1.30 | 0.98 | 38.07  | 1.4   |                    |
| 551       | 691         | 524.43  | -0.66 | 0.02 | 240.27 | 8.84  |                    |
| 552       | 692         | 472.55  | -0.66 | 0.02 | 211.58 | 7.78  |                    |
| 553       | 693         | 340.38  | -1.13 | 0.14 | 138.27 | 5.09  | Atonchede (P 27)   |
| 554       | 694         | 477.35  | -1.57 | 0.93 | 58.9   | 2.17  |                    |
| 555       | 695         | 364.05  | -2.01 | 0.38 | 129.07 | 4.75  |                    |
| 556       | 696         | 390.61  | -2.01 | 0.92 | 58.57  | 6.6   |                    |
| 557       | 697         | 465.95  | -2    | 0.23 | 181.01 | 6.66  |                    |
| 558       | 698         | 520.61  | -2.01 | 0.18 | 211.48 | 7.78  |                    |
| 559       | 699         | 575.08  | -2.02 | 0.15 | 242.64 | 8.93  |                    |
| 560       | 700         | 634.21  | -2.18 | 0.14 | 273.35 | 10.06 |                    |
| 561       | 701         | 690.52  | -2.18 | 0.12 | 301.12 | 11.08 |                    |
| 562       | 702         | 740.94  | -2.31 | 0.11 | 328.13 | 12.07 |                    |
| 563       | 703         | 753.08  | -2.32 | 0.11 | 333.59 | 12.27 |                    |
| 564       | 704         | 766.43  | -2.44 | 0.12 | 335.81 | 12.35 |                    |
| 565       | 705         | 776.46  | -2.46 | 0.12 | 339.05 | 12.47 |                    |
| 566       | 706         | 722.32  | -2.05 | 0.09 | 322.31 | 11.86 |                    |
| 567       | 707         | 610.47  | -1.64 | 0.08 | 277.51 | 10.21 |                    |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE     | LCI95 | Remarks          |
|-----------|-------------|---------|-------|------|---------|-------|------------------|
| 568       | 708         | 537.3   | -1.88 | 0.13 | 242.43  | 8.92  |                  |
| 569       | 709         | 509.27  | -2.03 | 0.2  | 202.69  | 7.46  |                  |
| 570       | 710         | 363.02  | -1.8  | 0.28 | 144.17  | 5.3   |                  |
| 571       | 711         | 271.83  | -1.62 | 0.43 | 94.08   | 3.46  |                  |
| 572       | 712         | 254.11  | -2.21 | 0.7  | 71.77   | 2.64  |                  |
| 573       | 713         | 196.25  | -1.76 | 0.83 | 40.17   | 1.48  |                  |
| 574       | 714         | 497.3   | -4.13 | 0.61 | 164.91  | 6.07  |                  |
| 575       | 715         | 904.59  | -3.88 | 0.26 | 327.44  | 12.05 |                  |
| 576       | 716         | 859.98  | -1.66 | 0.04 | 408.98  | 15.05 |                  |
| 577       | 717         | 695.88  | -1.32 | 0.04 | 337.68  | 12.42 |                  |
| 578       | 718         | 526     | -1.03 | 0.04 | 258.71  | 9.52  |                  |
| 579       | 719         | 2277.63 | -2.42 | 0.53 | 852.25  | 31.35 |                  |
| 580       | 720         | 2107.6  | -3.8  | 0.03 | 1036.82 | 38.14 | Akatakyie (P 28) |
| 581       | 721         | 1419.8  | -2.88 | 0.04 | 689.04  | 25.35 |                  |
| 582       | 722         | 772     | -2.11 | 0.08 | 351.31  | 12.92 |                  |
| 583       | 723         | 691.03  | -2.16 | 0.12 | 295.94  | 10.89 |                  |
| 584       | 724         | 642.55  | -2.14 | 0.15 | 256.11  | 9.42  |                  |
| 585       | 725         | 575.51  | -1.94 | 0.15 | 234.72  | 8.63  |                  |
| 586       | 726         | 565.23  | -1.76 | 0.12 | 237.71  | 8.74  |                  |
| 587       | 727         | 619.02  | -1.72 | 0.09 | 266.4   | 9.8   |                  |
| 588       | 754         | 789.5   | -1.96 | 0.07 | 348.85  | 12.83 |                  |
| 589       | 755         | 812.01  | -1.92 | 0.07 | 361.39  | 13.29 |                  |
| 590       | 756         | 843.02  | -1.92 | 0.06 | 377.24  | 13.88 |                  |
| 591       | 757         | 885.79  | -2    | 0.06 | 403.41  | 14.84 |                  |
| 592       | 758         | 937.63  | -2.11 | 0.06 | 428.7   | 15.77 |                  |
| 593       | 759         | 990.63  | -2.23 | 0.06 | 453.93  | 16.7  |                  |
| 594       | 760         | 1059    | -2.47 | 0.06 | 488.93  | 17.99 |                  |
| 595       | 761         | 1123.73 | -2.69 | 0.06 | 519.1   | 19.1  |                  |
| 596       | 762         | 1154.01 | -2.72 | 0.06 | 527.51  | 19.41 |                  |
| 597       | 763         | 1157.5  | -2.67 | 0.06 | 529.87  | 19.49 |                  |
| 598       | 764         | 1159.93 | -2.54 | 0.05 | 526.86  | 19.38 |                  |
| 599       | 765         | 1143.69 | -2.4  | 0.05 | 522.71  | 19.23 |                  |
| 600       | 766         | 1141.77 | -2.49 | 0.05 | 522.71  | 19.23 |                  |
| 601       | 767         | 1138.15 | -2.43 | 0.05 | 518.27  | 19.07 |                  |
| 602       | 768         | 1128.97 | -2.5  | 0.06 | 511.95  | 18.83 |                  |
| 603       | 769         | 1057.26 | -4.64 | 0.23 | 421.92  | 15.52 |                  |
| 604       | 770         | 580.86  | -1.31 | 0.06 | 258.03  | 9.49  |                  |
| 605       | 771         | 681.77  | -2.39 | 0.16 | 275.82  | 10.15 |                  |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks            |
|-----------|-------------|---------|-------|------|--------|-------|--------------------|
| 606       | 772         | 641.85  | -2.5  | 0.18 | 265.91 | 9.78  | Princes Town (P29) |
| 607       | 773         | 595.7   | -2.32 | 0.18 | 245.01 | 9.01  |                    |
| 608       | 774         | 470.92  | -1.89 | 0.2  | 189.13 | 6.96  |                    |
| 609       | 775         | 502.4   | -1.73 | 0.16 | 199.97 | 7.36  |                    |
| 610       | 776         | 570.42  | -1.79 | 0.13 | 228.99 | 8.42  |                    |
| 611       | 777         | 574.1   | -2.18 | 0.18 | 231.87 | 8.53  |                    |
| 612       | 778         | 536.39  | -2.08 | 0.2  | 210.34 | 7.74  |                    |
| 613       | 779         | 548.99  | -2.05 | 0.65 | 165.12 | 6.07  |                    |
| 614       | 780         | 571.06  | -2.03 | 0.62 | 174.5  | 6.42  |                    |
| 615       | 781         | 587.26  | -3.96 | 0.51 | 194.91 | 7.17  |                    |
| 616       | 782         | 639     | -3.01 | 0.27 | 244.44 | 8.99  |                    |
| 617       | 783         | 684.65  | -2.01 | 0.11 | 289.93 | 10.67 |                    |
| 618       | 784         | 753.47  | -1.78 | 0.07 | 330.58 | 12.16 |                    |
| 619       | 785         | 854.41  | -1.61 | 0.04 | 387.15 | 14.24 |                    |
| 620       | 786         | 989.57  | -1.81 | 0.04 | 455.09 | 16.74 |                    |
| 621       | 787         | 1121.01 | -1.83 | 0.03 | 526.33 | 19.36 |                    |
| 622       | 788         | 1247.7  | -2.39 | 0.04 | 579.01 | 21.3  |                    |
| 623       | 789         | 1366.4  | -3.2  | 0.06 | 626.83 | 23.06 |                    |
| 624       | 790         | 1428.97 | -3.28 | 0.06 | 663.92 | 24.42 |                    |
| 625       | 791         | 1437.52 | -3.14 | 0.05 | 671.38 | 24.7  |                    |
| 626       | 792         | 1419.48 | -2.67 | 0.04 | 669.08 | 24.61 |                    |
| 627       | 793         | 1331.05 | -2.41 | 0.06 | 611.47 | 22.49 |                    |
| 628       | 794         | 1205.57 | -2.15 | 0.23 | 447.48 | 16.46 |                    |
| 629       | 795         | 1084.12 | -2.03 | 0.23 | 399.89 | 14.71 |                    |
| 630       | 796         | 937.87  | -1.08 | 0.28 | 329.53 | 12.12 |                    |
| 631       | 797         | 968.03  | -1.34 | 0.37 | 323.4  | 11.9  |                    |
| 632       | 798         | 1157.63 | -1.40 | 0.13 | 520.59 | 19.15 |                    |
| 633       | 799         | 991.55  | -1.91 | 0.04 | 486.48 | 17.9  |                    |
| 634       | 800         | 888.87  | -1.61 | 0.03 | 434.24 | 15.97 |                    |
| 635       | 801         | 790.87  | -1.45 | 0.03 | 380.92 | 14.01 |                    |
| 636       | 802         | 715.22  | -1.44 | 0.04 | 337.51 | 12.42 |                    |
| 637       | 803         | 637.38  | -1.51 | 0.06 | 294.76 | 10.84 |                    |
| 638       | 804         | 1111.57 | -6.46 | 0.38 | 408.77 | 15.04 |                    |
| 639       | 805         | 982.27  | -2.36 | 0.06 | 458.34 | 16.86 | Miamea (P30)       |
| 640       | 806         | 921.13  | -2.26 | 0.07 | 416.49 | 15.32 |                    |
| 641       | 807         | 782.33  | -1.78 | 0.06 | 367.17 | 13.51 |                    |
| 642       | 808         | 677.62  | -1    | 0.02 | 315.57 | 11.61 |                    |
| 643       | 809         | 804.96  | -1.97 | 0.08 | 327.93 | 12.06 |                    |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks         |
|-----------|-------------|---------|-------|------|--------|-------|-----------------|
| 644       | 810         | 781.97  | -2.93 | 0.16 | 330.00 | 12.14 |                 |
| 645       | 811         | 725.01  | -3.07 | 0.2  | 303.34 | 11.16 |                 |
| 646       | 812         | 650.34  | -2.93 | 0.22 | 275.88 | 10.15 |                 |
| 647       | 813         | 620.31  | -2.59 | 0.19 | 268.72 | 9.89  |                 |
| 648       | 814         | 607.23  | -2.36 | 0.17 | 264.33 | 9.72  |                 |
| 649       | 815         | 535.57  | -1.88 | 0.14 | 233.41 | 8.59  | Egyembra (P 31) |
| 650       | 816         | 441.24  | -1.64 | 0.16 | 186.83 | 6.87  |                 |
| 651       | 817         | 394.21  | -1.39 | 0.14 | 170.57 | 6.27  |                 |
| 652       | 818         | 381.41  | -1.48 | 0.17 | 164.25 | 6.04  |                 |
| 653       | 819         | 411.93  | -1.85 | 0.23 | 168.22 | 6.19  |                 |
| 654       | 820         | 418.29  | -1.89 | 0.23 | 174.84 | 6.43  |                 |
| 655       | 821         | 460.48  | -2.1  | 0.24 | 185.01 | 6.81  |                 |
| 656       | 822         | 492.38  | -2.25 | 0.24 | 198.98 | 7.32  |                 |
| 657       | 823         | 531.91  | -2.49 | 0.24 | 220.08 | 8.1   |                 |
| 658       | 824         | 558.14  | -2.6  | 0.23 | 236.95 | 8.72  |                 |
| 659       | 825         | 577.09  | -2.59 | 0.21 | 251.1  | 9.24  |                 |
| 660       | 826         | 620.15  | -2.64 | 0.2  | 262.02 | 9.64  |                 |
| 661       | 827         | 640.63  | -2.72 | 0.19 | 277.27 | 10.2  |                 |
| 662       | 828         | 665.91  | -2.79 | 0.19 | 290.79 | 10.7  |                 |
| 663       | 829         | 709.09  | -2.79 | 0.17 | 305.46 | 11.24 |                 |
| 664       | 830         | 696.2   | -2.47 | 0.14 | 307.82 | 11.32 |                 |
| 665       | 844         | 837.51  | -2.71 | 0.11 | 385.66 | 14.19 |                 |
| 666       | 845         | 892.38  | -3.08 | 0.13 | 403.51 | 14.84 |                 |
| 667       | 846         | 859.54  | -2.75 | 0.11 | 394.34 | 14.51 |                 |
| 668       | 847         | 767.49  | -1.78 | 0.05 | 369.83 | 13.6  |                 |
| 669       | 848         | 825.61  | -2.09 | 0.07 | 389.57 | 14.33 |                 |
| 670       | 849         | 815.78  | -1.84 | 0.05 | 395.48 | 14.55 |                 |
| 671       | 850         | 767.59  | -1.42 | 0.03 | 373.62 | 13.74 |                 |
| 672       | 851         | 807.8   | -1.97 | 0.06 | 382.95 | 14.09 |                 |
| 673       | 852         | 796.48  | -2    | 0.07 | 375.1  | 13.8  |                 |
| 674       | 853         | 781.35  | -1.81 | 0.06 | 353.34 | 13    |                 |
| 675       | 854         | 644.69  | -1.01 | 0.03 | 309.04 | 11.37 |                 |
| 676       | 855         | 636     | -1.22 | 0.04 | 297.16 | 10.93 |                 |
| 677       | 856         | 645.32  | -1.02 | 0.03 | 309.58 | 11.39 |                 |
| 678       | 857         | 887.59  | -2.73 | 0.1  | 413.74 | 15.22 |                 |
| 679       | 858         | 1149.58 | -4.07 | 0.13 | 529.57 | 19.48 |                 |
| 680       | 859         | 1181.82 | -2.98 | 0.06 | 572.08 | 21.05 |                 |
| 681       | 860         | 997     | -1.51 | 0.02 | 504.53 | 18.56 |                 |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks      |
|-----------|-------------|---------|-------|------|--------|-------|--------------|
| 682       | 861         | 1359.51 | -3.9  | 0.08 | 648.87 | 23.87 | Adjan (P 32) |
| 683       | 862         | 1441.66 | -2.67 | 0.04 | 661.93 | 24.35 |              |
| 684       | 863         | 1549.22 | -3.8  | 0.06 | 741.13 | 27.26 |              |
| 685       | 864         | 1563.41 | -3    | 0.04 | 771.23 | 28.37 |              |
| 686       | 865         | 1560.4  | -2.42 | 0.02 | 779.31 | 28.67 |              |
| 687       | 866         | 1562.22 | -2.12 | 0.02 | 778.76 | 28.65 |              |
| 688       | 867         | 1577.46 | -2.11 | 0.02 | 784.76 | 28.87 |              |
| 689       | 868         | 1565.05 | -2.33 | 0.02 | 785.43 | 28.89 |              |
| 690       | 869         | 1761.2  | -3.77 | 0.05 | 843.1  | 31.02 |              |
| 691       | 870         | 1821.13 | -3.76 | 0.04 | 879.96 | 32.37 |              |
| 692       | 871         | 1827.94 | -3.78 | 0.04 | 884.02 | 32.52 |              |
| 693       | 872         | 1861.75 | -3.97 | 0.05 | 889.64 | 32.73 | P 33         |
| 694       | 873         | 1863.62 | -4.07 | 0.05 | 888.08 | 32.67 |              |
| 695       | 874         | 1838.32 | -4.07 | 0.05 | 879.95 | 32.37 |              |
| 696       | 875         | 1819.82 | -4.09 | 0.05 | 871.58 | 32.06 |              |
| 697       | 876         | 1806.53 | -4.17 | 0.06 | 862.43 | 31.73 |              |
| 698       | 877         | 1806.07 | -4.3  | 0.06 | 859.05 | 31.6  |              |
| 699       | 878         | 1818.14 | -4.5  | 0.06 | 857.71 | 31.55 |              |
| 700       | 879         | 1810.43 | -4.49 | 0.06 | 852.59 | 31.36 |              |
| 701       | 880         | 1809.05 | -4.35 | 0.06 | 855.19 | 31.46 | P34          |
| 702       | 881         | 1812.99 | -4.24 | 0.06 | 860.2  | 31.64 |              |
| 703       | 882         | 1818.5  | -4.23 | 0.06 | 860.99 | 31.67 |              |
| 704       | 883         | 1803.94 | -4.43 | 0.06 | 846.18 | 31.13 |              |
| 705       | 884         | 1774.55 | -4.55 | 0.07 | 829.68 | 30.52 |              |
| 706       | 885         | 1750.02 | -4.61 | 0.07 | 816.28 | 30.03 |              |
| 707       | 886         | 1752.59 | -4.58 | 0.07 | 820.45 | 30.18 |              |
| 708       | 887         | 1745.88 | -4.35 | 0.07 | 817.11 | 30.06 |              |
| 709       | 888         | 1754.23 | -4.22 | 0.06 | 819.33 | 30.14 |              |
| 710       | 889         | 1803.3  | -4.43 | 0.06 | 847.17 | 31.17 |              |
| 711       | 890         | 1833.57 | -4.21 | 0.06 | 869.52 | 31.99 |              |
| 712       | 891         | 1852.37 | -4.31 | 0.06 | 878.89 | 32.33 |              |
| 713       | 892         | 1866.17 | -4.48 | 0.06 | 884.48 | 32.54 |              |
| 714       | 893         | 1858.7  | -4.56 | 0.06 | 878.61 | 32.32 |              |
| 715       | 894         | 1844.27 | -4.8  | 0.07 | 865.33 | 31.83 |              |
| 716       | 895         | 1822.05 | -5.1  | 0.08 | 847.39 | 31.17 |              |
| 717       | 896         | 1784.4  | -5.32 | 0.09 | 827.73 | 30.45 |              |
| 718       | 897         | 1787.93 | -5.31 | 0.09 | 830.16 | 30.54 |              |
| 719       | 898         | 1804.59 | -5.09 | 0.08 | 842.26 | 30.98 |              |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE     | LCI95 | Remarks           |
|-----------|-------------|---------|-------|------|---------|-------|-------------------|
| 720       | 899         | 1768.34 | -4.71 | 0.07 | 833.66  | 30.67 |                   |
| 721       | 900         | 1757.81 | -4.94 | 0.08 | 817.99  | 30.09 |                   |
| 722       | 907         | 1889.12 | -5.26 | 0.08 | 881.56  | 32.43 |                   |
| 723       | 908         | 1746.04 | -4.7  | 0.07 | 832.16  | 30.61 | Axim Beach (P 35) |
| 724       | 909         | 1769.21 | -5.47 | 0.1  | 815.22  | 29.99 |                   |
| 725       | 910         | 1706.48 | -5.12 | 0.09 | 796.69  | 29.31 |                   |
| 726       | 911         | 1640.5  | -4.22 | 0.07 | 778.97  | 28.66 |                   |
| 727       | 912         | 1596.2  | -3.48 | 0.05 | 768.58  | 28.27 |                   |
| 728       | 913         | 1686.38 | -3.61 | 0.05 | 807.12  | 29.69 |                   |
| 729       | 914         | 1719.66 | -3.63 | 0.05 | 827.94  | 30.46 |                   |
| 730       | 915         | 1817.9  | -4.18 | 0.06 | 852.94  | 31.38 |                   |
| 731       | 916         | 1804.95 | -4.04 | 0.05 | 864.12  | 31.79 |                   |
| 732       | 917         | 1820.96 | -4.24 | 0.06 | 864.11  | 31.79 |                   |
| 733       | 918         | 1799.24 | -4.56 | 0.07 | 860.32  | 31.65 |                   |
| 734       | 919         | 1817.94 | -5.15 | 0.09 | 840.3   | 30.91 |                   |
| 735       | 920         | 1642.12 | -3.89 | 0.06 | 773.38  | 28.45 | Axim Nkekam (P36) |
| 736       | 921         | 1480.22 | -2.19 | 0.02 | 741.01  | 27.26 |                   |
| 737       | 922         | 1554.59 | -2.81 | 0.03 | 764.74  | 28.13 |                   |
| 738       | 923         | 2280.6  | -9.21 | 0.17 | 1028.23 | 37.83 |                   |
| 739       | 924         | 2265.37 | -8.61 | 0.15 | 1022.89 | 37.63 |                   |
| 740       | 925         | 2222.06 | -7.53 | 0.12 | 1014.53 | 37.32 |                   |
| 741       | 926         | 2150.13 | -6.27 | 0.09 | 1004.58 | 36.96 |                   |
| 742       | 927         | 2094.09 | -5.33 | 0.07 | 1001.15 | 36.83 |                   |
| 743       | 928         | 2021.26 | -5.09 | 0.06 | 975.04  | 35.87 |                   |
| 744       | 929         | 2037.12 | -5.41 | 0.07 | 971.4   | 35.74 |                   |
| 745       | 930         | 2195.18 | -6.08 | 0.08 | 1013.56 | 37.29 |                   |
| 746       | 931         | 2224.57 | -6.21 | 0.08 | 1038.94 | 38.22 |                   |
| 747       | 932         | 2383.31 | -7.13 | 0.1  | 1083.64 | 39.86 |                   |
| 748       | 933         | 2446.16 | -7.39 | 0.1  | 1127.69 | 41.48 |                   |
| 749       | 934         | 2253.89 | -5.25 | 0.05 | 1098.19 | 40.4  |                   |
| 750       | 935         | 2437.69 | -6.35 | 0.07 | 1159.03 | 42.64 |                   |
| 751       | 936         | 2457.77 | -5.84 | 0.06 | 1176.04 | 43.26 |                   |
| 752       | 937         | 2372.6  | -5.02 | 0.04 | 1171.51 | 43.1  |                   |
| 753       | 938         | 2363.51 | -4.28 | 0.03 | 1169.96 | 43.04 |                   |
| 754       | 939         | 2629    | -6.67 | 0.06 | 1266.89 | 46.61 |                   |
| 755       | 940         | 2785.79 | -7.64 | 0.08 | 1327.04 | 48.82 |                   |
| 756       | 941         | 2868.46 | -7.92 | 0.08 | 1369.66 | 50.39 |                   |
| 757       | 942         | 2959.01 | -8.12 | 0.08 | 1414.36 | 52.03 |                   |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE     | LCI95 | Remarks              |
|-----------|-------------|---------|-------|------|---------|-------|----------------------|
| 758       | 943         | 3068.47 | -8.27 | 0.07 | 1463.56 | 53.84 | Akyenim (P 37)       |
| 759       | 944         | 3124.95 | -7.95 | 0.07 | 1498.94 | 55.14 |                      |
| 760       | 945         | 3188.03 | -7.88 | 0.06 | 1532.45 | 56.38 |                      |
| 761       | 946         | 3250.37 | -7.71 | 0.06 | 1567.99 | 57.68 |                      |
| 762       | 947         | 3300.21 | -7.75 | 0.05 | 1604.59 | 59.03 |                      |
| 763       | 948         | 3316.39 | -7.66 | 0.05 | 1614.59 | 59.4  |                      |
| 764       | 949         | 3332.89 | -7.48 | 0.05 | 1621.84 | 59.66 |                      |
| 765       | 950         | 3347.63 | -7.4  | 0.05 | 1635.45 | 60.16 |                      |
| 766       | 951         | 3320.27 | -7.22 | 0.05 | 1611.01 | 59.27 |                      |
| 767       | 952         | 3269.74 | -7.11 | 0.05 | 1582.37 | 58.21 |                      |
| 768       | 953         | 3195.72 | -7.04 | 0.05 | 1548.95 | 56.98 |                      |
| 769       | 954         | 3117.36 | -6.8  | 0.05 | 1510.48 | 55.57 |                      |
| 770       | 955         | 3069.86 | -6.45 | 0.04 | 1490.26 | 54.82 |                      |
| 771       | 956         | 3022.3  | -6.19 | 0.04 | 1473.28 | 54.2  |                      |
| 772       | 957         | 2888.38 | -5.65 | 0.04 | 1407.11 | 51.76 |                      |
| 773       | 958         | 2764.97 | -5.29 | 0.04 | 1354.26 | 49.82 | Ankobra Beach (P 38) |
| 774       | 959         | 2592.38 | -4.33 | 0.03 | 1284.7  | 47.26 |                      |
| 775       | 960         | 2687.02 | -5.08 | 0.04 | 1322.48 | 48.65 |                      |
| 776       | 961         | 3262.98 | -7.24 | 0.05 | 1573.37 | 57.88 |                      |
| 777       | 962         | 3237.76 | -7.05 | 0.05 | 1559.53 | 57.37 |                      |
| 778       | 963         | 3101.85 | -6.37 | 0.04 | 1512.83 | 55.65 | Ankobra Town (P 39)  |
| 779       | 964         | 3053.59 | -6.44 | 0.04 | 1486.27 | 54.68 |                      |
| 780       | 965         | 3000.4  | -6.40 | 0.1  | 1397.04 | 51.39 |                      |
| 781       | 966         | 2960.24 | -6.74 | 0.12 | 1358.61 | 49.98 |                      |
| 782       | 967         | 2890.54 | -6.40 | 0.14 | 1315.98 | 48.41 |                      |
| 783       | 968         | 2817.69 | -6.40 | 0.14 | 1280.28 | 47.1  |                      |
| 784       | 969         | 2762.88 | -6.43 | 0.12 | 1272.73 | 46.82 |                      |
| 785       | 970         | 2693.02 | -7.29 | 0.08 | 1277.57 | 47    |                      |
| 786       | 971         | 2590.12 | -6.42 | 0.06 | 1239.26 | 45.59 |                      |
| 787       | 972         | 2555.54 | -6.74 | 0.07 | 1205.24 | 44.34 |                      |
| 788       | 973         | 2527.53 | -7.27 | 0.09 | 1188.02 | 43.7  |                      |
| 789       | 974         | 2489.28 | -7.51 | 0.09 | 1159.28 | 42.65 | Asenta (P 40)        |
| 790       | 975         | 2441.57 | -7.85 | 0.11 | 1129.22 | 41.54 |                      |
| 791       | 976         | 2439.41 | -8.43 | 0.13 | 1113.37 | 40.96 |                      |
| 792       | 977         | 2437.04 | -8.8  | 0.14 | 1102.82 | 40.57 |                      |
| 793       | 978         | 2421.61 | -7.62 | 0.1  | 1122.95 | 41.31 |                      |
| 794       | 979         | 2400.52 | -7.33 | 0.1  | 1122.08 | 41.28 |                      |
| 795       | 980         | 2396.77 | -7.41 | 0.1  | 1118.99 | 41.16 |                      |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE     | LCI95 | Remarks       |
|-----------|-------------|---------|-------|------|---------|-------|---------------|
| 796       | 981         | 2385.85 | -7.4  | 0.1  | 1113.34 | 40.96 |               |
| 797       | 982         | 2375.87 | -7.37 | 0.1  | 1106.63 | 40.71 |               |
| 798       | 983         | 2382.7  | -7.52 | 0.1  | 1105.27 | 40.66 |               |
| 799       | 984         | 2393.58 | -7.64 | 0.11 | 1104.85 | 40.64 |               |
| 800       | 985         | 2401.13 | -7.51 | 0.1  | 1102.74 | 40.57 |               |
| 801       | 986         | 2414.12 | -7.41 | 0.1  | 1111.22 | 40.88 |               |
| 802       | 987         | 2433.05 | -7.34 | 0.1  | 1120.17 | 41.21 |               |
| 803       | 988         | 2438.17 | -7.37 | 0.1  | 1123.26 | 41.32 |               |
| 804       | 989         | 2438.12 | -7.65 | 0.1  | 1123.29 | 41.32 |               |
| 805       | 990         | 2434.56 | -7.88 | 0.11 | 1122.06 | 41.28 |               |
| 806       | 991         | 2447.58 | -8.06 | 0.11 | 1125.8  | 41.42 |               |
| 807       | 992         | 2473.37 | -8.16 | 0.11 | 1134.59 | 41.74 |               |
| 808       | 993         | 2493.43 | -7.86 | 0.1  | 1151.69 | 42.37 |               |
| 809       | 994         | 2475.75 | -7.58 | 0.1  | 1149.2  | 42.28 |               |
| 810       | 995         | 2458.03 | -7.29 | 0.09 | 1146.64 | 42.18 |               |
| 811       | 996         | 2470.78 | -6.98 | 0.08 | 1159.38 | 42.65 |               |
| 812       | 997         | 2527.46 | -6.73 | 0.07 | 1193.97 | 43.92 |               |
| 813       | 998         | 2583.37 | -6.45 | 0.06 | 1227.71 | 45.16 |               |
| 814       | 999         | 2606.34 | -6.24 | 0.06 | 1243.92 | 45.76 |               |
| 815       | 1000        | 2636.31 | -6.27 | 0.06 | 1257.42 | 46.26 |               |
| 816       | 1001        | 2636.89 | -6.07 | 0.05 | 1262.49 | 46.44 |               |
| 817       | 1002        | 2634.99 | -5.98 | 0.05 | 1262.62 | 46.45 |               |
| 818       | 1003        | 2634.47 | -5.9  | 0.05 | 1263.44 | 46.48 |               |
| 819       | 1004        | 2643.65 | -5.89 | 0.05 | 1265.34 | 46.55 | Asemko (P 41) |
| 820       | 1005        | 2634.89 | -5.77 | 0.05 | 1263.65 | 46.49 |               |
| 821       | 1006        | 2621.58 | -5.64 | 0.05 | 1260.96 | 46.39 |               |
| 822       | 1007        | 2618.92 | -5.6  | 0.05 | 1261.24 | 46.4  |               |
| 823       | 1008        | 2610.71 | -5.52 | 0.05 | 1259.76 | 46.34 |               |
| 824       | 1009        | 2592.05 | -5.28 | 0.04 | 1253.38 | 46.11 |               |
| 825       | 1010        | 2578.14 | -5.25 | 0.04 | 1244.38 | 45.78 |               |
| 826       | 1011        | 2560.11 | -5.45 | 0.05 | 1235.96 | 45.47 |               |
| 827       | 1012        | 2538.4  | -5.55 | 0.05 | 1223.35 | 45    |               |
| 828       | 1013        | 2509.28 | -5.59 | 0.05 | 1208.15 | 44.44 |               |
| 829       | 1014        | 2491.57 | -5.69 | 0.05 | 1191.74 | 43.84 | P 42          |
| 830       | 1015        | 2458.81 | -5.64 | 0.05 | 1170.66 | 43.07 |               |
| 831       | 1016        | 2397.1  | -5.67 | 0.06 | 1150.74 | 42.33 |               |
| 832       | 1017        | 2342.58 | -5.7  | 0.06 | 1118.5  | 41.15 |               |
| 833       | 1018        | 2308.34 | -5.79 | 0.07 | 1095.03 | 40.28 |               |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE     | LCI95 | Remarks       |
|-----------|-------------|---------|-------|------|---------|-------|---------------|
| 834       | 1019        | 2249.57 | -5.72 | 0.07 | 1067.51 | 39.27 |               |
| 835       | 1020        | 2225.9  | -5.57 | 0.07 | 1051.46 | 38.68 |               |
| 836       | 1021        | 2220.1  | -5.62 | 0.07 | 1042.26 | 38.34 |               |
| 837       | 1022        | 2203.15 | -5.78 | 0.07 | 1033.04 | 38    |               |
| 838       | 1023        | 2174.47 | -6    | 0.08 | 1018.32 | 37.46 |               |
| 839       | 1024        | 2151.01 | -6.28 | 0.09 | 999.81  | 36.78 |               |
| 840       | 1025        | 2103.33 | -6.16 | 0.09 | 981.83  | 36.12 |               |
| 841       | 1026        | 2069.72 | -6.03 | 0.09 | 964.44  | 35.48 |               |
| 842       | 1027        | 2021.39 | -5.84 | 0.09 | 940.23  | 34.59 |               |
| 843       | 1028        | 1982.32 | -6.09 | 0.1  | 913.24  | 33.6  |               |
| 844       | 1029        | 1949.22 | -6.42 | 0.11 | 891.43  | 32.79 |               |
| 845       | 1030        | 1918.3  | -6.77 | 0.13 | 870.14  | 32.01 |               |
| 846       | 1031        | 1889.17 | -7.11 | 0.15 | 850.03  | 31.27 |               |
| 847       | 1032        | 1860.41 | -7.41 | 0.17 | 831.65  | 30.59 |               |
| 848       | 1033        | 1843.24 | -7.73 | 0.18 | 811.58  | 29.86 |               |
| 849       | 1034        | 1821.7  | -7.98 | 0.2  | 792.84  | 29.17 | P 43          |
| 850       | 1035        | 1802.59 | -7.97 | 0.2  | 784.13  | 28.85 |               |
| 851       | 1036        | 1771.34 | -7.81 | 0.2  | 770.96  | 28.36 |               |
| 852       | 1037        | 1759.99 | -7.82 | 0.21 | 762.38  | 28.05 |               |
| 853       | 1038        | 1742.26 | -7.82 | 0.21 | 757.47  | 27.87 |               |
| 854       | 1039        | 1733.25 | -7.64 | 0.2  | 752.03  | 27.67 |               |
| 855       | 1040        | 1716.24 | -7.4  | 0.2  | 747.55  | 27.5  |               |
| 856       | 1041        | 1692.73 | -7.22 | 0.19 | 742.96  | 27.33 |               |
| 857       | 1042        | 1670.98 | -7.06 | 0.19 | 732.61  | 26.95 |               |
| 858       | 1043        | 1644.58 | -6.9  | 0.19 | 721.48  | 26.54 |               |
| 859       | 1044        | 1637.64 | -6.84 | 0.18 | 719.13  | 26.45 | Esiana (P 44) |
| 860       | 1045        | 1708.86 | -7.1  | 0.19 | 739.65  | 27.21 |               |
| 861       | 1046        | 1694.03 | -6.79 | 0.17 | 746.97  | 27.48 |               |
| 862       | 1047        | 1713.72 | -6.68 | 0.16 | 752.73  | 27.69 |               |
| 863       | 1048        | 1712.13 | -6.57 | 0.16 | 756.53  | 27.83 |               |
| 864       | 1049        | 1712.48 | -6.82 | 0.17 | 754.93  | 27.77 |               |
| 865       | 1050        | 1708.36 | -7.06 | 0.18 | 753.48  | 27.72 |               |
| 866       | 1051        | 1725.67 | -7.35 | 0.19 | 758.63  | 27.91 |               |
| 867       | 1052        | 1754.8  | -7.6  | 0.2  | 769.84  | 28.32 |               |
| 868       | 1053        | 1781.99 | -7.82 | 0.2  | 779.73  | 28.68 |               |
| 869       | 1054        | 1803.55 | -7.95 | 0.2  | 785.95  | 28.91 |               |
| 870       | 1055        | 1818.76 | -7.94 | 0.2  | 794.22  | 29.22 |               |
| 871       | 1056        | 1837.47 | -7.95 | 0.2  | 802.66  | 29.53 |               |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks          |
|-----------|-------------|---------|-------|------|--------|-------|------------------|
| 872       | 1057        | 1854.82 | -7.84 | 0.19 | 813.13 | 29.91 |                  |
| 873       | 1058        | 1898.8  | -7.82 | 0.18 | 831.18 | 30.58 |                  |
| 874       | 1059        | 1926.2  | -7.71 | 0.17 | 847.09 | 31.16 |                  |
| 875       | 1060        | 1941.4  | -7.64 | 0.16 | 863.05 | 31.75 |                  |
| 876       | 1061        | 1932.54 | -7.5  | 0.16 | 852.94 | 31.38 |                  |
| 877       | 1062        | 1918.54 | -7.47 | 0.16 | 848.02 | 31.2  |                  |
| 878       | 1063        | 1909.73 | -7.45 | 0.16 | 842.91 | 31.01 |                  |
| 879       | 1064        | 1894.01 | -7.41 | 0.16 | 836.55 | 30.77 |                  |
| 880       | 1065        | 1861.87 | -7.33 | 0.17 | 822.71 | 30.27 |                  |
| 881       | 1066        | 1829.46 | -7.26 | 0.17 | 808.71 | 29.75 |                  |
| 882       | 1067        | 1799.29 | -7.13 | 0.17 | 794.55 | 29.23 |                  |
| 883       | 1068        | 1769.82 | -7    | 0.17 | 782.13 | 28.77 |                  |
| 884       | 1069        | 1743.32 | -6.88 | 0.16 | 774.64 | 28.5  |                  |
| 885       | 1070        | 1730.13 | -6.85 | 0.17 | 769.21 | 28.3  |                  |
| 886       | 1071        | 1712.74 | -6.73 | 0.16 | 760.33 | 27.97 |                  |
| 887       | 1072        | 1702.82 | -6.71 | 0.17 | 749.07 | 27.56 |                  |
| 888       | 1073        | 1675.3  | -6.64 | 0.17 | 734.25 | 27.01 |                  |
| 889       | 1074        | 1649.39 | -6.56 | 0.17 | 719.37 | 26.46 |                  |
| 890       | 1075        | 1623.93 | -6.45 | 0.17 | 705.94 | 25.97 |                  |
| 891       | 1076        | 1599.52 | -6.32 | 0.17 | 694.35 | 25.54 |                  |
| 892       | 1077        | 1575.1  | -6.18 | 0.17 | 682.45 | 25.11 |                  |
| 893       | 1078        | 1538.4  | -5.94 | 0.17 | 664.82 | 24.46 |                  |
| 894       | 1079        | 1483.54 | -5.51 | 0.16 | 642.16 | 23.62 | Azulenumu (P 45) |
| 895       | 1080        | 1434.87 | -5.08 | 0.14 | 634.04 | 23.32 |                  |
| 896       | 1081        | 1438.72 | -5.56 | 0.16 | 629.6  | 23.16 |                  |
| 897       | 1082        | 1453.2  | -6.34 | 0.21 | 620.31 | 22.82 |                  |
| 898       | 1083        | 1376.55 | -6.13 | 0.22 | 581.74 | 21.4  |                  |
| 899       | 1084        | 1203.33 | -5.09 | 0.19 | 520.15 | 19.14 |                  |
| 900       | 1085        | 1120.78 | -4.79 | 0.2  | 482.02 | 17.73 |                  |
| 901       | 1086        | 1042.35 | -4.55 | 0.21 | 445.81 | 16.4  |                  |
| 902       | 1087        | 972.92  | -4.32 | 0.22 | 412.16 | 15.16 |                  |
| 903       | 1088        | 913.06  | -4.26 | 0.24 | 381.28 | 14.03 |                  |
| 904       | 1089        | 836.58  | -4.09 | 0.26 | 346.19 | 12.74 |                  |
| 905       | 1090        | 836.53  | -4.13 | 0.26 | 345.2  | 12.7  |                  |
| 906       | 1091        | 832.81  | -4.1  | 0.26 | 343.51 | 12.64 |                  |
| 907       | 1092        | 837.03  | -4.16 | 0.26 | 345.84 | 12.72 |                  |
| 908       | 1093        | 822.91  | -4.19 | 0.28 | 338.66 | 12.46 |                  |
| 909       | 1094        | 807.84  | -4.15 | 0.28 | 328.19 | 12.07 |                  |

| Object ID | Transect ID | SCE    | LRR   | LR2  | LSE    | LCI95 | Remarks             |
|-----------|-------------|--------|-------|------|--------|-------|---------------------|
| 910       | 1095        | 795.2  | -4.23 | 0.3  | 322.61 | 11.87 |                     |
| 911       | 1096        | 811.26 | -4.28 | 0.3  | 329.53 | 12.12 |                     |
| 912       | 1097        | 832.54 | -4.28 | 0.29 | 336.99 | 12.4  |                     |
| 913       | 1098        | 849.58 | -4.31 | 0.28 | 344.63 | 12.68 |                     |
| 914       | 1099        | 863.79 | -4.39 | 0.28 | 348.83 | 12.83 |                     |
| 915       | 1100        | 861.27 | -4.49 | 0.29 | 349.64 | 12.86 |                     |
| 916       | 1101        | 856.51 | -4.5  | 0.3  | 346.57 | 12.75 |                     |
| 917       | 1102        | 866.91 | -4.49 | 0.29 | 349.65 | 12.86 |                     |
| 918       | 1103        | 881.19 | -4.62 | 0.29 | 359.79 | 13.24 |                     |
| 919       | 1104        | 903.43 | -4.6  | 0.29 | 363.54 | 13.37 |                     |
| 920       | 1105        | 906.91 | -4.66 | 0.29 | 366.64 | 13.49 |                     |
| 921       | 1106        | 893.42 | -4.68 | 0.29 | 365.46 | 13.44 | Ampemu (P46)        |
| 922       | 1107        | 886.42 | -4.67 | 0.29 | 362.27 | 13.33 |                     |
| 923       | 1108        | 888.19 | -4.59 | 0.28 | 364.89 | 13.42 |                     |
| 924       | 1109        | 899.69 | -4.61 | 0.28 | 368.96 | 13.57 |                     |
| 925       | 1110        | 906.64 | -4.6  | 0.28 | 372.67 | 13.71 |                     |
| 926       | 1111        | 904.03 | -4.6  | 0.28 | 370.29 | 13.62 |                     |
| 927       | 1112        | 882.91 | -4.52 | 0.28 | 362    | 13.32 |                     |
| 928       | 1113        | 873.45 | -4.5  | 0.28 | 355.83 | 13.09 | Beach Resort (P 47) |
| 929       | 1114        | 874.14 | -4.56 | 0.29 | 358.08 | 13.17 |                     |
| 930       | 1115        | 882.49 | -4.57 | 0.29 | 359.57 | 13.23 |                     |
| 931       | 1116        | 859.41 | -4.41 | 0.28 | 353.79 | 13.02 |                     |
| 932       | 1117        | 866.64 | -4.46 | 0.28 | 354.51 | 13.04 |                     |
| 933       | 1118        | 875.76 | -4.52 | 0.28 | 359.68 | 13.23 |                     |
| 934       | 1119        | 871.66 | -4.45 | 0.28 | 359.75 | 13.23 |                     |
| 935       | 1120        | 901.05 | -4.8  | 0.3  | 363.46 | 13.37 |                     |
| 936       | 1121        | 903.44 | -4.79 | 0.3  | 366.1  | 13.47 |                     |
| 937       | 1122        | 882.88 | -4.7  | 0.3  | 360.34 | 13.26 |                     |
| 938       | 1123        | 862.05 | -4.54 | 0.29 | 351.8  | 12.94 |                     |
| 939       | 1124        | 842.47 | -4.41 | 0.29 | 344.07 | 12.66 |                     |
| 940       | 1125        | 824.51 | -4.36 | 0.3  | 335.22 | 12.33 |                     |
| 941       | 1126        | 797.72 | -4.39 | 0.32 | 320.29 | 11.78 |                     |
| 942       | 1127        | 769.51 | -4.42 | 0.34 | 304.73 | 11.21 |                     |
| 943       | 1128        | 745.48 | -4.47 | 0.37 | 289.49 | 10.65 |                     |
| 944       | 1129        | 719.33 | -4.46 | 0.4  | 272.46 | 10.02 |                     |
| 945       | 1130        | 682.28 | -4.38 | 0.42 | 257.74 | 9.48  |                     |
| 946       | 1131        | 654.57 | -4.28 | 0.44 | 240.81 | 8.86  | Bakanta (P 48)      |
| 947       | 1132        | 629.84 | -4.32 | 0.47 | 229.19 | 8.43  |                     |

| Object ID | Transect ID | SCE    | LRR   | LR2  | LSE    | LCI95 | Remarks               |
|-----------|-------------|--------|-------|------|--------|-------|-----------------------|
| 948       | 1133        | 615.99 | -4.43 | 0.5  | 220.81 | 8.12  |                       |
| 949       | 1134        | 599.79 | -4.5  | 0.53 | 210.14 | 7.73  |                       |
| 950       | 1135        | 567.8  | -4.48 | 0.57 | 195.66 | 7.2   |                       |
| 951       | 1136        | 546.64 | -4.47 | 0.6  | 181.15 | 6.66  |                       |
| 952       | 1137        | 523.25 | -4.5  | 0.64 | 168.98 | 6.22  |                       |
| 953       | 1138        | 501.71 | -4.48 | 0.67 | 155.89 | 5.73  |                       |
| 954       | 1139        | 481.03 | -4.36 | 0.69 | 144.94 | 5.33  |                       |
| 955       | 1140        | 456.76 | -4.2  | 0.7  | 137.04 | 5.04  |                       |
| 956       | 1141        | 444.66 | -4.03 | 0.68 | 137.66 | 5.06  |                       |
| 957       | 1142        | 438.47 | -3.9  | 0.66 | 138.76 | 5.1   |                       |
| 958       | 1143        | 434.76 | -3.72 | 0.64 | 138.03 | 5.08  |                       |
| 959       | 1144        | 424.88 | -3.6  | 0.63 | 137.11 | 5.04  |                       |
| 960       | 1145        | 423.22 | -3.5  | 0.61 | 138.36 | 5.09  |                       |
| 961       | 1146        | 417.79 | -3.34 | 0.59 | 138.23 | 5.09  |                       |
| 962       | 1147        | 395.23 | -3.09 | 0.57 | 134.33 | 4.94  |                       |
| 963       | 1148        | 380.79 | -2.91 | 0.55 | 130.26 | 4.79  |                       |
| 964       | 1149        | 353.88 | -3.38 | 0.72 | 106.29 | 3.91  |                       |
| 965       | 1150        | 401.83 | -3.92 | 0.85 | 82.02  | 3.02  |                       |
| 966       | 1151        | 400.99 | -3.91 | 0.89 | 69.29  | 2.55  |                       |
| 967       | 1152        | 409.8  | -3.97 | 0.92 | 59.96  | 2.21  |                       |
| 968       | 1153        | 412.7  | -3.73 | 0.95 | 47.38  | 2.55  |                       |
| 969       | 1154        | 420.93 | -4.04 | 0.96 | 41.32  | 1.52  |                       |
| 970       | 1155        | 429.16 | -4.07 | 0.97 | 32.63  | 1.2   | Sanzule (P 49)        |
| 971       | 1156        | 437.38 | -4.12 | 0.98 | 26.7   | 0.98  |                       |
| 972       | 1157        | 443.24 | -4.17 | 0.99 | 24.35  | 0.9   |                       |
| 973       | 1158        | 452.86 | -4.23 | 0.98 | 26.4   | 0.97  |                       |
| 974       | 1159        | 453.64 | -4.24 | 0.98 | 26.39  | 0.97  |                       |
| 975       | 1160        | 456.9  | -4.26 | 0.98 | 27.52  | 1.01  |                       |
| 976       | 1161        | 462.08 | -4.34 | 0.99 | 26.05  | 0.96  |                       |
| 977       | 1162        | 472.28 | -4.44 | 0.99 | 23.89  | 0.88  |                       |
| 978       | 1163        | 481.4  | -4.51 | 0.99 | 25.29  | 0.93  |                       |
| 979       | 1164        | 491.58 | -4.6  | 0.99 | 26.46  | 0.97  |                       |
| 980       | 1165        | 495.05 | -4.66 | 0.99 | 24.67  | 0.91  | Krisan (Eikwe) (P 50) |
| 981       | 1166        | 497.14 | -4.7  | 0.99 | 22.18  | 0.82  |                       |
| 982       | 1167        | 514.71 | -4.82 | 0.99 | 26.4   | 0.97  |                       |
| 983       | 1168        | 523.91 | -4.9  | 0.99 | 28.49  | 1.05  |                       |
| 984       | 1169        | 526.79 | -4.94 | 0.98 | 31.59  | 1.16  |                       |
| 985       | 1170        | 536.41 | -4.99 | 0.98 | 37.08  | 1.36  |                       |

| Object ID | Transect ID | SCE    | LRR   | LR2  | LSE    | LCI95 | Remarks         |
|-----------|-------------|--------|-------|------|--------|-------|-----------------|
| 986       | 1171        | 543.05 | -4.99 | 0.98 | 39.81  | 1.46  |                 |
| 987       | 1172        | 523.14 | -4.86 | 0.98 | 38.08  | 1.4   |                 |
| 988       | 1173        | 519.64 | -4.79 | 0.97 | 40.24  | 1.48  |                 |
| 989       | 1174        | 516.02 | -4.73 | 0.97 | 41.93  | 1.54  |                 |
| 990       | 1175        | 511.86 | -4.66 | 0.97 | 43.61  | 1.6   |                 |
| 991       | 1176        | 509.94 | -4.6  | 0.96 | 45.69  | 1.68  |                 |
| 992       | 1177        | 509.45 | -4.53 | 0.95 | 54.5   | 2     |                 |
| 993       | 1178        | 508.96 | -4.44 | 0.9  | 73.47  | 2.7   |                 |
| 994       | 1179        | 494.6  | -4.23 | 0.84 | 90.8   | 3.34  |                 |
| 995       | 1180        | 473.52 | -3.99 | 0.77 | 109.31 | 4.02  |                 |
| 996       | 1181        | 474.65 | -3.79 | 0.71 | 122.33 | 4.5   |                 |
| 997       | 1182        | 488.75 | -3.6  | 0.64 | 134.53 | 4.95  |                 |
| 998       | 1183        | 502.03 | -3.39 | 0.57 | 146.73 | 5.4   |                 |
| 999       | 1184        | 504.16 | -3.2  | 0.52 | 152.82 | 5.62  | P 51            |
| 1000      | 1185        | 534.94 | -3.24 | 0.49 | 165.97 | 6.11  |                 |
| 1001      | 1186        | 566.83 | -3.34 | 0.47 | 178.13 | 6.55  |                 |
| 1002      | 1187        | 593.21 | -3.5  | 0.47 | 185.67 | 6.83  |                 |
| 1003      | 1188        | 612.03 | -3.7  | 0.49 | 188.2  | 6.92  |                 |
| 1004      | 1189        | 630.84 | -3.83 | 0.5  | 192.77 | 7.09  |                 |
| 1005      | 1190        | 649.29 | -3.96 | 0.5  | 197.81 | 7.28  |                 |
| 1006      | 1191        | 665.48 | -4.08 | 0.5  | 201.73 | 7.42  |                 |
| 1007      | 1192        | 681.27 | -4.15 | 0.5  | 206.96 | 7.61  |                 |
| 1008      | 1193        | 697.07 | -4.25 | 0.5  | 211.32 | 7.77  |                 |
| 1009      | 1194        | 711.19 | -4.33 | 0.5  | 215.57 | 7.93  |                 |
| 1010      | 1195        | 724.35 | -4.5  | 0.52 | 216.82 | 7.98  |                 |
| 1011      | 1196        | 737.51 | -4.66 | 0.53 | 218.15 | 8.03  |                 |
| 1012      | 1197        | 748.55 | -4.72 | 0.53 | 221.32 | 8.14  |                 |
| 1013      | 1198        | 759.58 | -4.81 | 0.53 | 224.06 | 8.24  |                 |
| 1014      | 1199        | 770.61 | -4.88 | 0.53 | 227.22 | 8.36  |                 |
| 1015      | 1200        | 758.38 | -4.78 | 0.53 | 224.19 | 8.25  |                 |
| 1016      | 1201        | 731.42 | -4.72 | 0.55 | 213.59 | 7.86  |                 |
| 1017      | 1202        | 696.99 | -4.67 | 0.58 | 199.1  | 7.32  |                 |
| 1018      | 1203        | 665.04 | -4.51 | 0.59 | 188.58 | 6.94  |                 |
| 1019      | 1204        | 668.74 | -4.49 | 0.58 | 191.23 | 7.03  |                 |
| 1020      | 1205        | 687.9  | -4.66 | 0.59 | 195.26 | 7.18  | Ngelechi (P 52) |
| 1021      | 1206        | 707.06 | -4.79 | 0.59 | 200    | 7.36  |                 |
| 1022      | 1207        | 719.47 | -4.89 | 0.59 | 203.13 | 7.47  |                 |
| 1023      | 1208        | 715.67 | -5.04 | 0.62 | 196.55 | 7.23  |                 |
| 1024      | 1209        | 711.87 | -5.13 | 0.64 | 191.98 | 7.06  |                 |
| 1025      | 1210        | 715.05 | -5.19 | 0.65 | 191.88 | 7.06  |                 |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks       |
|-----------|-------------|---------|-------|------|--------|-------|---------------|
| 1026      | 1211        | 743.76  | -5.29 | 0.63 | 202.39 | 7.45  |               |
| 1027      | 1212        | 772.48  | -5.38 | 0.61 | 213.24 | 7.84  |               |
| 1028      | 1213        | 801.19  | -5.49 | 0.6  | 223.26 | 8.21  |               |
| 1029      | 1214        | 825.09  | -5.62 | 0.6  | 230.78 | 8.49  |               |
| 1030      | 1215        | 846.08  | -5.76 | 0.6  | 236.61 | 8.7   |               |
| 1031      | 1216        | 867.06  | -5.94 | 0.6  | 241.13 | 8.87  |               |
| 1032      | 1217        | 890.66  | -6.13 | 0.61 | 246.85 | 9.08  |               |
| 1033      | 1218        | 933.67  | -6.18 | 0.57 | 265.56 | 9.77  |               |
| 1034      | 1219        | 962.98  | -6.05 | 0.53 | 283.03 | 10.41 |               |
| 1035      | 1220        | 976.02  | -5.95 | 0.51 | 292.59 | 10.76 |               |
| 1036      | 1221        | 987.29  | -5.85 | 0.48 | 301.14 | 11.08 |               |
| 1037      | 1222        | 998.56  | -5.85 | 0.48 | 306.28 | 11.27 |               |
| 1038      | 1223        | 1002.08 | -5.8  | 0.47 | 309.36 | 11.38 | Anochi (P 53) |
| 1039      | 1224        | 1000.23 | -5.77 | 0.46 | 309.37 | 11.38 |               |
| 1040      | 1225        | 1006.68 | -5.81 | 0.46 | 311.28 | 11.45 |               |
| 1041      | 1226        | 1043.27 | -5.8  | 0.44 | 328.98 | 12.1  |               |
| 1042      | 1227        | 1081.22 | -5.74 | 0.4  | 348.54 | 12.82 |               |
| 1043      | 1228        | 1117.49 | -5.63 | 0.37 | 369.26 | 13.58 |               |
| 1044      | 1229        | 1153.26 | -5.49 | 0.33 | 391.89 | 14.42 |               |
| 1045      | 1230        | 1200.34 | -5.6  | 0.32 | 410.02 | 15.08 |               |
| 1046      | 1231        | 1240.04 | -5.7  | 0.31 | 425.77 | 15.66 |               |
| 1047      | 1232        | 1264.6  | -5.81 | 0.31 | 433.69 | 15.95 |               |
| 1048      | 1233        | 1284.67 | -5.92 | 0.31 | 439.96 | 16.19 |               |
| 1049      | 1234        | 1292.43 | -6    | 0.32 | 441.13 | 16.23 |               |
| 1050      | 1235        | 1300.19 | -6.15 | 0.33 | 440.14 | 16.19 |               |
| 1051      | 1236        | 1329.39 | -6.28 | 0.33 | 449.69 | 16.54 |               |
| 1052      | 1237        | 1369.57 | -6.43 | 0.32 | 464.08 | 17.07 |               |
| 1053      | 1238        | 1411.76 | -6.6  | 0.32 | 478.79 | 17.61 |               |
| 1054      | 1239        | 1426.81 | -6.74 | 0.33 | 481.63 | 17.72 |               |
| 1055      | 1240        | 1445.71 | -6.94 | 0.34 | 485.16 | 17.85 |               |
| 1056      | 1241        | 1470.8  | -7.29 | 0.36 | 486.82 | 17.91 |               |
| 1057      | 1242        | 1495.89 | -7.73 | 0.39 | 485.78 | 17.87 |               |
| 1058      | 1243        | 1523.95 | -8.15 | 0.41 | 487.18 | 17.92 | P 54          |
| 1059      | 1244        | 1552.1  | -8.48 | 0.43 | 491.87 | 18.09 |               |
| 1060      | 1245        | 1573.72 | -8.7  | 0.43 | 495.46 | 18.23 |               |
| 1061      | 1246        | 1594.71 | -8.95 | 0.45 | 497.63 | 18.31 |               |
| 1062      | 1247        | 1614.87 | -9.03 | 0.44 | 505.7  | 18.6  |               |
| 1063      | 1248        | 1635.01 | -9.29 | 0.46 | 507.42 | 18.67 |               |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks        |
|-----------|-------------|---------|-------|------|--------|-------|----------------|
| 1064      | 1249        | 1655.17 | -9.5  | 0.46 | 510.81 | 18.79 |                |
| 1065      | 1250        | 1659.32 | -9.76 | 0.48 | 504.93 | 18.58 |                |
| 1066      | 1251        | 1655.27 | -9.87 | 0.49 | 500.12 | 18.4  |                |
| 1067      | 1252        | 1624.35 | -9.75 | 0.5  | 489.55 | 18.01 |                |
| 1068      | 1253        | 1593.42 | -9.81 | 0.52 | 472.01 | 17.36 |                |
| 1069      | 1254        | 1562.49 | -9.71 | 0.53 | 460.69 | 16.95 |                |
| 1070      | 1255        | 1534.84 | -9.7  | 0.54 | 447.7  | 16.47 |                |
| 1071      | 1256        | 1513.22 | -9.63 | 0.55 | 439.42 | 16.17 |                |
| 1072      | 1257        | 1491.6  | -9.51 | 0.55 | 433.37 | 15.94 |                |
| 1073      | 1258        | 1467.97 | -9.41 | 0.55 | 425.82 | 15.66 |                |
| 1074      | 1259        | 1437.05 | -9.36 | 0.56 | 412.96 | 15.19 |                |
| 1075      | 1260        | 1408.41 | -9.41 | 0.58 | 397.9  | 14.64 |                |
| 1076      | 1261        | 1370.16 | -9.45 | 0.61 | 378.47 | 13.92 |                |
| 1077      | 1262        | 1331.39 | -9.52 | 0.64 | 358.41 | 13.19 |                |
| 1078      | 1263        | 1292.63 | -9.61 | 0.67 | 337.66 | 12.42 | Atuabo (P 55)  |
| 1079      | 1264        | 1253.85 | -9.72 | 0.7  | 316.39 | 11.64 |                |
| 1080      | 1265        | 1205.83 | -9.78 | 0.74 | 291.29 | 10.72 |                |
| 1081      | 1266        | 1136.03 | -9.68 | 0.77 | 260.97 | 9.6   |                |
| 1082      | 1267        | 1095.82 | -9.45 | 0.81 | 230.36 | 8.47  |                |
| 1083      | 1268        | 1063.19 | -9.2  | 0.84 | 203.32 | 7.48  |                |
| 1084      | 1269        | 1030.56 | -8.98 | 0.86 | 184.5  | 6.79  |                |
| 1085      | 1270        | 997.34  | -8.74 | 0.87 | 166.41 | 6.12  |                |
| 1086      | 1271        | 960.15  | -8.43 | 0.89 | 148.58 | 5.47  |                |
| 1087      | 1272        | 922.97  | -8.1  | 0.9  | 133.62 | 4.92  |                |
| 1088      | 1273        | 885.79  | -7.79 | 0.91 | 121.95 | 4.49  |                |
| 1089      | 1274        | 852.73  | -7.53 | 0.92 | 108.61 | 4     |                |
| 1090      | 1275        | 822.03  | -7.3  | 0.94 | 94.26  | 3.47  |                |
| 1091      | 1276        | 793.98  | -7.08 | 0.95 | 80.97  | 2.98  |                |
| 1092      | 1277        | 768.6   | -6.85 | 0.96 | 69.55  | 2.56  |                |
| 1093      | 1278        | 743.23  | -6.61 | 0.96 | 64.54  | 2.37  |                |
| 1094      | 1279        | 719.08  | -6.39 | 0.97 | 58.95  | 2.17  |                |
| 1095      | 1280        | 720.11  | -6.42 | 0.97 | 57.17  | 2.1   |                |
| 1096      | 1281        | 722.76  | -6.49 | 0.97 | 54.22  | 1.99  |                |
| 1097      | 1282        | 725.86  | -6.58 | 0.98 | 50.87  | 1.87  | Ekabaku (P 56) |
| 1098      | 1283        | 728.95  | -6.6  | 0.98 | 49.81  | 1.83  |                |
| 1099      | 1284        | 732.04  | -6.63 | 0.98 | 48.95  | 1.8   |                |
| 1100      | 1285        | 733.89  | -6.65 | 0.97 | 53.5   | 1.97  |                |
| 1101      | 1286        | 732.34  | -6.67 | 0.97 | 56.41  | 2.08  |                |

| Object ID | Transect ID | SCE    | LRR   | LR2  | LSE    | LCI95 | Remarks         |
|-----------|-------------|--------|-------|------|--------|-------|-----------------|
| 1102      | 1287        | 730.8  | -6.68 | 0.97 | 58.89  | 2.17  |                 |
| 1103      | 1288        | 729.53 | -6.71 | 0.98 | 51.58  | 1.9   |                 |
| 1104      | 1289        | 729.59 | -6.7  | 0.98 | 44.29  | 1.63  |                 |
| 1105      | 1290        | 729.65 | -6.65 | 0.99 | 37.58  | 1.38  |                 |
| 1106      | 1291        | 729.71 | -6.68 | 0.99 | 29.8   | 1.1   |                 |
| 1107      | 1292        | 725.39 | -6.7  | 0.99 | 28.47  | 1.05  |                 |
| 1108      | 1293        | 715.09 | -6.54 | 0.99 | 26.16  | 0.96  |                 |
| 1109      | 1294        | 704.8  | -6.42 | 0.99 | 24.91  | 0.92  |                 |
| 1110      | 1295        | 694.51 | -6.3  | 0.99 | 24.38  | 0.9   |                 |
| 1111      | 1296        | 684.21 | -6.16 | 0.99 | 31.3   | 1.15  |                 |
| 1112      | 1297        | 673.92 | -6.04 | 0.98 | 37.32  | 1.37  |                 |
| 1113      | 1298        | 663.63 | -5.89 | 0.98 | 45.11  | 1.66  |                 |
| 1114      | 1299        | 653.34 | -5.77 | 0.97 | 51.09  | 1.88  |                 |
| 1115      | 1300        | 643.1  | -5.67 | 0.97 | 51.92  | 1.91  |                 |
| 1116      | 1301        | 657.61 | -5.81 | 0.96 | 56.79  | 2.09  | Benyin (P 57)   |
| 1117      | 1302        | 676.18 | -5.99 | 0.96 | 62.94  | 2.32  |                 |
| 1118      | 1303        | 696.99 | -6.16 | 0.94 | 76.67  | 2.82  |                 |
| 1119      | 1304        | 718.01 | -6.33 | 0.92 | 92.18  | 3.39  |                 |
| 1120      | 1305        | 706.94 | -6.19 | 0.9  | 102.01 | 3.75  |                 |
| 1121      | 1306        | 685.14 | -5.97 | 0.88 | 109.33 | 4.02  |                 |
| 1122      | 1307        | 663.34 | -5.73 | 0.85 | 119.6  | 4.4   |                 |
| 1123      | 1308        | 641.53 | -5.47 | 0.81 | 131.93 | 4.85  |                 |
| 1124      | 1309        | 619.73 | -5.24 | 0.77 | 143.06 | 5.26  |                 |
| 1125      | 1310        | 631.44 | -5.18 | 0.73 | 156.18 | 5.75  |                 |
| 1126      | 1311        | 656.98 | -5.37 | 0.73 | 161.48 | 5.94  |                 |
| 1127      | 1312        | 677.7  | -5.58 | 0.74 | 163.98 | 6.03  |                 |
| 1128      | 1313        | 698.42 | -5.71 | 0.74 | 169.93 | 6.25  |                 |
| 1129      | 1314        | 719.13 | -5.81 | 0.73 | 177.38 | 6.53  |                 |
| 1130      | 1315        | 740.4  | -5.97 | 0.73 | 182.79 | 6.72  |                 |
| 1131      | 1316        | 766.5  | -6.12 | 0.72 | 190.97 | 7.03  |                 |
| 1132      | 1317        | 757.56 | -5.96 | 0.71 | 191.43 | 7.04  |                 |
| 1133      | 1318        | 742.6  | -5.75 | 0.69 | 190.61 | 7.01  |                 |
| 1134      | 1319        | 732.5  | -5.52 | 0.67 | 193.1  | 7.1   |                 |
| 1135      | 1320        | 738.5  | -5.26 | 0.62 | 204.31 | 7.52  | Nglekazu (P 58) |
| 1136      | 1321        | 744.5  | -5.01 | 0.57 | 215.48 | 7.93  |                 |
| 1137      | 1322        | 774.33 | -5.01 | 0.55 | 228.25 | 8.4   |                 |
| 1138      | 1323        | 803.79 | -5.05 | 0.52 | 240.51 | 8.85  |                 |
| 1139      | 1324        | 831.74 | -5.02 | 0.49 | 255.34 | 9.39  |                 |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks |
|-----------|-------------|---------|-------|------|--------|-------|---------|
| 1140      | 1325        | 859.7   | -4.99 | 0.46 | 270.27 | 9.94  |         |
| 1141      | 1326        | 893.09  | -5.11 | 0.45 | 280.59 | 10.32 |         |
| 1142      | 1327        | 943.73  | -5.19 | 0.42 | 301.81 | 11.1  |         |
| 1143      | 1328        | 996.94  | -5.26 | 0.39 | 325.83 | 11.99 |         |
| 1144      | 1329        | 1033.75 | -5.41 | 0.39 | 338.72 | 12.46 |         |
| 1145      | 1330        | 1031.29 | -5.61 | 0.42 | 330.96 | 12.18 |         |
| 1146      | 1331        | 1028.84 | -5.76 | 0.44 | 325.64 | 11.98 |         |
| 1147      | 1332        | 1026.39 | -6.8  | 0.46 | 381.49 | 22.22 |         |
| 1148      | 1333        | 1023.94 | -6.1  | 0.49 | 313.89 | 11.55 |         |
| 1149      | 1334        | 1021.48 | -6.3  | 0.51 | 306.87 | 11.29 |         |
| 1150      | 1335        | 1019.04 | -6.53 | 0.54 | 298.86 | 10.99 |         |
| 1151      | 1336        | 1016.58 | -6.77 | 0.58 | 289.95 | 10.67 |         |
| 1152      | 1337        | 1014.13 | -6.96 | 0.6  | 283.2  | 10.42 |         |
| 1153      | 1338        | 1020.77 | -7.26 | 0.63 | 277.27 | 10.2  |         |
| 1154      | 1339        | 1044.65 | -7.65 | 0.65 | 277.48 | 10.21 |         |
| 1155      | 1340        | 1070.99 | -8.2  | 0.69 | 272.75 | 10.03 |         |
| 1156      | 1341        | 1121.23 | -8.68 | 0.7  | 281.85 | 10.37 |         |
| 1157      | 1342        | 1171.46 | -9.15 | 0.71 | 291.81 | 10.74 | P 59    |
| 1158      | 1343        | 1221.7  | -9.6  | 0.72 | 302.47 | 11.13 |         |
| 1159      | 1344        | 1267.04 | -9.98 | 0.72 | 312.89 | 11.51 |         |
| 1160      | 1345        | 1251.67 | -9.9  | 0.72 | 307.95 | 11.33 |         |
| 1161      | 1346        | 1231.7  | -9.82 | 0.73 | 300.87 | 11.07 |         |
| 1162      | 1347        | 1211.73 | -9.76 | 0.73 | 293.24 | 10.79 |         |
| 1163      | 1348        | 1191.75 | -9.71 | 0.74 | 285.13 | 10.49 |         |
| 1164      | 1349        | 1171.84 | -9.66 | 0.75 | 277.24 | 10.2  |         |
| 1165      | 1350        | 1152.69 | -9.6  | 0.76 | 270.01 | 9.93  |         |
| 1166      | 1351        | 1133.54 | -9.44 | 0.76 | 265.46 | 9.77  |         |
| 1167      | 1352        | 1114.39 | -9.41 | 0.77 | 257.46 | 9.47  |         |
| 1168      | 1353        | 1095.25 | -9.35 | 0.78 | 250.21 | 9.2   |         |
| 1169      | 1354        | 1071.44 | -9.21 | 0.78 | 242.94 | 8.94  |         |
| 1170      | 1355        | 1051.23 | -9.17 | 0.79 | 232.76 | 8.56  |         |
| 1171      | 1356        | 1047.15 | -9.22 | 0.81 | 221.45 | 8.15  |         |
| 1172      | 1357        | 1043.07 | -9.14 | 0.82 | 214.39 | 7.89  |         |
| 1173      | 1358        | 1039    | -9.05 | 0.81 | 215.78 | 7.94  |         |
| 1174      | 1359        | 1034.92 | -8.94 | 0.8  | 220.34 | 8.11  |         |
| 1175      | 1360        | 1030.84 | -8.92 | 0.8  | 221.86 | 8.16  |         |
| 1176      | 1361        | 1026.76 | -8.85 | 0.79 | 225.16 | 8.28  |         |
| 1177      | 1362        | 1022.66 | -8.8  | 0.79 | 228.85 | 8.42  | P 60    |

| Object ID | Transect ID | SCE     | LRR   | LR2  | LSE    | LCI95 | Remarks |
|-----------|-------------|---------|-------|------|--------|-------|---------|
| 1178      | 1363        | 1019.55 | -8.7  | 0.77 | 234.53 | 8.63  |         |
| 1179      | 1364        | 1024.25 | -8.64 | 0.77 | 238.1  | 8.76  |         |
| 1180      | 1365        | 1026.52 | -8.61 | 0.76 | 239.71 | 8.82  |         |
| 1181      | 1366        | 1023.48 | -8.58 | 0.76 | 239.06 | 8.79  |         |
| 1182      | 1367        | 1020.44 | -8.53 | 0.76 | 239.00 | 8.79  |         |
| 1183      | 1368        | 1017.41 | -8.44 | 0.75 | 240.33 | 8.84  |         |
| 1184      | 1369        | 1014.37 | -8.4  | 0.75 | 240.05 | 8.83  |         |
| 1185      | 1370        | 1008.46 | -8.34 | 0.75 | 238.9  | 8.79  |         |
| 1186      | 1371        | 1000.67 | -8.32 | 0.76 | 235.69 | 8.67  |         |
| 1187      | 1372        | 992.87  | -8.24 | 0.75 | 234.43 | 8.62  |         |
| 1188      | 1373        | 985.08  | -8.15 | 0.75 | 233.31 | 8.58  |         |
| 1189      | 1374        | 978.74  | -8.06 | 0.75 | 232.65 | 8.56  |         |
| 1190      | 1375        | 977.27  | -7.95 | 0.74 | 235.19 | 8.65  |         |
| 1191      | 1376        | 977.84  | -7.85 | 0.73 | 238.33 | 8.77  |         |
| 1192      | 1377        | 987.72  | -7.9  | 0.73 | 241.09 | 8.87  |         |
| 1193      | 1378        | 997.59  | -7.93 | 0.72 | 244.83 | 9.01  |         |
| 1194      | 1379        | 1014.6  | -7.95 | 0.71 | 252.28 | 9.28  |         |
| 1195      | 1380        | 1033.39 | -7.91 | 0.69 | 262.16 | 9.64  |         |
| 1196      | 1381        | 1052.19 | -7.86 | 0.67 | 272.81 | 10.04 | P 61    |
| 1197      | 1382        | 1061.9  | -7.87 | 0.67 | 277.3  | 10.2  |         |
| 1198      | 1383        | 1062.22 | -7.98 | 0.68 | 273.96 | 10.08 |         |
| 1199      | 1384        | 1062.55 | -8.09 | 0.69 | 270.56 | 9.95  |         |
| 1200      | 1385        | 1063.07 | -8.05 | 0.69 | 272.17 | 10.01 |         |
| 1201      | 1386        | 1076.76 | -8.08 | 0.68 | 278.28 | 10.24 |         |
| 1202      | 1387        | 1090.45 | -8.15 | 0.68 | 282.35 | 10.39 |         |
| 1203      | 1388        | 1104.13 | -8.18 | 0.67 | 288.05 | 10.6  |         |
| 1204      | 1389        | 1117.81 | -8.19 | 0.66 | 294.05 | 10.82 |         |
| 1205      | 1390        | 1131.51 | -8.16 | 0.65 | 301.71 | 11.1  |         |
| 1206      | 1391        | 1145.19 | -8.24 | 0.65 | 305.4  | 11.23 |         |
| 1207      | 1392        | 1158.87 | -8.25 | 0.64 | 311.68 | 11.47 |         |
| 1208      | 1393        | 1170.15 | -8.24 | 0.63 | 317.49 | 11.68 |         |
| 1209      | 1394        | 1175.06 | -8.24 | 0.62 | 319.94 | 11.77 |         |
| 1210      | 1395        | 1179.97 | -8.3  | 0.63 | 320.44 | 11.79 |         |
| 1211      | 1396        | 1184.89 | -8.44 | 0.64 | 318.94 | 11.73 |         |
| 1212      | 1397        | 1189.34 | -8.56 | 0.64 | 317.78 | 11.69 |         |
| 1213      | 1398        | 1191.68 | -8.68 | 0.65 | 316.07 | 11.63 |         |
| 1214      | 1399        | 1194.01 | -8.77 | 0.66 | 314.87 | 11.58 |         |
| 1215      | 1400        | 1190.24 | -8.76 | 0.66 | 313.26 | 11.52 |         |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks             |
|-----------|-------------|---------|--------|------|--------|-------|---------------------|
| 1216      | 1401        | 1185.59 | -9.41  | 0.68 | 367.9  | 19.8  | Twene (P 62)        |
| 1217      | 1402        | 1177.7  | -8.6   | 0.65 | 312.02 | 11.48 |                     |
| 1218      | 1403        | 1166.93 | -8.61  | 0.66 | 306.34 | 11.27 |                     |
| 1219      | 1404        | 1156.16 | -8.53  | 0.66 | 303.15 | 11.15 |                     |
| 1220      | 1405        | 1145.4  | -8.45  | 0.66 | 300.36 | 11.05 |                     |
| 1221      | 1406        | 1134.63 | -8.39  | 0.67 | 296.22 | 10.9  |                     |
| 1222      | 1407        | 1117.65 | -8.39  | 0.68 | 287.97 | 10.59 |                     |
| 1223      | 1408        | 1100.24 | -8.37  | 0.69 | 280.38 | 10.31 |                     |
| 1224      | 1409        | 1082.83 | -8.37  | 0.7  | 272.19 | 10.01 |                     |
| 1225      | 1410        | 1065.42 | -8.38  | 0.72 | 263.7  | 9.7   |                     |
| 1226      | 1411        | 1047.31 | -8.4   | 0.73 | 254.76 | 9.37  |                     |
| 1227      | 1412        | 1032.71 | -8.44  | 0.74 | 246.75 | 9.08  |                     |
| 1228      | 1413        | 1018.79 | -8.48  | 0.76 | 238.98 | 8.79  |                     |
| 1229      | 1414        | 1004.88 | -8.6   | 0.78 | 229.17 | 8.43  |                     |
| 1230      | 1415        | 1001.39 | -8.73  | 0.79 | 222.19 | 8.17  |                     |
| 1231      | 1416        | 1015.61 | -8.83  | 0.8  | 219.04 | 8.06  |                     |
| 1232      | 1417        | 1026.63 | -8.94  | 0.81 | 216.02 | 7.95  |                     |
| 1233      | 1418        | 1036.98 | -9.04  | 0.82 | 213.29 | 7.85  |                     |
| 1234      | 1419        | 1047.33 | -9.14  | 0.82 | 211.19 | 7.77  |                     |
| 1235      | 1420        | 1058.26 | -9.22  | 0.82 | 212.25 | 7.81  |                     |
| 1236      | 1421        | 1069.28 | -9.32  | 0.83 | 213.39 | 7.85  | Egyiza (P 63)       |
| 1237      | 1422        | 1079.97 | -9.4   | 0.83 | 214.46 | 7.89  |                     |
| 1238      | 1423        | 1090.36 | -9.48  | 0.83 | 215.45 | 7.93  |                     |
| 1239      | 1424        | 1100.76 | -9.57  | 0.83 | 213.71 | 7.86  |                     |
| 1240      | 1425        | 1111.16 | -9.66  | 0.84 | 211.98 | 7.8   |                     |
| 1241      | 1426        | 1121.54 | -9.74  | 0.84 | 210.26 | 7.74  |                     |
| 1242      | 1427        | 1131.94 | -9.84  | 0.85 | 208.88 | 7.68  |                     |
| 1243      | 1428        | 1138.16 | -9.93  | 0.85 | 209.14 | 7.69  | Allengenzule (P 64) |
| 1244      | 1429        | 1143.2  | -9.99  | 0.85 | 209.57 | 7.71  |                     |
| 1245      | 1430        | 1144.55 | -10    | 0.85 | 208.73 | 7.68  |                     |
| 1246      | 1431        | 1141.91 | -9.99  | 0.85 | 207.5  | 7.63  |                     |
| 1247      | 1432        | 1139.25 | -9.99  | 0.86 | 202.85 | 7.46  |                     |
| 1248      | 1433        | 1136.04 | -10.00 | 0.87 | 193.14 | 7.11  |                     |
| 1249      | 1434        | 1131.74 | -10.00 | 0.88 | 183.53 | 6.75  |                     |
| 1250      | 1435        | 1127.33 | -9.98  | 0.89 | 177.07 | 6.51  |                     |
| 1251      | 1436        | 1122.87 | -9.94  | 0.88 | 179.39 | 6.6   |                     |
| 1252      | 1437        | 1132.81 | -10.03 | 0.88 | 184.19 | 6.78  |                     |
| 1253      | 1438        | 1165.27 | -10.35 | 0.88 | 192.89 | 7.1   |                     |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks         |
|-----------|-------------|---------|--------|------|--------|-------|-----------------|
| 1254      | 1439        | 1197.72 | -10.67 | 0.87 | 201.65 | 7.42  |                 |
| 1255      | 1440        | 1221.59 | -10.91 | 0.87 | 208.29 | 7.66  |                 |
| 1256      | 1441        | 1230.85 | -11.02 | 0.87 | 211.76 | 7.79  |                 |
| 1257      | 1442        | 1240.62 | -11.13 | 0.87 | 214.99 | 7.91  |                 |
| 1258      | 1443        | 1251.51 | -11.23 | 0.87 | 216.97 | 7.98  |                 |
| 1259      | 1444        | 1262.62 | -11.32 | 0.87 | 218.56 | 8.04  |                 |
| 1260      | 1445        | 1273.73 | -11.43 | 0.87 | 223.32 | 8.22  |                 |
| 1261      | 1446        | 1283.08 | -11.51 | 0.86 | 228.8  | 8.42  |                 |
| 1262      | 1447        | 1291.97 | -11.58 | 0.86 | 234.12 | 8.61  |                 |
| 1263      | 1448        | 1301.43 | -11.66 | 0.85 | 241.19 | 8.87  |                 |
| 1264      | 1449        | 1318.81 | -11.77 | 0.85 | 248.63 | 9.15  |                 |
| 1265      | 1450        | 1336.19 | -11.89 | 0.84 | 256.35 | 9.43  |                 |
| 1266      | 1451        | 1342.48 | -11.91 | 0.84 | 262.25 | 9.65  |                 |
| 1267      | 1452        | 1330.06 | -11.78 | 0.83 | 266.77 | 9.81  | Ezilinbo (P 65) |
| 1268      | 1453        | 1309.98 | -11.58 | 0.82 | 274.3  | 10.09 |                 |
| 1269      | 1454        | 1289.9  | -11.39 | 0.8  | 281.96 | 10.37 |                 |
| 1270      | 1455        | 1288.95 | -11.23 | 0.79 | 290.23 | 10.68 |                 |
| 1271      | 1456        | 1297.14 | -11.06 | 0.77 | 298.8  | 10.99 |                 |
| 1272      | 1457        | 1306.82 | -10.93 | 0.76 | 306.19 | 11.26 |                 |
| 1273      | 1458        | 1316.51 | -10.79 | 0.75 | 313.91 | 11.55 |                 |
| 1274      | 1459        | 1323.24 | -10.63 | 0.73 | 321.22 | 11.82 |                 |
| 1275      | 1460        | 1315.59 | -10.43 | 0.72 | 323.03 | 11.88 |                 |
| 1276      | 1461        | 1307.94 | -10.28 | 0.72 | 323.7  | 11.91 |                 |
| 1277      | 1462        | 1302.56 | -10.14 | 0.71 | 325.45 | 11.97 |                 |
| 1278      | 1463        | 1341.36 | -10.37 | 0.7  | 337.27 | 12.41 |                 |
| 1279      | 1464        | 1380.32 | -10.56 | 0.69 | 350.57 | 12.9  | Bonyere (P 66)  |
| 1280      | 1465        | 1432.78 | -10.74 | 0.68 | 369.86 | 13.61 |                 |
| 1281      | 1466        | 1435.98 | -10.91 | 0.69 | 366.32 | 13.48 |                 |
| 1282      | 1467        | 1437.78 | -11.1  | 0.7  | 361.67 | 13.31 |                 |
| 1283      | 1468        | 1439.59 | -11.29 | 0.71 | 357.02 | 13.13 |                 |
| 1284      | 1469        | 1441.65 | -11.5  | 0.73 | 352.19 | 12.96 |                 |
| 1285      | 1470        | 1450.78 | -11.7  | 0.73 | 351.41 | 12.93 |                 |
| 1286      | 1471        | 1459.9  | -11.92 | 0.74 | 350.45 | 12.89 |                 |
| 1287      | 1472        | 1469.01 | -12.16 | 0.75 | 348.58 | 12.82 |                 |
| 1288      | 1473        | 1478.17 | -12.37 | 0.76 | 346.74 | 12.76 |                 |
| 1289      | 1474        | 1481.68 | -12.52 | 0.77 | 344.2  | 12.66 |                 |
| 1290      | 1475        | 1460.73 | -12.44 | 0.77 | 336.66 | 12.38 |                 |
| 1291      | 1476        | 1439.77 | -12.33 | 0.78 | 330.15 | 12.15 |                 |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks        |
|-----------|-------------|---------|--------|------|--------|-------|----------------|
| 1292      | 1477        | 1418.61 | -12.21 | 0.78 | 323.27 | 11.89 |                |
| 1293      | 1478        | 1397.1  | -12.13 | 0.79 | 315.97 | 11.62 |                |
| 1294      | 1479        | 1375.59 | -12.07 | 0.79 | 309.29 | 11.38 |                |
| 1295      | 1480        | 1353.47 | -11.98 | 0.8  | 301.78 | 11.1  |                |
| 1296      | 1481        | 1314.48 | -11.75 | 0.81 | 288.64 | 10.62 |                |
| 1297      | 1482        | 1291.61 | -11.54 | 0.82 | 272.77 | 10.03 |                |
| 1298      | 1483        | 1268.74 | -11.33 | 0.83 | 256.99 | 9.45  | Bonyere (P 67) |
| 1299      | 1484        | 1245.85 | -11.15 | 0.84 | 241.05 | 8.87  |                |
| 1300      | 1485        | 1223.08 | -10.99 | 0.85 | 228.11 | 8.39  |                |
| 1301      | 1486        | 1233.33 | -11.12 | 0.86 | 223.01 | 8.2   |                |
| 1302      | 1487        | 1243.76 | -11.25 | 0.87 | 217.8  | 8.01  |                |
| 1303      | 1488        | 1254.19 | -11.39 | 0.88 | 213.24 | 7.84  |                |
| 1304      | 1489        | 1263.29 | -11.51 | 0.89 | 205.52 | 7.56  |                |
| 1305      | 1490        | 1271.34 | -11.62 | 0.9  | 196.56 | 7.23  |                |
| 1306      | 1491        | 1277.42 | -11.72 | 0.91 | 188.14 | 6.92  |                |
| 1307      | 1492        | 1277.96 | -11.76 | 0.92 | 178.22 | 6.56  |                |
| 1308      | 1493        | 1278.51 | -11.8  | 0.93 | 167.78 | 6.17  |                |
| 1309      | 1494        | 1283.28 | -11.88 | 0.93 | 158.47 | 5.83  |                |
| 1310      | 1495        | 1288.06 | -11.95 | 0.94 | 148.21 | 5.45  |                |
| 1311      | 1496        | 1292.84 | -12    | 0.95 | 136.73 | 5.03  |                |
| 1312      | 1497        | 1292.99 | -12.02 | 0.95 | 133.14 | 4.9   |                |
| 1313      | 1498        | 1305.5  | -12.1  | 0.96 | 131.08 | 4.82  |                |
| 1314      | 1499        | 1297.43 | -12.07 | 0.95 | 134.24 | 4.94  |                |
| 1315      | 1500        | 1294.4  | -12.05 | 0.95 | 134.67 | 4.95  |                |
| 1316      | 1501        | 1297.55 | -12.08 | 0.95 | 137.9  | 5.07  |                |
| 1317      | 1502        | 1309.85 | -12.15 | 0.95 | 141.09 | 5.19  |                |
| 1318      | 1503        | 1315.74 | -12.15 | 0.95 | 141.93 | 5.22  | P 68           |
| 1319      | 1504        | 1312.86 | -12.05 | 0.94 | 145.28 | 5.34  |                |
| 1320      | 1505        | 1332.93 | -12.23 | 0.93 | 161.2  | 5.93  |                |
| 1321      | 1506        | 1356.7  | -12.47 | 0.93 | 171    | 6.29  |                |
| 1322      | 1507        | 1380.46 | -12.71 | 0.92 | 181.34 | 6.67  |                |
| 1323      | 1508        | 1404.21 | -12.94 | 0.92 | 190.39 | 7     |                |
| 1324      | 1509        | 1427.98 | -13.17 | 0.92 | 198.86 | 7.32  |                |
| 1325      | 1510        | 1454.25 | -13.4  | 0.91 | 210.42 | 7.74  |                |
| 1326      | 1511        | 1489.16 | -13.66 | 0.9  | 225.73 | 8.3   |                |
| 1327      | 1512        | 1524.07 | -13.91 | 0.89 | 239.05 | 8.79  |                |
| 1328      | 1513        | 1539.47 | -13.98 | 0.89 | 247.97 | 9.12  |                |
| 1329      | 1514        | 1530.96 | -13.86 | 0.89 | 246.65 | 9.07  |                |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks       |
|-----------|-------------|---------|--------|------|--------|-------|---------------|
| 1330      | 1515        | 1522.45 | -13.74 | 0.89 | 245.66 | 9.04  |               |
| 1331      | 1516        | 1502.76 | -13.56 | 0.88 | 246.47 | 9.07  |               |
| 1332      | 1517        | 1482.91 | -13.37 | 0.88 | 247.87 | 9.12  | P 69          |
| 1333      | 1518        | 1490.89 | -13.43 | 0.87 | 256.77 | 9.45  |               |
| 1334      | 1519        | 1508.47 | -13.58 | 0.86 | 268.3  | 9.87  |               |
| 1335      | 1520        | 1526.04 | -13.75 | 0.86 | 281.94 | 10.37 |               |
| 1336      | 1521        | 1545.46 | -13.88 | 0.84 | 303.43 | 11.16 |               |
| 1337      | 1522        | 1565.38 | -14.03 | 0.82 | 326.01 | 11.99 |               |
| 1338      | 1523        | 1582.36 | -14.13 | 0.81 | 345.46 | 12.71 |               |
| 1339      | 1524        | 1605.04 | -14.1  | 0.79 | 360.51 | 13.26 |               |
| 1340      | 1525        | 1637.69 | -14.08 | 0.78 | 376.35 | 13.84 |               |
| 1341      | 1526        | 1649.89 | -14.08 | 0.77 | 382.33 | 14.06 |               |
| 1342      | 1527        | 1655.28 | -14.09 | 0.77 | 384.83 | 14.16 |               |
| 1343      | 1528        | 1660.67 | -14.11 | 0.77 | 387.31 | 14.25 |               |
| 1344      | 1529        | 1667.25 | -14.12 | 0.77 | 390.09 | 14.35 |               |
| 1345      | 1530        | 1678.02 | -14.12 | 0.76 | 394.97 | 14.53 |               |
| 1346      | 1531        | 1688.8  | -14.12 | 0.76 | 399.5  | 14.7  |               |
| 1347      | 1532        | 1699.58 | -14.12 | 0.75 | 404.41 | 14.88 |               |
| 1348      | 1533        | 1699.77 | -14.12 | 0.75 | 403.19 | 14.83 |               |
| 1349      | 1534        | 1680.41 | -14.17 | 0.76 | 393.59 | 14.48 |               |
| 1350      | 1535        | 1661.05 | -14.21 | 0.77 | 383.45 | 14.11 | Egbazo (P 70) |
| 1351      | 1536        | 1641.69 | -14.26 | 0.78 | 373.76 | 13.75 |               |
| 1352      | 1537        | 1638.01 | -14.26 | 0.79 | 371.6  | 13.67 |               |
| 1353      | 1538        | 1634.56 | -14.27 | 0.79 | 370.17 | 13.62 |               |
| 1354      | 1539        | 1631.11 | -14.28 | 0.79 | 368.8  | 13.57 |               |
| 1355      | 1540        | 1627.75 | -14.28 | 0.79 | 367.25 | 13.51 |               |
| 1356      | 1541        | 1631.69 | -14.35 | 0.79 | 367.36 | 13.51 |               |
| 1357      | 1542        | 1636.77 | -14.43 | 0.79 | 368.29 | 13.55 |               |
| 1358      | 1543        | 1643.04 | -14.5  | 0.79 | 370.04 | 13.61 |               |
| 1359      | 1544        | 1649.31 | -14.57 | 0.79 | 371.49 | 13.67 |               |
| 1360      | 1545        | 1655.57 | -14.66 | 0.79 | 372.42 | 13.7  |               |
| 1361      | 1546        | 1661.84 | -14.74 | 0.8  | 373.01 | 13.72 |               |
| 1362      | 1547        | 1648.53 | -14.64 | 0.8  | 369.04 | 13.58 |               |
| 1363      | 1548        | 1619.04 | -14.39 | 0.8  | 361.67 | 13.3  |               |
| 1364      | 1549        | 1587.09 | -14.14 | 0.8  | 353.73 | 13.01 |               |
| 1365      | 1550        | 1555.13 | -13.88 | 0.8  | 346    | 12.73 |               |
| 1366      | 1551        | 1523.19 | -13.62 | 0.8  | 337.03 | 12.4  |               |
| 1367      | 1552        | 1497.08 | -13.38 | 0.8  | 332.5  | 12.23 |               |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks          |
|-----------|-------------|---------|--------|------|--------|-------|------------------|
| 1368      | 1553        | 1511.35 | -13.4  | 0.8  | 338.34 | 12.45 |                  |
| 1369      | 1554        | 1539.1  | -13.54 | 0.79 | 346.79 | 12.76 |                  |
| 1370      | 1555        | 1566.86 | -13.68 | 0.79 | 354.86 | 13.05 |                  |
| 1371      | 1556        | 1594.6  | -13.82 | 0.78 | 363.24 | 13.36 | Ahobre (P 71)    |
| 1372      | 1557        | 1614.13 | -13.98 | 0.78 | 367.73 | 13.53 |                  |
| 1373      | 1558        | 1631.56 | -14.14 | 0.78 | 371.22 | 13.66 |                  |
| 1374      | 1559        | 1633.64 | -14.17 | 0.78 | 371.4  | 13.66 |                  |
| 1375      | 1560        | 1635.98 | -14.19 | 0.78 | 371.68 | 13.67 |                  |
| 1376      | 1561        | 1643.99 | -14.21 | 0.78 | 374.97 | 13.79 |                  |
| 1377      | 1562        | 1652.00 | -14.22 | 0.78 | 377.98 | 13.91 |                  |
| 1378      | 1563        | 1660.03 | -14.22 | 0.78 | 381.88 | 14.05 |                  |
| 1379      | 1564        | 1668.04 | -14.21 | 0.77 | 387.15 | 14.24 |                  |
| 1380      | 1565        | 1676.08 | -14.17 | 0.77 | 391.2  | 14.39 |                  |
| 1381      | 1566        | 1680.3  | -14.02 | 0.76 | 397.19 | 14.61 |                  |
| 1382      | 1567        | 1679.72 | -13.79 | 0.75 | 401.94 | 14.79 |                  |
| 1383      | 1568        | 1679.14 | -13.57 | 0.73 | 407.15 | 14.98 |                  |
| 1384      | 1569        | 1677.74 | -13.36 | 0.72 | 412.2  | 15.16 |                  |
| 1385      | 1570        | 1667.03 | -13.19 | 0.72 | 412.03 | 15.16 |                  |
| 1386      | 1571        | 1669.49 | -13.15 | 0.72 | 414.43 | 15.25 |                  |
| 1387      | 1572        | 1671.96 | -13.11 | 0.71 | 416.88 | 15.34 |                  |
| 1388      | 1573        | 1667.71 | -13.07 | 0.71 | 415.9  | 15.3  |                  |
| 1389      | 1574        | 1662.08 | -13.05 | 0.71 | 414.02 | 15.23 |                  |
| 1390      | 1575        | 1656.44 | -13.03 | 0.71 | 411.99 | 15.16 |                  |
| 1391      | 1576        | 1650.81 | -13.01 | 0.72 | 409.96 | 15.08 |                  |
| 1392      | 1577        | 1644.41 | -12.99 | 0.72 | 407.56 | 14.99 |                  |
| 1393      | 1578        | 1634.42 | -12.97 | 0.72 | 403.4  | 14.84 | Old Edobo (P 72) |
| 1394      | 1579        | 1624.44 | -12.95 | 0.72 | 399.39 | 14.69 |                  |
| 1395      | 1580        | 1614.46 | -12.93 | 0.73 | 395.56 | 14.55 |                  |
| 1396      | 1581        | 1606.98 | -12.9  | 0.73 | 392.97 | 14.46 |                  |
| 1397      | 1582        | 1615.05 | -12.85 | 0.72 | 398.01 | 14.64 |                  |
| 1398      | 1583        | 1623.13 | -12.8  | 0.72 | 403.05 | 14.83 |                  |
| 1399      | 1584        | 1631.2  | -12.76 | 0.71 | 407.99 | 15.01 |                  |
| 1400      | 1585        | 1639.28 | -12.71 | 0.7  | 412.78 | 15.19 |                  |
| 1401      | 1586        | 1647.34 | -12.66 | 0.7  | 417.66 | 15.36 |                  |
| 1402      | 1587        | 1655.41 | -12.63 | 0.69 | 422.66 | 15.55 |                  |
| 1403      | 1588        | 1663.49 | -12.59 | 0.68 | 427.61 | 15.73 |                  |
| 1404      | 1589        | 1669.35 | -12.55 | 0.68 | 431.39 | 15.87 |                  |
| 1405      | 1590        | 1644.92 | -12.54 | 0.69 | 420.21 | 15.46 |                  |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks             |
|-----------|-------------|---------|--------|------|--------|-------|---------------------|
| 1406      | 1591        | 1620.5  | -12.52 | 0.7  | 410.12 | 15.09 |                     |
| 1407      | 1592        | 1594.63 | -12.46 | 0.71 | 399.87 | 14.71 |                     |
| 1408      | 1593        | 1562.77 | -12.29 | 0.71 | 389.64 | 14.33 |                     |
| 1409      | 1594        | 1533.08 | -12.14 | 0.72 | 379.87 | 13.97 | Atwebansi (P73)     |
| 1410      | 1595        | 1503.39 | -12.01 | 0.72 | 369.33 | 13.59 |                     |
| 1411      | 1596        | 1473.71 | -11.89 | 0.73 | 359.04 | 13.21 |                     |
| 1412      | 1597        | 1452.29 | -11.75 | 0.73 | 352.72 | 12.98 |                     |
| 1413      | 1598        | 1446.55 | -11.69 | 0.73 | 351.00 | 12.91 |                     |
| 1414      | 1599        | 1448.02 | -11.71 | 0.74 | 351.19 | 12.92 |                     |
| 1415      | 1600        | 1449.51 | -11.74 | 0.74 | 351.39 | 12.93 |                     |
| 1416      | 1601        | 1449.7  | -11.76 | 0.74 | 350.73 | 12.9  |                     |
| 1417      | 1602        | 1432.4  | -11.8  | 0.75 | 341.88 | 12.58 |                     |
| 1418      | 1603        | 1415.09 | -11.81 | 0.76 | 332.43 | 12.23 |                     |
| 1419      | 1604        | 1397.77 | -11.89 | 0.77 | 323.14 | 11.89 |                     |
| 1420      | 1605        | 1363.2  | -12.01 | 0.8  | 299.87 | 11.03 | Ekpo (P 74)         |
| 1421      | 1606        | 1361.99 | -12.08 | 0.83 | 271.44 | 9.99  |                     |
| 1422      | 1607        | 1358.87 | -12.16 | 0.86 | 244.78 | 9     |                     |
| 1423      | 1608        | 1355.76 | -12.18 | 0.87 | 236.29 | 8.69  |                     |
| 1424      | 1609        | 1354.35 | -12.21 | 0.87 | 231.43 | 8.51  |                     |
| 1425      | 1610        | 1355.2  | -12.24 | 0.88 | 225.49 | 8.3   |                     |
| 1426      | 1611        | 1350.46 | -12.23 | 0.89 | 219.75 | 8.08  |                     |
| 1427      | 1612        | 1333.13 | -12.11 | 0.89 | 213.83 | 7.87  |                     |
| 1428      | 1613        | 1314.94 | -11.96 | 0.89 | 210    | 7.73  |                     |
| 1429      | 1614        | 1297.15 | -11.8  | 0.89 | 205.19 | 7.55  |                     |
| 1430      | 1615        | 1288.36 | -11.7  | 0.9  | 198.59 | 7.31  |                     |
| 1431      | 1616        | 1283.71 | -11.62 | 0.9  | 191.71 | 7.05  |                     |
| 1432      | 1617        | 1279.74 | -11.54 | 0.91 | 184.44 | 6.79  |                     |
| 1433      | 1618        | 1275.78 | -11.46 | 0.91 | 176.89 | 6.51  |                     |
| 1434      | 1619        | 1262.08 | -11.34 | 0.92 | 171.89 | 6.32  |                     |
| 1435      | 1620        | 1248.41 | -11.27 | 0.91 | 172.49 | 6.35  | Half Assini ( P 75) |
| 1436      | 1621        | 1246.31 | -11.29 | 0.9  | 183.17 | 6.74  |                     |
| 1437      | 1622        | 1254.12 | -11.36 | 0.9  | 193.77 | 7.13  |                     |
| 1438      | 1623        | 1264.33 | -11.44 | 0.89 | 200.36 | 7.37  |                     |
| 1439      | 1624        | 1272.51 | -11.51 | 0.89 | 204.13 | 7.51  |                     |
| 1440      | 1625        | 1279.42 | -11.59 | 0.89 | 208.07 | 7.65  |                     |
| 1441      | 1626        | 1287.61 | -11.69 | 0.9  | 199.55 | 7.34  |                     |
| 1442      | 1627        | 1296.3  | -11.79 | 0.9  | 191.5  | 7.04  |                     |
| 1443      | 1628        | 1307.44 | -11.89 | 0.91 | 183.21 | 6.74  |                     |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks        |
|-----------|-------------|---------|--------|------|--------|-------|----------------|
| 1444      | 1629        | 1317.98 | -12.01 | 0.92 | 176.48 | 6.49  |                |
| 1445      | 1630        | 1316.81 | -12.05 | 0.93 | 171.37 | 6.3   |                |
| 1446      | 1631        | 1308.16 | -12.03 | 0.93 | 165.48 | 6.09  |                |
| 1447      | 1632        | 1284.52 | -11.87 | 0.94 | 156.05 | 5.74  |                |
| 1448      | 1633        | 1268.93 | -11.73 | 0.94 | 143.84 | 5.29  |                |
| 1449      | 1634        | 1257.21 | -11.63 | 0.95 | 131.65 | 4.84  |                |
| 1450      | 1635        | 1245.48 | -11.54 | 0.96 | 119.81 | 4.41  |                |
| 1451      | 1636        | 1233.76 | -11.43 | 0.97 | 100.68 | 3.7   |                |
| 1452      | 1637        | 1220.43 | -11.32 | 0.98 | 88.52  | 3.26  |                |
| 1453      | 1638        | 1200.79 | -11.17 | 0.98 | 83.69  | 3.08  |                |
| 1454      | 1639        | 1197.38 | -11.16 | 0.98 | 78.12  | 2.87  | Benglow (P 76) |
| 1455      | 1640        | 1194.04 | -11.17 | 0.98 | 81.29  | 2.99  |                |
| 1456      | 1641        | 1190.7  | -11.17 | 0.98 | 81.04  | 2.98  |                |
| 1457      | 1642        | 1187.35 | -11.18 | 0.98 | 87.96  | 3.24  |                |
| 1458      | 1643        | 1184.01 | -11.19 | 0.97 | 93.96  | 3.46  |                |
| 1459      | 1644        | 1183.03 | -11.23 | 0.97 | 105.92 | 3.9   |                |
| 1460      | 1645        | 1183.2  | -11.26 | 0.96 | 117.75 | 4.33  |                |
| 1461      | 1646        | 1183.36 | -11.3  | 0.95 | 130.86 | 4.81  |                |
| 1462      | 1647        | 1183.53 | -11.33 | 0.94 | 143.83 | 5.29  |                |
| 1463      | 1648        | 1189.08 | -11.39 | 0.93 | 152    | 5.59  |                |
| 1464      | 1649        | 1196.8  | -11.48 | 0.93 | 159.04 | 5.85  |                |
| 1465      | 1650        | 1204.52 | -11.54 | 0.93 | 153.81 | 5.66  |                |
| 1466      | 1651        | 1212.23 | -11.58 | 0.94 | 147.65 | 5.43  |                |
| 1467      | 1652        | 1219.34 | -11.61 | 0.95 | 134.23 | 4.94  |                |
| 1468      | 1653        | 1224.79 | -11.61 | 0.96 | 119.31 | 4.39  |                |
| 1469      | 1654        | 1230.23 | -11.6  | 0.97 | 102.73 | 3.78  |                |
| 1470      | 1655        | 1235.68 | -11.58 | 0.98 | 88.3   | 3.25  | P 77 (Metika)  |
| 1471      | 1656        | 1241.13 | -11.56 | 0.98 | 88.57  | 3.26  |                |
| 1472      | 1657        | 1246.58 | -11.55 | 0.97 | 103.27 | 3.8   |                |
| 1473      | 1658        | 1252.57 | -11.55 | 0.96 | 112.01 | 4.12  |                |
| 1474      | 1659        | 1258.71 | -11.55 | 0.95 | 126.57 | 4.66  |                |
| 1475      | 1660        | 1266.54 | -11.57 | 0.94 | 146.89 | 5.4   |                |
| 1476      | 1661        | 1274.52 | -11.56 | 0.92 | 170.76 | 6.28  |                |
| 1477      | 1662        | 1282.6  | -11.59 | 0.9  | 196.53 | 7.23  |                |
| 1478      | 1663        | 1290.88 | -11.64 | 0.88 | 211.3  | 7.77  |                |
| 1479      | 1664        | 1299.17 | -11.68 | 0.87 | 225.41 | 8.29  |                |
| 1480      | 1665        | 1307.44 | -11.73 | 0.86 | 240.37 | 8.84  |                |
| 1481      | 1666        | 1315.7  | -11.76 | 0.83 | 263.95 | 9.71  |                |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks            |
|-----------|-------------|---------|--------|------|--------|-------|--------------------|
| 1482      | 1667        | 1327.86 | -11.74 | 0.8  | 296.68 | 10.91 |                    |
| 1483      | 1668        | 1359.79 | -11.78 | 0.78 | 309.63 | 11.39 |                    |
| 1484      | 1669        | 1380.93 | -11.87 | 0.78 | 317.06 | 11.66 |                    |
| 1485      | 1670        | 1402.06 | -11.97 | 0.77 | 324.74 | 11.95 |                    |
| 1486      | 1671        | 1420.82 | -12.02 | 0.77 | 331.9  | 12.21 |                    |
| 1487      | 1672        | 1430.83 | -12.09 | 0.76 | 335.22 | 12.33 |                    |
| 1488      | 1673        | 1441.31 | -12.2  | 0.76 | 337.76 | 12.43 |                    |
| 1489      | 1674        | 1453.12 | -12.32 | 0.77 | 340.66 | 12.53 |                    |
| 1490      | 1675        | 1463.69 | -12.4  | 0.77 | 341.29 | 12.56 |                    |
| 1491      | 1676        | 1465.44 | -12.51 | 0.77 | 339.34 | 12.48 |                    |
| 1492      | 1677        | 1467.17 | -12.6  | 0.78 | 338.27 | 12.44 |                    |
| 1493      | 1679        | 1471.85 | -12.7  | 0.78 | 338.01 | 12.43 |                    |
| 1494      | 1680        | 1474.33 | -12.76 | 0.78 | 337.85 | 12.43 |                    |
| 1495      | 1681        | 1476.08 | -12.85 | 0.79 | 335.47 | 12.34 |                    |
| 1496      | 1682        | 1481.2  | -13.01 | 0.79 | 334.1  | 12.29 |                    |
| 1497      | 1683        | 1479.92 | -13.04 | 0.79 | 334.04 | 12.29 |                    |
| 1498      | 1684        | 1476.5  | -13.03 | 0.79 | 332.33 | 12.23 |                    |
| 1499      | 1685        | 1464.47 | -13.01 | 0.81 | 319.3  | 11.75 |                    |
| 1500      | 1686        | 1456.39 | -12.98 | 0.82 | 300.37 | 11.05 | Jaway (P 78)       |
| 1501      | 1687        | 1448.31 | -12.96 | 0.84 | 281.59 | 10.36 |                    |
| 1502      | 1688        | 1440.22 | -12.94 | 0.86 | 263.37 | 9.69  |                    |
| 1503      | 1689        | 1432.14 | -12.92 | 0.87 | 245.72 | 9.04  |                    |
| 1504      | 1690        | 1424.58 | -12.91 | 0.89 | 231.68 | 8.52  |                    |
| 1505      | 1691        | 1417.54 | -12.89 | 0.9  | 219.07 | 8.06  |                    |
| 1506      | 1692        | 1410.5  | -12.86 | 0.91 | 204.91 | 7.54  |                    |
| 1507      | 1693        | 1403.47 | -12.83 | 0.92 | 191.22 | 7.03  |                    |
| 1508      | 1694        | 1387.72 | -12.71 | 0.92 | 183.09 | 6.74  |                    |
| 1509      | 1695        | 1369.11 | -12.56 | 0.93 | 178.57 | 6.57  |                    |
| 1510      | 1696        | 1347.36 | -12.39 | 0.93 | 173.58 | 6.39  |                    |
| 1511      | 1697        | 1328.11 | -12.24 | 0.93 | 168.06 | 6.18  |                    |
| 1512      | 1698        | 1311.16 | -12.09 | 0.93 | 161.96 | 5.96  | Anlomatuope (P 79) |
| 1513      | 1699        | 1301.03 | -12.01 | 0.94 | 157.45 | 5.79  |                    |
| 1514      | 1700        | 1334.78 | -12.34 | 0.93 | 163.99 | 6.03  |                    |
| 1515      | 1701        | 1364.89 | -12.65 | 0.93 | 170.7  | 6.28  |                    |
| 1516      | 1702        | 1393.98 | -12.95 | 0.93 | 178.09 | 6.55  |                    |
| 1517      | 1703        | 1387.16 | -12.88 | 0.93 | 172.44 | 6.34  |                    |
| 1518      | 1704        | 1369.77 | -12.72 | 0.94 | 165.36 | 6.08  |                    |
| 1519      | 1705        | 1346.85 | -12.53 | 0.94 | 159.22 | 5.86  |                    |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks                |
|-----------|-------------|---------|--------|------|--------|-------|------------------------|
| 1520      | 1706        | 1323.92 | -12.34 | 0.94 | 154.83 | 5.7   |                        |
| 1521      | 1707        | 1328.34 | -12.34 | 0.95 | 146.79 | 5.4   |                        |
| 1522      | 1708        | 1350.47 | -12.51 | 0.95 | 145.23 | 5.34  |                        |
| 1523      | 1709        | 1364.78 | -12.64 | 0.95 | 144.98 | 5.33  |                        |
| 1524      | 1710        | 1378.34 | -12.75 | 0.95 | 142.65 | 5.25  |                        |
| 1525      | 1711        | 1389.73 | -12.85 | 0.95 | 141.9  | 5.22  | Anlomatuope No4 (P 80) |
| 1526      | 1712        | 1398.51 | -12.95 | 0.96 | 138.76 | 5.1   |                        |
| 1527      | 1713        | 1407.29 | -13.06 | 0.96 | 138.53 | 5.1   |                        |
| 1528      | 1714        | 1415.87 | -13.17 | 0.96 | 135.9  | 5     |                        |
| 1529      | 1715        | 1418.83 | -13.22 | 0.96 | 132.59 | 4.88  |                        |
| 1530      | 1716        | 1404.71 | -13.14 | 0.96 | 131.65 | 4.84  |                        |
| 1531      | 1717        | 1392.79 | -13.05 | 0.96 | 125.42 | 4.61  |                        |
| 1532      | 1718        | 1387.25 | -13    | 0.97 | 117.55 | 4.32  |                        |
| 1533      | 1719        | 1375.74 | -12.91 | 0.97 | 110.74 | 4.07  |                        |
| 1534      | 1720        | 1352.17 | -12.76 | 0.97 | 111.55 | 4.1   | Buoko (P 81 )          |
| 1535      | 1721        | 1337.73 | -12.67 | 0.97 | 114.63 | 4.22  |                        |
| 1536      | 1722        | 1323.29 | -12.54 | 0.97 | 105.31 | 3.87  |                        |
| 1537      | 1723        | 1308.85 | -12.41 | 0.97 | 103.98 | 3.83  |                        |
| 1538      | 1724        | 1294.98 | -12.29 | 0.97 | 105.76 | 3.89  |                        |
| 1539      | 1725        | 1283.3  | -12.17 | 0.97 | 106.4  | 3.91  |                        |
| 1540      | 1726        | 1272.01 | -12.07 | 0.97 | 108.66 | 4.00  |                        |
| 1541      | 1727        | 1260.95 | -11.96 | 0.97 | 110.11 | 4.05  |                        |
| 1542      | 1728        | 1249.88 | -11.83 | 0.97 | 105.46 | 3.88  |                        |
| 1543      | 1729        | 1238.8  | -11.7  | 0.97 | 96.9   | 3.56  |                        |
| 1544      | 1730        | 1227.73 | -11.57 | 0.98 | 91.85  | 3.38  |                        |
| 1545      | 1731        | 1217.08 | -11.45 | 0.98 | 91.09  | 3.35  |                        |
| 1546      | 1732        | 1209.13 | -11.33 | 0.97 | 98.66  | 3.63  |                        |
| 1547      | 1733        | 1201.26 | -11.21 | 0.97 | 105.45 | 3.88  |                        |
| 1548      | 1734        | 1193.97 | -11.11 | 0.96 | 114.22 | 4.2   |                        |
| 1549      | 1735        | 1186.68 | -10.99 | 0.95 | 119.97 | 4.41  |                        |
| 1550      | 1736        | 1180.4  | -10.89 | 0.95 | 122.12 | 4.49  |                        |
| 1551      | 1737        | 1174.62 | -10.81 | 0.95 | 125.88 | 4.63  |                        |
| 1552      | 1738        | 1166.47 | -10.7  | 0.95 | 128.43 | 4.72  |                        |
| 1553      | 1739        | 1157.17 | -10.58 | 0.94 | 130.15 | 4.79  |                        |
| 1554      | 1740        | 1147.88 | -10.45 | 0.94 | 132.77 | 4.88  |                        |
| 1555      | 1741        | 1143.69 | -10.34 | 0.93 | 136.34 | 5.02  |                        |
| 1556      | 1742        | 1148.08 | -10.36 | 0.93 | 145.35 | 5.35  |                        |
| 1557      | 1743        | 1159.78 | -10.42 | 0.92 | 155.09 | 5.71  |                        |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks        |
|-----------|-------------|---------|--------|------|--------|-------|----------------|
| 1558      | 1744        | 1170.64 | -10.5  | 0.91 | 163.45 | 6.01  |                |
| 1559      | 1745        | 1178.88 | -10.55 | 0.91 | 168.71 | 6.21  |                |
| 1560      | 1746        | 1179.14 | -10.56 | 0.9  | 175.99 | 6.47  | Mpeasem (P 82) |
| 1561      | 1747        | 1179.45 | -10.58 | 0.89 | 183.06 | 6.73  |                |
| 1562      | 1748        | 1183.13 | -10.6  | 0.89 | 188.67 | 6.94  |                |
| 1563      | 1749        | 1185.56 | -10.62 | 0.88 | 197.95 | 7.28  |                |
| 1564      | 1750        | 1167.01 | -10.51 | 0.86 | 215.00 | 7.91  |                |
| 1565      | 1751        | 1148.45 | -10.42 | 0.83 | 233.34 | 8.58  |                |
| 1566      | 1752        | 1153.19 | -10.38 | 0.83 | 232.27 | 8.54  |                |
| 1567      | 1753        | 1131.26 | -10.18 | 0.83 | 229.86 | 8.46  |                |
| 1568      | 1754        | 1104.42 | -9.95  | 0.83 | 228.27 | 8.4   |                |
| 1569      | 1755        | 1081.49 | -9.73  | 0.82 | 225.26 | 8.29  |                |
| 1570      | 1756        | 1066.22 | -9.58  | 0.83 | 219.63 | 8.08  |                |
| 1571      | 1757        | 1054.13 | -9.48  | 0.82 | 218.15 | 8.03  |                |
| 1572      | 1758        | 1048.51 | -9.43  | 0.82 | 217.41 | 8     |                |
| 1573      | 1759        | 1054.74 | -9.48  | 0.83 | 216.10 | 7.95  |                |
| 1574      | 1760        | 1053.62 | -9.49  | 0.83 | 216.45 | 7.96  |                |
| 1575      | 1761        | 1061.51 | -9.54  | 0.84 | 209.51 | 7.71  |                |
| 1576      | 1762        | 1078.99 | -9.6   | 0.86 | 195.61 | 7.2   |                |
| 1577      | 1763        | 1061.65 | -9.39  | 0.87 | 180.28 | 6.63  |                |
| 1578      | 1764        | 1033.09 | -9.13  | 0.88 | 166.89 | 6.14  |                |
| 1579      | 1765        | 1004.55 | -8.83  | 0.88 | 159.11 | 5.85  |                |
| 1580      | 1766        | 972.38  | -8.53  | 0.89 | 153.05 | 5.63  |                |
| 1581      | 1767        | 960.69  | -8.43  | 0.88 | 152.83 | 5.62  |                |
| 1582      | 1768        | 974.3   | -8.57  | 0.88 | 158.53 | 5.83  | Nsemsea (P 83) |
| 1583      | 1769        | 991.19  | -8.73  | 0.87 | 166.17 | 6.11  |                |
| 1584      | 1770        | 1015.86 | -8.93  | 0.87 | 173.29 | 6.37  |                |
| 1585      | 1771        | 1040.62 | -9.13  | 0.87 | 179.97 | 6.62  |                |
| 1586      | 1772        | 1059.33 | -9.28  | 0.86 | 187.15 | 6.88  |                |
| 1587      | 1773        | 1074.14 | -9.42  | 0.86 | 191.14 | 7.03  |                |
| 1588      | 1774        | 1092.05 | -9.61  | 0.87 | 188.7  | 6.94  |                |
| 1589      | 1775        | 1107.51 | -9.79  | 0.87 | 186.94 | 6.88  |                |
| 1590      | 1776        | 1102.91 | -9.8   | 0.88 | 182.25 | 6.7   |                |
| 1591      | 1777        | 1096.69 | -9.78  | 0.88 | 176.38 | 6.49  |                |
| 1592      | 1778        | 1094.9  | -9.78  | 0.89 | 169.5  | 6.24  |                |
| 1593      | 1779        | 1093.13 | -9.75  | 0.89 | 169.81 | 6.25  |                |
| 1594      | 1780        | 1090.26 | -9.73  | 0.89 | 171.32 | 6.3   |                |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks       |
|-----------|-------------|---------|--------|------|--------|-------|---------------|
| 1595      | 1781        | 1086.29 | -9.7   | 0.89 | 173.24 | 6.37  |               |
| 1596      | 1782        | 1093.33 | -9.71  | 0.89 | 171.69 | 6.32  |               |
| 1597      | 1783        | 1113.36 | -9.84  | 0.89 | 172.89 | 6.36  |               |
| 1598      | 1784        | 1128.98 | -10.01 | 0.89 | 176.88 | 6.51  |               |
| 1599      | 1785        | 1144.61 | -10.15 | 0.89 | 178.81 | 6.58  |               |
| 1600      | 1786        | 1160.23 | -10.28 | 0.89 | 179.44 | 6.6   |               |
| 1601      | 1787        | 1173.24 | -10.42 | 0.89 | 181.27 | 6.67  |               |
| 1602      | 1788        | 1188.99 | -10.59 | 0.89 | 183.68 | 6.76  | Mangea (P 84) |
| 1603      | 1789        | 1204.95 | -10.77 | 0.89 | 186.63 | 6.87  |               |
| 1604      | 1790        | 1200.15 | -10.75 | 0.89 | 185.95 | 6.84  |               |
| 1605      | 1791        | 1186.56 | -10.66 | 0.89 | 184.1  | 6.77  |               |
| 1606      | 1792        | 1175.45 | -10.58 | 0.89 | 181.81 | 6.69  |               |
| 1607      | 1793        | 1170.24 | -10.54 | 0.9  | 178.38 | 6.56  |               |
| 1608      | 1794        | 1165.59 | -10.48 | 0.89 | 181.72 | 6.68  |               |
| 1609      | 1795        | 1161.16 | -10.41 | 0.88 | 189.38 | 6.97  |               |
| 1610      | 1796        | 1156.03 | -10.33 | 0.87 | 197.15 | 7.25  |               |
| 1611      | 1797        | 1149.6  | -10.22 | 0.86 | 204.61 | 7.53  |               |
| 1612      | 1798        | 1139.82 | -10.14 | 0.85 | 214.2  | 7.88  |               |
| 1613      | 1799        | 1129.3  | -10.04 | 0.84 | 218.29 | 8.03  |               |
| 1614      | 1800        | 1122.53 | -9.99  | 0.84 | 220.57 | 8.11  |               |
| 1615      | 1801        | 1116.86 | -9.92  | 0.83 | 222.03 | 8.17  |               |
| 1616      | 1802        | 1109.97 | -9.86  | 0.83 | 224.04 | 8.24  |               |
| 1617      | 1803        | 1101.08 | -9.77  | 0.82 | 225.9  | 8.31  |               |
| 1618      | 1804        | 1092.19 | -9.69  | 0.82 | 227.53 | 8.37  |               |
| 1619      | 1805        | 1095.59 | -9.67  | 0.82 | 227.2  | 8.36  |               |
| 1620      | 1806        | 1096.45 | -9.7   | 0.82 | 230.39 | 8.48  |               |
| 1621      | 1807        | 1097.67 | -9.72  | 0.81 | 233.63 | 8.59  |               |
| 1622      | 1808        | 1099.07 | -9.72  | 0.81 | 236.55 | 8.7   |               |
| 1623      | 1809        | 1101.67 | -9.75  | 0.81 | 239.1  | 8.8   | Effasu (P 85) |
| 1624      | 1810        | 1104.46 | -9.81  | 0.82 | 231.53 | 8.52  |               |
| 1625      | 1811        | 1107.23 | -9.85  | 0.83 | 223.67 | 8.23  |               |
| 1626      | 1812        | 1105.79 | -9.87  | 0.84 | 215.98 | 7.95  |               |
| 1627      | 1813        | 1102.1  | -9.85  | 0.85 | 207.52 | 7.63  |               |
| 1628      | 1814        | 1102.57 | -9.86  | 0.86 | 198.26 | 7.29  |               |
| 1629      | 1815        | 1107.63 | -9.92  | 0.87 | 189.68 | 6.98  |               |
| 1630      | 1816        | 1106.85 | -9.94  | 0.88 | 182.67 | 6.72  |               |
| 1631      | 1817        | 1102.52 | -9.94  | 0.89 | 175.92 | 6.47  | P 86          |
| 1632      | 1818        | 1093.06 | -9.91  | 0.89 | 171.3  | 6.3   |               |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks |
|-----------|-------------|---------|--------|------|--------|-------|---------|
| 1633      | 1819        | 1083.17 | -9.82  | 0.9  | 159.37 | 5.86  |         |
| 1634      | 1820        | 1059.69 | -9.65  | 0.91 | 150.58 | 5.54  |         |
| 1635      | 1821        | 1038.76 | -9.48  | 0.92 | 141.69 | 5.21  |         |
| 1636      | 1822        | 1016.43 | -9.29  | 0.93 | 131.97 | 4.85  |         |
| 1637      | 1823        | 996.33  | -9.11  | 0.93 | 121.56 | 4.47  |         |
| 1638      | 1824        | 979.62  | -8.93  | 0.94 | 116.93 | 4.3   |         |
| 1639      | 1825        | 978.08  | -8.89  | 0.94 | 116.7  | 4.29  |         |
| 1640      | 1826        | 971.93  | -8.84  | 0.93 | 117.81 | 4.33  |         |
| 1641      | 1827        | 973.87  | -8.82  | 0.93 | 117.21 | 4.31  |         |
| 1642      | 1829        | 973.33  | -8.78  | 0.93 | 117.67 | 4.33  |         |
| 1643      | 1830        | 970.04  | -8.74  | 0.93 | 121.46 | 4.47  |         |
| 1644      | 1831        | 962.61  | -8.67  | 0.92 | 125.33 | 4.61  |         |
| 1645      | 1832        | 955.18  | -8.62  | 0.92 | 130.71 | 4.81  |         |
| 1646      | 1833        | 947.74  | -8.55  | 0.91 | 134.57 | 4.95  |         |
| 1647      | 1834        | 951.38  | -8.56  | 0.9  | 138.81 | 5.11  |         |
| 1648      | 1835        | 957.91  | -8.61  | 0.9  | 144.36 | 5.31  |         |
| 1649      | 1836        | 964.44  | -8.66  | 0.89 | 150.14 | 5.52  |         |
| 1650      | 1837        | 970.97  | -8.7   | 0.89 | 155.12 | 5.71  |         |
| 1651      | 1838        | 975.33  | -8.75  | 0.89 | 153.03 | 5.63  |         |
| 1652      | 1839        | 983.98  | -8.84  | 0.89 | 151.19 | 5.56  |         |
| 1653      | 1840        | 996.53  | -8.97  | 0.9  | 150.57 | 5.54  |         |
| 1654      | 1841        | 1009.07 | -9.1   | 0.9  | 150.36 | 5.53  |         |
| 1655      | 1842        | 1022.03 | -9.23  | 0.9  | 150.02 | 5.52  |         |
| 1656      | 1843        | 1036.57 | -9.36  | 0.9  | 151.76 | 5.58  |         |
| 1657      | 1844        | 1051.13 | -9.47  | 0.89 | 161.94 | 5.96  |         |
| 1658      | 1845        | 1065.67 | -9.57  | 0.89 | 172.16 | 6.33  |         |
| 1659      | 1846        | 1080.22 | -9.62  | 0.88 | 177.94 | 6.55  |         |
| 1660      | 1847        | 1101.17 | -9.79  | 0.87 | 190.56 | 7.01  |         |
| 1661      | 1848        | 1129.71 | -10.04 | 0.86 | 205.16 | 7.55  |         |
| 1662      | 1849        | 1155.8  | -10.25 | 0.85 | 219.11 | 8.06  |         |
| 1663      | 1850        | 1186.42 | -10.48 | 0.84 | 231.6  | 8.52  |         |
| 1664      | 1851        | 1218.98 | -10.74 | 0.83 | 244.92 | 9.01  |         |
| 1665      | 1852        | 1250.54 | -11    | 0.82 | 254.55 | 9.36  | P 87    |
| 1666      | 1853        | 1268.79 | -11.2  | 0.82 | 259.94 | 9.56  |         |
| 1667      | 1854        | 1261.58 | -11.14 | 0.82 | 257.62 | 9.48  |         |
| 1668      | 1855        | 1254.82 | -11.14 | 0.83 | 256.26 | 9.43  |         |
| 1669      | 1856        | 1243.6  | -11.05 | 0.81 | 268.13 | 9.86  |         |
| 1670      | 1857        | 1240.59 | -10.92 | 0.79 | 278.74 | 10.25 |         |

| Object ID | Transect ID | SCE     | LRR    | LR2  | LSE    | LCI95 | Remarks         |
|-----------|-------------|---------|--------|------|--------|-------|-----------------|
| 1671      | 1858        | 1261.94 | -10.85 | 0.78 | 290.42 | 10.68 |                 |
| 1672      | 1859        | 1280.63 | -10.8  | 0.76 | 301.38 | 11.09 |                 |
| 1673      | 1860        | 1289.17 | -10.74 | 0.75 | 306.23 | 11.27 |                 |
| 1674      | 1861        | 1297.72 | -10.69 | 0.75 | 310.9  | 11.44 |                 |
| 1675      | 1862        | 1301.84 | -10.61 | 0.74 | 314.78 | 11.58 |                 |
| 1676      | 1863        | 1275.25 | -10.21 | 0.73 | 313.17 | 11.52 |                 |
| 1677      | 1864        | 1250.02 | -9.81  | 0.71 | 312.29 | 11.49 |                 |
| 1678      | 1865        | 1240.03 | -9.36  | 0.68 | 319.27 | 11.75 |                 |
| 1679      | 1866        | 1230.03 | -8.95  | 0.65 | 325.57 | 11.98 |                 |
| 1680      | 1867        | 1220.04 | -8.5   | 0.62 | 332.8  | 12.24 |                 |
| 1681      | 1868        | 1205.93 | -8.15  | 0.59 | 336.27 | 12.37 |                 |
| 1682      | 1869        | 1189.31 | -7.8   | 0.57 | 338.74 | 12.46 |                 |
| 1683      | 1870        | 1172.69 | -7.35  | 0.53 | 343.63 | 12.64 | New Town (P 88) |
| 1684      | 1871        | 1156.08 | -6.91  | 0.49 | 348.79 | 12.83 |                 |
| 1685      | 1872        | 1144.04 | -6.54  | 0.46 | 353.43 | 13    |                 |
| 1686      | 1873        | 1139.86 | -6.7   | 0.48 | 346.41 | 12.74 |                 |
| 1687      | 1874        | 1134.98 | -6.85  | 0.5  | 339.71 | 12.5  |                 |
| 1688      | 1875        | 1130.12 | -7     | 0.52 | 333.03 | 12.25 |                 |
| 1689      | 1876        | 1125.25 | -7.15  | 0.55 | 326.43 | 12.01 |                 |
| 1690      | 1877        | 1125.63 | -7.34  | 0.57 | 321.16 | 11.81 |                 |
| 1691      | 1878        | 1140.95 | -7.5   | 0.57 | 323.92 | 11.92 |                 |
| 1692      | 1879        | 1156.27 | -7.64  | 0.58 | 326.99 | 12.03 |                 |
| 1693      | 1880        | 1171.59 | -7.78  | 0.58 | 330.3  | 12.15 |                 |
| 1694      | 1881        | 1186.91 | -7.96  | 0.59 | 332.4  | 12.23 |                 |
| 1695      | 1882        | 1184.24 | -8.17  | 0.61 | 325.46 | 11.97 |                 |
| 1696      | 1883        | 1179.36 | -8.38  | 0.63 | 317.49 | 11.68 |                 |
| 1697      | 1884        | 1184.79 | -8.57  | 0.65 | 314.52 | 11.57 |                 |
| 1698      | 1885        | 1193.86 | -8.76  | 0.66 | 313.5  | 11.53 |                 |
| 1699      | 1886        | 1202.93 | -8.92  | 0.67 | 312.81 | 11.51 |                 |
| 1700      | 1887        | 1226.68 | -9.1   | 0.67 | 319.01 | 11.74 |                 |
| 1701      | 1888        | 1262.73 | -9.27  | 0.66 | 331.22 | 12.18 |                 |
| 1702      | 1889        | 1294.4  | -9.43  | 0.66 | 341.82 | 12.57 |                 |
| 1703      | 1890        | 1294.07 | -9.55  | 0.67 | 338.31 | 12.45 |                 |
| 1704      | 1891        | 1289.17 | -9.64  | 0.68 | 334.01 | 12.29 |                 |
| 1705      | 1892        | 1281.9  | -11.43 | 0.73 | 365.61 | 21.3  |                 |

**Appendix III: Computation of Short Term Mean Shoreline Change Rates**

| Chainages | Transect ID | EPR_1994_2005 | EPR_1974_1994 | Mean Rates<br>(2005-1974) | Remarks                |
|-----------|-------------|---------------|---------------|---------------------------|------------------------|
| 0         | 1           |               | -1.24         | -1.24                     | Shama Pra estuary (P1) |
| 0.6       | 12          | -1.62         | -0.77         | -1.195                    | Shama (P2)             |
| 2.5       | 30          | -3.06         | -8.57         | -5.815                    | Abuesi (P3)            |
| 5.8       | 83          | -0.64         | -0.41         | -0.525                    | Aboadze (P4)           |
| 7.6       | 99          | -0.13         | -0.21         | -0.17                     | Bongo Beach (P5)       |
| 10.7      | 111         | -1.72         | -0.34         | -1.03                     | Ngyiresia (P6)         |
| 17.6      | 128         | -5.65         | -0.1          | -2.875                    | Ekuasi/Sekondi (P7)    |
| 22.5      | 144         | -4.57         | -0.03         | -2.3                      | Nkontompo (P8)         |
| 24        | 175         | -3.42         | -1.07         | -2.245                    | New Takoradi (P9)      |
| 26        | 283         | -2.03         | -0.28         | -1.155                    | New Amanful (P 10)     |
| 29        | 293         | -2.22         | -1.16         | -1.69                     | Funku (P 11)           |
| 32.7      | 312         | -0.71         | -0.48         | -0.595                    | Adwowa (P12)           |
| 35        | 341         | 0.06          | -0.48         | -0.21                     | Pumpuni (P13)          |
| 37.7      | 372         | -1.86         | -0.49         | -1.175                    | Mpatano (P14)          |
| 41.4      | 394         | -0.67         | -0.09         | -0.38                     | Asemkaw (P15)          |
| 43        | 422         | -1.6          | 0.14          | -0.73                     | Butre (P16)            |
| 46.5      | 446         | -5.81         | -1.17         | -3.49                     | Busua (P17)            |
| 46.8      | 458         | -0.51         | -0.73         | -0.62                     | Dixcove (P18)          |
| 51.2      | 495         | -3            | -0.68         | -1.84                     | Akyinim (P19)          |
| 53.6      | 498         | -4.37         | -3.1          | -3.735                    | Atwiwa (P20)           |
| 55.2      | 568         | -2.79         | -1.06         | -1.925                    | Ahonakrom (P21)        |
| 56.5      | 583         | -2.6          | -1.21         | -1.905                    | Bebianiha (P 22)       |
| 61.8      | 609         | -3.81         | -1.72         | -2.765                    | P 23                   |

| <b>Chainages</b> | <b>Transect ID</b> | <b>EPR_1994_2005</b> | <b>EPR_1974_1994</b> | <b>Mean Rates<br/>(2005-1974)</b> | <b>Remarks</b>          |
|------------------|--------------------|----------------------|----------------------|-----------------------------------|-------------------------|
| 62.5             | 622                | -8.25                | -2.21                | -5.23                             | Ketaakor (P24)          |
| 64.2             | 661                | -9.57                | -1.8                 | -5.685                            | Trinity Yard (P25)      |
| 68.8             | 668                | -5.41                | -2.09                | -3.75                             | P 26                    |
| 72.2             | 694                | -5.63                | -2.29                | -3.96                             | Atonchede (P 27)        |
| 77.9             | 720                | -4.01                | -2                   | -3.005                            | Akatakyie (P 28)        |
| 78.9             | 772                | -6.39                | -2.5                 | -4.445                            | Princes Town (P29)      |
| 82               | 806                |                      | 0.39                 | 0.39                              | Miamea (P30)            |
| 84.1             | 816                | -5.8                 | 0.69                 | -2.555                            | Egyembra (P 31)         |
| 84.9             | 861                | -1.75                | 0.59                 | -0.58                             | Adjan (P 32)            |
| 87.3             | 872                | -6.66                | -2.82                | -4.74                             | P 33                    |
| 90.5             | 880                | -5.48                | -3.46                | -4.47                             | P34                     |
| 92.7             | 908                | -5.92                | -1.7                 | -3.81                             | Axim Beach (P 35)       |
| 93.9             | 920                | -5.02                | -4.83                | -4.925                            | Axim Nkekam (P 36)      |
| 96.2             | 943                | -2.12                | -4.22                | -3.17                             | Akyenim (P 37)          |
| 97.3             | 958                | -1.6                 | -7.02                | -4.31                             | Ankobra Beach (P 38)    |
| 97.7             | 963                | -1.48                | -6.94                | -4.21                             | Ankobra Township (P 39) |
| 99.7             | 974                | -4.98                | -7.02                | -6                                | Asenta (P 40)           |
| 100.7            | 1004               | -3.81                | -6.98                | -5.395                            | Asemko (P 41)           |
| 103.3            | 1014               | -1.6                 | -6.92                | -4.26                             | P 42                    |
| 106.4            | 1034               | -4.4                 | -6.96                | -5.68                             | P 43                    |
| 107.4            | 1044               | -7.07                | -6.96                | -7.015                            | Esiamia (P 44)          |
| 109.3            | 1079               | 0.33                 | -7.01                | -3.34                             | Azulenumu (P 45)        |
| 111.3            | 1106               | -1.05                | -6.91                | -3.98                             | Ampemu (P46)            |
| 112.2            | 1113               | -1.67                | -6.86                | -4.265                            | Beach Resort (P 47)     |
| 114.1            | 1131               | -0.69                | -6.88                | -3.785                            | Bakanta (P 48)          |

| <b>Chainages</b> | <b>Transect ID</b> | <b>EPR_1994_2005</b> | <b>EPR_1974_1994</b> | <b>Mean Rates<br/>(2005-1974)</b> | <b>Remarks</b>           |
|------------------|--------------------|----------------------|----------------------|-----------------------------------|--------------------------|
| 116.3            | 1155               | 0.65                 | -6.83                | -3.09                             | Sanzule (P 49)           |
| 118              | 1165               | 4.55                 | -6.78                | -1.115                            | Krisan (Eikwe) (P 50)    |
| 120              | 1184               | 0.11                 | -6.99                | -3.44                             | P 51                     |
| 122.1            | 1205               | -1.61                | -6.88                | -4.245                            | Ngelechi (P 52)          |
| 124              | 1223               | -12.45               | -6.89                | -9.67                             | Anochi (P 53)            |
| 125.9            | 1243               | -4.77                | -6.87                | -5.82                             | P 54                     |
| 127.8            | 1263               | -6.61                | -6.91                | -6.76                             | Atuabo (P 55)            |
| 130              | 1282               | -6.52                | -6.87                | -6.695                            | Ekabaku (P 56)           |
| 132              | 1301               | -6.5                 | -6.94                | -6.72                             | Beyin (P 57)             |
| 133.9            | 1320               | -9.46                | -6.97                | -8.215                            | Nglekazu (P 58)          |
| 136              | 1342               | -5.14                | -6.82                | -5.98                             | P 59                     |
| 137.8            | 1362               | -9.68                | -6.89                | -8.285                            | P 60                     |
| 138.5            | 1381               | -10.38               | -4.04                | -7.21                             | P 61                     |
| 141              | 1401               | -11.95               | -3.95                | -7.95                             | Twene (P 62)             |
| 142.4            | 1421               | -9.54                | -4.56                | -7.05                             | Egyiza (P 63)            |
| 144.1            | 1428               | -9.77                | -3.66                | -6.715                            | Allengenzule (P 64)      |
| 146              | 1452               | -6.74                | -5.09                | -5.915                            | Ezilinbo (P 65)          |
| 147.5            | 1464               | -9.25                | -3.96                | -6.605                            | Bonyere (P 66)           |
| 149.3            | 1483               | -8.18                | -4.28                | -6.23                             | Bonyere(outskirt) (P 67) |
| 151.5            | 1503               | -8.17                | -4.32                | -6.245                            | P 68                     |
| 153.7            | 1517               | -11.06               | -3.31                | -7.185                            | P 69                     |
| 155.2            | 1535               | -11.45               | -2.4                 | -6.925                            | Egbazo (P 70)            |
| 157.9            | 1556               | -8.53                | -4.56                | -6.545                            | Ahobre (P 71)            |
| 159.7            | 1578               | -7.93                | -4.44                | -6.185                            | Old Edobo (P 72)         |
| 161.3            | 1594               | -8.92                | -3.83                | -6.375                            | Atwebansi (P73)          |

| <b>Chainages</b> | <b>Transect ID</b> | <b>EPR_1994_2005</b> | <b>EPR_1974_1994</b> | <b>Mean Rates<br/>(2005-1974)</b> | <b>Remarks</b>       |
|------------------|--------------------|----------------------|----------------------|-----------------------------------|----------------------|
| 164.2            | 1605               | -8.27                | -3.36                | -5.815                            | Ekpo (P 74)          |
| 165.4            | 1620               | -6.1                 | -3.86                | -4.98                             | Half Assini ( P 75)  |
| 166.7            | 1639               | -7.15                | -4.59                | -5.87                             | Benglow (P 76)       |
| 167.7            | 1655               | -4.96                | -4.73                | -4.845                            | P 77 (Metika)        |
| 170.2            | 1686               | -9.08                | -4.08                | -6.58                             | Jaway (P 78)         |
| 172.4            | 1698               | -9.69                | -3.86                | -6.775                            | Anlomatuope (P 79)   |
| 174.4            | 1711               | -9.99                | -4.07                | -7.03                             | Anlomatuope 4 (P 80) |
| 176.6            | 1720               | -6.54                | -4.8                 | -5.67                             | Buoko (P 81 )        |
| 178.7            | 1746               | -7.24                | -3.73                | -5.485                            | Mpeasem (P 82)       |
| 180.7            | 1768               | -10.71               | -3.09                | -6.9                              | Nsemtsea (P 83)      |
| 182.5            | 1788               | -8.86                | -2.94                | -5.9                              | Mangea (P 84)        |
| 184.1            | 1809               | -8.11                | -3.07                | -5.59                             | Effasu (P 85)        |
| 184              | 1817               | -6.32                | -4.41                | -5.365                            | P 86                 |
| 186              | 1852               | -10.75               | -3.09                | -6.92                             | P 87                 |
| 188              | 1870               | -8.5                 | -2.94                | -5.72                             | New Town (P 88)      |

**Appendix IV: Computation of Potential Alongshore Sediment Transport Rates**

| Chainage<br>(km) | Mean<br>Shore<br>Direction | Breaking<br>Wave<br>Direction | Angle of Breaking<br>Wave Crest with<br>Shore ( $\alpha$ ) | Wave Energy<br>Flux Factor | Potential<br>Alongshore<br>Sediment Transport | Log10 (Potential<br>Alongshore<br>Transport) | Remarks                |
|------------------|----------------------------|-------------------------------|--|----------------------------|---|--|------------------------|
| 0.000            | 204.00                     | 189.08                        | -14.920  | 119255.714                 | 894417852.60                                  | 8.944178526                                  | Shama Pra Estuary (P1) |
| 0.600            | 204.00                     | 189.08                        | -14.920  | 119255.714                 | 894417852.60                                  | 8.944178526                                  | Shama (P2)             |
| 2.500            | 185.00                     | 189.08                        | 4.080  | 113716.667                 | 852875003.63                                  | 8.528750036                                  | Abuesi (P3)            |
| 5.800            | 214.00                     | 189.08                        | -24.920  | 49224.668                  | 369185013.65                                  | 3.691850136                                  | Aboadze (P4)           |
| 7.600            | 258.00                     | 189.08                        | -68.920  | 45348.704                  | 340115278.99                                  | 3.40115279                                   | Bongo Beach (P5)       |
| 10.700           | 259.50                     | 189.08                        | -70.420  | -60460.224                 | -453451683.64                                 | -4.534516836                                 | Ngyiresia (P6)         |
| 17.600           | 185.00                     | 189.08                        | 4.080  | 113716.667                 | 852875003.63                                  | 8.528750036                                  | Ekuasi/Sekondi (P7)    |
| 22.500           | 252.50                     | 189.08                        | -63.420  | -110096.881                | -825726608.41                                 | -8.257266084                                 | Nkontompo (P8)         |
| 24.000           | 242.50                     | 189.08                        | -53.420  | -3082.431                  | -23118232.30                                  | -0.231182323                                 | New Takoradi (P9)      |
| 26.000           | 199.50                     | 189.08                        | -10.420  | -108909.629                | -816822215.39                                 | -8.168222154                                 | New Amanful (P 10)     |
| 29.000           | 194.50                     | 189.08                        | -5.420   | 117816.978                 | 883627336.25                                  | 8.836273363                                  | Funku (P 11)           |
| 32.700           | 253.00                     | 189.08                        | -63.920  | -98055.606                 | -735417047.83                                 | -7.354170478                                 | Adwowa (P12)           |
| 35.000           | 268.50                     | 189.08                        | -79.420  | -117120.809                | -878406064.98                                 | -8.78406065                                  | Pumpuni (P13)          |
| 37.700           | 269.50                     | 189.08                        | -80.420  | 69173.691                  | 518802679.78                                  | 5.188026798                                  | Mpatano (P14)          |
| 41.400           | 249.50                     | 189.08                        | -60.420  | -118519.157                | -888893675.77                                 | -8.888936758                                 | Asemkaw (P15)          |
| 43.000           | 230.00                     | 189.08                        | -40.920  | -18833.951                 | -141254633.80                                 | -1.412546338                                 | Butre (P16)            |
| 46.500           | 243.50                     | 189.08                        | -54.420  | -107121.368                | -803410261.55                                 | -8.034102616                                 | Busua (P17)            |
| 46.800           | 258.50                     | 189.08                        | -69.420  | -68311.114                 | -512333352.17                                 | -5.123333522                                 | Dixcove (P18)          |
| 51.200           | 242.00                     | 189.08                        | -52.920  | 98652.573                  | 739894295.33                                  | 7.398942953                                  | Akyinim (P19)          |
| 53.600           | 230.00                     | 189.08                        | -40.920  | -18833.951                 | -141254633.80                                 | -1.412546338                                 | Atwiwa (P20)           |
| 55.200           | 296.00                     | 189.08                        | -106.920   | -25058.557                 | -187939176.80                                 | -1.879391768                                 | Ahonakrom (P21)        |
| 55.200           | 296.00                     | 189.08                        | -106.920   | -25058.557                 | -187939176.80                                 | -1.879391768                                 | Ahonakrom (P21)        |

| Chainage<br>(km) | Mean Shore<br>Direction | Breaking<br>Wave<br>Direction | Angle of Breaking<br>Wave Crest with<br>Shore ( $\alpha$ ) | Wave Energy<br>Flux Factor | Potential Alongshore<br>Sediment Transport | Log10 (Potential<br>Alongshore<br>Transport) | Remarks              |
|------------------|-------------------------|-------------------------------|--|----------------------------|--|--|----------------------|
| 56.500           | 256.00                  | 189.08                        | -66.920  | -113116.193                | -848371446.49                              | -8.483714465                                 | Bebianiha (P 22)     |
| 61.800           | 208.00                  | 189.08                        | -18.920  | -16746.409                 | -125598067.58                              | -1.255980676                                 | P 23                 |
| 62.500           | 249.00                  | 189.08                        | -59.920  | -52888.381                 | -396662856.62                              | -3.966628566                                 | Ketaakor (P24)       |
| 64.200           | 222.50                  | 189.08                        | -33.420  | 90886.275                  | 681647059.49                               | 6.816470595                                  | Trinity Yard (P25)   |
| 68.800           | 226.00                  | 189.08                        | -36.920  | 119247.858                 | 894358931.94                               | 8.943589319                                  | P 26                 |
| 72.200           | 263.50                  | 189.08                        | -74.420  | 110498.280                 | 828737103.42                               | 8.287371034                                  | Atonchede (P 27)     |
| 77.900           | 274.00                  | 189.08                        | -84.920  | -22990.676                 | -172430073.33                              | -1.724300733                                 | Akatakyie (P 28)     |
| 78.900           | 264.00                  | 189.08                        | -74.920  | 97450.958                  | 730882182.46                               | 7.308821825                                  | Princes Town (P29)   |
| 82.000           | 254.50                  | 189.08                        | -65.420  | 106653.232                 | 799899241.54                               | 7.998992415                                  | Miamea (P30)         |
| 84.100           | 246.00                  | 189.08                        | -56.920  | -80648.113                 | -604860844.23                              | -6.048608442                                 | Egyembra (P 31)      |
| 84.900           | 215.50                  | 189.08                        | -26.420  | -64061.110                 | -480458325.06                              | -4.804583251                                 | Adjan (P 32)         |
| 87.300           | 300.00                  | 189.08                        | -110.920   | -111708.095                | -837810710.10                              | -8.378107101                                 | P 33                 |
| 90.500           | 285.00                  | 189.08                        | -95.920  | 24025.558                  | 180191683.82                               | 1.801916838                                  | P34                  |
| 92.700           | 245.50                  | 189.08                        | -56.420  | 30351.542                  | 227636564.77                               | 2.276365648                                  | Axim Beach (P 35)    |
| 93.900           | 251.00                  | 189.08                        | -61.920  | 115463.521                 | 865976403.90                               | 8.659764039                                  | Axim Nkekam (P 36)   |
| 96.200           | 213.00                  | 189.08                        | -23.920  | 78287.077                  | 587153079.00                               | 5.87153079                                   | Akyenim (P 37)       |
| 97.300           | 248.00                  | 189.08                        | -58.920  | 119202.631                 | 894019734.67                               | 8.940197347                                  | Ankobra Beach (P 38) |
| 97.700           | 283.00                  | 189.08                        | -93.920  | 72699.554                  | 545246652.81                               | 5.452466528                                  | Ankobra Town (P 39)  |
| 99.700           | 241.50                  | 189.08                        | -52.420  | 109686.856                 | 822651420.02                               | 8.2265142                                    | Asenta (P 40)        |
| 100.700          | 33.00                   | 189.08                        | 156.080  | -108476.770                | -813575778.74                              | -8.135757787                                 | Asemko (P 41)        |
| 103.300          | 311.50                  | 189.08                        | -122.420   | 24186.601                  | 181399509.22                               | 1.813995092                                  | P 42                 |

| Chainage<br>(km) | Mean<br>Shore<br>Direction | Breaking<br>Wave<br>Direction | Angle of Breaking<br>Wave Crest with<br>Shore ( $\alpha$ ) | Wave Energy<br>Flux Factor | Potential<br>Alongshore<br>Sediment Transport | Log10 (Potential<br>Alongshore<br>Transport) | Remarks               |
|------------------|----------------------------|-------------------------------|--|----------------------------|---|--|-----------------------|
| 106.400          | 279.50                     | 189.08                        | -90.420  | 116917.309                 | 876879818.12                                  | 8.768798181                                  | P 43                  |
| 107.400          | 297.00                     | 189.08                        | -107.920   | -95591.394                 | -716935454.44                                 | -7.169354544                                 | Esiamu (P 44)         |
| 109.300          | 271.50                     | 189.08                        | -82.420  | -118735.101                | -890513254.76                                 | -8.905132548                                 | Azulenumu (P 45)      |
| 111.300          | 256.50                     | 189.08                        | -67.420  | -29329.529                 | -219971464.72                                 | -2.199714647                                 | Ampemu (P46)          |
| 112.200          | 246.50                     | 189.08                        | -57.420  | -117500.264                | -881251982.51                                 | -8.812519825                                 | Beach Resort (P 47)   |
| 114.100          | 303.50                     | 189.08                        | -114.420   | -56783.556                 | -425876671.10                                 | -4.258766711                                 | Bakanta (P 48)        |
| 116.300          | 286.50                     | 189.08                        | -97.420  | -7300.594                  | -54754456.66                                  | -0.547544567                                 | Sanzule (P 49)        |
| 118.000          | 330.00                     | 189.08                        | -140.920   | 93664.430                  | 702483223.79                                  | 7.024832238                                  | Krisan (Eikwe) (P 50) |
| 120.000          | 330.00                     | 189.08                        | -140.920   | 93664.430                  | 702483223.79                                  | 7.024832238                                  | P 51                  |
| 122.100          | 298.00                     | 189.08                        | -108.920   | 104618.669                 | 784640019.55                                  | 7.846400195                                  | Ngelechi (P 52)       |
| 124.000          | 289.50                     | 189.08                        | -100.420   | 26250.022                  | 196875168.50                                  | 1.968751685                                  | Anochi (P 53)         |
| 125.900          | 355.00                     | 189.08                        | -165.920   | 109751.294                 | 823134708.10                                  | 8.231347081                                  | P 54                  |
| 127.800          | 341.00                     | 189.08                        | -151.920   | -93007.364                 | -697555230.77                                 | -6.975552308                                 | Atuabo (P 55)         |
| 130.000          | 329.50                     | 189.08                        | -140.420   | 112723.822                 | 845428661.30                                  | 8.454286613                                  | Ekabaku (P 56)        |
| 132.000          | 288.50                     | 189.08                        | -99.420  | 94856.922                  | 711426913.04                                  | 7.11426913                                   | Beyin (P 57)          |
| 133.900          | 354.00                     | 189.08                        | -164.920   | -3246.811                  | -24351081.28                                  | -0.243510813                                 | Nglekazu (P 58)       |
| 136.000          | 287.50                     | 189.08                        | -98.420  | -105198.838                | -788991287.10                                 | -7.889912871                                 | P 59                  |
| 137.800          | 291.00                     | 189.08                        | -101.920   | -42404.160                 | -318031197.85                                 | -3.180311979                                 | P 60                  |
| 138.500          | 290.50                     | 189.08                        | -101.420   | -116704.649                | -875284870.17                                 | -8.752848702                                 | P 61                  |
| 141.000          | 287.00                     | 189.08                        | -97.920  | -104107.859                | -780808942.14                                 | -7.808089421                                 | Twene (P 62)          |
| 142.400          | 287.50                     | 189.08                        | -98.420  | -105198.838                | -788991287.10                                 | -7.889912871                                 | Egyiza (P 63)         |

| Chainage<br>(km) | Mean<br>Shore<br>Direction | Breaking<br>Wave<br>Direction | Angle of Breaking<br>Wave Crest with<br>Shore ( $\alpha$ ) | Wave Energy<br>Flux Factor | Potential<br>Alongshore<br>Sediment Transport | Log10 (Potential<br>Alongshore<br>Transport) | Remarks                  |
|------------------|----------------------------|-------------------------------|--|----------------------------|---|--|--------------------------|
| 144.100          | 287.50                     | 189.08                        | -98.420  | -105198.838                | -788991287.10                                 | -7.889912871                                 | Allengenzule (P 64)      |
| 146.000          | 286.50                     | 189.08                        | -97.420  | -7300.594                  | -54754456.66                                  | -0.547544567                                 | Ezilinbo (P 65)          |
| 147.500          | 287.50                     | 189.08                        | -98.420  | -105198.838                | -788991287.10                                 | -7.889912871                                 | Bonyere (P 66)           |
| 149.300          | 275.00                     | 189.08                        | -85.920  | -96838.674                 | -726290054.51                                 | -7.262900545                                 | Bonyere(outskirt) (P 67) |
| 151.500          | 284.00                     | 189.08                        | -94.920  | -116215.123                | -871613422.14                                 | -8.716134221                                 | P 68                     |
| 153.700          | 282.50                     | 189.08                        | -93.420  | 118829.123                 | 891218420.77                                  | 8.912184208                                  | P 69                     |
| 155.200          | 282.00                     | 189.08                        | -92.920  | 55707.744                  | 417808082.73                                  | 4.178080827                                  | Egbazo (P 70)            |
| 157.900          | 280.00                     | 189.08                        | -90.920  | 43389.099                  | 325418246.10                                  | 3.254182461                                  | Ahobre (P 71)            |
| 159.700          | 281.50                     | 189.08                        | -92.420  | -58631.077                 | -439733079.75                                 | -4.397330797                                 | Old Edobo (P 72)         |
| 161.300          | 276.00                     | 189.08                        | -86.920  | 103588.892                 | 776916690.53                                  | 7.769166905                                  | Atwebansi (P73)          |
| 164.200          | 275.00                     | 189.08                        | -85.920  | -96838.674                 | -726290054.51                                 | -7.262900545                                 | Ekpo (P 74)              |
| 165.400          | 278.00                     | 189.08                        | -88.920  | -112429.761                | -843223204.08                                 | -8.432232041                                 | Half Assini ( P 75)      |
| 166.700          | 279.00                     | 189.08                        | -89.920  | 82952.284                  | 622142129.30                                  | 6.221421293                                  | Benglow (P 76)           |
| 167.700          | 280.00                     | 189.08                        | -90.920  | 43389.099                  | 325418246.10                                  | 3.254182461                                  | P 77 (Metika)            |
| 170.200          | 277.50                     | 189.08                        | -88.420  | -94213.429                 | -706600719.01                                 | -7.06600719                                  | Jaway (P 78)             |
| 172.400          | 279.50                     | 189.08                        | -90.420  | 116917.309                 | 876879818.12                                  | 8.768798181                                  | Anlomatuope (P 79)       |
| 174.400          | 280.00                     | 189.08                        | -90.920  | 43389.099                  | 325418246.10                                  | 3.254182461                                  | Anlomatuope (P 80)       |
| 176.600          | 280.50                     | 189.08                        | -91.420  | -70030.848                 | -525231360.64                                 | -5.252313606                                 | Buoko (P 81 )            |
| 178.700          | 280.50                     | 189.08                        | -91.420  | -70030.848                 | -525231360.64                                 | -5.252313606                                 | Mpeasem (P 82)           |
| 180.700          | 280.50                     | 189.08                        | -91.420  | -70030.848                 | -525231360.64                                 | -5.252313606                                 | Nsemsea (P 83)           |
| 182.500          | 280.50                     | 189.08                        | -91.420  | -70030.848                 | -525231360.64                                 | -5.252313606                                 | Mangea (P 84)            |
| 184.100          | 279.50                     | 189.08                        | -90.420  | 116917.309                 | 876879818.12                                  | 8.768798181                                  | Effasu (P 85)            |
| 186.000          | 279.50                     | 189.08                        | -90.420  | 116917.309                 | 876879818.12                                  | 8.768798181                                  | P 86                     |

**Appendix V: Correlation Table for Short Term Rates and Variables**

|                 | Short Term | Exp Beach Width | Exp Beach Slope | Soil Thickness | SoilKPa_0.5m | Rock KPa | Log Sed Rivers | Log Along shore | Human Impacts |
|-----------------|------------|-----------------|-----------------|----------------|--------------|----------|----------------|-----------------|---------------|
| Short Term      | 1          | 0.225           | -0.162          | -0.21          | 0.426        | 0.489    | 0.103          | 0.034           | -0.45         |
| Exp Beach Width | 0.225      | 1               | -0.615          | -0.206         | 0.267        | 0.012    | 0.052          | -0.037          | -0.152        |
| Exp Beach Slope | -0.162     | -0.615          | 1               | 0.408          | -0.153       | 0.019    | -0.091         | -0.049          | -0.022        |
| Soil Thickness  | -0.21      | -0.206          | 0.408           | 1              | -0.334       | -0.259   | -0.101         | -0.077          | 0.178         |
| Soil KPa_0.5m   | 0.426      | 0.267           | -0.153          | -0.334         | 1            | 0.275    | -0.045         | -0.026          | -0.213        |
| Rock KPa        | 0.489      | 0.012           | 0.019           | -0.259         | 0.275        | 1        | 0.159          | 0.08            | -0.566        |
| Log Sed Rivers  | 0.103      | 0.052           | -0.091          | -0.101         | -0.045       | 0.159    | 1              | 0.354           | 0.013         |
| Log Along shore | 0.034      | -0.037          | -0.049          | -0.077         | -0.026       | 0.08     | 0.354          | 1               | -0.048        |
| Human Impacts   | -0.45      | -0.152          | -0.022          | 0.178          | -0.213       | -0.566   | 0.013          | -0.048          | 1             |

**Appendix VI: Table of Shoreline Change Independent Variables**

| <b>Chainage<br/>(km)</b> | <b>Exposed<br/>Beach<br/>Width (m)</b> | <b>Exposed<br/>Beach<br/>Slope(m)</b> | <b>Soil<br/>Thickness<br/>(m)</b> | <b>Soil<br/>Strength<br/>(kPa)_0.5m</b> | <b>Rock Strength<br/>(kPa)</b> | <b>Log of<br/>Sediment<br/>by Rivers<br/>(m<sup>3</sup>/sec)</b> | <b>Log Alongshore<br/>(Nm/sec)</b> | <b>Human<br/>Impacts</b> | <b>Remarks</b>      |
|--------------------------|--|---------------------------------------|-----------------------------------|---|--------------------------------|--|------------------------------------|--------------------------|---------------------|
| 0.000                    | 9.000                                  | 0.123                                 | 1.200                             | 2951.829                                | 51312500.000                   | 10.032   | 894417852.595                      | 215.684                  | Shama Pra Est. (P1) |
| 0.600                    | 10.900                                 | 0.067                                 | 2.800                             | 3302.046                                | 51312500.000                   | 10.032   | 894417852.595                      | 174.350                  | Shama (P2)          |
| 2.500                    | 24.600                                 | 0.045                                 | 0.800                             | 3602.232                                | 45900000.000                   | 10.032   | 852875003.626                      | 62.480                   | Aboesi (P3)         |
| 5.800                    | 20.550                                 | 0.118                                 | 3.500                             | 2001.240                                | 0.000                          | 3.022  | 369185013.648                      | 148.710                  | Aboadze (P4)        |
| 7.600                    | 27.650                                 | 0.040                                 | 1.300                             | 4936.392                                | 0.000                          | 3.022  | 340115278.991                      | 61.940                   | Bongo Beach (P5)    |
| 10.700                   | 11.033                                 | 0.059                                 | 2.300                             | 3602.232                                | 13400000.000                   | 3.495  | -453451683.644                     | 61.670                   | Ngyiresia (P6)      |
| 17.600                   | 20.467                                 | 0.091                                 | 0.700                             | 4069.188                                | 18800000.000                   | 3.495  | 852875003.626                      | 302.219                  | Ekuasi/Sekondi (P7) |
| 22.500                   | 17.833                                 | 0.175                                 | 3.000                             | 3302.046                                | 33750000.000                   | 3.495  | -825726608.413                     | 262.470                  | Nkontompo (P8)      |
| 24.000                   | 20.967                                 | 0.125                                 | 2.000                             | 8705.394                                | 33750000.000                   | 3.054  | -23118232.296                      | 248.435                  | New Takoradi (P9)   |
| 26.000                   | 7.633                                  | 0.115                                 | 0.700                             | 2301.426                                | 40400000.000                   | 3.054  | -816822215.386                     | 90.902                   | New Amanful (P 10)  |
| 29.000                   | 10.000                                 | 0.138                                 | 1.400                             | 6537.384                                | 44500000.000                   | 4.331  | 883627336.254                      | 74.085                   | Funku (P 11)        |
| 32.700                   | 20.433                                 | 0.115                                 | 1.900                             | 4469.436                                | 53615384.620                   | 4.331  | -735417047.830                     | 74.085                   | Adwowa (P12)        |
| 35.000                   | 12.500                                 | 0.194                                 | 2.900                             | 2801.736                                | 44083333.330                   | 4.331  | -878406064.977                     | 74.085                   | Pumpuni (P13)       |
| 37.700                   | 9.317                                  | 0.102                                 | 1.000                             | 3101.922                                | 56800000.000                   | 4.331  | 518802679.778                      | 86.635                   | Mpatano (P14)       |
| 41.400                   | 8.233                                  | 0.060                                 | 1.400                             | 4702.914                                | 0.000                          | 4.331  | -888893675.766                     | 639.370                  | Asemkaw (P15)       |
| 43.000                   | 12.767                                 | 0.173                                 | 2.300                             | 5203.224                                | 56800000.000                   | 3.559  | -141254633.796                     | 86.500                   | Butre (P16)         |
| 46.500                   | 29.333                                 | 0.069                                 | 0.800                             | 3201.984                                | 49731250.000                   | 4.027  | -803410261.551                     | 99.320                   | Busua (P17)         |
| 46.800                   | 18.300                                 | 0.131                                 | 1.600                             | 4736.268                                | 0.000                          | 5.999  | -512333352.169                     | 101.946                  | Dixcove (P18)       |
| 51.200                   | 18.300                                 | 0.129                                 | 3.300                             | 1867.824                                | 0.000                          | 5.999  | 739894295.328                      | 87.850                   | Akyinim (P19)       |
| 53.600                   | 15.967                                 | 0.103                                 | 1.700                             | 2468.196                                | 0.000                          | 5.999  | -141254633.796                     | 75.030                   | Atwiwa (P20)        |
| 55.200                   | 25.500                                 | 0.080                                 | 2.400                             | 2701.674                                | 0.000                          | 5.999  | -187939176.800                     | 74.760                   | Ahonakrom (P21)     |

| Chainage (km) | Exposed Beach Width (m) | Exposed Beach Slope (m) | Soil Thickness (m) | Soil Strength (kPa) 0.5m | Rock Strength (kPa) | Log of Sediment Rivers (m <sup>3</sup> /sec) | Log Alongshore (Nm/sec) | Human Impacts | Remarks              |
|---------------|-------------------------|-------------------------|--------------------|--------------------------|---------------------|--|-------------------------|---------------|----------------------|
| 56.500        | 17.333                  | 0.119                   | 2.300              | 4536.144                 | 58562500.000        | 5.999  | -848371446.489          | 31.240        | Bebianiha (P 22)     |
| 61.800        | 13.033                  | 0.165                   | 2.600              | 1000.620                 | 56750000.000        | 3.421  | -125598067.579          | 30.970        | P 23                 |
| 62.500        | 28.167                  | 0.082                   | 1.500              | 4936.392                 | 0.000               | 3.421  | -396662856.619          | 43.385        | Ketaakor (P24)       |
| 64.200        | 15.733                  | 0.096                   | 1.500              | 3402.108                 | 0.000               | 5.229  | 681647059.487           | 30.835        | Trinity Yard (P25)   |
| 68.800        | 4.300                   | 0.256                   | 2.700              | 2067.948                 | 50875000.000        | 5.229  | 894358931.944           | 31.240        | P 26                 |
| 72.200        | 10.467                  | 0.169                   | 2.300              | 3468.816                 | 52250000.000        | 5.229  | 828737103.425           | 74.220        | Atonchede (P 27)     |
| 77.900        | 12.633                  | 0.140                   | 2.900              | 2668.320                 | 44083333.330        | 5.229  | -172430073.328          | 99.185        | Akatakylie (P 28)    |
| 78.900        | 11.133                  | 0.172                   | 1.500              | 3335.400                 | 44083333.330        | 3.293  | 730882182.458           | 99.185        | Princes Town (P29)   |
| 82.000        | 20.233                  | 0.119                   | 2.300              | 5536.764                 | 37700000.000        | 3.293  | 799899241.538           | 74.085        | Miamea (P30)         |
| 84.100        | 14.800                  | 0.109                   | 1.800              | 5136.516                 | 0.000               | 3.293  | -604860844.232          | 74.085        | Egyembra (P 31)      |
| 84.900        | 14.233                  | 0.197                   | 2.000              | 4602.852                 | 0.000               | 4.430  | -480458325.055          | 74.760        | Adjan (P 32)         |
| 87.300        | 18.000                  | 0.099                   | 1.200              | 4202.604                 | 53600000.000        | 4.430  | -837810710.104          | 31.240        | P 33                 |
| 90.500        | 8.533                   | 0.086                   | 0.400              | 1400.868                 | 0.000               | 1.914  | 180191683.822           | 30.970        | P34                  |
| 92.700        | 8.167                   | 0.116                   | 1.600              | 2901.798                 | 49731250.000        | 1.914  | 227636564.774           | 101.946       | Axim Beach (P 35)    |
| 93.900        | 14.133                  | 0.119                   | 3.200              | 4202.604                 | 27600000.000        | 7.169  | 865976403.895           | 86.770        | Axim Nkekam (P 36)   |
| 96.200        | 16.600                  | 0.058                   | 1.700              | 4002.480                 | 0.000               | 7.169  | 587153079.000           | 627.090       | Akyenim (P 37)       |
| 97.300        | 21.867                  | 0.044                   | 0.600              | 2601.612                 | 0.000               | 7.169  | 823155803.650           | 627.360       | Ankobra Beach (P 38) |
| 97.700        | 18.200                  | 0.051                   | 0.800              | 5203.224                 | 0.000               | 7.169  | 545246652.812           | 332.235       | Ankobra Town (P 39)  |
| 99.700        | 17.633                  | 0.024                   | 0.700              | 6103.782                 | 0.000               | 1.728  | 822651420.024           | 332.235       | Asenta (P 40)        |
| 100.700       | 8.100                   | 0.222                   | 2.400              | 7871.544                 | 0.000               | 4.438  | -813575778.744          | 332.235       | Asemko (P 41)        |
| 103.300       | 14.800                  | 0.104                   | 2.800              | 4202.604                 | 0.000               | 4.438  | 181399509.225           | 307.135       | P 42                 |
| 106.400       | 5.600                   | 0.211                   | 1.900              | 2801.736                 | 0.000               | 4.438  | 876879818.120           | 332.235       | P 43                 |
| 107.400       | 17.867                  | 0.081                   | 1.900              | 6337.260                 | 0.000               | 4.438  | -716935454.441          | 337.255       | Esiama (P 44)        |

| Chainage (k) | Exposed Beach Width (m) | Exposed Beach Slope (m) | Soil Thickness (m) | Soil Strength (kPa) 0.5m | Rock Strength (kPa) | Log of Sedime Rivers (m <sup>3</sup> /sec) | Log Alongshore (Nm/sec) | Human Impacts | Remarks               |
|--------------|-------------------------|-------------------------|--------------------|--------------------------|---------------------|--|-------------------------|---------------|-----------------------|
| 109.300      | 14.567                  | 0.100                   | 3.900              | 3535.524                 | 0.000               | 3.184                                      | -890513254.758          | 332.235       | Azulenumu (P 45)      |
| 111.300      | 16.033                  | 0.067                   | 2.600              | 2401.488                 | 0.000               | 3.035                                      | -219971464.718          | 332.235       | Ampemu (P46)          |
| 112.200      | 14.200                  | 0.072                   | 2.400              | 2801.736                 | 0.000               | 3.035                                      | -881251982.511          | 61.535        | Beach Resort (P 47)   |
| 114.100      | 13.583                  | 0.085                   | 2.600              | 2001.240                 | 0.000               | 3.035                                      | -425876671.105          | 332.235       | Bakanta (P 48)        |
| 116.300      | 9.700                   | 0.251                   | 3.000              | 4202.604                 | 0.000               | 2.633                                      | -54754456.663           | 332.235       | Sanzule (P 49)        |
| 118.000      | 14.200                  | 0.148                   | 3.300              | 1534.284                 | 0.000               | 6.155                                      | 702483223.789           | 319.685       | Krisan (Eikwe) (P 50) |
| 120.000      | 8.967                   | 0.223                   | 2.800              | 2668.320                 | 0.000               | 6.155                                      | 702483223.789           | 61.535        | P 51                  |
| 122.100      | 6.233                   | 0.241                   | 4.500              | 2067.948                 | 0.000               | 6.155                                      | 784640019.548           | 319.685       | Ngelechi (P 52)       |
| 124.000      | 12.733                  | 0.150                   | 4.200              | 1801.116                 | 0.000               | 6.155                                      | 196875168.504           | 319.685       | Anochi (P 53)         |
| 125.900      | 15.133                  | 0.114                   | 2.700              | 2501.550                 | 0.000               | 3.164                                      | 823134708.095           | 61.535        | P 54                  |
| 127.800      | 11.700                  | 0.125                   | 3.700              | 2268.072                 | 0.000               | 3.164                                      | -697555230.773          | 332.235       | Atuabo (P 55)         |
| 130.000      | 7.033                   | 0.166                   | 1.900              | 2201.364                 | 0.000               | 3.974                                      | 845428661.303           | 307.135       | Ekabaku (P 56)        |
| 132.000      | 7.783                   | 0.230                   | 2.900              | 2534.904                 | 0.000               | 2.943                                      | 711426913.039           | 337.255       | Beyin (P 57)          |
| 133.900      | 11.917                  | 0.161                   | 2.300              | 1067.328                 | 0.000               | 2.943                                      | -24351081.279           | 332.235       | Nglekazu (P 58)       |
| 136.000      | 10.150                  | 0.182                   | 2.300              | 1000.620                 | 0.000               | 2.943                                      | -788991287.096          | 319.685       | P 59                  |
| 137.800      | 8.500                   | 0.146                   | 1.900              | 1067.328                 | 0.000               | 3.760                                      | -318031197.854          | 307.135       | P 60                  |
| 138.500      | 6.167                   | 0.272                   | 2.400              | 1267.452                 | 0.000               | 3.760                                      | -875284870.175          | 307.135       | P 61                  |
| 141.000      | 13.033                  | 0.064                   | 1.400              | 1534.284                 | 0.000               | 3.760                                      | -780808942.138          | 332.235       | Twene (P 62)          |
| 142.400      | 7.533                   | 0.192                   | 1.900              | 1734.408                 | 0.000               | 3.760                                      | -788991287.096          | 332.235       | Egyiza (P 63)         |
| 144.100      | 9.067                   | 0.200                   | 3.700              | 2868.444                 | 0.000               | 3.328                                      | -788991287.096          | 332.235       | Allengenzule (P 64)   |
| 146.000      | 15.267                  | 0.124                   | 2.500              | 2067.948                 | 0.000               | 3.328                                      | -54754456.663           | 332.235       | Ezilinbo (P 65)       |
| 147.500      | 18.000                  | 0.124                   | 2.000              | 3535.524                 | 0.000               | 3.328                                      | -788991287.096          | 332.235       | Bonyere (P 66)        |
| 149.300      | 10.033                  | 0.190                   | 2.800              | 3001.860                 | 0.000               | 3.260                                      | -726290054.506          | 332.235       | Bonyere (P 67)        |

| Chainage<br>(km) | Exposed<br>Beach<br>Width (m) | Exposed<br>Beach<br>Slope (m) | Soil<br>Thickness<br>(m) | Soil<br>Strength<br>(kPa)<br>_0.5m | Rock Strength<br>(kPa) | Log of Sedime<br>Rivers<br>(m <sup>3</sup> /sec) | Log Alongshore<br>(Nm/sec) | Human<br>Impacts | Remarks              |
|------------------|-------------------------------|-------------------------------|--------------------------|------------------------------------|------------------------|--|----------------------------|------------------|----------------------|
| 151.500          | 13.800                        | 0.116                         | 4.000                    | 2334.780                           | 0.000                  | 3.260  | -871613422.143             | 332.235          | P 68                 |
| 153.700          | 14.200                        | 0.117                         | 3.500                    | 1267.452                           | 0.000                  | 3.186  | 891218420.766              | 333.720          | P 69                 |
| 155.200          | 14.967                        | 0.118                         | 3.700                    | 800.496                            | 0.000                  | 3.186  | 417808082.732              | 333.450          | Egbazo (P 70)        |
| 157.900          | 13.900                        | 0.110                         | 2.600                    | 1867.824                           | 0.000                  | 3.186  | 325418246.097              | 333.180          | Ahobre (P 71)        |
| 159.700          | 12.000                        | 0.153                         | 2.700                    | 1400.868                           | 0.000                  | 6.528  | -439733079.745             | 358.010          | Old Edobo (P 72)     |
| 161.300          | 6.700                         | 0.130                         | 2.100                    | 1134.036                           | 0.000                  | 6.528  | 776916690.525              | 332.640          | Atwebansi (P73)      |
| 164.200          | 20.100                        | 0.131                         | 3.000                    | 2001.240                           | 0.000                  | 1.678  | -726290054.506             | 332.370          | Ekpo (P 74)          |
| 165.400          | 17.000                        | 0.098                         | 2.500                    | 1534.284                           | 0.000                  | 3.744  | -843223204.080             | 344.785          | Half Assini ( P 75)  |
| 166.700          | 14.833                        | 0.109                         | 3.100                    | 1801.116                           | 0.000                  | 3.744  | 622142129.301              | 332.235          | Benglow (P 76)       |
| 167.700          | 14.800                        | 0.077                         | 2.300                    | 1334.160                           | 0.000                  | 3.992  | 325418246.097              | 332.235          | P 77 (Metika)        |
| 170.200          | 15.967                        | 0.104                         | 3.100                    | 2067.948                           | 0.000                  | 3.992  | -706600719.011             | 332.235          | Jaway (P 78)         |
| 172.400          | 10.033                        | 0.146                         | 2.400                    | 3468.816                           | 0.000                  | 3.992  | 876879818.120              | 332.235          | Anlomatuope (P 79)   |
| 174.400          | 12.300                        | 0.241                         | 2.900                    | 1600.992                           | 0.000                  | 3.992  | 325418246.097              | 332.235          | Anlomatuope 4 (P 80) |
| 176.600          | 14.167                        | 0.118                         | 2.800                    | 1267.452                           | 0.000                  | 1.930  | -525231360.644             | 332.235          | Buoko (P 81 )        |
| 178.700          | 13.133                        | 0.111                         | 3.300                    | 1334.160                           | 0.000                  | 1.930  | -525231360.644             | 332.235          | Mpeasem (P 82)       |
| 180.700          | 6.000                         | 0.207                         | 2.300                    | 933.912                            | 0.000                  | 8.141  | -525231360.644             | 332.235          | Nsemtsea (P 83)      |
| 182.500          | 13.900                        | 0.124                         | 1.800                    | 1400.868                           | 0.000                  | 8.141  | -525231360.644             | 332.235          | Mangea (P 84)        |
| 184.100          | 18.700                        | 0.097                         | 2.600                    | 1200.744                           | 0.000                  | 8.141  | 876879818.120              | 332.235          | Effasu (P 85)        |
| 184.000          | 21.733                        | 0.070                         | 2.300                    | 1000.620                           | 0.000                  | 8.141  | 876879818.120              | 347.546          | P 86                 |

**Appendix VII: Table of Human Impact on Shoreline Change Computations**

| <b>Chainage (Km)</b> | <b>Distance from Coastal struct.(km)</b> | <b>Mining of Coastal mat.</b> | <b>Population Density</b> | <b>61.4%*Mining of coastal material</b> | <b>25.1%*Pop.Density</b> | <b>13.5%*Dist offcoastal struc.</b> | <b>Human Impact</b> | <b>Remarks</b> |
|----------------------|--|-------------------------------|---------------------------|---|--------------------------|-------------------------------------|---------------------|----------------|
| 0.00                 | 12                                       | 200                           | 363.6                     | 122.8                                   | 91.264                   | 1.62                                | 215.6836            | Shama          |
| 0.60                 | 10                                       | 200                           | 200                       | 122.8                                   | 50.200                   | 1.35                                | 174.35              | Shama          |
| 2.50                 | 8  | 100                           | 0                         | 61.4                                    | 0.000                    | 1.08                                | 62.48               | P3             |
| 5.80                 | 6  | 200                           | 100                       | 122.8                                   | 25.100                   | 0.81                                | 148.71              | Aboadze        |
| 7.60                 | 4  | 100                           | 0                         | 61.4                                    | 0.000                    | 0.54                                | 61.94               | Pt.5           |
| 10.70                | 2  | 100                           | 0                         | 61.4                                    | 0.000                    | 0.27                                | 61.67               | Pt.6           |
| 17.60                | 1  | 100                           | 958.9                     | 61.4                                    | 240.684                  | 0.135                               | 302.2189            | Sekondi        |
| 22.50                | 2  | 100                           | 800                       | 61.4                                    | 200.800                  | 0.27                                | 262.47              | Pt.8           |
| 24.00                | 1  | 200                           | 500                       | 122.8                                   | 125.500                  | 0.135                               | 248.435             | New Takoradi   |
| 26.00                | 1  | 100                           | 117                       | 61.4                                    | 29.367                   | 0.135                               | 90.902              | New Amanful    |
| 29.00                | 1  | 100                           | 50                        | 61.4                                    | 12.550                   | 0.135                               | 74.085              | Funko          |
| 32.70                | 1  | 100                           | 50                        | 61.4                                    | 12.550                   | 0.135                               | 74.085              | Adwowa         |
| 35.00                | 1  | 100                           | 50                        | 61.4                                    | 12.550                   | 0.135                               | 74.085              | Pumponi        |
| 37.70                | 1  | 100                           | 100                       | 61.4                                    | 25.100                   | 0.135                               | 86.635              | Mpatano        |
| 41.40                | 2  | 100                           | 100                       | 61.4                                    | 25.100                   | 0.27                                | 86.77               | Asemkaw        |
| 43.00                | 0  | 100                           | 100                       | 61.4                                    | 25.100                   | 0                                   | 86.5                | Butre          |
| 46.50                | 2  | 100                           | 150                       | 61.4                                    | 37.650                   | 0.27                                | 99.32               | Busua          |
| 46.80                | 1  | 100                           | 161                       | 61.4                                    | 40.411                   | 0.135                               | 101.946             | Dixcove        |
| 51.20                | 10                                       | 100                           | 100                       | 61.4                                    | 25.100                   | 1.35                                | 87.85               | Akyinim        |
| 53.60                | 8  | 100                           | 50                        | 61.4                                    | 12.550                   | 1.08                                | 75.03               | Atwiwa         |
| 55.20                | 6  | 100                           | 50                        | 61.4                                    | 12.550                   | 0.81                                | 74.76               | Ahonakrom      |
| 56.50                | 4  | 50                            | 0                         | 30.7                                    | 0.000                    | 0.54                                | 31.24               | Bebianiha      |
| 61.80                | 2  | 50                            | 0                         | 30.7                                    | 0.000                    | 0.27                                | 30.97               | Pt.23          |

| Chainage (Km) | Distance from Coastal struct.(km) | Mining of Coastal mat. | Population Density | 61.4%*Mining of coastal material | 25.1%*Pop.Density | 13.5%*Dist off coastal struc. | Human Impact | Remarks        |
|---------------|-----------------------------------|------------------------|--------------------|----------------------------------|-------------------|-------------------------------|--------------|----------------|
| 62.50         | 1                                 | 50                     | 50                 | 30.7                             | 12.550            | 0.135                         | 43.385       | Ketaakor       |
| 64.20         | 1                                 | 50                     | 0                  | 30.7                             | 0.000             | 0.135                         | 30.835       | Pt.25          |
| 68.80         | 4                                 | 50                     | 0                  | 30.7                             | 0.000             | 0.54                          | 31.24        | Pt.26          |
| 72.20         | 2                                 | 100                    | 50                 | 61.4                             | 12.550            | 0.27                          | 74.22        | Atonchin       |
| 77.90         | 1                                 | 100                    | 150                | 61.4                             | 37.650            | 0.135                         | 99.185       | Prusi Akatakyi |
| 78.90         | 1                                 | 100                    | 150                | 61.4                             | 37.650            | 0.135                         | 99.185       | Princess Town  |
| 82.00         | 1                                 | 100                    | 50                 | 61.4                             | 12.550            | 0.135                         | 74.085       | Miamea         |
| 84.10         | 1                                 | 100                    | 50                 | 61.4                             | 12.550            | 0.135                         | 74.085       | Egyembra       |
| 84.90         | 6                                 | 100                    | 50                 | 61.4                             | 12.550            | 0.81                          | 74.76        | Adjan          |
| 87.3          | 4                                 | 50                     | 0                  | 30.7                             | 0                 | 0.54                          | 31.24        | Adjan utskirts |
| 90.5          | 2                                 | 50                     | 0                  | 30.7                             | 0                 | 0.27                          | 30.97        | Pt.34          |
| 92.7          | 1                                 | 100                    | 161                | 61.4                             | 40.411            | 0.135                         | 101.946      | Axim           |
| 93.9          | 2                                 | 100                    | 100                | 61.4                             | 25.1              | 0.27                          | 86.77        | Axim Nkekan    |
| 96.2          | 4                                 | 1000                   | 50                 | 614                              | 12.55             | 0.54                          | 627.09       | Akyenim        |
| 97.3          | 6                                 | 1000                   | 50                 | 614                              | 12.55             | 0.81                          | 627.36       | Ankobra beach  |
| 97.7          | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Ankobra Town   |
| 99.7          | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Asenta         |
| 100.7         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Asemko         |
| 103.3         | 1                                 | 500                    | 0                  | 307                              | 0                 | 0.135                         | 307.135      | Pt.42          |
| 106.4         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | kokam          |
| 107.4         | 1                                 | 500                    | 120                | 307                              | 30.12             | 0.135                         | 337.255      | Esiamia        |
| 109.3         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Azulewanu      |
| 111.3         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Ampemu         |
| 112.2         | 1                                 | 100                    | 0                  | 61.4                             | 0                 | 0.135                         | 61.535       | Pt. 47         |
| 114.1         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Bankata        |
| 116.3         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Sanzule        |

| Chainage (Km) | Distance from Coastal struct.(km) | Mining of Coastal mat. | Population Density | 61.4%*Mining of coastal material | 25.1%*Pop.Density | 13.5%*Dist off coastal struc. | Human Impact | Remarks          |
|---------------|-----------------------------------|------------------------|--------------------|----------------------------------|-------------------|-------------------------------|--------------|------------------|
| 118           | 1                                 | 500                    | 50                 | 307                              | 12.55             | 0.135                         | 319.685      | Krisan Eikwe     |
| 120           | 1                                 | 100                    | 0                  | 61.4                             | 0                 | 0.135                         | 61.535       | Pt.51            |
| 122.1         | 1                                 | 500                    | 50                 | 307                              | 12.55             | 0.135                         | 319.685      | Ngelechi         |
| 124           | 1                                 | 500                    | 50                 | 307                              | 12.55             | 0.135                         | 319.685      | Anochi           |
| 125.9         | 1                                 | 100                    | 0                  | 61.4                             | 0                 | 0.135                         | 61.535       | Pt.54            |
| 127.8         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Atuabo           |
| 130           | 1                                 | 500                    | 0                  | 307                              | 0                 | 0.135                         | 307.135      | Ekabaku utskirt  |
| 132           | 1                                 | 500                    | 120                | 307                              | 30.12             | 0.135                         | 337.255      | Benyin           |
| 133.9         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Nglekazu         |
| 136           | 1                                 | 500                    | 50                 | 307                              | 12.55             | 0.135                         | 319.685      | Pt.59 (Outskirt) |
| 137.8         | 1                                 | 500                    | 0                  | 307                              | 0                 | 0.135                         | 307.135      | Pt.60            |
| 138.5         | 1                                 | 500                    | 0                  | 307                              | 0                 | 0.135                         | 307.135      | Pt.61            |
| 141           | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Twene            |
| 142.4         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Egyiza           |
| 144.1         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Allengensule     |
| 146           | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Ezilinbo         |
| 147.5         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Bonyere          |
| 149.3         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Bonyereoutskirts |
| 151.5         | 1                                 | 500                    | 100                | 307                              | 25.1              | 0.135                         | 332.235      | Pt. 68           |
| 153.7         | 12                                | 500                    | 100                | 307                              | 25.1              | 1.62                          | 333.72       | Kabelensuoso     |
| 155.2         | 10                                | 500                    | 100                | 307                              | 25.1              | 1.35                          | 333.45       | Egbazo           |
| 157.9         | 8                                 | 500                    | 100                | 307                              | 25.1              | 1.08                          | 333.18       | Ahobre           |
| 159.7         | 6                                 | 500                    | 200                | 307                              | 50.2              | 0.81                          | 358.01       | Old Elubo        |
| 161.3         | 4                                 | 500                    | 100                | 307                              | 25.1              | 0.54                          | 332.64       | Atwebanso        |
| 164.2         | 2                                 | 500                    | 100                | 307                              | 25.1              | 0.27                          | 332.37       | Ekpo             |
| 165.4         | 1                                 | 500                    | 150                | 307                              | 37.65             | 0.135                         | 344.785      | Half Assini      |

| <b>Chainage (Km)</b> | <b>Distance from Coastal struct.(km)</b> | <b>Mining of Coastal mat.</b> | <b>Population Density</b> | <b>61.4%*Mining of coastal material</b> | <b>25.1%*Pop.Density</b> | <b>13.5%*Dist off coastal struc.</b> | <b>Human Impact</b> | <b>Remarks</b> |
|----------------------|--|-------------------------------|---------------------------|---|--------------------------|--------------------------------------|---------------------|----------------|
| 166.7                | 1  | 500                           | 100                       | 307                                     | 25.1                     | 0.135                                | 332.235             | Benglow        |
| 167.7                | 1  | 500                           | 100                       | 307                                     | 25.1                     | 0.135                                | 332.235             | Metika         |
| 170.2                | 1  | 500                           | 100                       | 307                                     | 25.1                     | 0.135                                | 332.235             | Jaway          |
| 172.4                | 1  | 500                           | 100                       | 307                                     | 25.1                     | 0.135                                | 332.235             | Anomatuope     |
| 174.4                | 1  | 500                           | 100                       | 307                                     | 25.1                     | 0.135                                | 332.235             | Anomatuope 4   |
| 176.6                | 1  | 500                           | 100                       | 307                                     | 25.1                     | 0.135                                | 332.235             | Buoko          |
| 178.7                | 1  | 500                           | 100                       | 307                                     | 25.1                     | 0.135                                | 332.235             | Mpeasem        |
| 180.7                | 1  | 500                           | 100                       | 307                                     | 25.1                     | 0.135                                | 332.235             | Nzemtsea       |
| 182.5                | 1  | 500                           | 100                       | 307                                     | 25.1                     | 0.135                                | 332.235             | Mangea         |
| 184.1                | 1  | 500                           | 100                       | 307                                     | 25.1                     | 0.135                                | 332.235             | Effasu         |
| 184                  | 1  | 500                           | 161                       | 307                                     | 40.411                   | 0.135                                | 347.546             | Pt. 86         |

**Appendix VIII: Criteria Weight Vectors and Pairwise Comparisons of Human Impact Factors**

## Criteria weight Vector

|                             |          |
|-----------------------------|----------|
| Coastal mining              | 0.613728 |
| Population Density          | 0.251307 |
| Dist off Coastal Structures | 0.134966 |

## Matrix of the Pairwise Comparison

|          |          |          | Alternate Options | Rank of Options |
|----------|----------|----------|-------------------|-----------------|
| 0.368061 | 0.033335 | 0.064351 | Very low          | 0.242951        |
| 0.331785 | 0.063377 | 0.061487 | Low               | 0.227851        |
| 0.197328 | 0.128976 | 0.086909 | Moderate          | 0.165248        |
| 0.077629 | 0.261499 | 0.212957 | High              | 0.142101        |
| 0.025198 | 0.512813 | 0.574296 | Very high         | 0.221848        |

## Genral Equation

Human Impact=61.3%\*Coastal Mining + 25.1% \* Population density + 13.5%\*Distance off Coastal Structures

**Appendix IX: Correlation Table for Short Term Shoreline Change for the Eastern Region**

|               | Short<br>Term | ExpBeach<br>Width | ExpBeach<br>Slope | Soil<br>Thickness | Soil<br>KPa_0.5m | Rock<br>KPa | LogSed<br>Rivers | LogAlong<br>shore | Human<br>Impacts |
|---------------|---------------|-------------------|-------------------|-------------------|------------------|-------------|------------------|-------------------|------------------|
| ShortTerm     | 1.000         | -.065             | .069              | .237              | .193             | -.036       | -.115            | -.241             | .279             |
| ExpBeachWidth | -.065         | 1.000             | -.450             | -.059             | .276             | -.289       | -.005            | -.166             | -.113            |
| ExpBeachSlope | .069          | -.450             | 1.000             | .448              | -.118            | .323        | -.134            | .035              | -.181            |
| SoilThickness | .237          | -.059             | .448              | 1.000             | -.134            | .017        | .121             | .043              | -.062            |
| SoilKPa_0.5m  | .193          | .276              | -.118             | -.134             | 1.000            | -.014       | -.107            | -.076             | .215             |
| RockKPa       | -.036         | -.289             | .323              | .017              | -.014            | 1.000       | .176             | .090              | -.152            |
| LogSedRivers  | -.115         | -.005             | -.134             | .121              | -.107            | .176        | 1.000            | .349              | .023             |
| logAlongshore | -.241         | -.166             | .035              | .043              | -.076            | .090        | .349             | 1.000             | -.108            |
| HumanImpacts  | .279          | -.113             | -.181             | -.062             | .215             | -.152       | .023             | -.108             | 1.000            |

**Appendix X: Sample Field Record of Hard Shore Compressive Strength**

| Town       | Location  |           | Rebound values (V) | Deviation (x-u)      | (x-u) <sup>2</sup> | Strike/Dip direction | Description                    |
|------------|-----------|-----------|--------------------|----------------------|--------------------|----------------------|--------------------------------|
|            | X         | Y         |                    |                      |                    | Dip Amount           |                                |
| Akatakylie | 151065.09 | 12254.222 | 48                 | -2.875               | 8.265625           |                      | Fine grained dark metamorphic  |
|            |           |           | 50                 | -0.875               | 0.765625           |                      | rock with network of quartzo   |
|            |           |           | 47                 | -3.875               | 15.015625          |                      | Felspathic vein lets likely to |
|            |           |           | 50                 | -0.875               | 0.765625           |                      | be a shear zone                |
|            |           |           | 68                 | 17.125               | 293.265625         |                      | sample AKC1                    |
|            |           |           | 41                 | -9.875               | 97.515625          |                      |                                |
|            |           |           | 55                 | 4.125                | 17.015625          |                      |                                |
|            |           |           | 41                 | -9.875               | 97.515625          |                      |                                |
|            |           |           | 52                 | 1.125                | 1.265625           |                      |                                |
|            |           |           | 65                 | 14.125               | 199.515625         |                      |                                |
|            |           |           | 63                 | 12.125               | 147.015625         |                      |                                |
|            |           |           | 54                 | 3.125                | 9.765625           |                      |                                |
|            |           |           | 40                 | -10.875              | 118.265625         |                      |                                |
|            |           |           | 40                 | -10.875              | 118.265625         |                      |                                |
|            |           |           | 45                 | -5.875               | 34.515625          |                      |                                |
|            |           |           | 55                 | 4.125                | 17.015625          |                      |                                |
|            |           | Mean      | 50.875             | Variance             | <b>1175.75</b>     |                      |                                |
|            |           |           |                    | std                  | <b>8.572302783</b> |                      |                                |
|            |           |           |                    | Compressive Strength | <b>56.8</b>        |                      |                                |